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W.Va.Univ. Dept. of Geology & Geography

ANNUAL PROGRESS REPORT

CONTRACT E(40-1)-5194

SUBMITTED BY

DEPARTMENT OF GEOLOGY AND GEOGRAPHY
WEST VIRGINIA UNIVERSITY

OCTOBER 1977

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PERSONNEL

Robert C. Shumaker	Project Director
Henry Rauch	Task Director Hydrology
Russell Wheeler	Task Director Structural Geology
Jane Negus de Wys	Principal investigator Production Geology
Jeanette M. Dixon	Principal investigator Structural Geology
Keith G. Kirk	Principal investigator Geophysics
Brian R. Long	Principal investigator Structural Geology (fractures)
Ernest B. Nuckols III	Principal investigator Production Geology
Thomas H. Wilson	Principal investigator Structural Geology
open	Principal investigator Structural Geology
open	Principal investigator Geophysics
Melissa Farris-Lanyi	Secretary
Philip E. Haring	Geologic Drafting Specialist

INTRODUCTION

This report is written to document progress made during the first year of our study for the Eastern Gas Shales Project. The report is organized to meet the needs of readers who have varied interests in the project. The first portion of the report, ranging from objectives through finances, gives a general overview which highlights our progress and problems for the first year. The second portion of the report, by individual task investigators, is designed primarily for scientists interested in technical details of the first years work. The third portion of the report consists of appendices of data compiled by the principal investigators. Each appendix serves as a data bank for each task. These data can be used for analysis by other scientists with the permission of the principal investigator responsible for its compilation.

OBJECTIVES

The general objective of our project under contract E(40-1)-5194 is to study the structural parameters of the Devonian shales that effect gas production in eastern Kentucky and West Virginia.

To that end our program is specifically designed to:

1. Collect, compile, and analyze geologic data to construct regional structure maps of eastern Kentucky and West Virginia.

2. Determine if structural types and styles effect production, and determine if minor structures as mapped in outcrop could influence production characteristics.

3. Determine if shallow seismic surveys can detect near-surface faults and fracture zones, and if such structures can be detected, to further determine how fractures relate to both production from the shale and to lineations observed on remotely sensed data.

4. Determine if a relationship exists between groundwater movement and shale gas productivity.

Through the integration of our work with others it is our ultimate goal to discover if relationships exist between Devonian shale gas production and geologic structure. If such a relationship is established, we will attempt to develope a method or methods for selecting favorable sites to drill shale wells that have a greater potential for gas production than the norm for that region.

ORGANIZATION

In order to attain the stated objectives we have designed several tasks which have been organized into five study groups. Four of these groups: regional structure studies, fracture studies, structural type studies, and production studies, are carried under ERDA's Resource Inventory Tasks. One group, geophysical studies, is carried under Shale Characterization Tasks.

In essence, the regional structure and fracture studies are designed to provide a regional or basin structure data base for the entire project. The structural type studies seek to document, by analytical field work, details of structures which are either producing gas at the present time or which we feel are prospective. The production studies will seek out and study those gas fields where detailed well production records are available that permit thorough analysis and documentation of the geologic parameters that influence gas production from the shale. The geophysical studies are charged with the task of developing inexpensive geophysical techniques that can locate shallow fracture zones of high permeability.

SCHEDULE OF MILESTONES

I. Resource Inventory Milestones	Due Date	Status
Start Project	July 1, 1976	October 1, 1976
Complete collection of existing lineament, joint and stress data for Kentucky and West Virginia and gain access to remote sensing imagery.		In progress
Complete structure contour maps for Berea sandstone, Onondaga, top of the Ordovician and Pre-Cambrian Basement.	July 1, 1977	Completed: Berea, Onondaga Precambrian, Greenbrier (Data unavailable for top of the Ordovician. (see Fig. 2).
Complete lineament overlays utilizing lineament data available from the U.S. Geological Survey and other agencies and sources.	July 1, 1977	Data unavailable
Complete oil and gas pool maps.	July 1, 1977	Completed
II. Shale Characterization Milestones		
Select areas of major faults or fractures for seismic and resistivity.	September 1, 1976	Completed
Complete planning and grid layout for conducting seismic and resistivity surveys over faults and fractures.	November 1, 1976	Completed
Select areas to conduct ground water studies.	January 1, 1977	Completed

EDUCATION

The two principal investigators hired during the first year of the project have made satisfactory progress toward advanced degrees in Geology. This fall, all six principal investigators employed by ERDA under this grant are enrolled half-time in graduate studies leading toward advanced degrees in geology. In addition, several graduate students have been paid on an hourly basis for their part-time work in the project. It is difficult to estimate the long term benefits that other University students will derive from use of equipment purchased with ERDA funds. We know that it will be significant.

EQUIPMENT

During the first year of the project the following major pieces of equipment were aquired:

1. One Bison seismograph Model 1580 and one Bison earth resistivity meter model 2350B.

2. Equipment truck for geophysical equipment.

3. International Imaging Systems multi-spectral camera (on loan from NASA-Clear Lake-Johnson Space Center).

4. International Imaging Systems multi-spectral color additive viewer model 6000 (on loan from NASA-Clear Lake-Johnson Space Center).

During the second year of the project the follwoing major pieces of equipment will be purchased:

1. Multi-spectral edge enhancer.

2. Portable drill rig for mounting on seismic truck.

3. Portable recording and direct reading altimeters.

4. Mounting of multi-spectral camera in WVU-Cessna aircraft.

FINANCES

The responsibility for financial accounting for this grant lies with the comptroller of West Virginia University. Detailed financial reports are forwarded to ERDA by the comptroller's office as separate reports.

In general, our spending has been as budgeted with the exception of salaries. The late starting data for the project (October 1977) required delay of hiring certain personnel. Therefore, we have spent less in salaries than expected for the first year. However, all personnel planned to be hired will be hired; therefore, these first year salary funds will eventually be spent as salaries but on a delayed basis.

A possible revision to our planned budgetary needs may be found in funds required for computer expenses. The West Virginia Board of Regents has revamped computer time charges so that much of our work which would have been carried as no-expense items will now be billed to the grant on a cost basis. We will estimate the cost of our computer needs based on the new rate schedule covering our usage over the next six months. We will then revise our budget for the upcoming year.

Another expected increase in cost for the next year will be in the amount of overhead as the University has increased this figure from the current 58.8% to 62% for the coming year.

PUBLICATIONS

During the past year several articles were published by the project director relating to the Devonian shales grant. The following are titles of papers published:

Shumaker, Robert C. and Overbey, W. K., 1976, Devonian Shale Production and Potential: edited proceedings volume ERDA, MERC S -76/2, 271 p.

Shumaker, Robert C., 1976, A Digest of Appalachian Structural Geology:in Shumaker R. C., and Overbey, W. K., ed., Devonian Shale Production and Potential, ERDA, MERC Sp-76/2, p. 75-93.

Wheeler, R. L., Shumaker, R. C., Woodfork, L. D. , and Overbey, W. K., 1976, Gas from Devonian Shale; Geotimes, v., p. 18, 19.

Shumaker, Robert C., 1977, Analysis of Structural Geologic Parameters that influence Gas Production from the Devonian Shale in the Appalachian Basin; Enhanced Oil Gas Recovery and Improved Drilling Methods, University of Tulsa and Oil and Gas Journal ed., Proceedings v. 2, paper G 13, p. 1-6.

Shumaker, Robert C., 1977, Devonian Shale Research Undertaken by West Virginia University, West Virginia Geological Survey Newsletter (in press).

During the upcoming year several papers will be presented by members of our staff at scientific meetings. Three papers have been accepted for the First Eastern Gas Shales Meeting to be held in Morgantown, West Virginia in October, and an abstract has been accepted by the Geological Society of America for a paper to be presented at its southeastern regional meeting in the spring of 1978.

PROGRESS and PROBLEMS - A SUMMARY

The major portion of our efforts for the first year of the contract centered on recruiting, hiring of personnel, ordering equipment, and planning and initiating specific tasks designed to accomplish the objectives of the project.

Satisfactory progress was made in recruiting and hiring of personnel so that each task of the project is now in progress by at least one principal investigator. As of the date of this report, two positions remain open, one in structural geology and one in geophysics.

We consider overall technical progress to be quite satisfactory in that we have initiated each task specified in the contract, and we have completed all contractually specified deliverable items for which data is available.

Regional Structure and Fracture Tasks

The regional structural tasks, designed to compile structure for the project area (Figure 1) have not only been completed on schedule, but we have completed structure maps on more horizons than the number required by the contract. A total of thirty eight(38) quadrangle maps (Figure 2) covering part or all of the project area were completed (Appendix A).

Field work was initiated in eastern Kentucky to document the regional fracture pattern. The principal investigator, hired in mid-May, worked dilligently to collect some one hundred and fifty four (154) data stations across most of eastern Kentucky (appendix B).

The only major problem in regard to these tasks related to the lack of time which the project director, who is also a principal investigator, had for comparative analysis of structural data. The estimated 20% figure for the project director's time to manage the grant was far too small. Over 50% of his time is spent directing the project. As a result, the comparative structural analysis which he intended to do has suffered.

Production Studies

Production studies started in January of 1977 with the hiring of our first production geologist. The Mount Alto (Cottageville) field was selected as the initial study area (Figure 1). Availability of data and ERDA's interest in this field were instrumental in its selection. The first half year has largely been spent visiting with various companies that have drilled wells within the field to borrow and organize the data and to initiate our analysis. Variability in the quantity and quality of production data will complicate this analysis, but we are presently attacking this problem. Plans call for completion of the field study late in the spring or early in the summer of 1978. We are several months behind schedule because of health problems within the family of the principal investigator. However, we expect to complete this study on time.

A second production geologist, hired this fall, is presently in the process of selecting a field study area. We feel that the production of Devonian shale gas in eastern Kentucky, the primary producing area, takes top priority on our list of important producing areas to be studied. However, while the prominence of the Big Sandy field may be a good reason for selecting it as our next study area, of determinant influence is the availability of quality production data to support a meaningful analysis. By mid-winter we should have selected the second field for analysis, and by early spring we should be into the data collection phase of the study.

Groundwater Studies

Because Cottageville is the site of our first gas production study, it is a logical choice as the site for our initial groundwater study. Field work started there this summer, and it is to be completed this fall. The analysis will be based on volumetric and water quality data collected in the field. The final report for the Cottageville area is scheduled for completion in late spring of 1978. The second groundwater study area will be selected and intiated next summer. Again, a likely area would be the site of our second production study.

Field Structure Studies

Study of surface structural types was initiated this September with the hiring of two structural geologists. Study areas will be selected this fall and analysis will begin this winter. Field studies will start next summer. Our efforts will be made in conjunction and coordination with the U. S. Geological Survey as they will be making similar studies in adjacent states. We are presently recruiting a third geologist for this task.

Geophysical Tasks

In geophysical tasks, we have purchased, designed, and built seismic and resistivity equipment. We are approximately four months behind schedule; a circumstance caused by the delay both in delivery of the equipment truck and in certain design problems of filtering equipment. We expect to be back on schedule by the end of March, 1978. During this past year, several innovative ideas of the principal investigator have been implemented to modify commercial seismic equipment to correct noise problems and to enhance real high-frequency reflection events.

A second geophysicist was scheduled for hiring this fall. But at the last minute, the applicant, who had been offered and tentatively accepted the position, decided to decline the offer. This circumstance will require modification of plans and an additional recruiting effort to be made this coming fall.

Plans call first for the field testing of the seismic system this fall and early winter, then design of a software package for data display this coming winter, and finally, field investigation of designated producing areas is scheduled for next summer.

DETAILED REPORT ON RESOURCE INVENTORY TASKS

REGIONAL STRUCTURE TASKS - Robert C. Shumaker

The primary task of this group is to collect structural data and to construct maps that will provide a regional structural framework for eastern Kentucky and West Virginia (Figure 1). Naturally, it is important that the regional structure background be available for the primary producing area of the Devonian shale gas so that shale project geologists can evaluate the effect that geologic structure has on production and in order that they can compare structure with the mapped results of other geologic or geochemical investigations. The standard 1:250,000 map scale of the compilation will facilitate such comparisons. As of this date we have compiled the following subsurface structure maps:

Preliminary structure maps on the top of the Precambrian basement, preliminary structure maps on the base of the Onondaga Limestone, preliminary structure maps on the top of the Greenbrier Limestone, and preliminary structure maps on the top of the Berea Sandstone. Maps (scale 1:250,000) showing the general outline of gas production from the Devonian shale have also been compiled for eastern Kentucky and West Virginia (see Appendix A).

The status of our mapping program is shown in Figure 2. According to the milestones of our contract (page 4), we were to complete structure maps on the Berea, Onondaga, Ordovician, and Precambrian basement by July 1, 1977. Data for the Ordovician map was not available, so we could not construct that map. However, we completed the other maps on time. Reduced copies of the overlay sheets can be found in Appendix A. These maps will be issued at the scale of 1:250,000, on a topo-cultural base when the printing contract for the shale project is let.

In addition to these maps specified by the contract, we have completed the following maps because the data was readily available for their construction, and we felt that they would be useful to the project structural analysis: structure on top of the Greenbrier Limestone, surface structure form-line maps, surface drainage maps.

In as much as we are a leader in generating maps for the project, we were a driving force in initiating standardization of legends and drafting procedures. Progress has been made on this effort by Scientific Applications Incorporated, and the project is approaching a standard map format.

In looking through the maps we have completed, it will be noted that the structure maps of the Berea, Greenbrier, and Onondaga lack contours for an interpretation of the Kentucky portion of our project area (see Appendix A). We simply did not have sufficient well data, formation tops, to complete the Kentucky portion of the project area. We felt it inappropriate to estimate the structure for that area. The only published structure map for eastern Kentucky is a page-sized and rather generalized map on the Pennsylvanian Fire Clay Coal published by MacFarland in 1939. The Fire Clay map is far less detailed than our surface structure form-line map, so we did not use the Fire Clay map. We have plotted on our work maps that well information which is available through

Petroleum Information Corporation microfiche file data. This data is a start, but it is too widespread to make a meaningful interpretation of shallow structure at the 1:250,000 scale. We hope that far more well data will become available during the life of the project either through the Kentucky Geological Survey or through Petroleum Information Corporation which will then permit us to extend our detailed structure maps into eastern Kentucky to give a more complete regional picture for that portion of the basin.

Nearly all of the maps in Appendix A come from published sources. The Preliminary Basement Structure Map is a new interpretation, however, the position and trend of the faults shown on these maps are essentially the same as those shown by Shumaker (1974). The depths-to-basement and well locations are more accurate than those shown by Shumaker (1974). The new data on which the maps (Appendix A) are based were supplied by Edward Wilson of the Kentucky Geological Survey and Dudley Cardwell of the West Virginia Geologic and Economic Survey. We thank these gentlemen for their assistance.

The major portion of offsets shown along the faults disappear at the base of the Cambrian formation. However, in Kentucky, faults do extend through the entire section to be exposed at the surface. The Warfield Fault of southwestern West Virginia is the only basement fault exposed in the western part of that state. Even though minor movement has occurred on many of the faults through time it is clear that the major activity along them occurred during Cambrian time. In the Kentucky portion of the map, the position of the faults is determined by either the position of the surface trace of that fault or by numerous control wells. In West Virginia we primarlly use the total magnetic intensity map published by the West Virginia Geologic and Economic Survey along with a few basement test wells to postulate the location of faults. We have made this speculative interpretation in West Virginia because we believe that the shape of the basement and the location of basement faults may be important to shale gas production. We base this proposition on several observations and reasoning: First, the structural low visible on the basement map, which is primarily a Cambrian age structure, is also visible on the Devonian shale isopach maps. Thus, at least the thickness of the shale was affected by the buried trough. As detailed stratigraphic and geochemical data become available it would not be surprising to see more precise interrelationships established between shale stratigraphy and basement faults. Secondarily, the basement may have affected Devonian shale in regard to fracturing. Basement faults have been active throughout much of the Paleozic time perhaps both by minor periodic and episodic movements. We have mentioned the subtle effect of what are presumed minor fault movement during the Devonian to affect shale sedimentation. We feel that such minor movements may also have been important in determining areas in which fractures within the shale might remain open to pass fluids and hydrocarbons. Such fractures could be mineralized to impart a fracture porosity to a unit that would otherwise be tight. Only as more precise production data and structural data become available will we be able to compare these data and estimate the effect that minor minor basement fault movements have had on shale production.

A third influence which basement faults or configuration might have on shale production relates to the offset of detached bedding plane thrust within the shale. Basement faults that offset detachment surfaces within the shale could localize upward movement and ramping of the thrust plane at the point of offset to form a structure with attenuant fracture porosity in the shale. The suggestion of an interrelationship between basement structure and detached structure is visible by comparing maps on the several structural horizons in the area of Devonian shale production. For instance, compare shallow structure on the Berea (Figure 3) or the Greenbrier (Figure 4) with deeper structure on the Onondaga (Figure 5) and the structure of the basement (Figure 6). Note that the structure configuration visible on the Greenbrier or the Berea, which is the top of the shale, is considerably different than that shown for the Onondaga, which is the base of the shale. There are several more structures shown on the Berea than on the Onondaga and the Basement. Therefore, the Devonian shale unit of structural disharmony. We intend to assess the importance of such deformation on shale production (Figure 7) if the data quality permits such.

Normally, geologists think that joints form as a result of regional tectonic forces, and that they occur in sets of regular trends that extend across wide areas and through the entire sedimentary section. However, the origin of specific joints and fracture patterns if often in doubt. Occassionally, unique fractures occur in distinct lithological units. This may be the case for the basal portion of the Devonian shale. Beyers and Trumbo (1976) logged mineralized fractures in the basal portion in a core from the Coombs well of eastern Kentucky. The dipmeter for that well showed anomolous readings on the same interval and gas flowed into the well presumably from fracture porosity at that same depth. Inasmuch as the Pine Mountain Thrust is detached in the basal portion of the shale only thirty miles to the east, it seems likely to us that the basal shale was a zone of abnormal high-pressure during the late Paleozoic deformation. Such over-pressured shale zones are undercompacted, and they form avenues for the migration of formation fluids. The rocks of these zones may contain a unique stress field and unique physical characteristics wiich permit the rocks to fracture more readily than surrounding sediments. Presumably, if the Pine Mountain Thrust moved northwestward as its trace and ramp trend suggest, then the tectonic stress during the late Paleozoic was from the southeast. Tension tractures formed by such movement should have a southeast-northwest trend, and this is precisely the dominant trend of mineralized fractures logged in the core taken from the Hazard well. This trend is at a large angle to the northeast trend of induced fractures that reflect the present stress field within the rocks. We know that there are other reasons why fractures could form within a fixed stratigraphic interval, so it would be premature to regard the suggested interpretation as anything more than preliminary. However, we feel that it is important that this interpretation be considered by geologists within the project to evaluate its worth. If the fractures are related to tectonic over-pressuring then the areal extent of the prospect shale is limited.

Plans for the upcoming year call for continued construction of subsurface maps. Already we intend to collect tha data and construct maps for the base of Silurian and the base of the Knox - Beekmantown Dolomite. Data collection should be complete by December 1977, and a preliminary structure map will be completed by the end of May 1978. As indicated above, if the data become available we would like to extend existing preliminary map series (Appendix A) into eastern Kentucky.

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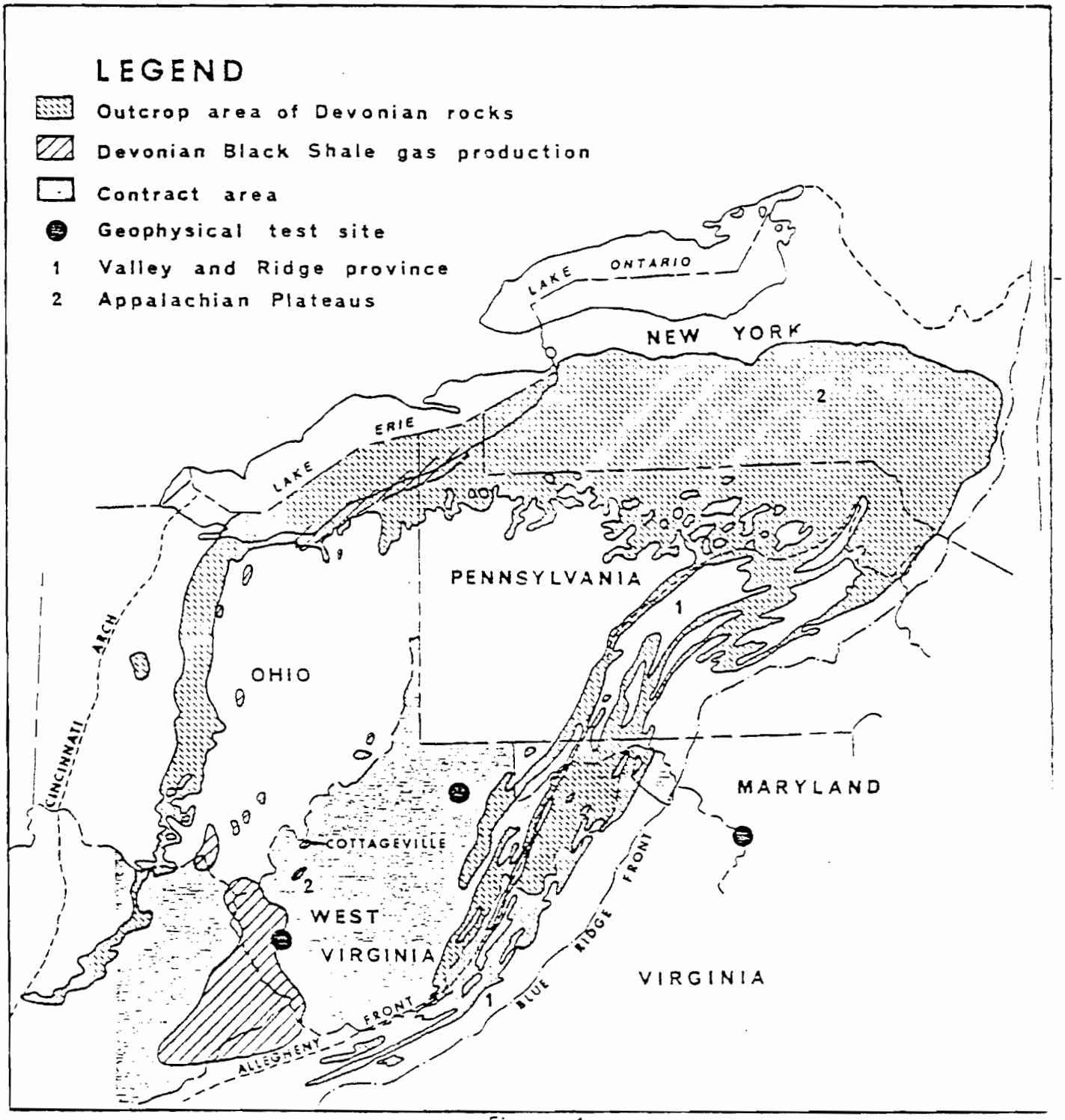
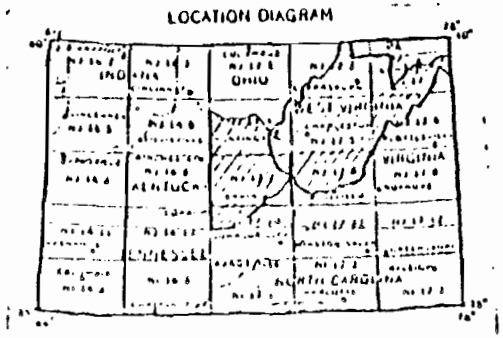


Figure 1

	Dev - oil/gas	Linears	Joints	Drainage	Surface Form Lin	Surface Tectonic	Greenbrier	Berea	Dev. Shale	Shale Outcrop	Penetration Sha	Tully	Onondaga	Newburg	Conasauga - ?	Precambrian									
Clarksburg NJ 17-2	P			C	R	C	P				PI		P		C	P									
Cumberland NJ 17-3	N				R		P				PI		P		C	P									
Huntington NJ 17-4	P		C	R	R	C	P	P		R	PI		P		C	P									
Charleston NJ 17-5	P			R	R	C	P	P			PI		P		C	P									
Charlottesville NJ 17-6	N						P						P			P									
Jenkins NJ 17-7	P		C			C	P	P			PI		P		C	P									
Bluefield NJ 17-8	P			R	R	C	P	P			PI		P		C	P									
Louisville NJ 16-6					R*	C*																			
Winchester NJ 16-9					R*	C*																			
Corbin NJ 16-12					R*	C*																			
Johnson City NJ 17-10					R	C																			

LOCATION DIAGRAM



Regional Structure
MAP STATUS

scale 1:250,000

R.C. Shumaker (304) 293-5603

N = Formation or Production not present
C = Compiling data
R = Rough copy completed
P = Preliminary map completed
X = Final draft completed
* = Not within area of responsibility but available upon request
PI = Petroleum information map on hand

FIGURE 2

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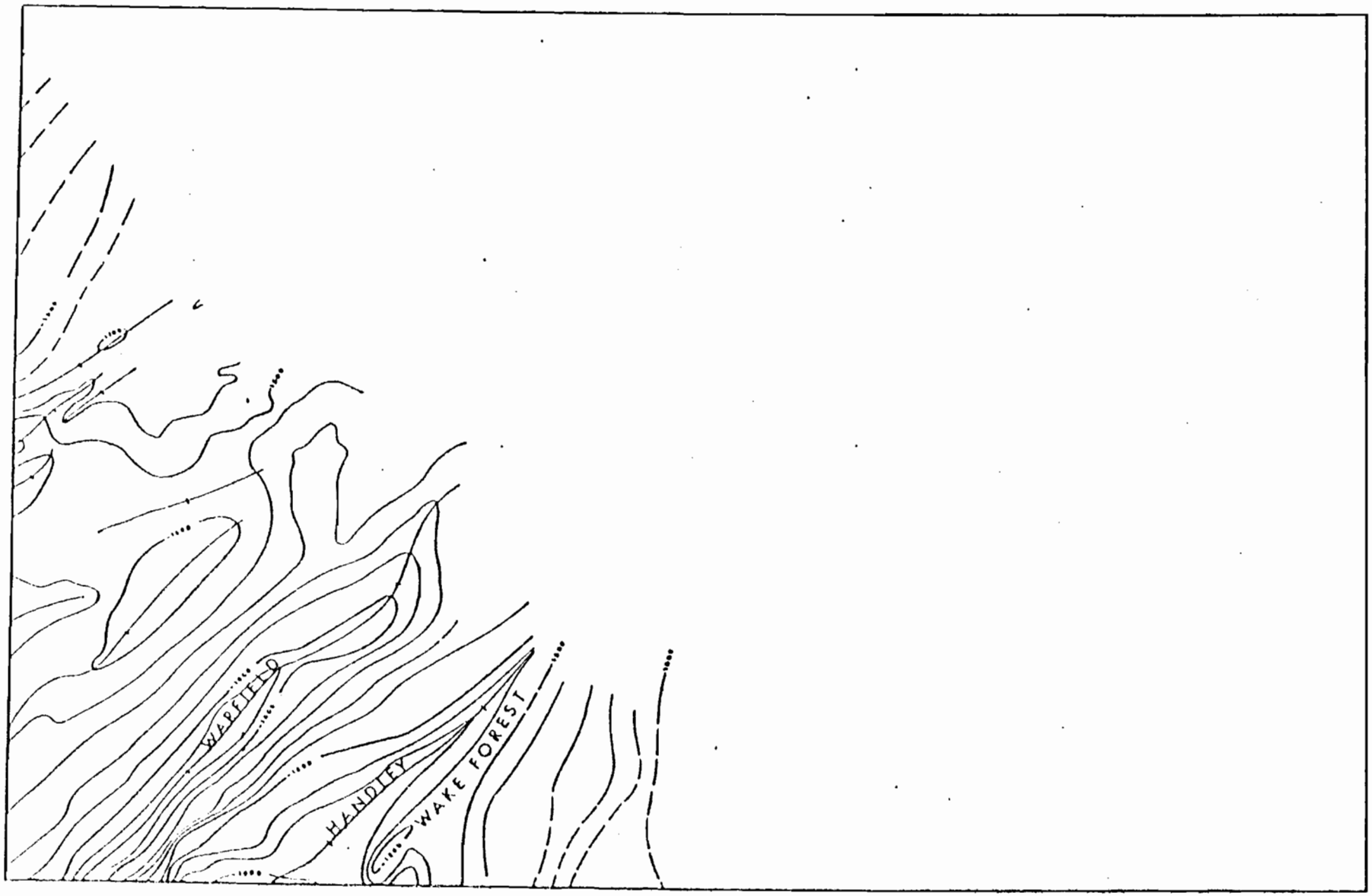
Figure 3

PRELIMINARY

BEREA STRUCTURE



Datum: Top of the Berea
CREDITS: J. L. Hoefner,
West Virginia Geological
and Economic Survey,
1983

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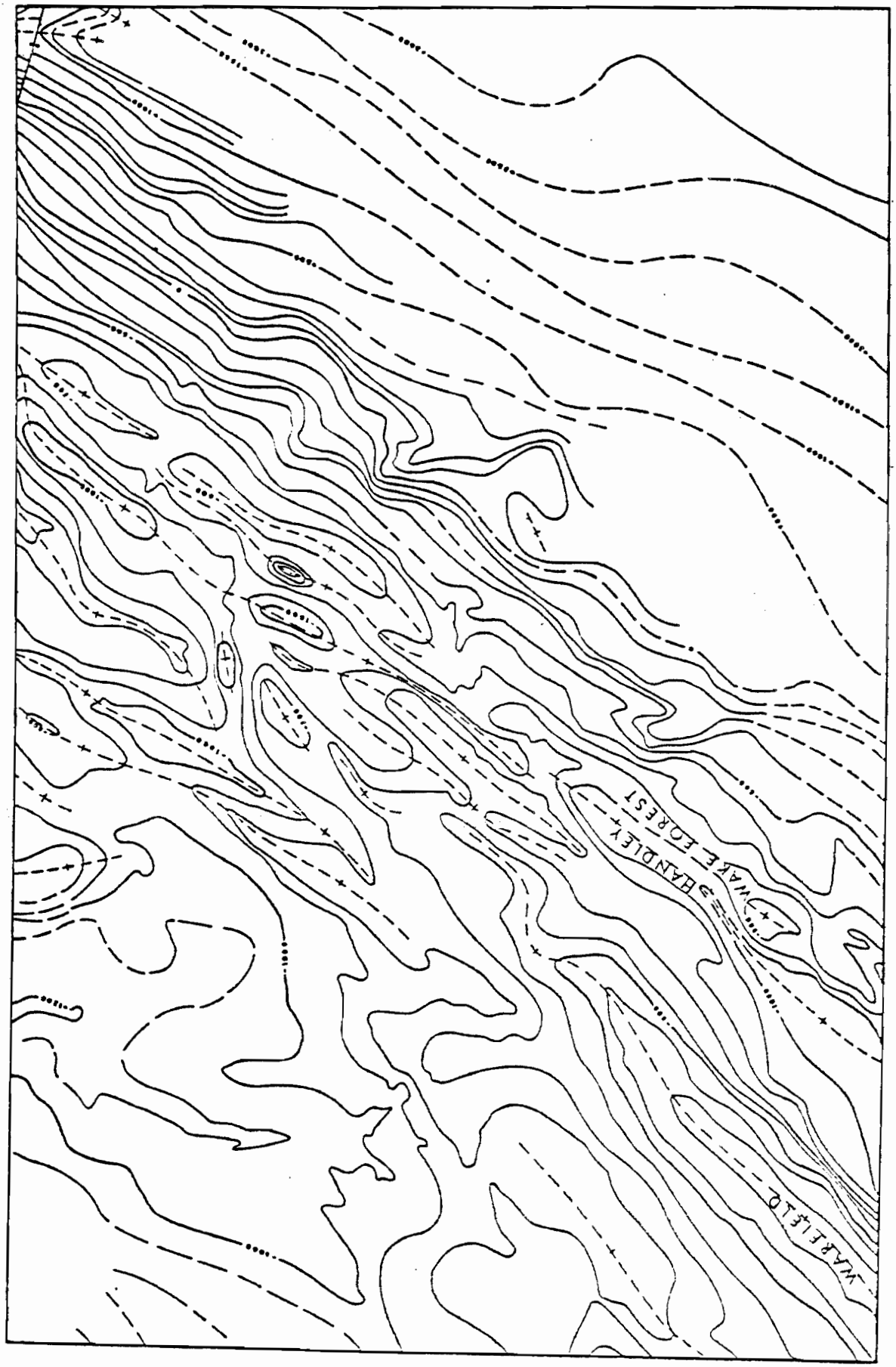
PRELIMINARY

GREENBRIER STRUCTURE

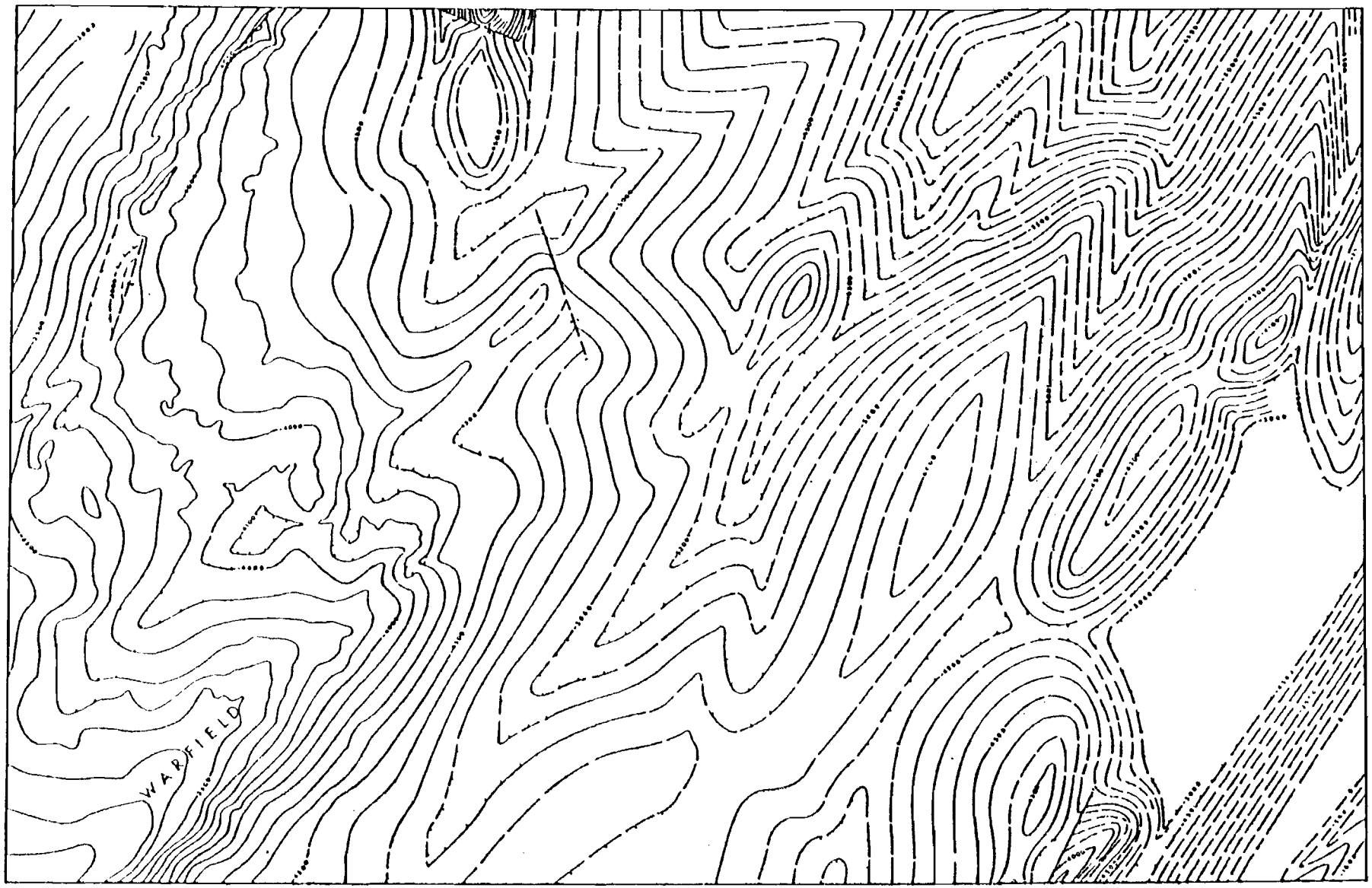
Figure 4



PRELIMINARY

ONONDAGA STRUCTURE

Figure 5



Datum: Top of the Onondaga or equivalent
CREDITS: D. H. Caldwell, West Virginia Geological and Economic Survey, 1973

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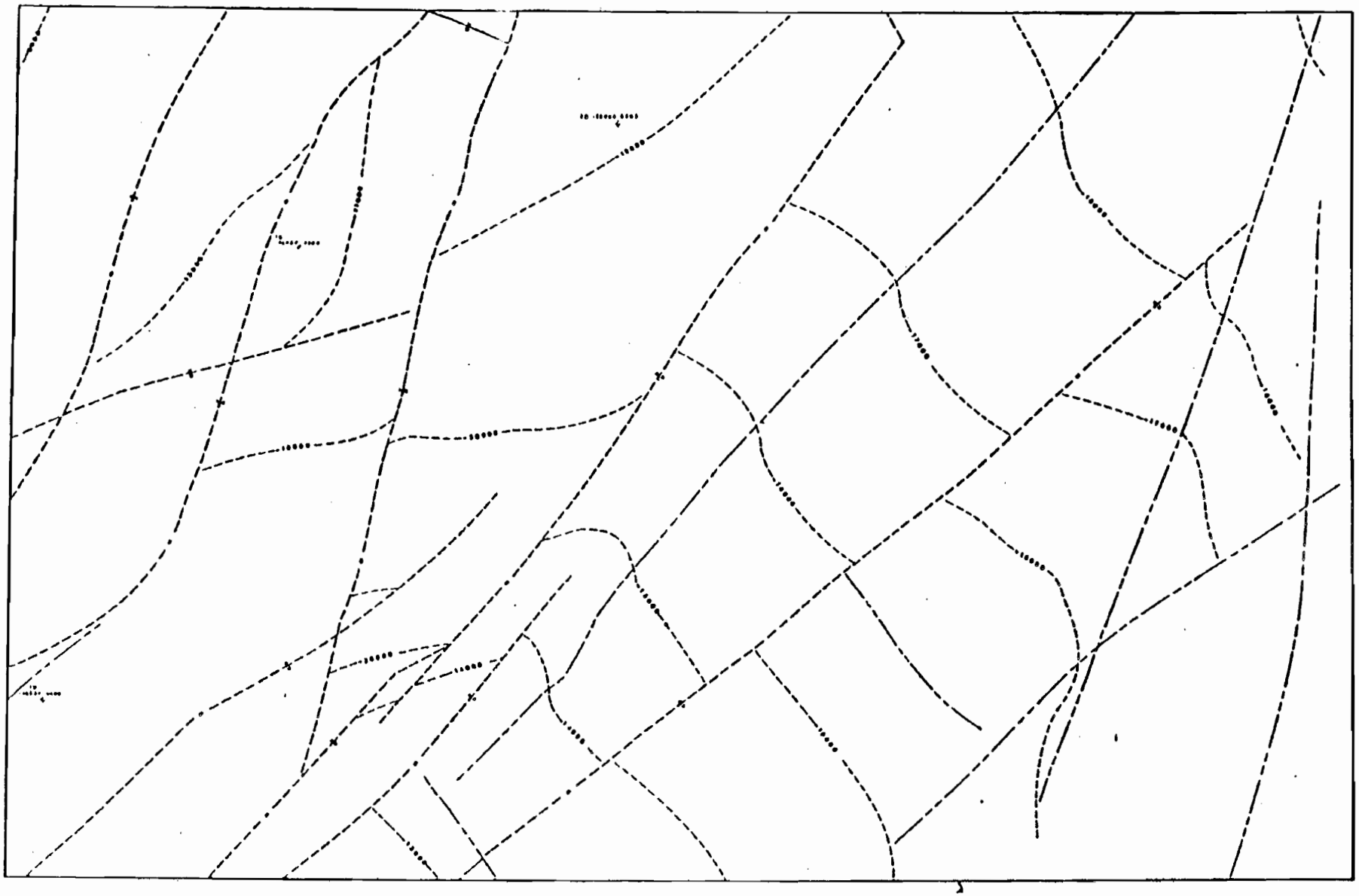
Figure 6

PRELIMINARY

BASEMENT STRUCTURE



Datum: Top of the Basement
CREDITS: Well data from
D. H. Cardwell, West
Virginia Geological and
Economic Survey, 1977
and S. Dean and
B. Kulander, 1977

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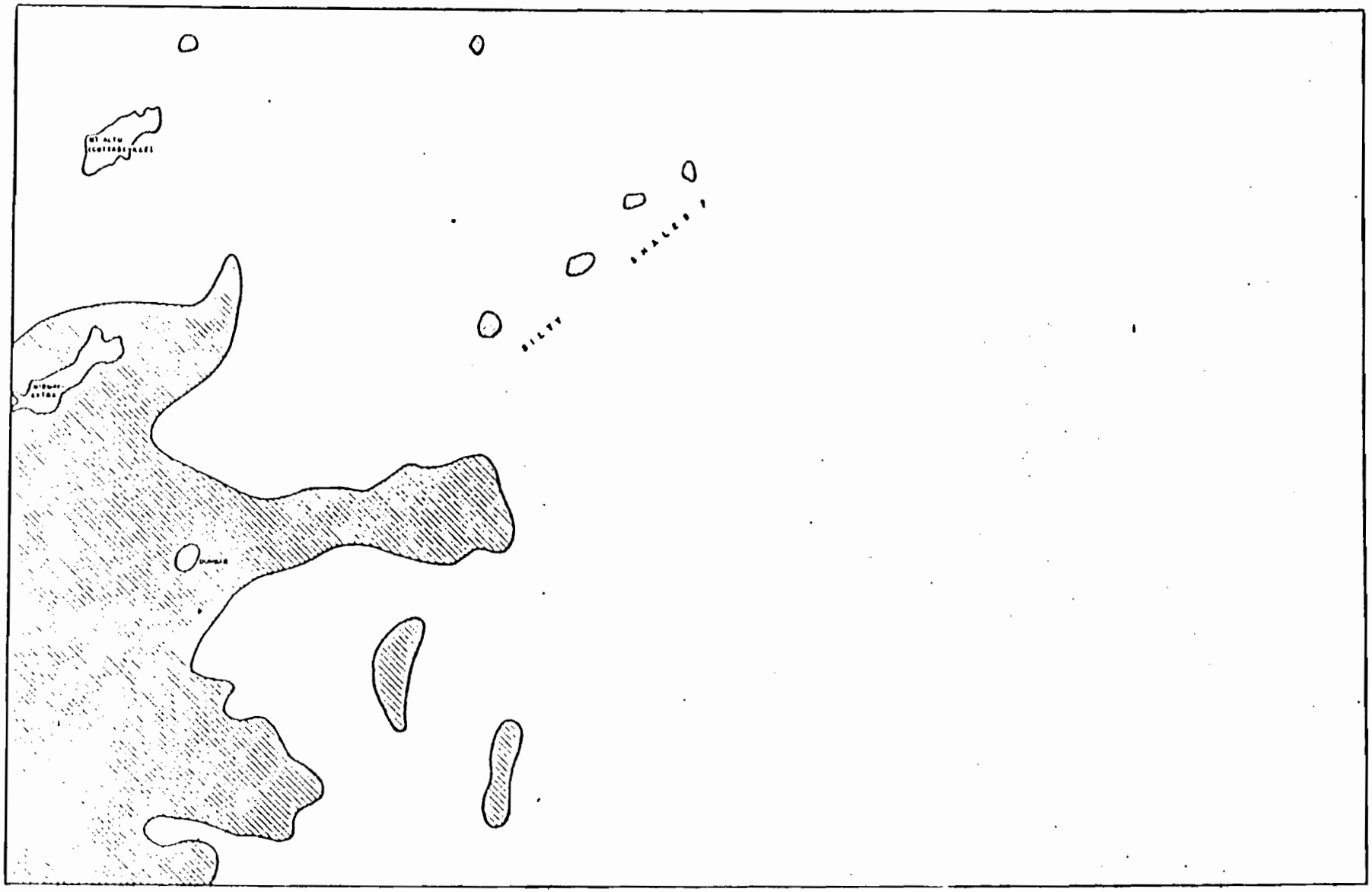
Figure 7

PRELIMINARY

DEVONIAN SHALE GAS PRODUCTION



CREDITS D.H. Cardwell and staff, West Virginia Geological and Economic Survey, 1976. P. Martin and E.B. Nuckols III, 1976 and W.D. Reynolds and W.M. Ryan, 1976

0 5 10 15 20
MILES

CHARLESTON

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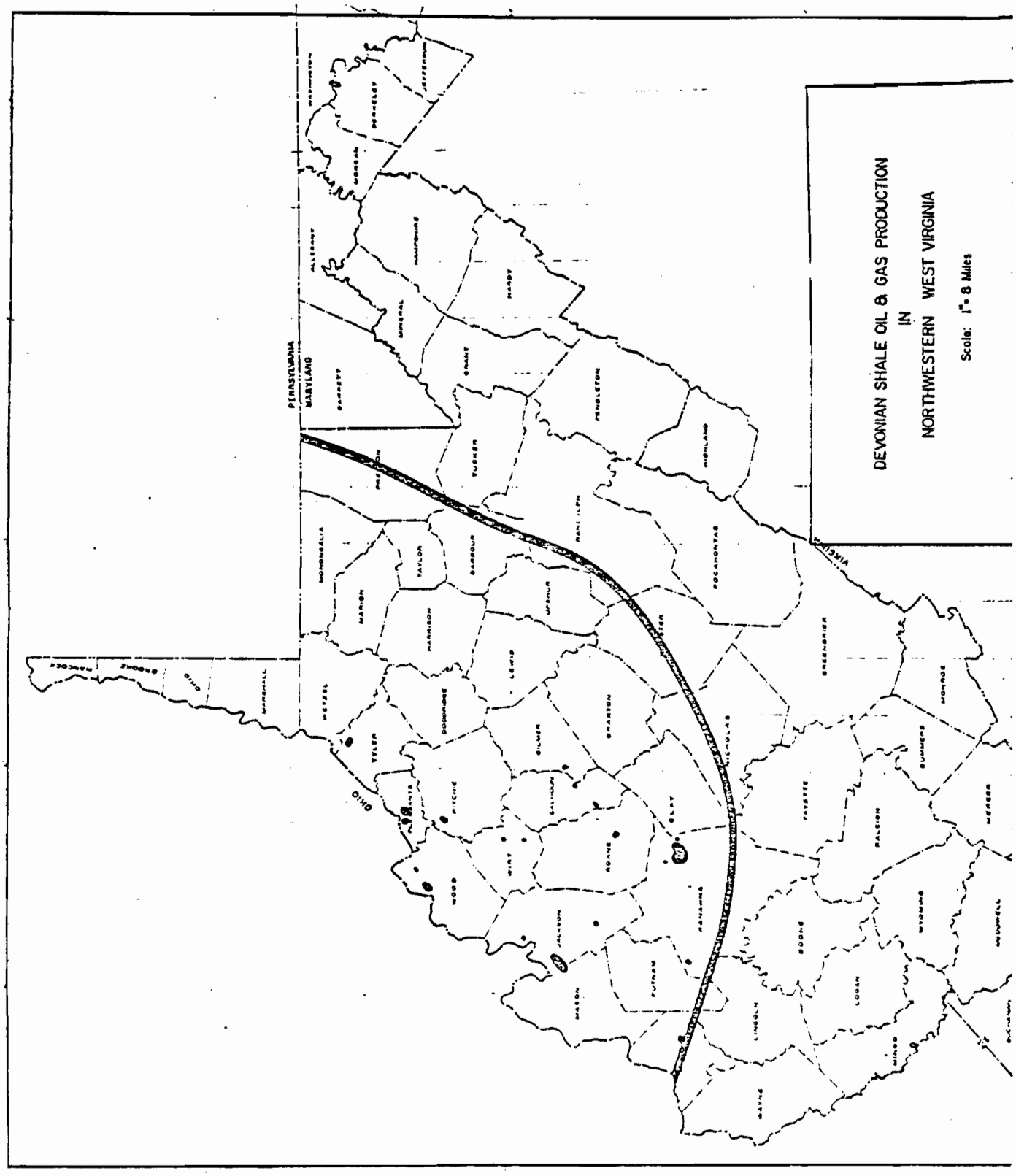


EXISTING DEVONIAN SHALE OIL AND GAS PRODUCTION IN NORTHWESTERN WEST VIRGINIA.
(Martin and Nuckols, 1976). Figure 8

FRACTURE TASK - Brian R. Long

Task 5 under the ERDA grant has begun with a field survey of joints in Devonian shales and associated lithologies in eastern Kentucky. The survey encompassed 130 quadrangles located east of a north-south line running from Maysville to Middlesboro, Kentucky to the state line. Generally, the Kentucky portion of Figure 1 approximates the study area.

The Survey consisted of collecting one or more data points per quadrangle throughout the survey area. Each data point includes a latitude-longitude location, a generalized description of lithologies present, bedding attitude, outcrop trend direction and joint set information.

The joint set information noted in the survey includes strike and dip of the joints arranged in rough trend sets, the average bedding thickness in which a trend set is found, the set's average vertical and horizontal extent, frequency of jointing, relative roughness of the joint surfaces and notations for systematic, non-systematic sets and other information.

Data collected from the survey has not been processed to data, however, a preliminary computer listing of locations, strike, bedding thicknesses, joint frequency and roughness can be found in subsequent pages of this report.

Future work in Task 5 should include the consideration and investigation of several possible joint trend correlations. These should include:

1. Lateral and vertical joint trend directions within units of the same general age.

2. Lateral and vertical joint trend directions within general lithologies (shales, limestones, etc.).

3. Joint trend directions around known natural gas or oil pools.

4. Systematic and non-systematic joint trend variations.

5. Lateral and vertical joint trend directions in specific Devonian shale units.

6. Joint correlation with structural contours.

7. Joint correlation with outcrop trends.

8. Compilation of existing fracture data for the project area.

Other areas of possible future work include the correlation between jointing and faults of different size and type.

Future field work is planned in Kentucky and possibly parts of West Virginia, Ohio and Pennsylvania. This field work will emphasize collection of joint data around oil and gas fields and the vertical and lateral variation of joints in the Devonian shale units.

PRODUCTION TASKS - E. B. Nuckols III

Production search and evaluation of the Cottageville Gas Field near Ripley, West Vriginia was started in January 1977. The field is located near the West Virginia-Ohio border in the West Virginia counties of Mason and Jackson. The purpose of the study is to evaluate and characterize natural gas production from Devonian organic rich shales. Devonian shale production in northwestern West Virginia (Figure 8) may not be truly from shale but from middle and upper Devonian siltstone and sand-siltstones. The only true "shale" producing field may be the Cottageville field.

Geologic Setting

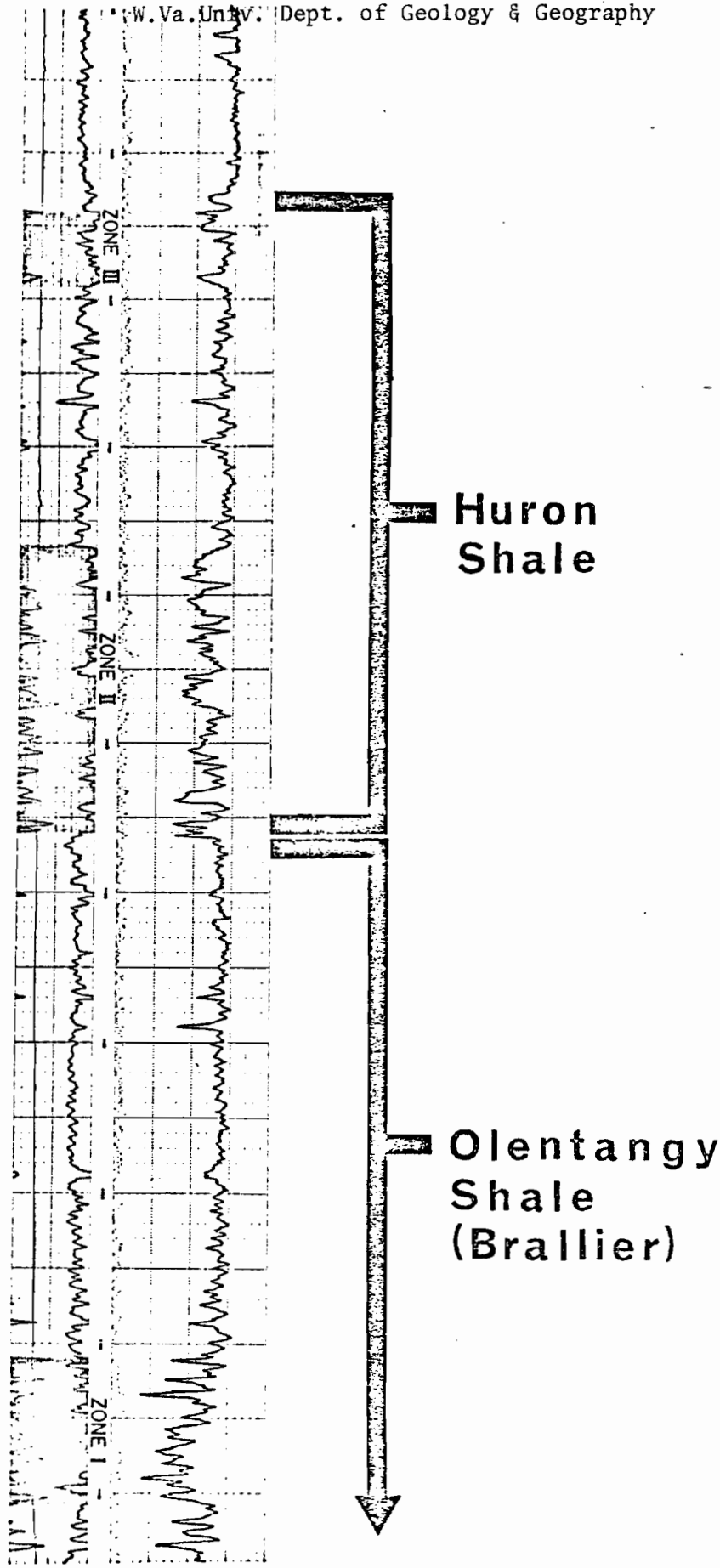
The Devonian age formations that underlie the Cottageville gas field are approximately 2,300 feet thick. The Middle and Upper Devonian shales comprise the upper 2,100 feet of the total Devonian section. The upper contact of the Devonian shales is placed at the base of the Mississippian Age Berea Sandstone, and the lower contact is at the top of the Onondaga Limestone. Within this predominantly shale section are found light grey to

brown-black shales, and light to medium grey siltstones and sandstones. Of the different lithologies, the dark organic rich shale zones occupy approximately 350 feet of 15 percent of the entire shale section. These highly organic shale zones, which are in three stratigraphically distinct portions of the shale section, are easily recognizable on gamma-ray and density logs (Figure 9). The upper two organic zones (Zones II and III) are found within the Huron Shale member of the Ohio Shale. These two zones are mainly composed of dark brown-black organic rich shales, but occasionally they have light to medium grey shale and siltstone interbeds. Separating the lower and upper organic rich shale zones of the Huron are lithologies of shale and siltstone with an occassional thin organic shale bed. Within the Cottageville gas field, these two zones have an average combined thickness of 250 feet, and they are the main reservoirs of Devonian shale gas production. Below the two organic zones found in the Huron is a third organic zone found in the Olentangy Formation. Like the younger organic shales, this organic rich shale has interbeds of light to medium grey shale and siltstones. The lowest organic shale has an average thickness of 100 feet, but it rarely has produced any gas within the Cottageville area. This is mainly due to the fact that it usually has not been drilled.

Production Characteristics

Drilling for shale gas in the Cottageville area began October 9. 1929, when Cities Service spudded their first "shale" well. This well proved to be a meager beginning for the shale field as their well had a natural open flow of only 4.6 Mcf and a 213 Mcf final flow after stimulation by "shooting". At that time, a well with such a small flow could hardly compete with the shallower "plays" in the Berea and Injun sands which annually produced wells with natural flows of several million cubic feet of gas. However, as the field developed, wells with open flows up to 3.4 million cubic feet of gas were drilled, and this encouraged additional developmental drilling.

The primary target for drilling has been the highly organic rich shale zones of the Huron Shale member of the Ohio Shale (known to drillers in Ohio as the Big and Little Cinnamon). A typical drilling program involves setting a string of casing just below the Berea Sandstone. The Berea Sandstone and shallower Salt sands of this area produce large volumes of saltwater and therefor , must be cased off to insure a completion in the Devonian shale section. After the casing is set, the well is usually drilled to a point just below the lower organic shale zone (Zone II) of the Huron Shale. At that depth, the formation is usually tested and a decision is made whether to produce the well naturally if there is sufficient natural flow, or to stimulate the well by shooting if there is no flow of gas or a flow up to several hundred thousand cubic feet of gas. Shooting a well means that canisters of 80% gelled nitroglycerine are lowered into the bore hole and then detonated. Historically, this has proved to be the best method of stimulating shale wells with small natural flows. Some variation in shooting techniques have been tested. One such variation has been "tamping" the shot with pea gravel to contain the explosion. The tamping is designed to retain more energy to fracture the shale. Until the late 1960's, drilling within the field was done exclusively by cable tool drilling rigs so that wells which were stimulated by shooting open hole, without tamping the shot, ran the risk of being clogged by rubble from the shot. If the shot went smoothly,



GAMMA RAY AND DENSITY LOGS PORTRAYING ORGANIC SHALE CHARACTERISTICS IN THE COTTAGEVILLE GAS FIELD, WEST VIRGINIA. Figure 9

the hole would "blow" itself clean. This clean-up aspect of production stimulation was very critical, because a shot that did not clean the hole stood the chance of losing a part or even all of its production potential. With the adoption of air rotary drilling, wells could either be "tamped" or shot naturally, and then careful reentry techniques could be used to successfully clean out the remaining rubble.

After some fourty-eight years of in-field drilling, approximately one hundred and three shale wells have been drilled in the Cottageville field. Consolidated Supply Corporation has drilled more wells than any company (43); Columbia Gas Transmission Corporation and Cities Service have drilled 17 and 16 respectively. The highest natural flow encountered was 3480 Mcf., and the highest stimulated flow was 1981 Mcf (this well had only a natural flow of 36 Mcf). With the passage of time, rock pressures have generally decreased as the number of wells drilled to the reservoir increased. The highest initial rock pressure taken was 1000 pounds per square inch early in the history of this field.

At the present time, wells encounter rock pressures of 150-300 pounds per square inch. Several wells have good production histories, but one in particular has produced over 952,500 Mcf in twenty-six years. Found below are a few statistical averages concerning production within the field:

NATURAL OPEN FLOWS (81 wells)	180.2 Mcf
FLOWS AFTER SHOT STIMULATION (90 wells)	355 Mcf
ROCK PRESSURE TEST (77 wells)	639.6 lbs/psi
ACCUMULATIVE PRODUCTION (77 wells)	10.08 Bcf
AVERAGE ACCUMULATIVE PRODUCTION PER WELL	137.7 Mcf

Specific well results for individual wells can be found in Appendix As of this time, approximately 85% of all production and production related data has been inspected. The remaining 15% of the well data to be inspected by November 1977. Of this 15% it seems probable that we will not be able to obtain half of the data.

Effect of Reservoir Fracturing

Of the three organic rich shale zones within the Devonian shale section, only the Huron organic shales have been extensively drilled and stimulated. The primary gas reservoir in the Cottageville gas field is the lower organic shale zone of the Huron member (Martin and Nuckols, 1974). Stimulation of this organic shale zone by shooting has greatly increased the volume of gas produced from this field. However, the gas probably comes from naturally occuring open fractures that were either penetrated by drilling or that were interconnected to the well bore by shooting.

In 1975, Consolidated Gas Supply Corporation and the Energy Research and Development Administration entered into an agreement to core and analyze the organic shale section from two wells (Figure 10) in the Cottageville field. The first core was taken in a well near the Jackson-Mason County line (Figure 10). Coring of the lower Huron shale was interrupted when an initial gas flow of approximately 3.5 MMcf was encountered. This flow finally stabilized at 1007 Mcf. Close inspection of the core revealed natural fractures with secondary deposits of dolomite and calcite along the fracture plane the zone that encountered the large gas flow. A core was taken in a second well drilled in the northwest portion of the field. Unlike the first core, there were few natural fractures in the organic shales, and the well tested

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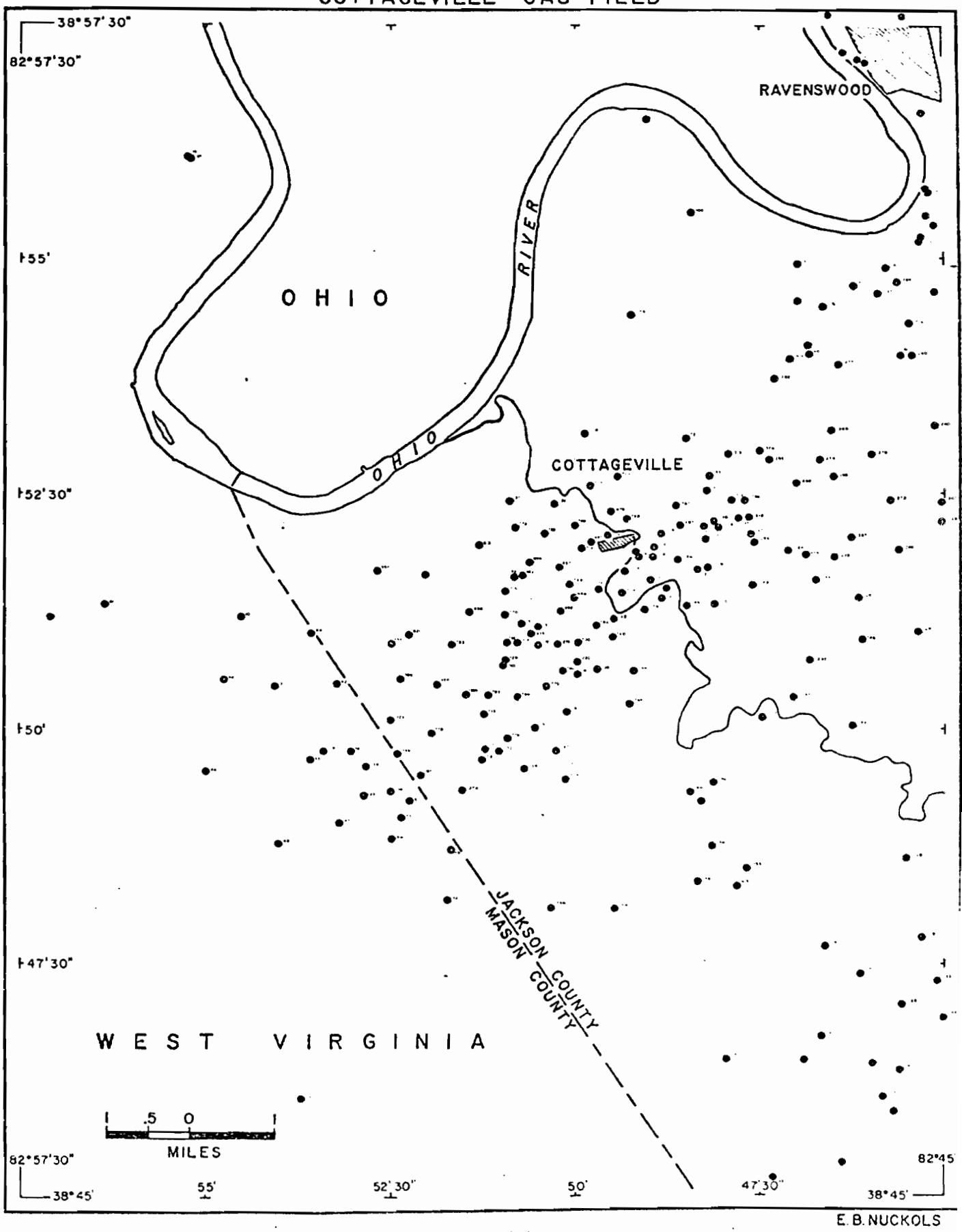
COTTAGEVILLE GAS FIELD



E.B.NUCKOLS

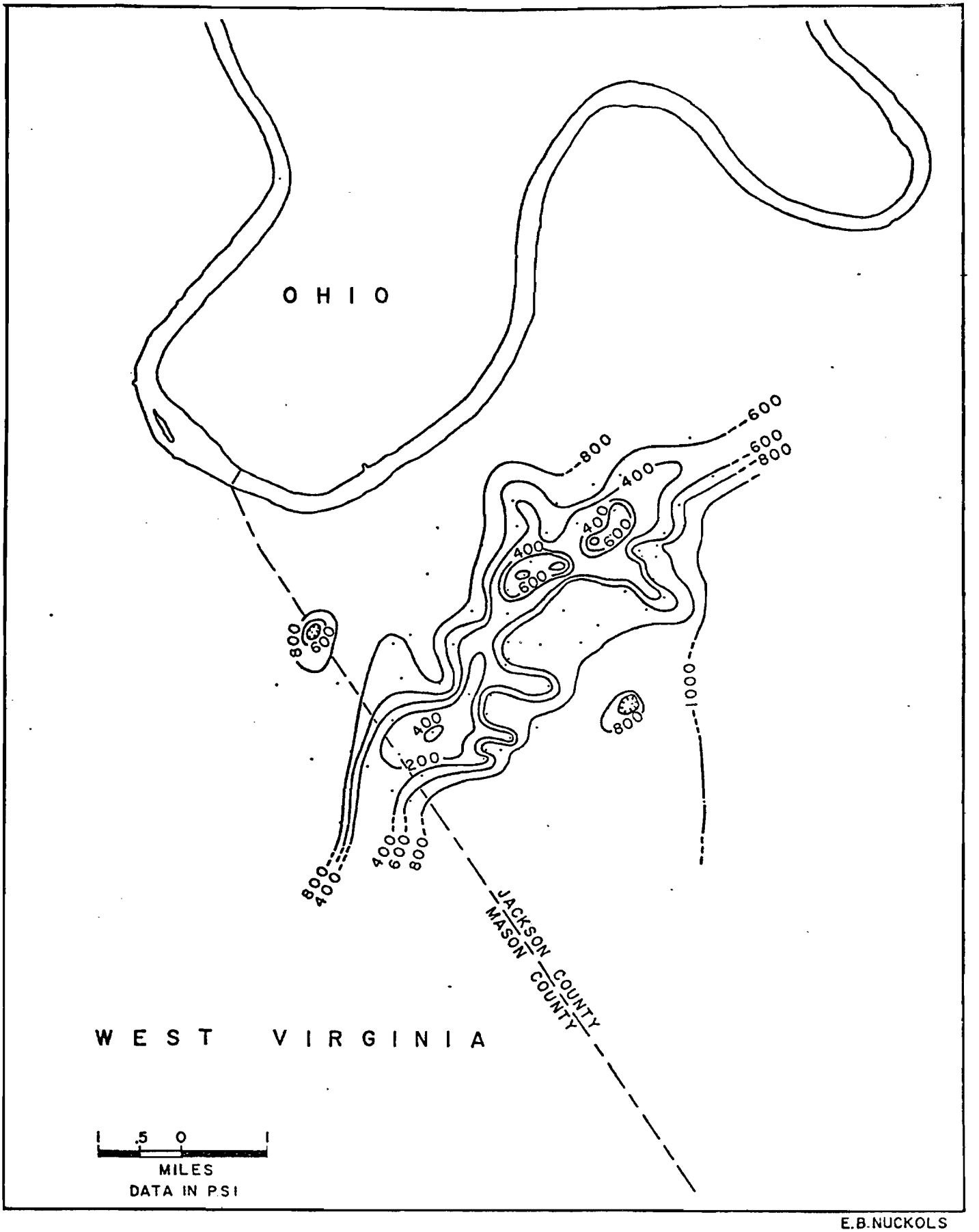
COTTAGEVILLE GAS FIELD WITH FLANKING DEVONIAN ORISKANY AND SILURIAN "NEWBURG" WELLS TO THE EAST. Figure 10

dry. Detailed laboratory analysis of both cores revealed low matrix porosities of less than 3% average and low permeabilities of less than .01 millidarcy. In as much as the rock of both cores are lithologically similar, we presume that the main difference in permeability relates directly to the mineralized fractures. This was the first diredt evi-eence that fracturing is critical to production, a conclusion that most geologists and engineers has presumed to be true.

Production characteristics of the field may indirectly indicate fracture trends in the reservoir. It would be expected that the trend of open fractures would be reflected by linearity of many producing parameters. To test this assumption preliminary isopressure, isoflow, and isoproduction maps were drawn to see if there were any prominent linear trends.

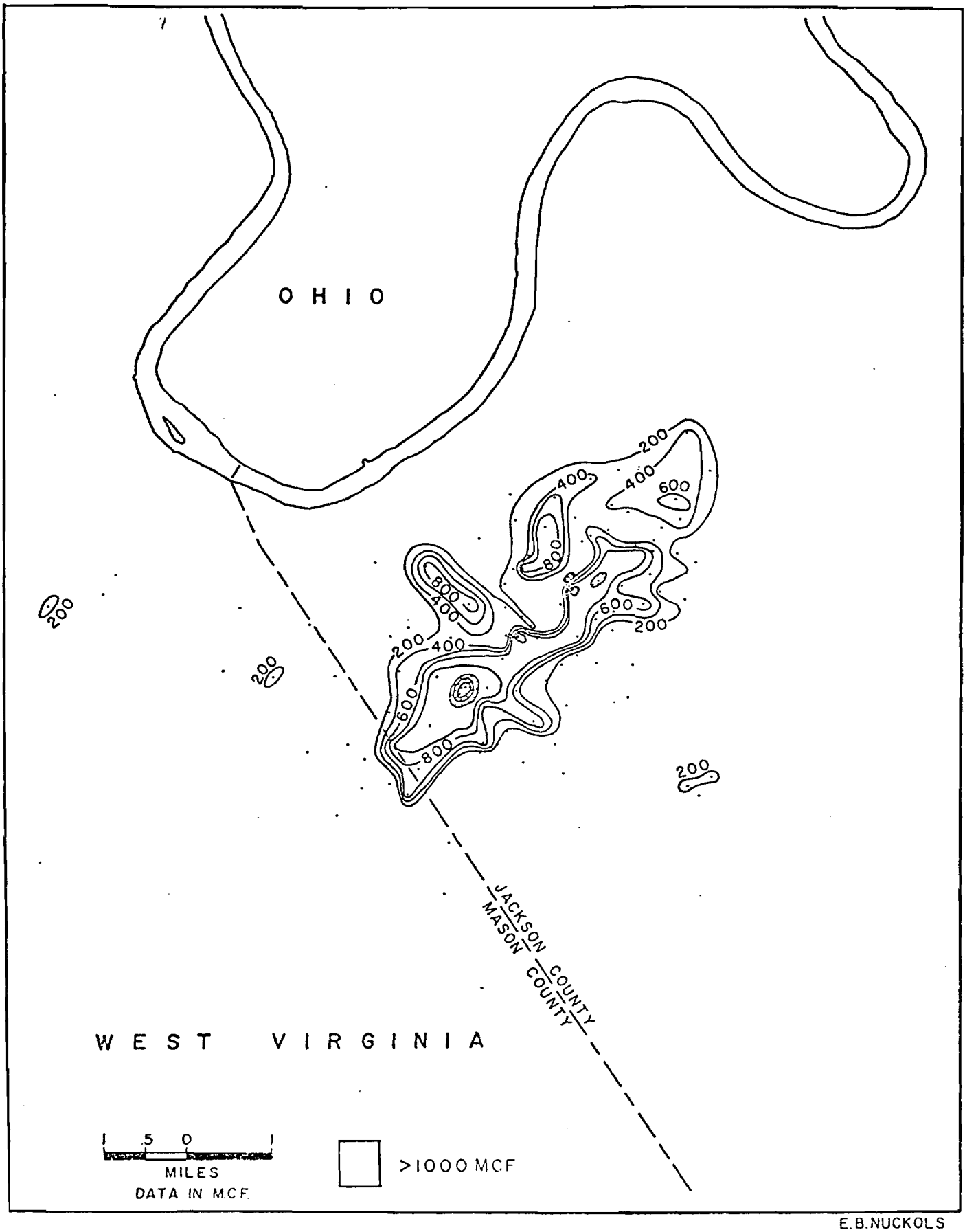
An isopressure map (Figure 11) was constructed from well-head pressures taken immediately after completion of a well but prior to the wells initial production. There are two important modifying factors that complicate interpretation of the data and resulting map. First, the well-head pressures were taken at various times after completion of the wells. Shut-in times ranged from a few hours to fourteen days. Wells that were shut-in for only a few hours probably did not reach their full potential rock pressure. Secondly, registration of true formation pressure may be altered by rubble in a well bore from the shot or caving shortly after the withdrawal of drilling equipment. This rubble may block off some production and reduce the initial rock pressure test. A less important factor in analyzing initial rock pressure test is the possibility that not all of the gas is being produced from the zone of interest, and that gas could be coming from a shallow zone with less pressure. From the isopressure map (Figure 11) a linear trend of approximately N 40° can be seen. A general linear trough of low pressures trends through the axis of the field, but there are two areas of high pressure in the north central portion of the field. Flanking this trough on either side are areas that are interpreted to be at their "virgin" rock pressures. The two high pressure areas in the north central portion of the field were drilled early in the development of the field. The figures in these two areas may be indicative of virgin rock pressures. Low "bulge" areas of low rock pressures normal to the axial trend of the field are thought to reflect the more recent drilling activity in these areas. Preliminary inspection of initial rock-pressure data indicates a linear relationship between field rock pressure and time. As wells are drilled rock pressures decline. At the present time, drilling encounters pressures that are only 35 to 40 percent of originil field pressures. We intend to more thoroughly investigate the relationships between field production and declining reservoir pressure. Of major interest will be the extent of linearity with the passage of time.

An isoflow map (Figure 12) was constructed from open flow data. The data on this preliminary map does not discriminate as to whether the well produced naturally or whether it has been stimulated. Open flow tests should also be affected by the amount of time permitted between the test and the time the well was completed. Natural open-flow tests on several wells were taken immediately after the well was stimulated by shooting (less than three hours). Other tests were taken several days after completion. We hope to normalize the data for more accurate comparison between wells.



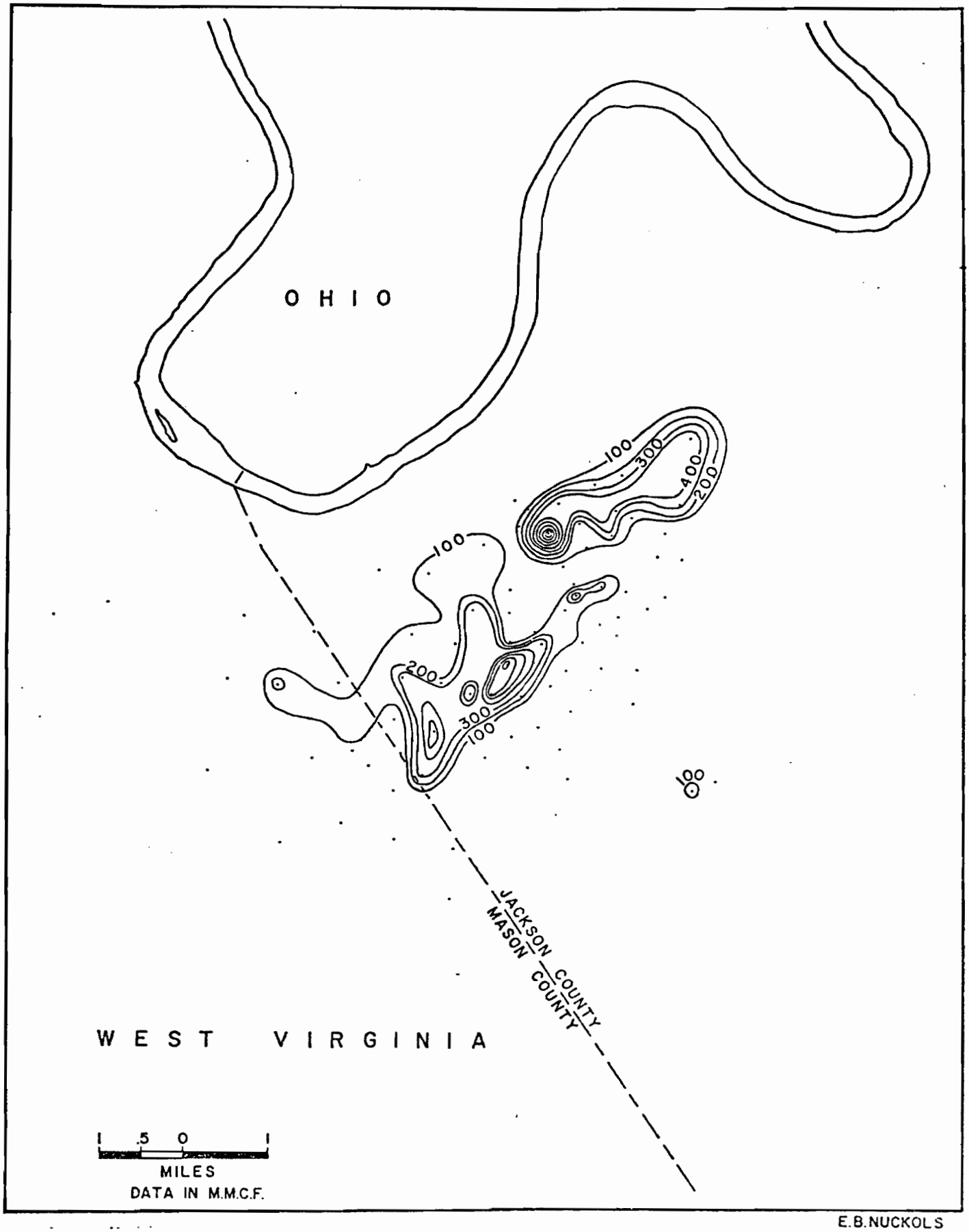
E.B.NUCKOLS

ISOPRESSURE MAP: ROCK PRESSURE TESTS TAKEN AFTER COMPLETION OF WELLS BUT PRIOR TO PRODUCTION. CONTOUR INTERVAL: 100 lbs/sq.in. Figure 11



E.B.NUCKOLS

ISOFLOW MAP: FINAL OPEN FLOWS REGARDLESS OF NATURAL OR STIMULATED PRODUCTION.
CONTOUR INTERVAL: 200 Mcf (0-1000 Mcf) 1000 Mcf (1000-3000 Mcf). Figure 12



E.B.NUCKOLS

ISOPRODUCTION MAP: TOTAL ACCUMULATIVE PRODUCTION PER WELL AS OF DECEMBER 31, 1976.
CONTOUR INTERVAL: 200 MMcf. Figure 13

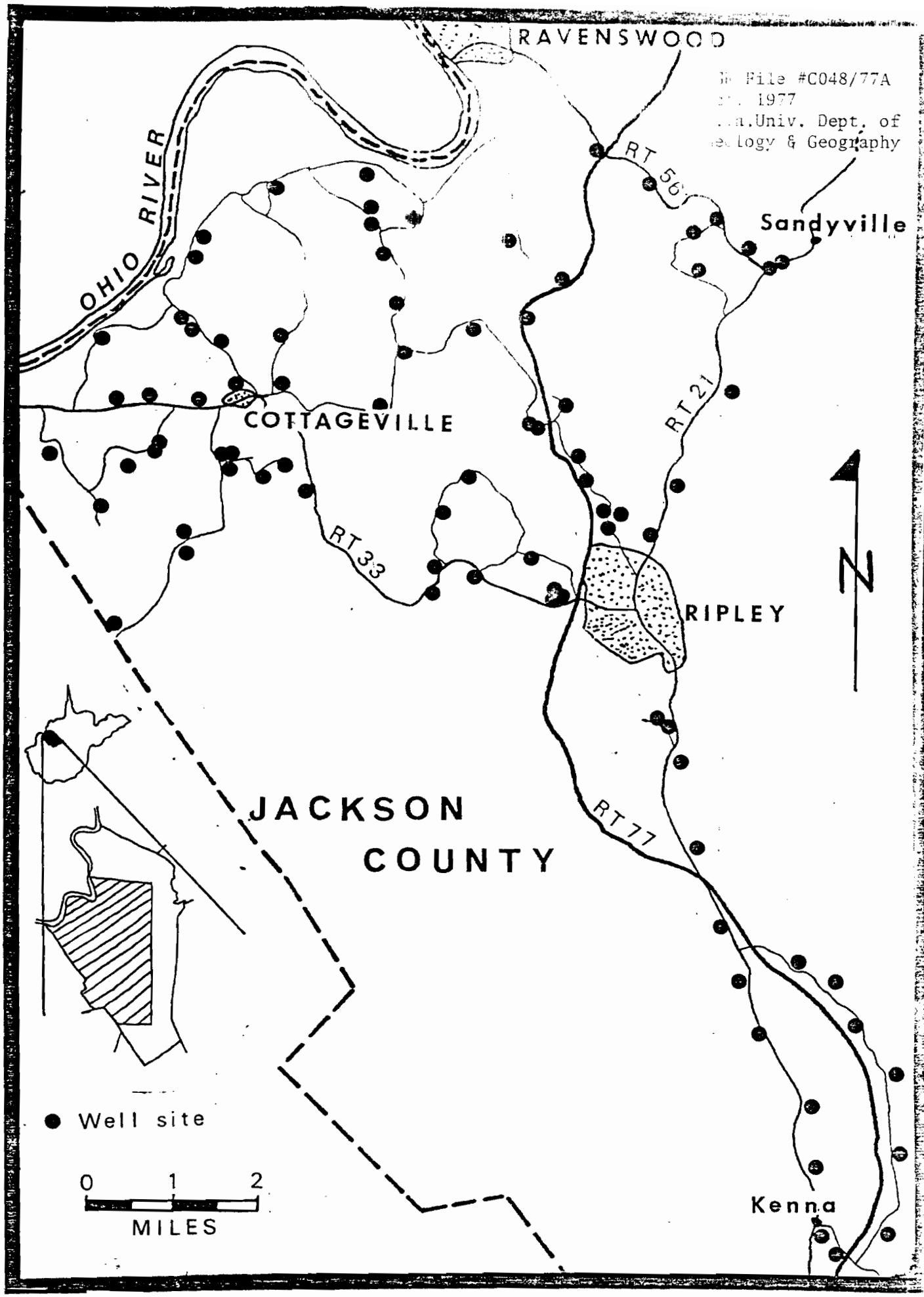


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Figure 14 GROUNDWATER TASK STUDY AREA SHOWING WATER WELL LOCATIONS

The area of highest flow is in the southern part of the field just north of the Jackson-Mason county line. The northeast-southeast linear trends seen in the isoflow map (Figure 12) may again reflect the trend of open fractures in the reservoir.

An isoproduction map (Figure 13) was drawn based on inspection of production records of Consolidated Gas Supply Corporation, Columbia Gas Transmission Company and Cities Service. Certain of the wells have been abandoned while others have just been completed, so the amount of data varies greatly from well to well. This map, like the isopressure and isoflow maps, shows a general linear trend of N 40° E. Unlike the other map configurations, there are two definite areas of better production; one area being in the southern end of the field, near the Jackson-Mason County line, and the other to the north. The exact significance of this observation is not known. We can only presume that there wells encountered more open fractures.

These preliminary production related maps will be revised and reevaluated as more data becomes available. To characterize the field in greater detail structural, isopach, and production related maps will be made. Three different horizons will be considered for structural contouring; the top of the Mississippian Berea Sandstone, the bottom of the Devonian Huron Shale, and the top of the Devonian Onondaga Limestone. Isopach maps of each of the organic shale zones will be constructed, but the construction of an isopach map of the organic shale of Zone 1 may not be practical due to limited data. From production data, decline curves will be made and compared to see if significant groups of wells exist from these curves. We also hope to more precisely determine what effect treatment has had on production characteristics and at what point in the life of the wells should data be selected to make meaningful maps for display and analysis. In addition to the above maps, several cross sections will be made that relate stratigraphy to production. All of the above maps and illustrations will be completed as of February 1, 1978 and a final report will be completed by April 1, 1978.

GROUNDWATER TASK - D. Scott Jones and Henry Rauch

The area of study lies in the western portion of Jackson County West Virginia (Figure 14). It is bounded on the west by the Ohio River, and to the north and east by the towns of Ravenswood, Sandyville, and Ripley. The field area extends southwestward through the town of Cottageville, terminating at the Jackson-Mason County line. The final portion of the area of study consists of a two mile wide strip of land which is centered upon Route 77 and extends southward from Ripley to the town of Kenna. The entire region is included within five 7 1/2 minute quadrangle maps, namely: Ravenswood, Sandyville, Ripley, Cottageville, and Kenna.

Geologic Setting

Western Jackson County lies within the Appalachian Plateau geologic province. Elevation ranges from over 1000 feet in the Eastern portions of the region

to 550 feet along the Ohio River. The Permo-Pennsylvanian Dunkard Group composed mainly of cyclic sequences of basically horizontally-bedded sandstone, siltstone, grey and red shale, limestone and coal underlies a large portion of the study area. The remainder is made up of Quaternary alluvium--sand, gravel, silt, and clay which is found along the Ohio River.

Purpose and Scope

The overall objective of this study is to determine if water well data are useful in delineating zones of increased fracture permeability and hence future locations for high yielding Devonian shale gas wells. To meet this objective, water well data from this study will be compared statistically to high altitude satellite imagery to lineaments mapped by others, to low-altitude photo lineaments mapped by Mr. Jones and to zones of high-yielding gas wells as determined by others; water-well data to be studied in detail are well yield (in gallons per minute or gallons per minute per foot of drawdown) as well as selected well water quality parameters. This study will in addition, provide a basis for improved future groundwater exploration in Jackson County with respect to anticipated well yield and groundwater quality for new well sites.

Methods of Investigation

Selection of Wells

Approximately eighty wells and one spring were selected for study between May 17, 1977 and September 18, 1977. All were selected by scattered sampling throughout the region under study. The selected spacing between well locations along the study area's roadways was about one mile (see Figure 8).

Physical Well Data

Physical well data for each well were derived from several sources. Information concerning well use, well depth, well diameter, water depth, depth of casing, and well yield were obtained from the well owner or driller or through actual measurement by Mr. Jones. Well elevation and topographic setting were found through the use of selected 7 1/2 minute quadrangle maps. These physical well data are listed in Table 1. The major aquifers supplying water to a well will be determined and reported at a future date.

Field Water Sampling and Analysis

In obtaining well water samples for chemical analysis, a spigot (usually outside the house) was turned on, allowing the water to run for several minutes to obtain fresh ground water samples. The lowest temperature of the water was then recorded using a Celsius thermometer. Next, the specific conductance of the water was determined using a Beckman Solu Bridge Specific conductance meter. Two water samples were taken from each well in one-liter plastic bottles. One sample was treated with 5-10 drops of concentrated HCl to prevent the precipitation of dissolved iron, while the other sample was treated with an organic liquid biocide to destroy any living organisms that might have been present in the well water. Organisms, especially algae, are capable of changing the concentration or nitrate and certain other water parameters. During later water sampling, a mercuric chloride biocide

was substituted, and added to the acidified samples instead. The samples, particularly the unacidified ones, were stored in an ice chest until they reached the geochemistry laboratory for further analysis.

Laboratory Chemical Analysis

The following laboratory chemical analysis were performed on each well-water sample; in room 206 White Hall: West Virginia University.

(1) pH PH was measured with a Beckman Electromate pH meter.

(2) HCO_3^{-1} Bicarbonate was determined by the alkalinity titration method similar to that used by the U.S. Geological Survey (Brown, et al: 1970). Twenty-five ml of each unacidified samples were titrated by hand with a standard HCl solution (0.0158N). The pH of the solution was constantly monitored, especially in the 4.0-5.0 pH range. The end inflection points of plotted titration curves were then determined, which enabled the calculation of alkalinity and hence bicarbonate (HCO_3^{-1}) concentrations.

(3) Ca^{+2} Both calcium and total hardness were determined by EDTA titration, using a modified procedure modified after that recommended by the Hach Company. Twenty five ml of each acidified sample were titrated for each hardness test.

(4) Cl^{-1} The dissolved chloride concentration was determined by titration with $Hg(NO_3)_2$. using a technique modified after that recommended by the Hach Chemical Company. Twenty five ml of the unacidified samples were titrated for each test.

(5) Na H The concentration of dissolved sodium was determined by atomic absorption analysis of acidified samples, using an EEL atomic absorption spectrophotometer and prepared NaCL standard solutions. This analysis technique is recommended by Brown, et al (1970).

(6) SO_4^{-2} Dissolved sulfate concentration was determined using 25 ml acidified samples and a turbidimetric analysis technique as modified after the recommended Hach company's procedure; the Hach DR-EL colorimetric unit was used in this analysis.

(7) Total iron The total iron content of each acidified sample, originally containing both dissolved and suspended colloidal iron oxyhydroxides, was analyzed using the bipyridine method as modified after the Hach company's procedure. The Hach DR-EL colorimeter and 25 ml samples were used.

(8) NO_3^{-1} The concentration of dissolved nitrate was determined by a modified Hach Chemical Company cadmium reduction analysis method and the Hach DR-EL colorimeter. Thirty five ml samples, previously treated with a biocidal agent, were analyzed.

Photo-lineament Mapping

Photo-lineaments are being mapped from low-altitude black and white aerial photography onto 7 1/2 minute topographic maps of the study area; the photography was obtained from the U.S. Agricultural Stabilization and Conservation Service and the West Virginia University Library. Such photo-lineaments are between one quarter mile and one mile long, and are defined by linear or nearly linear streams, valley depressions and soil tonal streaks. This definition is in accord with that recommended by Lattman (1958) and Lattman and Parizek (1964); these authors believe that such lineaments often represent subsurface zones of concentrated fracturing and fracture permeability, as evidenced in surface outcrops and in association with higher water-well yields in Pennsylvania.

Statistical Data Analysis

All well yield and well water chemistry data will be analyzed for statistical trends and associations with the photo-lineaments mapped by Mr. Jones as well as with photo-lineaments and satellite imagery lineaments mapped by Eberhard Werner, E. B. Nuckols, and others for the study area. Following this analysis, possible associations of gas well yields with water well yield and ground-water chemistry will be explored by E. B. Nuckols; this final phase will test the ultimate usefulness of the hydrogeologic well data to Devonian shale gas exploration in the Cottageville area. Non-parametric statistical tests will be employed in the data analysis.

Results and Discussion

Physical Well Data

Table 1 lists the physical well data collected for sixty nine wells that were inventoried for this study. A general overview of this table reveals some notable trends. All wells are less than 500 feet deep, while most are domestic wells less than 300 feet in depth. Most well locations range between 600 and 900 feet in elevation above sea level. Reported well yields are extremely variable, ranging from 0.3 to 105 gallons per minute; the media well yield is 3.0 gpm, and almost all wells yield adequate supplies for domestic purposes.

Chemical Water Well Data

Table 2 presents the results of chemical analyses of about sixty five sampled water well A general data overview reveals that most well waters have a high specific conductance and hence a high concentration of total dissolved solids. However, very few wells are apparently polluted with nitrate, sulfate, iron, chloride, or sodium. Only eight wells contain excessive iron (over 0.10 mg/l), one well contains excessive sulfate (over 250 mg/l) one well contains excessive chloride (over 250 mg/l), and one well contains excessive nitrate (over 45 mg/l). Well water quality is in general good, except for the noted cases and also a few wells containing especially hard water.

Acknowledgments

The writers would like to thank Larry Sturm of the West Virginia Soil Conservation Service (Ripley) and Jay Sanders of the mid Ohio Valley Regional Council for their help during this study. Gratitude is also extended Dr. Robert Shumaker,

Keith Kirk and the West Virginia University archives for their valuable support.

Appreciation is expressed to Sally Holland and Eberhard Werner for their helpful comments during the study. And a special thanks is owed to the well owners and well drillers of Jackson county, without whose help this project would not have been possible.

GEOPHYSICS TASK - Keith G. Kirk

The objectives of our geophysical investigations are to determine the feasability of using shallow penetration resistivity and seismic surveys to detect near surface faults of small offset, fractures, and fracture zones; and then to determine if a relationship exists between such fractures and lineations observed on remote sensing imagery.

In order to accomplish these objectives we are developing a new seismic technique that has the potential of locating faults of small displacement and fracture zones at a low cost compared to normal seismic investigations. This technique is known as the Shallow High-Resolution Reflection Profiling method.

Most of the first year of the project has been spent acquiring equipment; designing, building, and testing special seismic amplifiers and filters; and designing and testing a seismic impact source capable of generating sonic signals of sufficient strength and high frequencies.

Shallow High-Resolution Reflection Profiling Technique

In the past ten years advances in digital electronics have led to a new generation of seismographs. These signal-enhancement dynamic digital seismographs have enabled a signal resolution increase up to sixty fold when compared to analog models.

Theoretically, these new instruments using high frequency reflections are capable of detecting beds or fault displacements as small as six inches. Unlike their analog counterparts, these new digital instruments are capable of investigating shallow as well as deep structures. This capability opens up new areas of seismic investigation. These include applications to the coal industry, site evaluation capabilities for the engineering geologist, but most important for the project, a capability of detecting fractures and minor structures for the exploration for natural gas and oil.

During the first quarter of the 1976-1977 fiscal year various pieces of seismic equipment were studied for applicability to the high resolution work. It was determined that a Bison model 1580 signal enhancement seismograph has the greatest capability to accomplish the objectives of our research project considering the budget constraints. We felt that this instrument could be modified to record the high frequency response necessary for high resolution investigations.

Shallow high-resolution reflection profiling (SHRRP) is a new and still developing technique, and for this reason much of the equipment necessary for the method had to be designed and built at West Virginia University. The design, construction and testing of the equipment has taken most of the first years work load.

A very important piece of equipment that was designed, built, tested, and then modified and rebuilt was the special analog filter and amplifier. This system enables high-frequency seismic signals to be received by the seismograph.

High-frequency recording is an absolute must if the detailed investigations required in this task are to be accomplished. Figure 18 illustrates the dependence of resolution on velocity and frequency. One can readily observe that as higher frequencies are used much better resolution is obtained for a given velocity. Figure 18 further illustrates this concept as it shows that for given velocities of 8000 and 12000 ft/sec the resolution varies as a function of frequency alone. Note that as frequency increases thinner and thinner beds can be identified, and thus interpretations of minor offsets are easier to identify.

From this it can be concluded that one simply must use the highest frequency possible to obtain the best resolution. Even though this is true, there are several complicating factors that must be resolved before high-frequency waves can be recorded.

One problem to be overcome is wave attenuation, which is frequently dependent. Experiments have shown that various earth materials, in our case sediments, will pass or filter out certain frequencies. Shales and clays attenuate a given frequency the least, while fine grained sands attenuate a given frequency the most. Field observations have shown that there can be as much as 100 decibels difference between clay and sand in the frequency range of 100 to 500 hz. Figure 15 shows an idealized attenuation curve for the earth. The high frequency work that is being performed at West Virginia University is in the range of 100 to 500 hz. It can be readily observed from figure 15 that between these two frequencies the attenuation varies between -24 and -150 decibels. Unfortunately, the greatest attenuation in the earth is occurring in those frequencies which we find most useful for high resolution work.

In order to resolve this problem we had to attenuate the stronger low-frequency (4-90hz) seismic signals and enhance the weaker high-frequency signals (100-500hz). Solving this problem has occupied most of our time this year. But we have found at least a partial answer. A special seismic amplifier was designed that would filter out low frequency waves and differentially amplify the high-frequency waves. Several breadboard models of this amplifier were constructed and tested before a final design was found to be satisfactory. The response curve for this amplifier is shown in Figure 20 . Note that careful attention has been given to constructing a response curve that closely approximates the inverse earth attenuation function, so that the net result is that frequencies between 100 and 500 hz will have a straight line response. That is to say that these frequencies will all arrive at the

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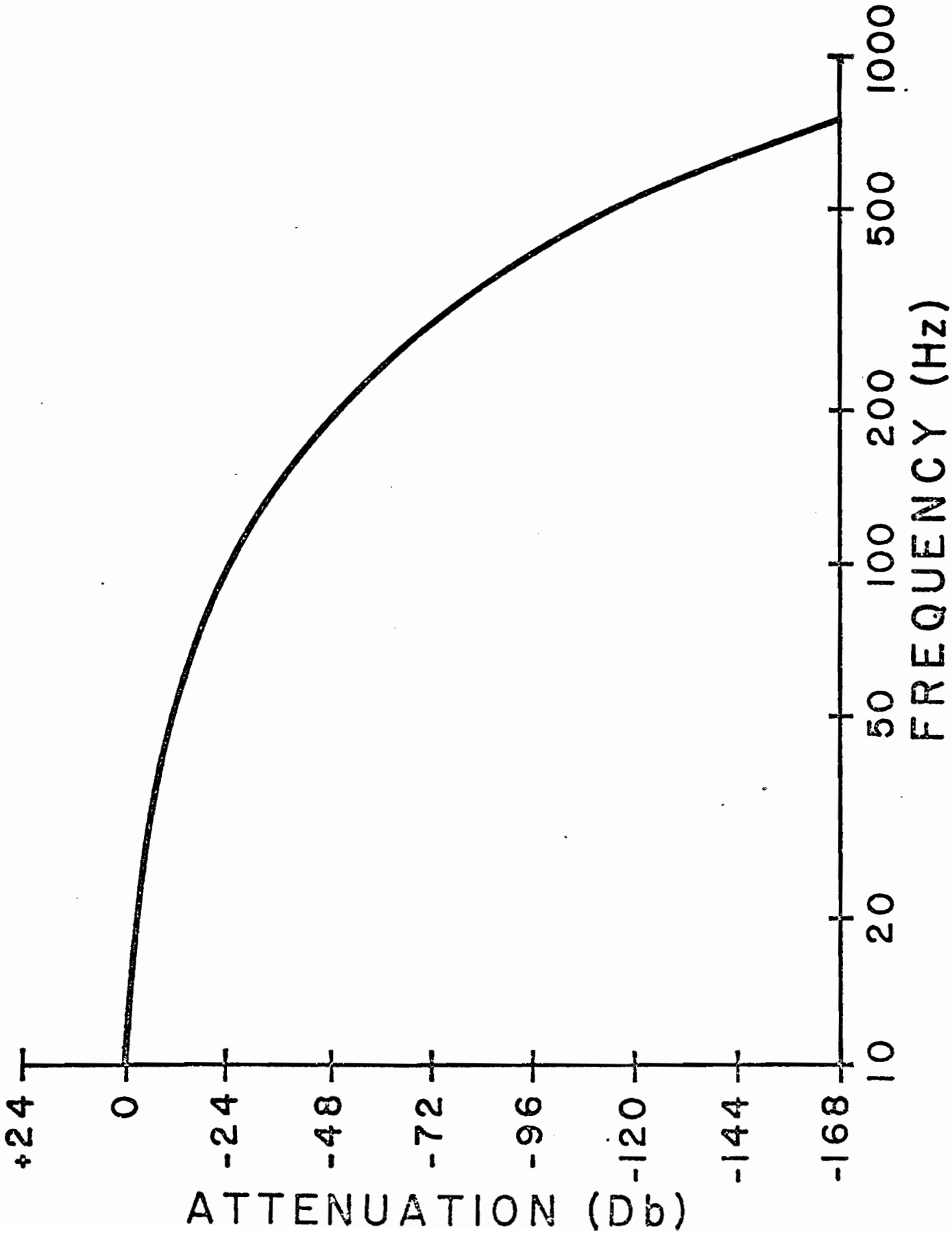

Figure 15

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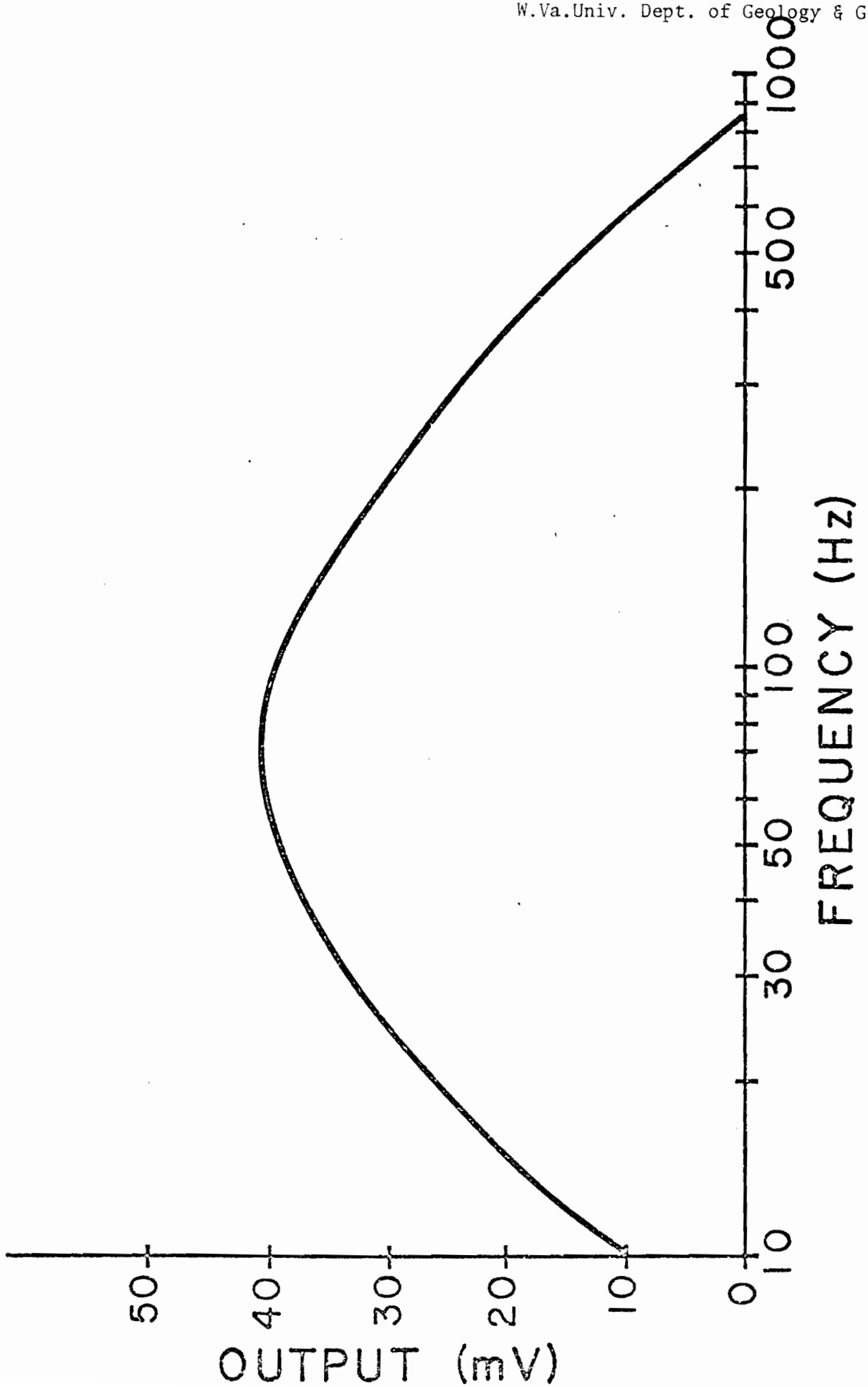

Figure 16

seismograph with approximately equal amplitudes. The amplifier as designed has the capability of changing the response curve to fit the attenuation curve at a given field location. Figure 19 shows a schematic diagram for a single channel of the amplifier. Six channels are incorporated into the final design which is presently under construction.

An additional problem encountered is that commercially available geophones are generally designed to pick up the low frequencies which the earth transmits most effeciently. This problem has been solved with the introduction of the Mark Products L-100 series geophones. Figure 16 illustrates the frequency response of this new generation geophone. Note that the attenuation of the higher frequencies is somewhat accounted for by the slope of the response curve.

Another problem that had to be solved was to determine what seismic source could be used to generate high frequency waves. Traditionally, explosive sources have been used to generate high frequency waves. However, setting explosives charges is both time consuming and expensive, so it was decided to experiment with an impact source in order to keep down expense and to speed up the field survey procedure. Spectrum analysis was run using the Mark Product L-100 geophone on an impact source to determine what frequencies were produced by such a source. As expected, the impact source generated primarily low frequency waves, but as can be seen from the results of the spectrum analysis (Figure 16), frequencies up to 800 hz are obtained. As a result of these experiments a hydraulic impacter was designed and built to be mounted on the front of the geophysics vehicle. This impacter is a modified post driver that has the capability of impacting the ground with 30,000 lbs of force 10 times/minute. Not only does this impacter generate the desired frequencies, it also is an integral part in the signal enhancement process that is critical to the success of the SHRRP tecnnique.

Signal Enhancement

As the size of electrical components have decreased over the years, it has become practical to actually take small computers into the field and incorporate them into the new generation seismographs. These new seismographs are no longer the analog machines of the fifties and sixties, but they are now digital instruments that open up many new areas to seismic investigation. For the purposes of this research, the most significant improvement in this new generation seismic equipment is in field stacking, which is known as signal enhancement. Signal enhancement of deeper reflection permits recognition and correlation of coherent events and a cancellation of random events which reduces background noise.

In the case of the Bison seismograph used for this research endeavor, (see Figure 17) the seismic wave train is received and stored in an active digital memory. Each time the earth is impacted at a given station the reflected signal is added digitally to the active memory for each separate channel. This process discriminates against random background noise by enhancing the desired reflection from the target bed. Figure 17 illustrates the signal enhancement process. Notice that initially the target reflection is indistinguishable from the background noise, but as the number of impacts increase, this reflection becomes prominant and easily identifiable on the seismic record. Generally, without this enhancement capability, the weak

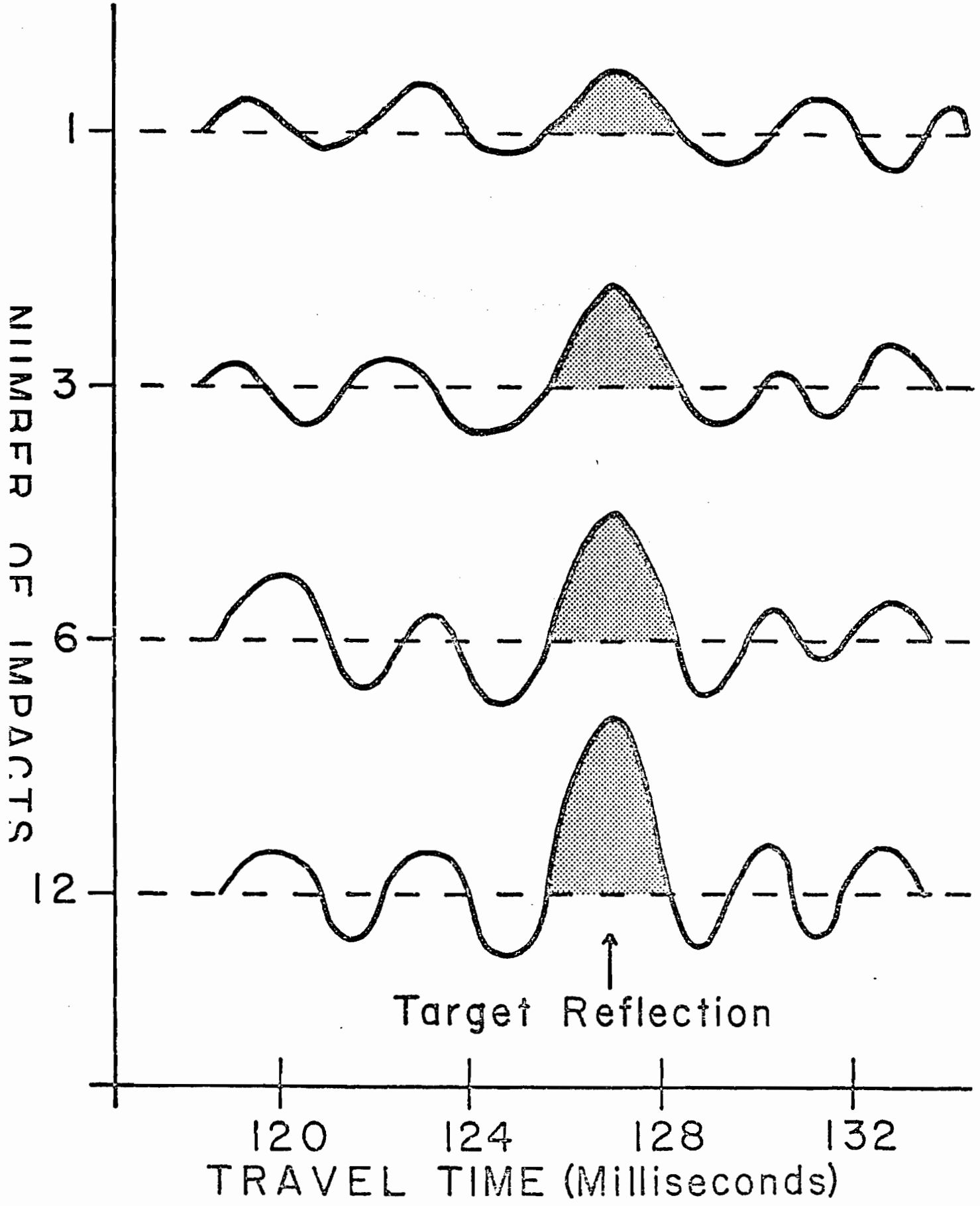
NUMBER OF IMPACTS
1
3
6
12
Target Reflection
120
124
128
132
TRAVEL TIME (Milliseconds)

Figure 17

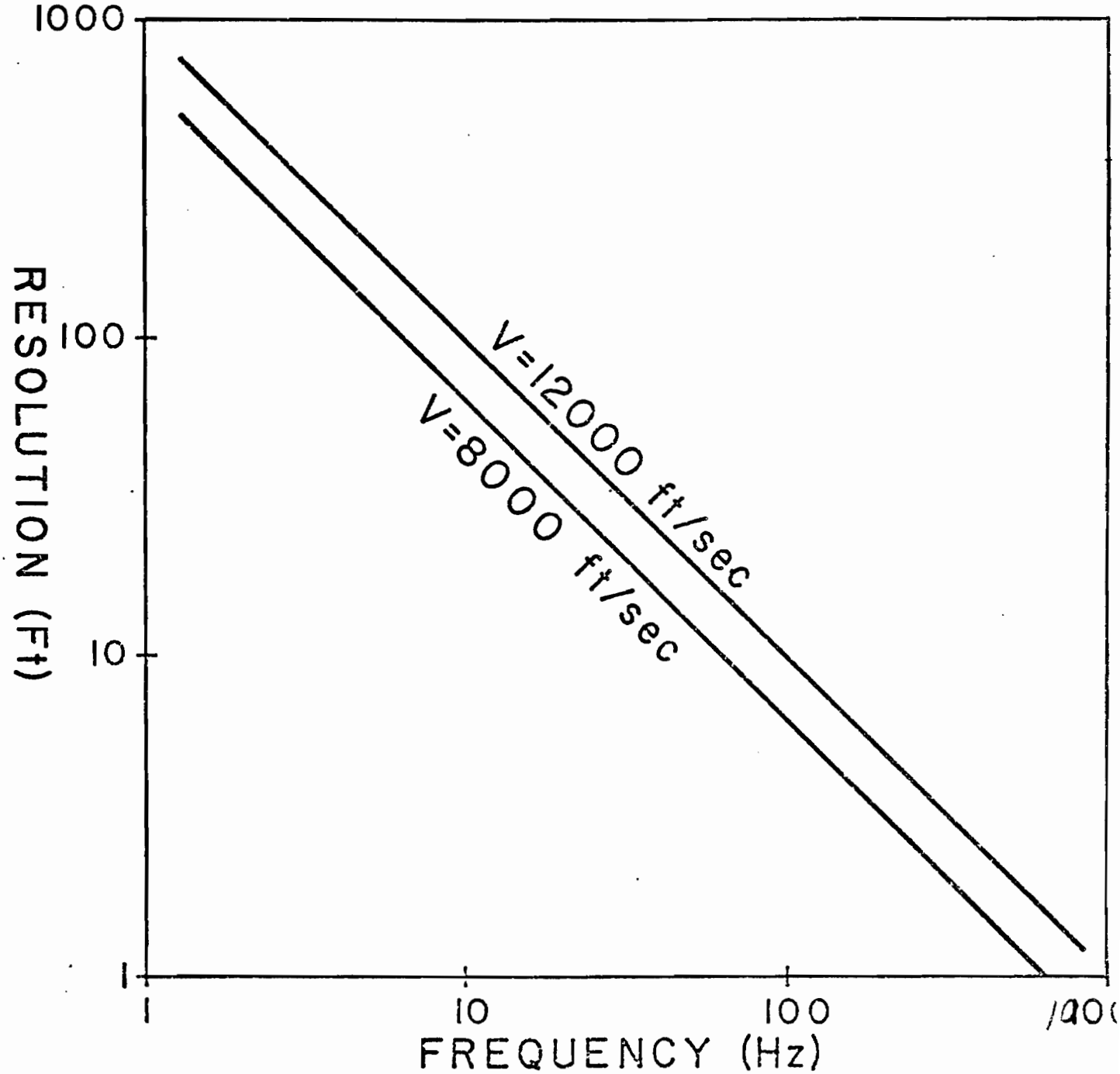

FIGURE 18
PLOT OF RESOLUTION vs FREQUENCY FOR COMMON SEISMIC VELOCITIES

high-frequency reflections would not be identifiable.

Another problem encountered during initial field tests of the seismograph was that of ground roll with noise. The traditional method of eliminating this noise is through the use of mul iple geophones for each channel in order to discriminate against the low-frequency high amplitude surface roll wave train. Experimentation during the third quarter of 1977 showed the multiple geophone array solution to the ground roll problem is unworkable for our equipment. This is because of the extreme difference in the wave lengths involved between ground roll and the signal we desire to record. The typical ground roll wave may have a wavelength of several hundred feet while the wavelengths desired for the high resolution work may be on the order of a few feet. In order to eliminate the ground roll problem the multiple geophone traces are normally strung out about one half wavelength between the two outermost geophones. This often means that the geophones arrays are separated by more than one whole wavelength of the high-frequency waves. The net effect of this procedure is to cancel out both the low frequency ground roll and the high frequency waves; a highly undesirable situation. Experimentation during the third quarter has shown that the best approach to the problem was to dispense with a multiple phone array and use one high-frequency geophone per channel. The low-frequency ground roll was eliminated by the geophone response and by the seismic amplifier response. Both discriminated against low-frequency waves.

Resistivity Program

A second approach to locating fractures will be through the use of resistivity surveys. During 1977, resistivity equipment was purchased and tested. A special switching box was designed and built that permits the use of the tripotential method of resistivity profiling that past research has shown to be extremely effective in locating shallow fracture zones (ref Kirk 1977).

Field Test Sites

As part of the last years activities three sites were chosen to test the two geophysical techniques just described (Figure 1).

The site where the initial testing of the whole system will be performed is near Washington D.C. This site is located at the proposed location of a Washington Metro Subway Station. It was chosen because there are known fractures in the rock at the site and, because as part of a research project sponsored by the Department of Transportation, a large battery of geophysical tests will be performed by other universities and by industry. This information will be used to calibrate the geophysical equipment and to compare resistivity and SHRRP with the other techniques that will be used to locate the known fractures at the site.

The second test site is near Warfield West Virginia. The actual survey will be run across the Warfield Fault. This area was chosen because of the wealth of well data available and because detailed photo lineament analysis has already been performed in this area by ERDA as part of a project involving deviated wells.

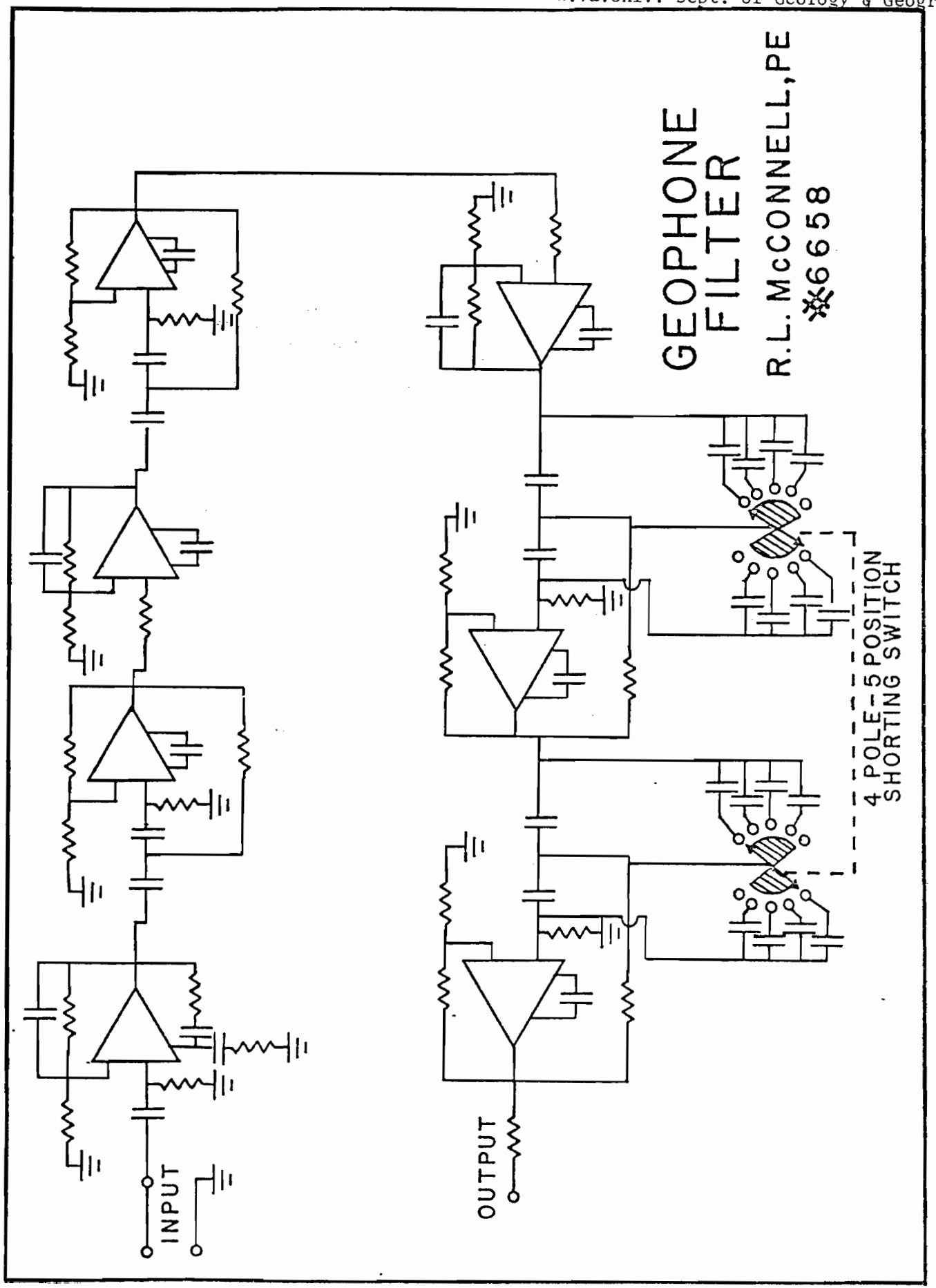
GEOPHONE
FILTER
R.L. McCONNELL, PE
#6658
INPUT
OUTPUT
4 POLE-5 POSITION
SHORTING SWITCH

Figure 19

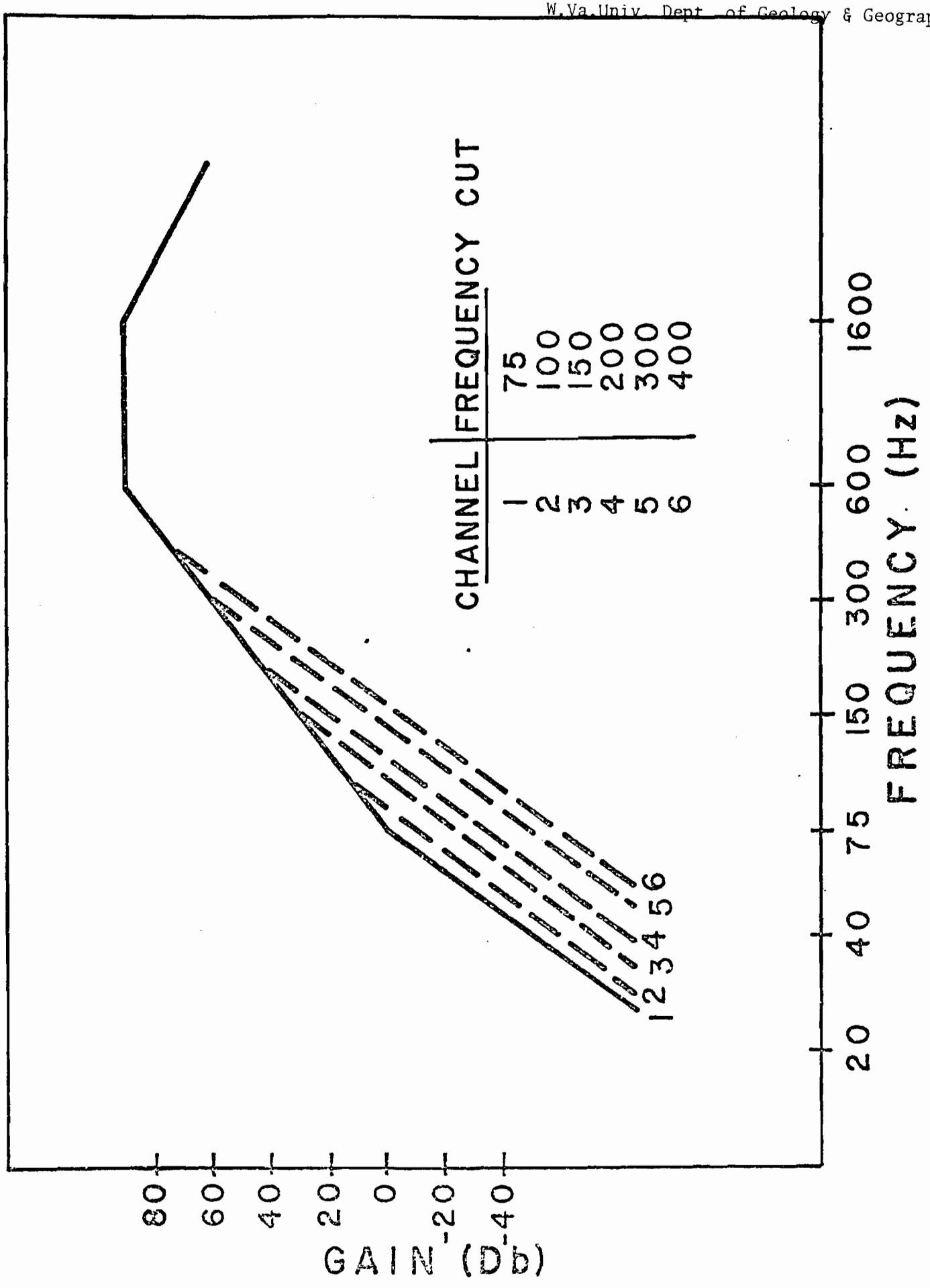
CHANNEL | FREQUENCY CUT
1 | 75
2 | 100
3 | 150
4 | 200
5 | 300
6 | 400
1 2 3 4 5 6
20
40
75
150
300
600
1600
FREQUENCY (Hz)
80
60
40
20
0
-20
-40
GAIN (Db)

Figure 20

REFERENCES

Brown, E., M. W. Skougstad, and M. J. Fishman, 1970, Methods for Collection and Analysis of Water Samples for Dissolved Minerals and Gases; Chapter A1 of Book 5 Techniques of Water-Resources Investigations of the United States Geological Survey.

Lattman, L. H., 1958, Technique of Mapping Geologic Fracture Traces and Lineaments on Aerial Photographs, Photogrammetric Engineering, Vol. 24, pp. 568-576.

Lattman, L. H., and R. R. Parizek, 1964, Relationship between Fracture Traces and the Occurrence of Ground Water in Carbonate Rocks, Journal of Hydrology, Vol. 2, pp. 73-91.

The third site is located near Morgantown, West Virginia where a prominent photo lineament shows dramatic expression as a fracture zone in the Greenbriar limestone. This fracture zone is approximately twenty feet wide and will be used to test the limits of the technique in locating fracture zones.

Summary of Progress

To summarize, the geophysics portion of the contract has accompanied the following in the 1976-1977 fiscal year:

1. Purchase of necessary equipment.
2. Testing of equipment.
3. Design and construction of special seismic amplifier.
4. Testing of seismic amplifier.
5. Design of hydraulic impacter source.
6. Testing of hydraulic impacter source.
7. Solution of ground roll problem.
8. Design and construction of tri-potential resistivity switching circuit.
9. Selection of three sites to test equipment.

Plans for fiscal 1977-78

It is presently anticipated that the entire first quarter will be spent performing the field tests at the three field sites mentioned above. The second quarter will be analyzing the test data. This will involve developing some soft ware to analyze the seismic data. Also during the second quarter a digital filtering software package will be developed as part of the data analysis phase of the research.

The third quarter will be spent planning the summers field work and initiating field work in the Cottageville area. The fourth quarter will be entirely in the field collecting additional data from areas that will be selected based on analysis of our test sites and those studies made by other task groups. It is likely that emphasis will be placed on investigating lineaments and sites of high shale gas production.

The primary study area will be at the Mount Alto (Cottageville) West Virginia gas field (Figure 1). This field, producing natural gas from the Devonian shale, has recently been studied by a detailed three dimensional seismic reflection program performed by Geophysical Services Incorporated. The results of their work, which will be available by mid October of 1977, will serve as a standard for analysis of the quality of our SHRRP and resistivity interpretations.

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APPENDIX A

Preliminary Structure Maps
reduced copies of 1:250,000 mylar overlay sheets

and

Preliminary Devonian Shale Gas Production
reduced copies of 1:250,000 mylar overlay sheets

PRELIMINARY MAP SERIES

DEVONIAN SHALE GAS PRODUCTION

West Virginia and eastern Kentucky

West Virginia University ERDA Contract E(40-1)-5194

LEGEND

- Production from Devonian Shales and other units
- Production from primarily Devonian Shales
- Production from silty Devonian Shales

SCALE 1:250,000

CREDITS

D.H. Cardwell and staff, West Virginia Geological and Economic Survey, 1976

E.N. Wilson and D.G. Sutton, Kentucky Geological Survey, 1975

W.D. Bagnall and W.M. Ryan, 1976

and P. Martin and E.B. Nuckols III, 1976

Oct. 1977
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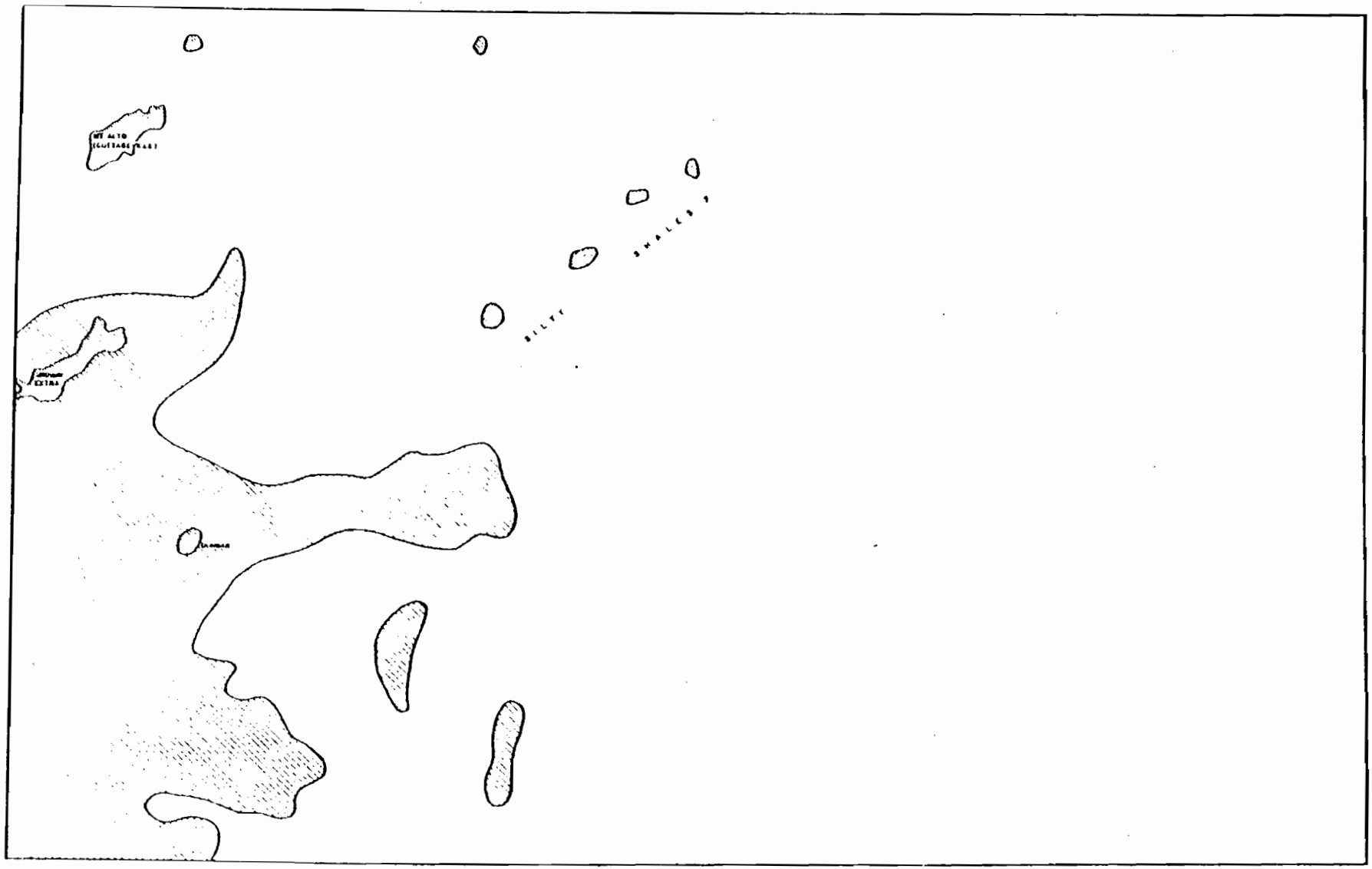
PRELIMINARY

DEVONIAN SHALE GAS PRODUCTION



CREDITS D.H. Cardwell and staff, West Virginia Geological and Economic Survey, 1976, P. Martin and L.B. Nuckols III, 1976, and W.D. Bagnell and W.M. Ryan, 1976

5 0 5 10 15 20
MILES

CHARLESTON

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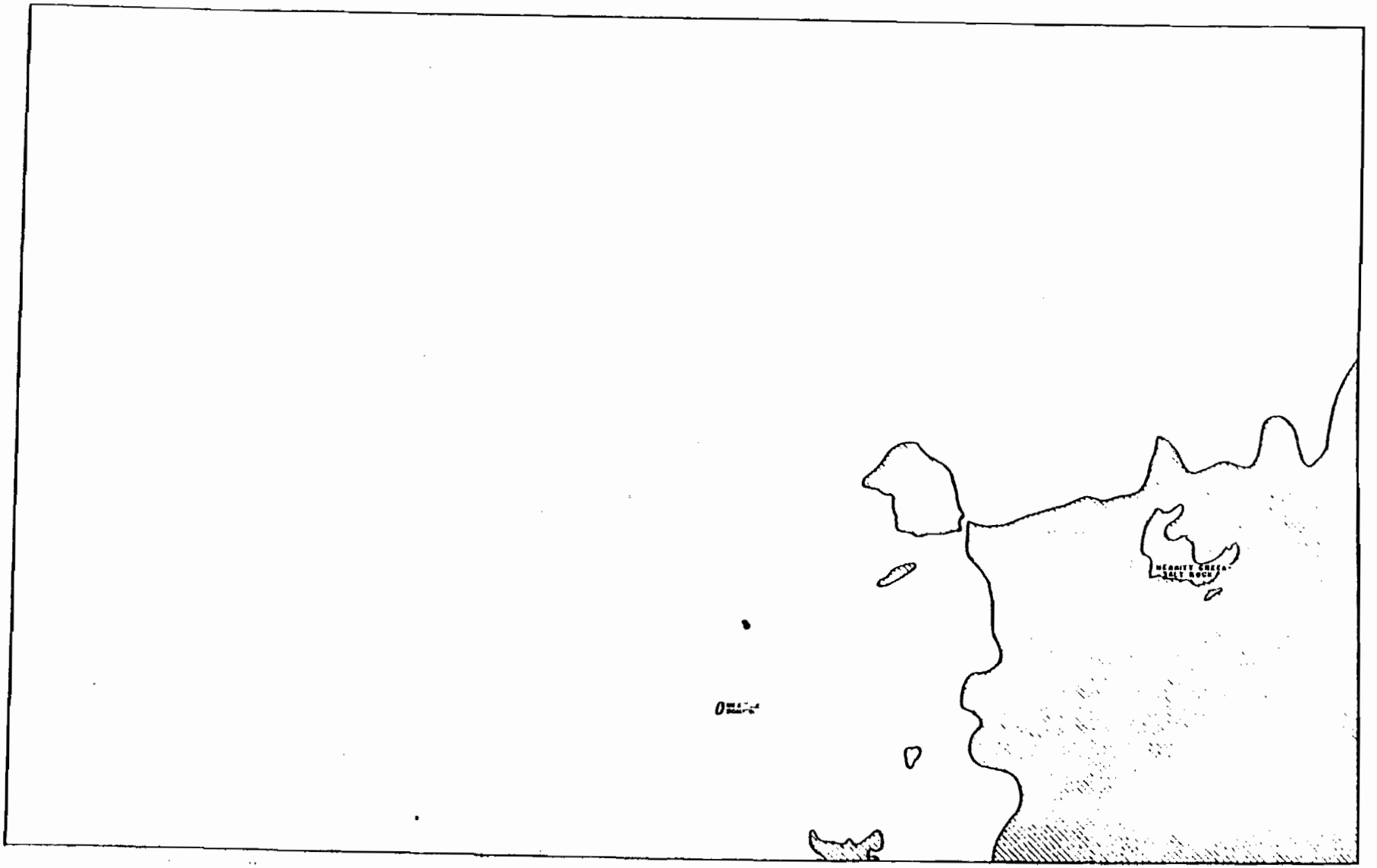
PRELIMINARY

DEVONIAN SHALE GAS PRODUCTION



CREDITS. D H. Cardwell and staff, West Virginia Geological and Economic Survey, 1976, E H Wilson and D G Sutton, Kentucky Geological Survey, 1975, and W D Bagnall and W M Ryan 1976

Oct. 1977

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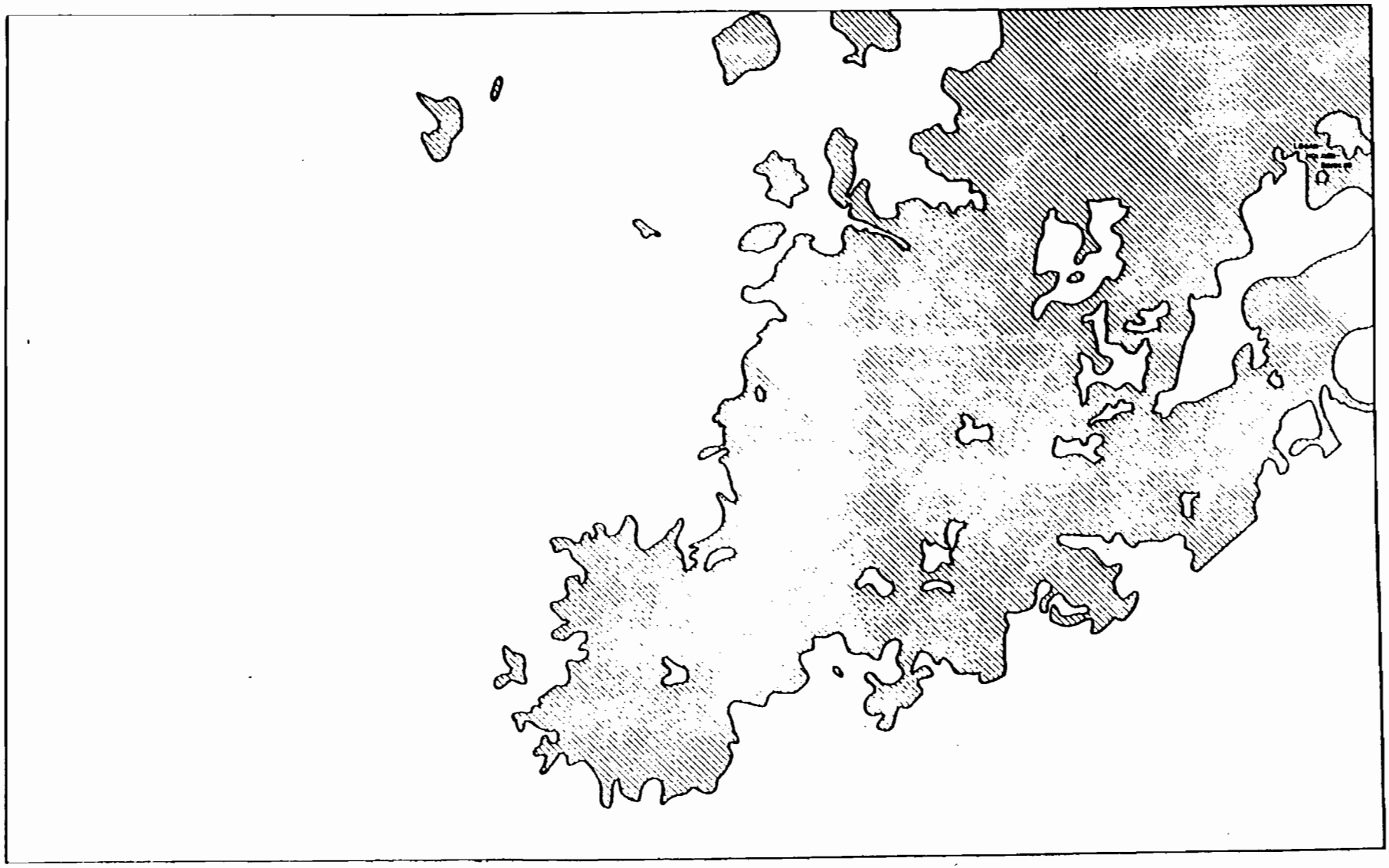
4

PRELIMINARY

DEVONIAN SHALE GAS PRODUCTION



CREDITS: D.H. Cardwell and staff, West Virginia Geological and Economic Survey, 1976; E.N. Wilson and D.G. Sutton, Kentucky Geological Survey, 1976; and W.D. Bagnall and W.J. Wyen, 1976

5 0 5 10 15 20
MILES

JENKINS

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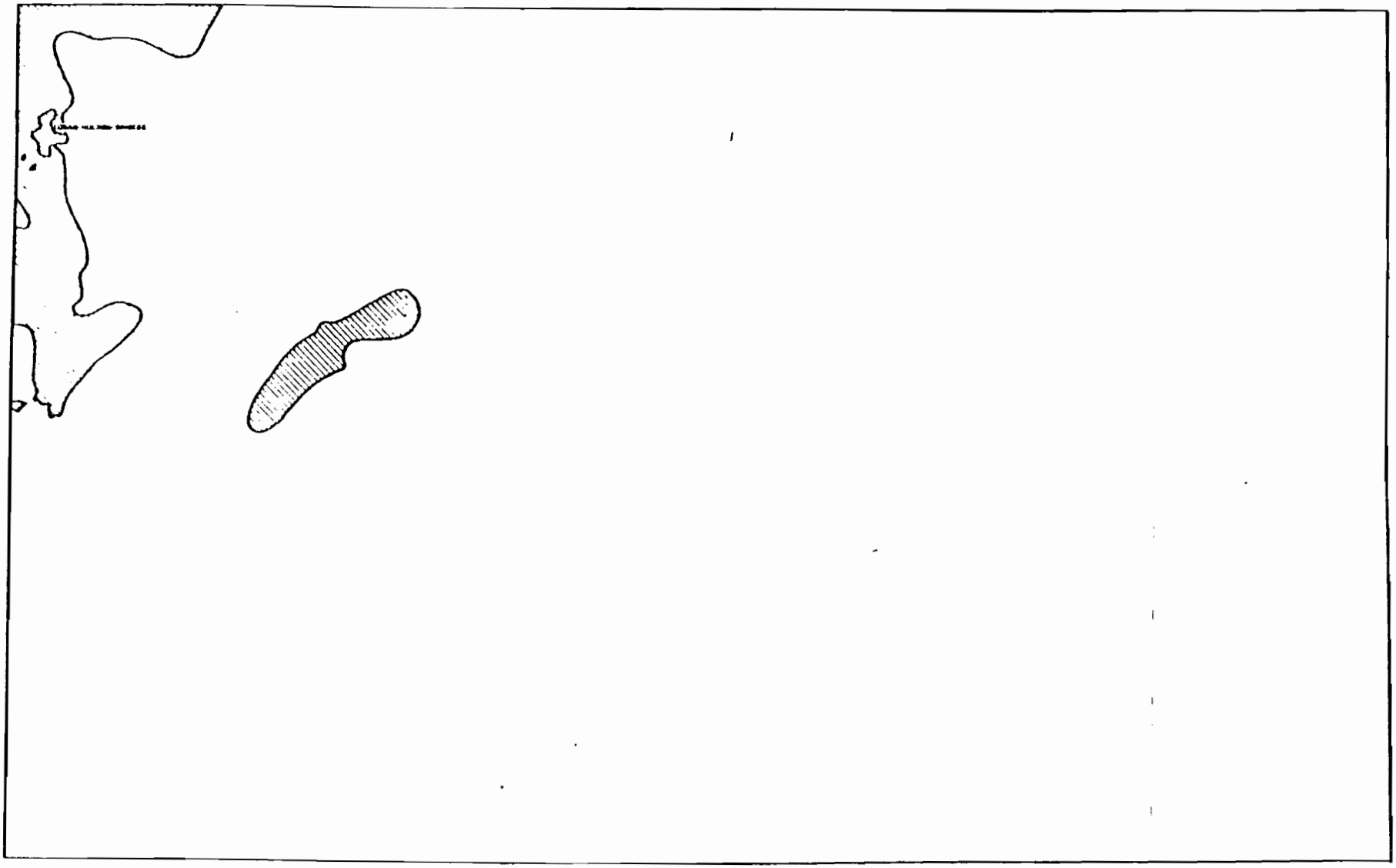
DEVONIAN SHALE GAS PRODUCTION



CREDITS D H Cardwell and staff, West Virginia Geological and Economic Survey, 1976, and W D Bagnall and W M Ryan, 1978

5 0 5 10 15 20
MILES

BLUEFIELD

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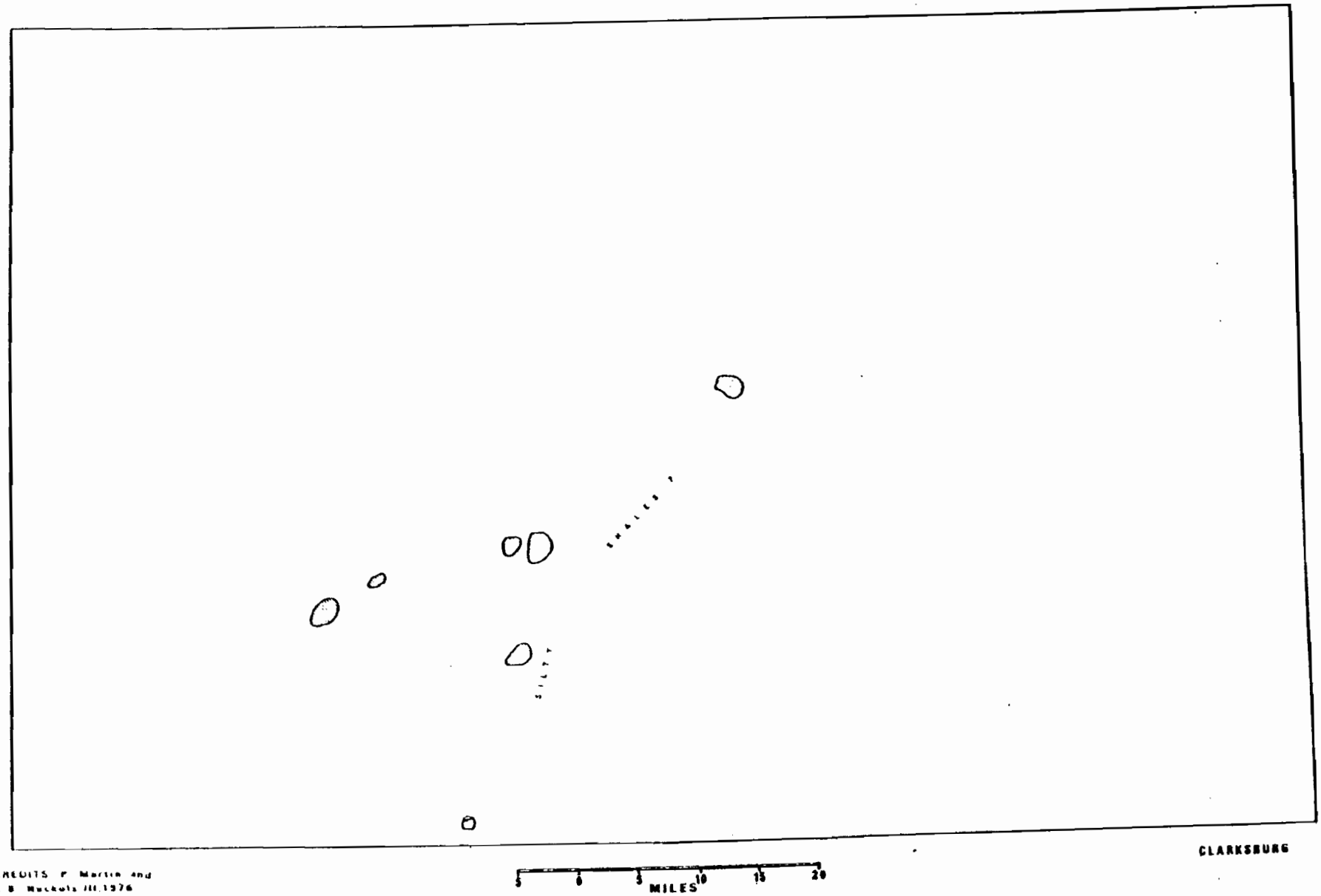
PRELIMINARY

DEVONIAN SHALE GAS PRODUCTION



CREDITS P. Martin and E. B. Mckaels III, 1976

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7

PRELIMINARY MAP SERIES

STRUCTURE ON THE TOP OF THE GREENBRIER

West Virginia and eastern Kentucky (Incomplete)

West Virginia University ERDA Contract E 40 1 5194

LEGEND

Synclines

Anticlines

Contours

Faults

SCALE 1:250,000

CREDITS

O.L. Haught, West Virginia Geological and Economic Survey, 1968

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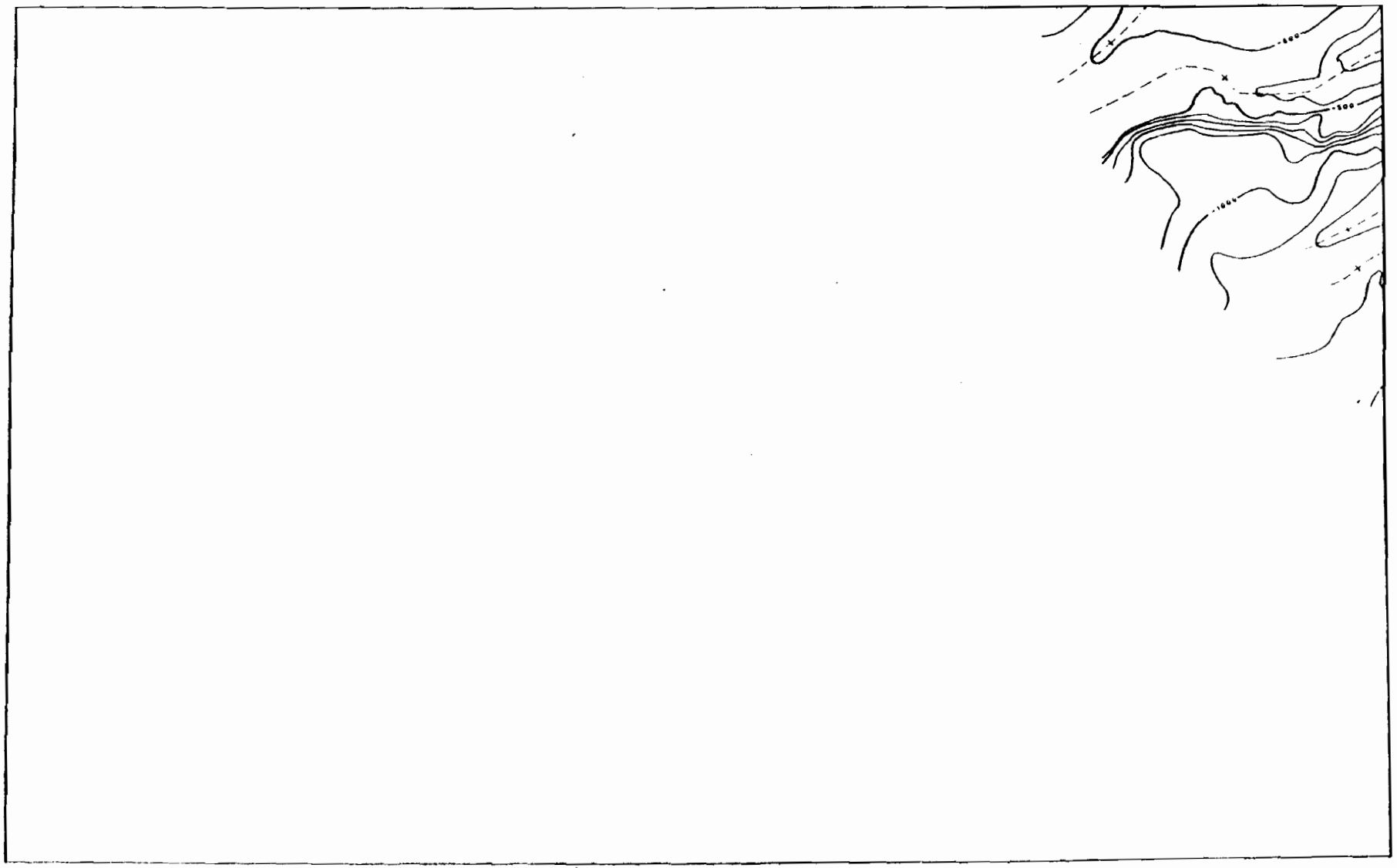
PRELIMINARY

GREENBRIER STRUCTURE



Detail Top of the Greenbrier
CREDITS: D.L. Haught, West Virginia
Geological and Economic Survey
1966

5 0 5 10 15 20
MILES

JENKINS

Open File Report
Oct. 1977
W.Va. Univ. Dept. of Geology & Geography

PRELIMINARY

GREENBRIER STRUCTURE

Datum: top of the Greenbrier
CREDITS: D.L. Haught West Virginia Geological and Economic Survey 1968

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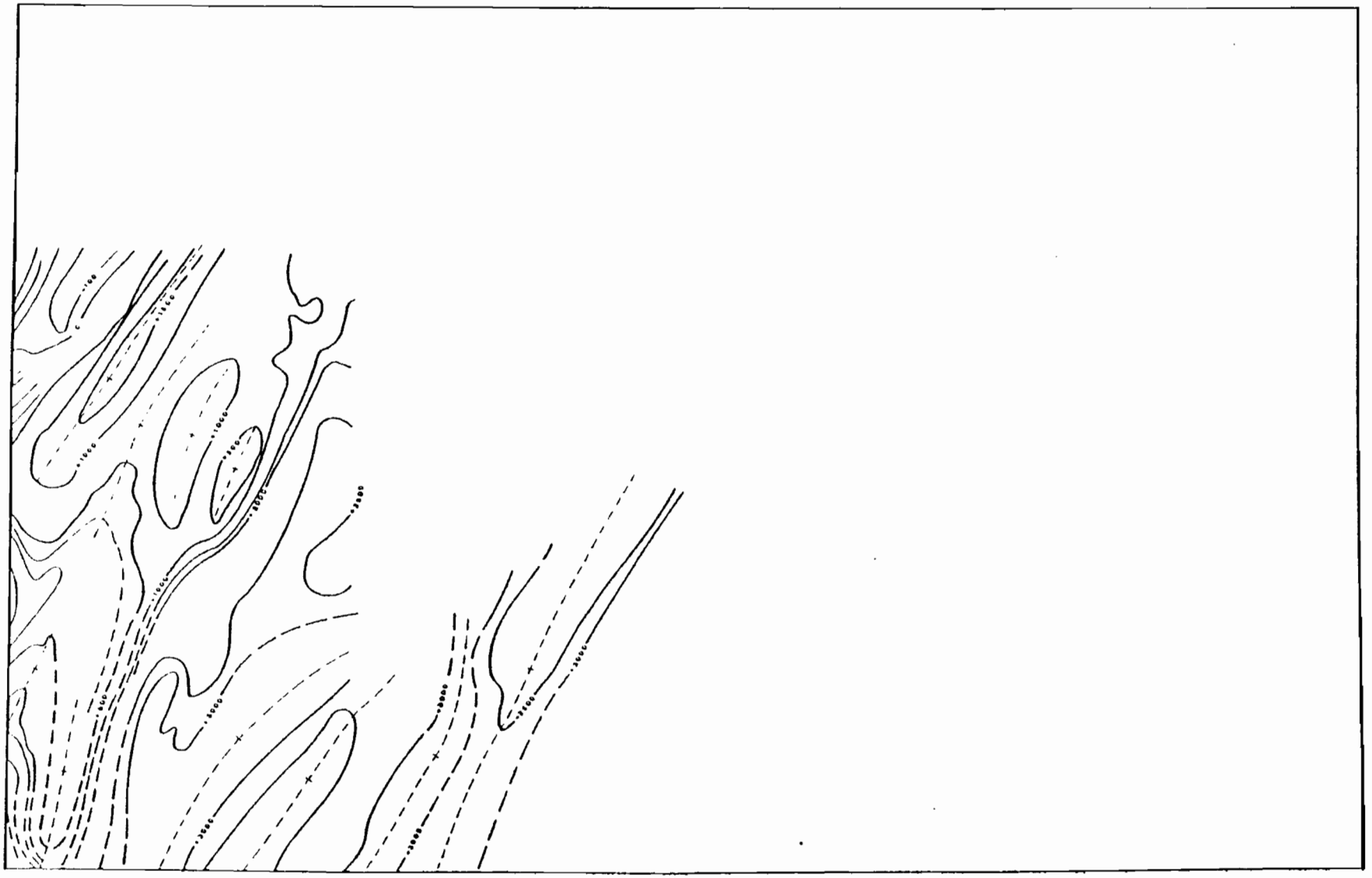
PRELIMINARY

GREENBRIER STRUCTURE



Datum: Top of the Greenbrier
CREDITS: D.E. Haught West Virginia Geological and Economic Survey 1968

5 0 5 10 15 20
MILES

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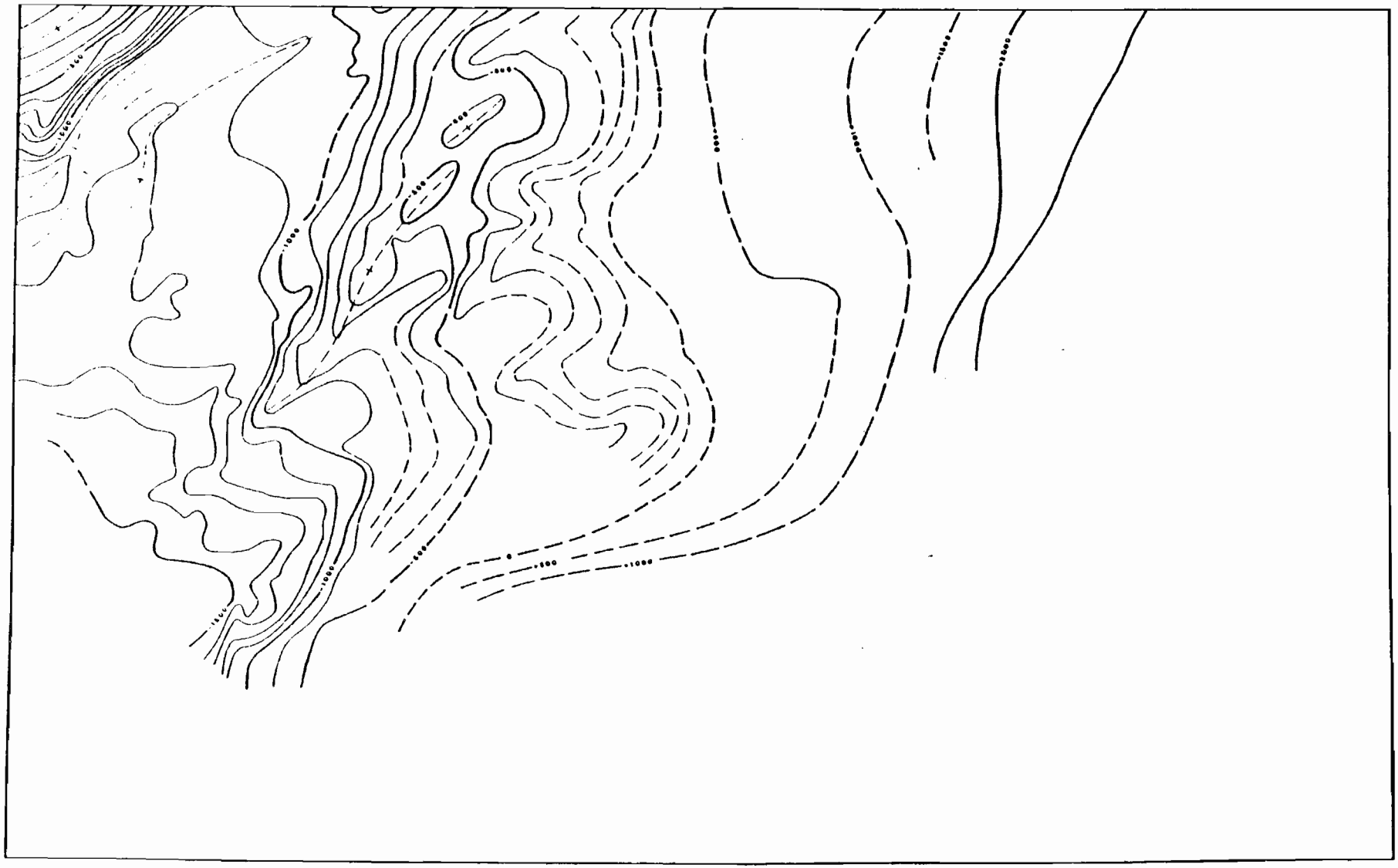
GREENBRIER STRUCTURE



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Datum: Top of the Greenbrier
CREDITS: W.L. Haught, West Virginia Geological and Economic Survey 1968

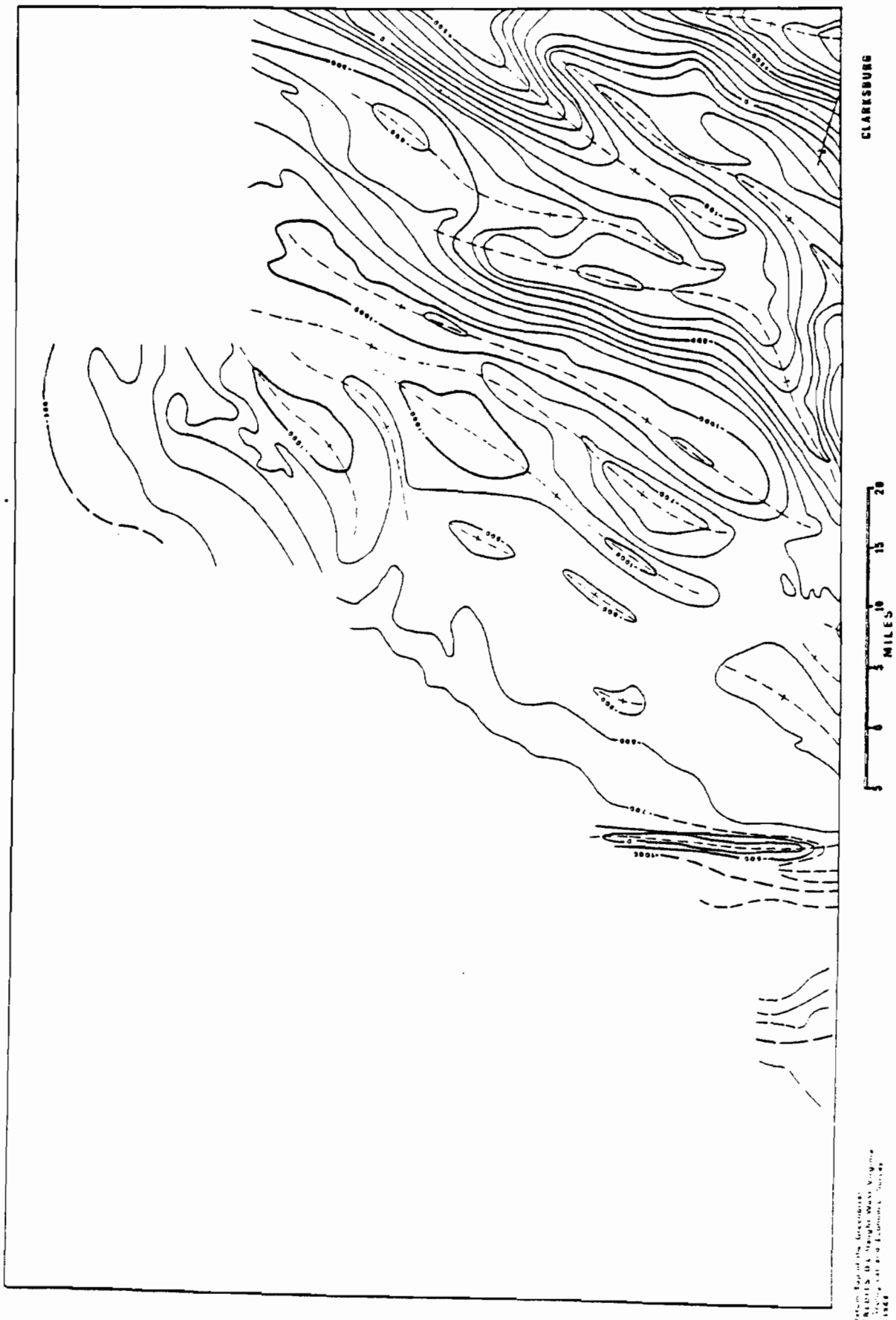
5 0 5 10 15 20
MILES

BLUEFIELD

12

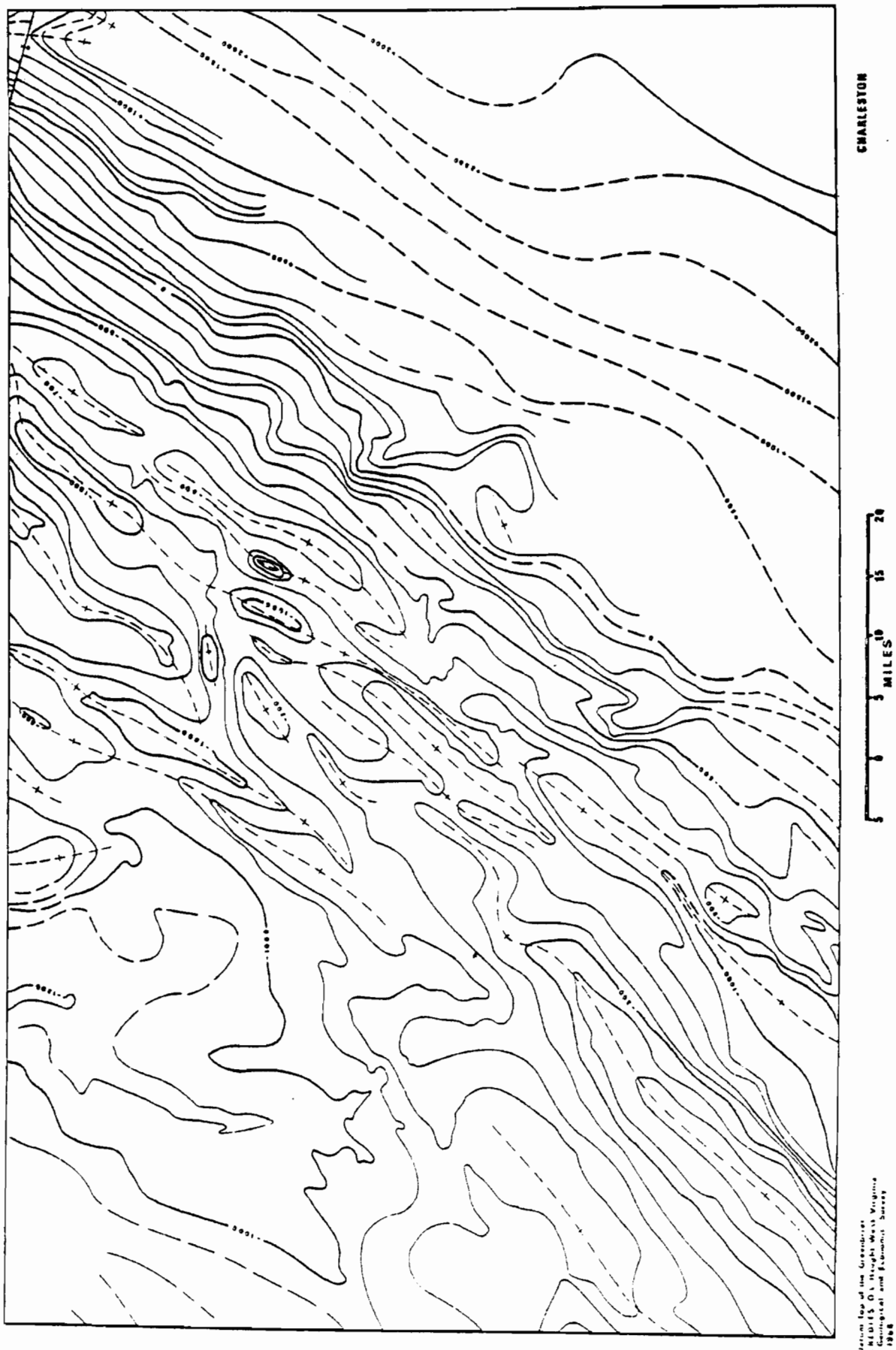
PRELIMINARY

GREENBRIER STRUCTURE



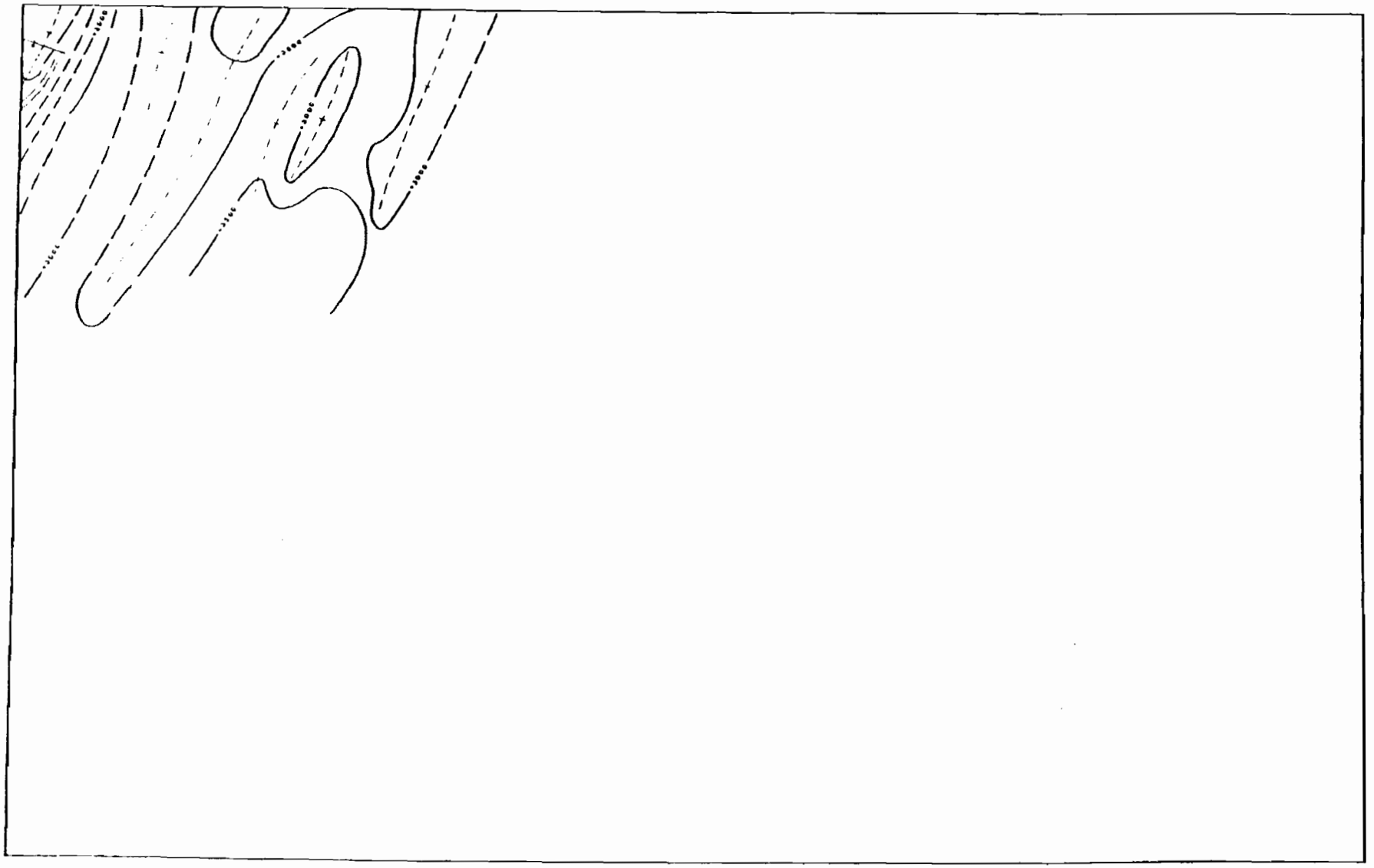
PRELIMINARY

GREENBRIER STRUCTURE



PRELIMINARY

GREENBRIER STRUCTURE



Datum: top of the Greenbrier
CREDITS Oil Haught West Virginia
Geological and Economic Survey
1968

5 0 5 10 15 20
MILES

CHARLOTTESVILLE

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PRELIMINARY MAP SERIES

STRUCTURE ON THE TOP OF THE BASEMENT

West Virginia and eastern Kentucky (Incomplete)

West Virginia University ERDA Contract E 40 1 5194

LEGEND

Faults

Normal Fault

Detached Thrust Fault
(Sawteeth on upper plate)

Strike Slip

Unclassified Fault
(Solid where mapped long dashed where approximated short dashed where inferred)

Upthrown side

Downthrown side

Inferred fault trend determined by magnetic survey

Contours

Solid where mapped long dashed where approximated short dashed where inferred

Magnetic Lineation (Probable fault)

Wells

Depth to Basement County Permit Number

Total depth presumed to be at or near basement

Estimated depth

Gas well

Shut in well

Show of gas

Oil well

Dry hole

Drilling well

SCALE 1:250,000

CREDITS

D.H. Cardwell, West Virginia Geological and Economic Survey, 1977,
E.N. Wilson and D.G. Sutton, Kentucky Geological Survey, 1975,
S. Dean and B. Kulander, 1977 In press, R.S. Goble, 1972,
M. Zurgani, 1975, and Jacobeen and Kanes, 1974

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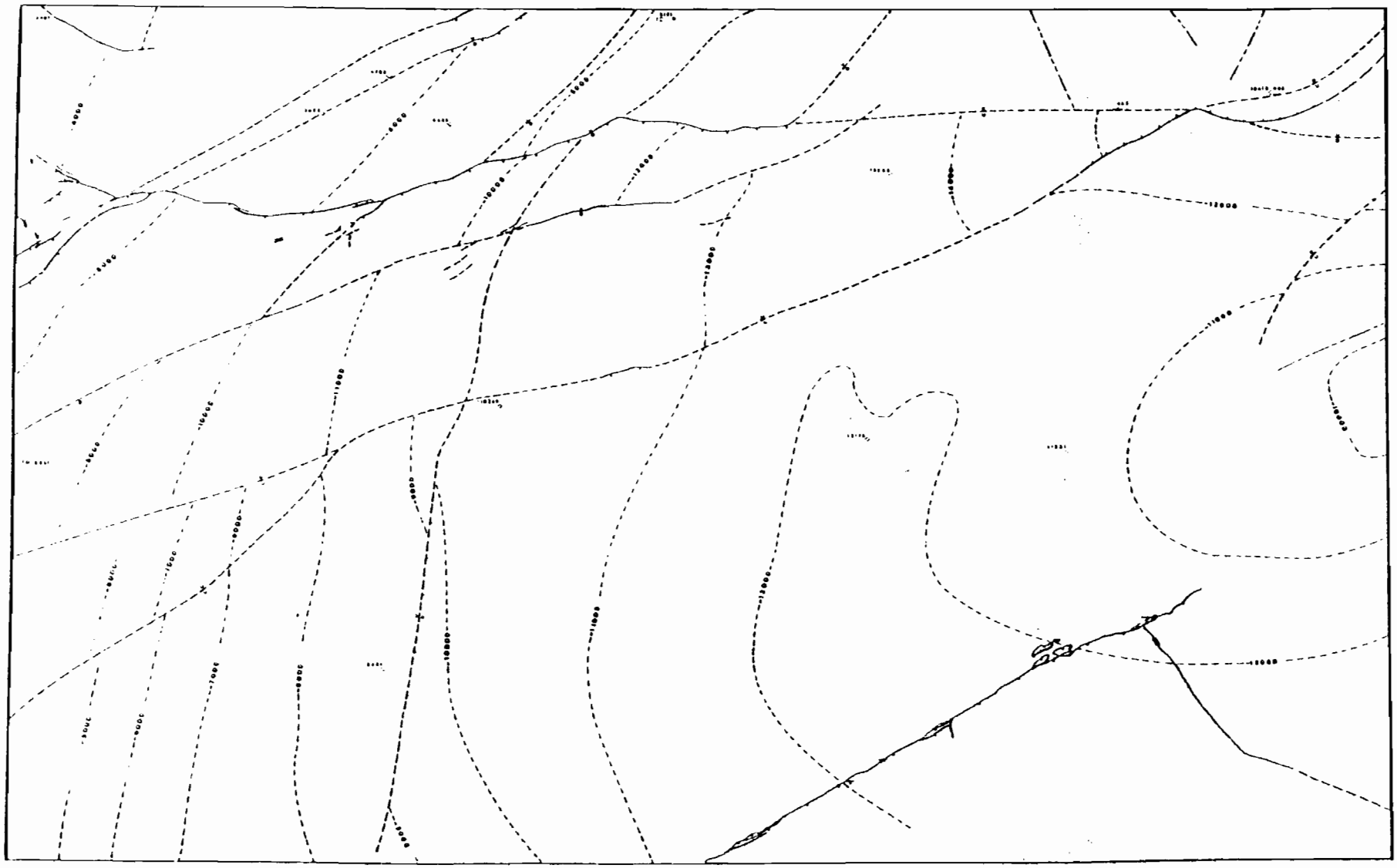
PRELIMINARY

BASEMENT STRUCTURE



Datum: Top of the Basement
CREDITS: Well data from D. H. Cardwell, West Virginia Geological and Economic Survey 1977, and E. N. Wilson, Kentucky Geological Survey, 1977

5 0 5 10 15 20
MILES

JENKINS

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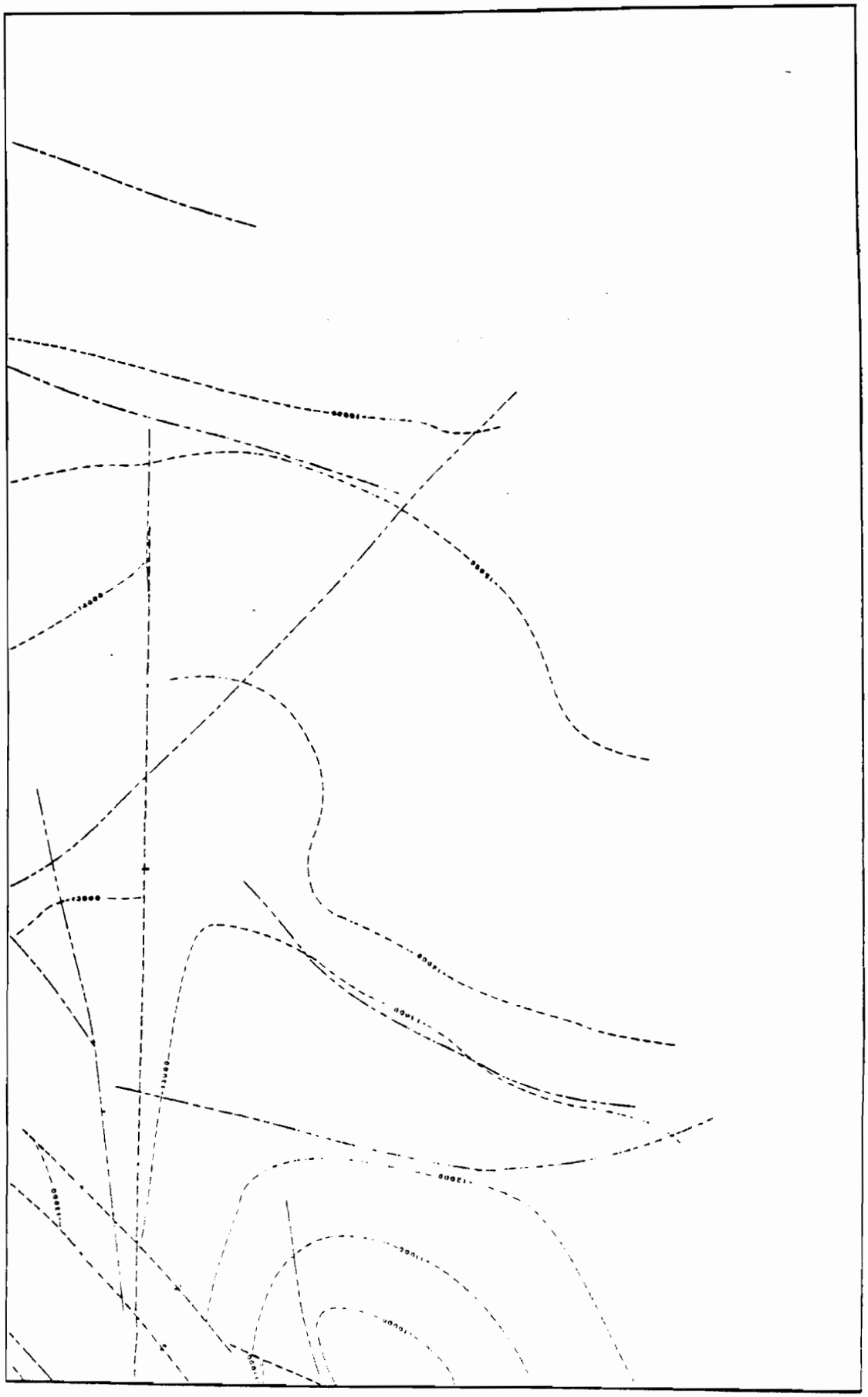
PRELIMINARY BASEMENT STRUCTURE



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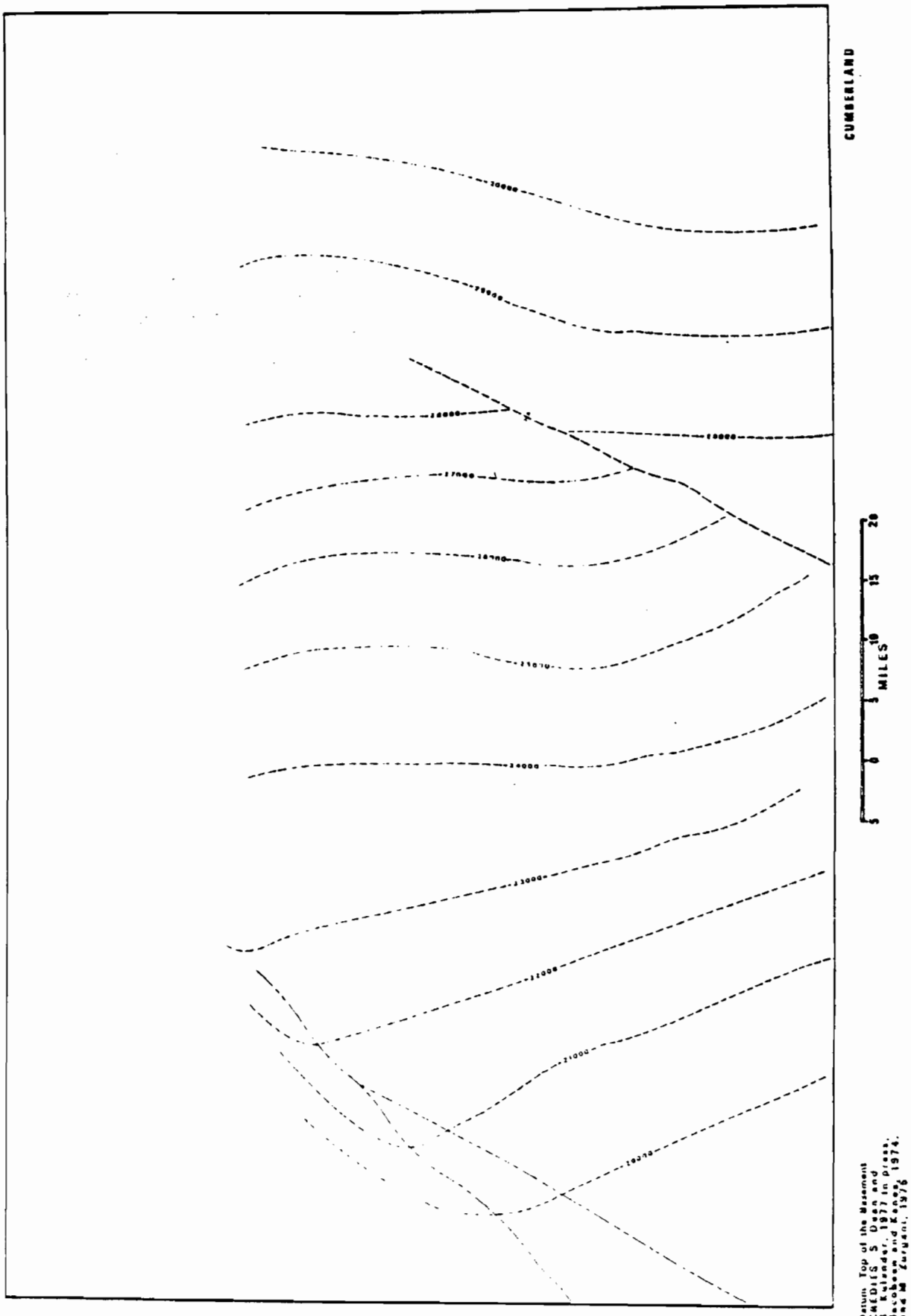
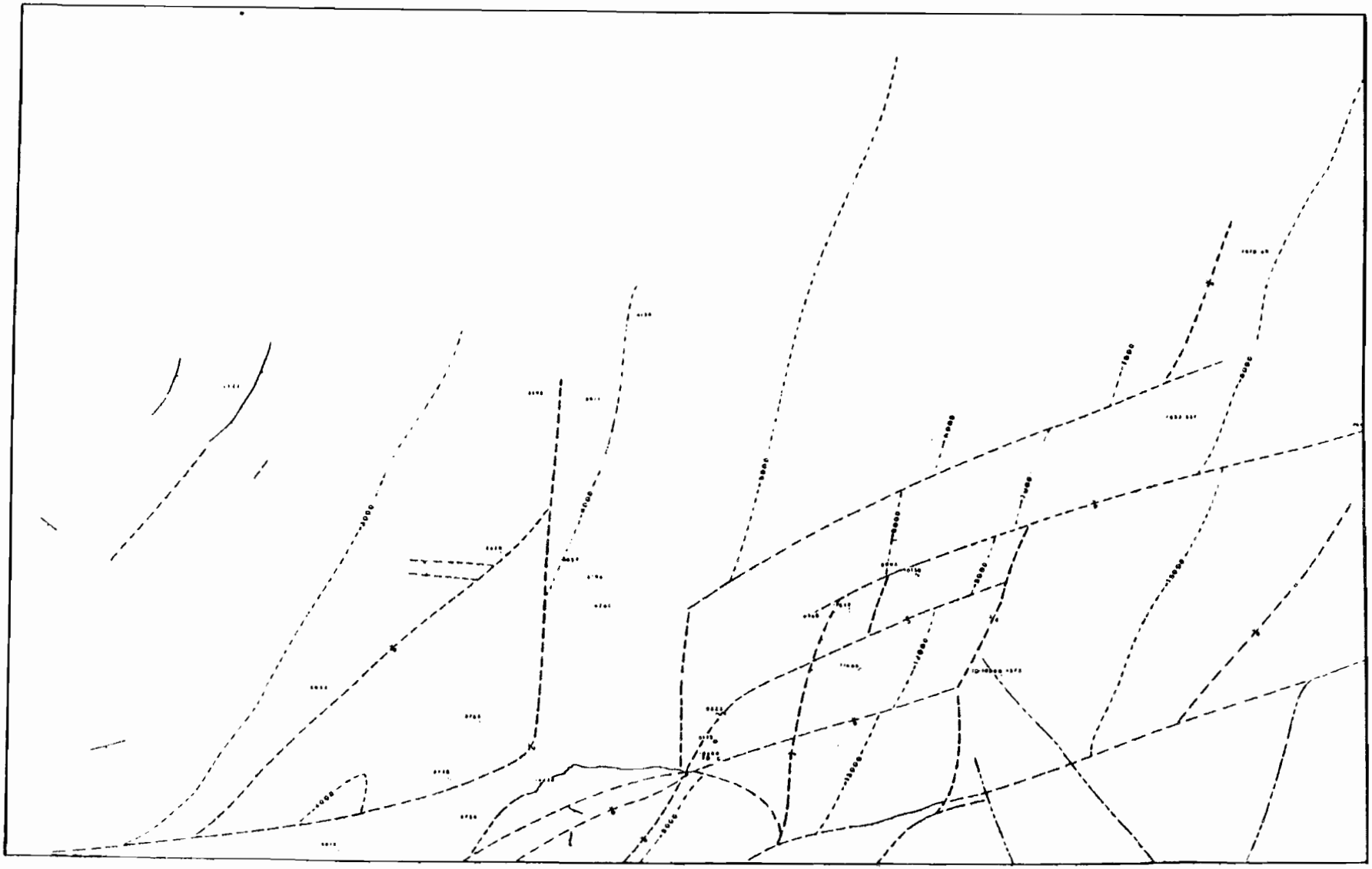
PRELIMINARY BASEMENT STRUCTURE



Datum: Top of the Basement
CREDITS: S. Dean and
B. Kulander, 1977 in press,
Jacobsen and Kanes, 1974,
and M. Zurgani, 1975

PRELIMINARY

BASEMENT STRUCTURE



Datum: Top of the Basement
CREDITS: Well data from D.H. Cardwell, West Virginia Geological and Economic Survey, 1977, and E.N. Wilson, Kentucky Geological Survey, R.S. Gable, 1972
Surface structure from Kentucky Oil and Gas map 1978

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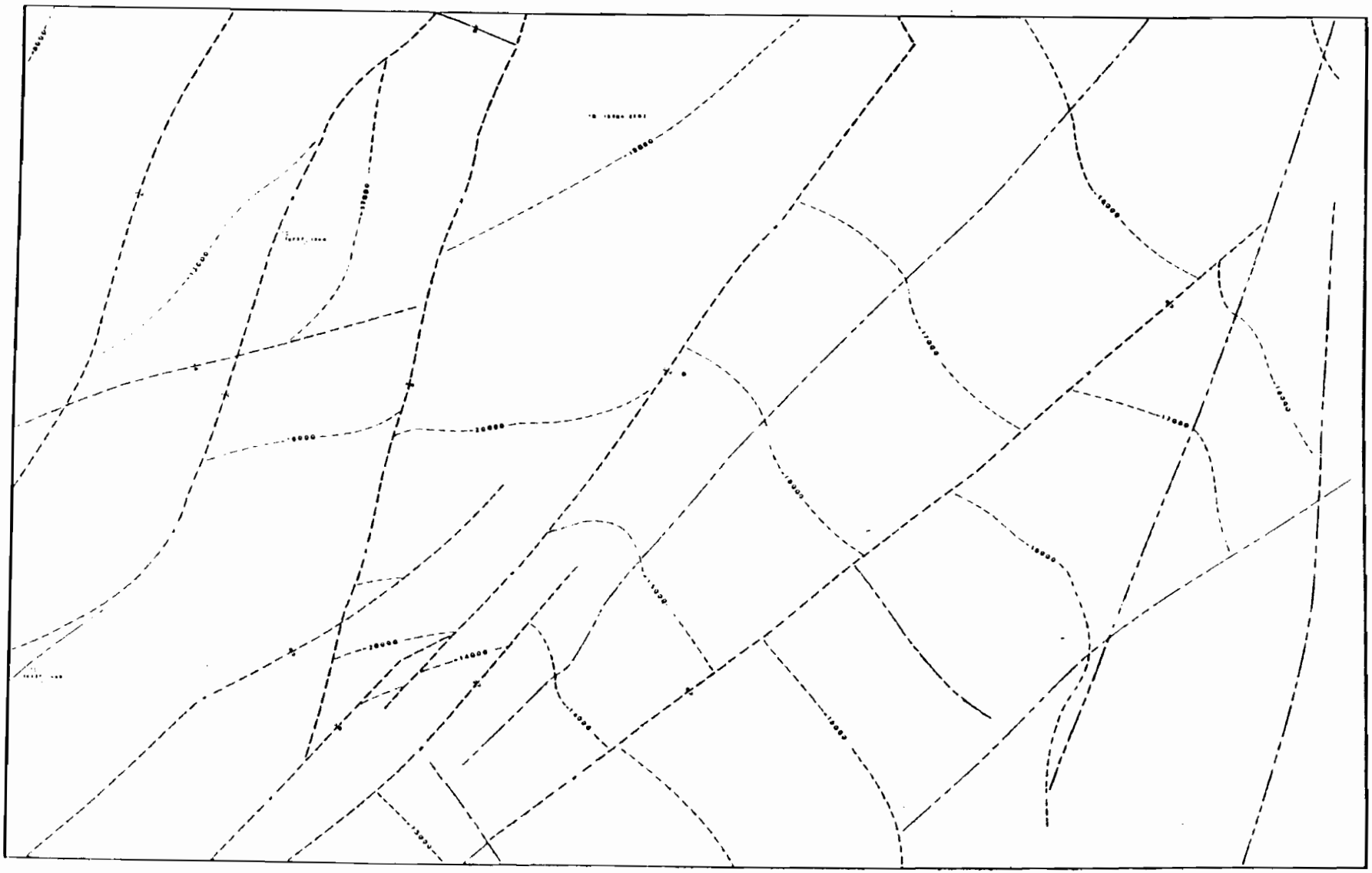
PRELIMINARY

BASEMENT STRUCTURE



Datum: Top of the Basement
CREDITS: Well data from D.H. Cardwell, West Virginia Geological and Economic Survey, 1977 and S. Dean and B. Kulander, 1977

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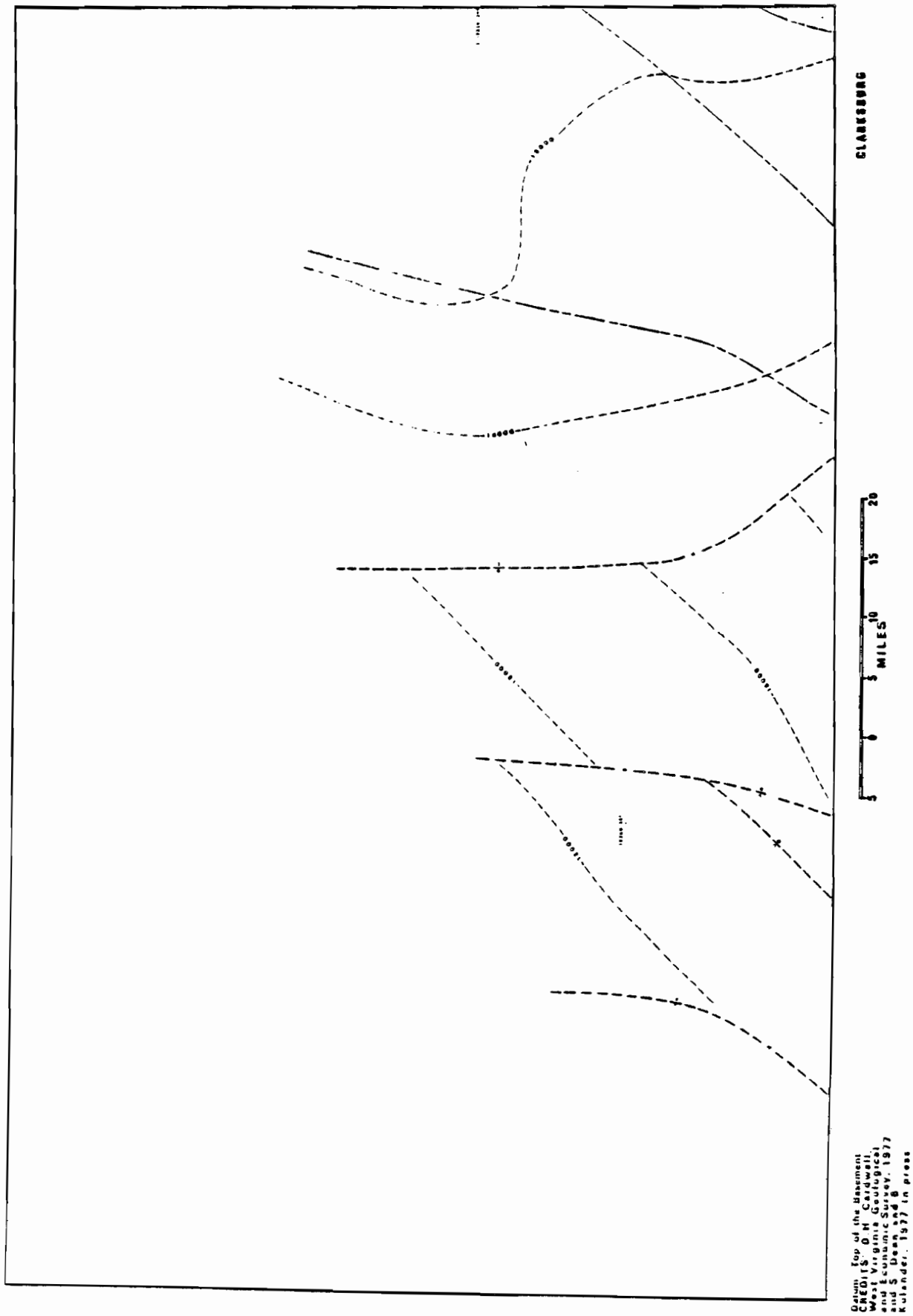
Oct. 1977
W.Va.Univ. Dept. of Geology & Geography.

PRELIMINARY BASEMENT STRUCTURE



PRELIMINARY MAP SERIES

STRUCTURE ON THE TOP OF THE BEREA

West Virginia and eastern Kentucky (Incomplete)

West Virginia University ERDA Contract E 40 1 5194

LEGEND

Synclines

Anticlines

Contours

100 ft

500 ft

SCALE 1:250,000

CREDITS

O.L. Haught, West Virginia Geological and Economic Survey, 1959

UGR File #C048/77A
Oct. 1977
W.Va.Univ. Dept. of Geology & Geography

PRELIMINARY MAP SERIES

STRUCTURE ON THE TOP OF THE BEREA

West Virginia and eastern Kentucky (Incomplete)

West Virginia University ERDA Contract E 40 1 5194

LEGEND

Synclines

Anticlines

Contours

100 ft

500 ft

SCALE 1:250,000

CREDITS

O.L. Haught, West Virginia Geological and Economic Survey, 1959

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UGR File #C048///A
Oct. 1977
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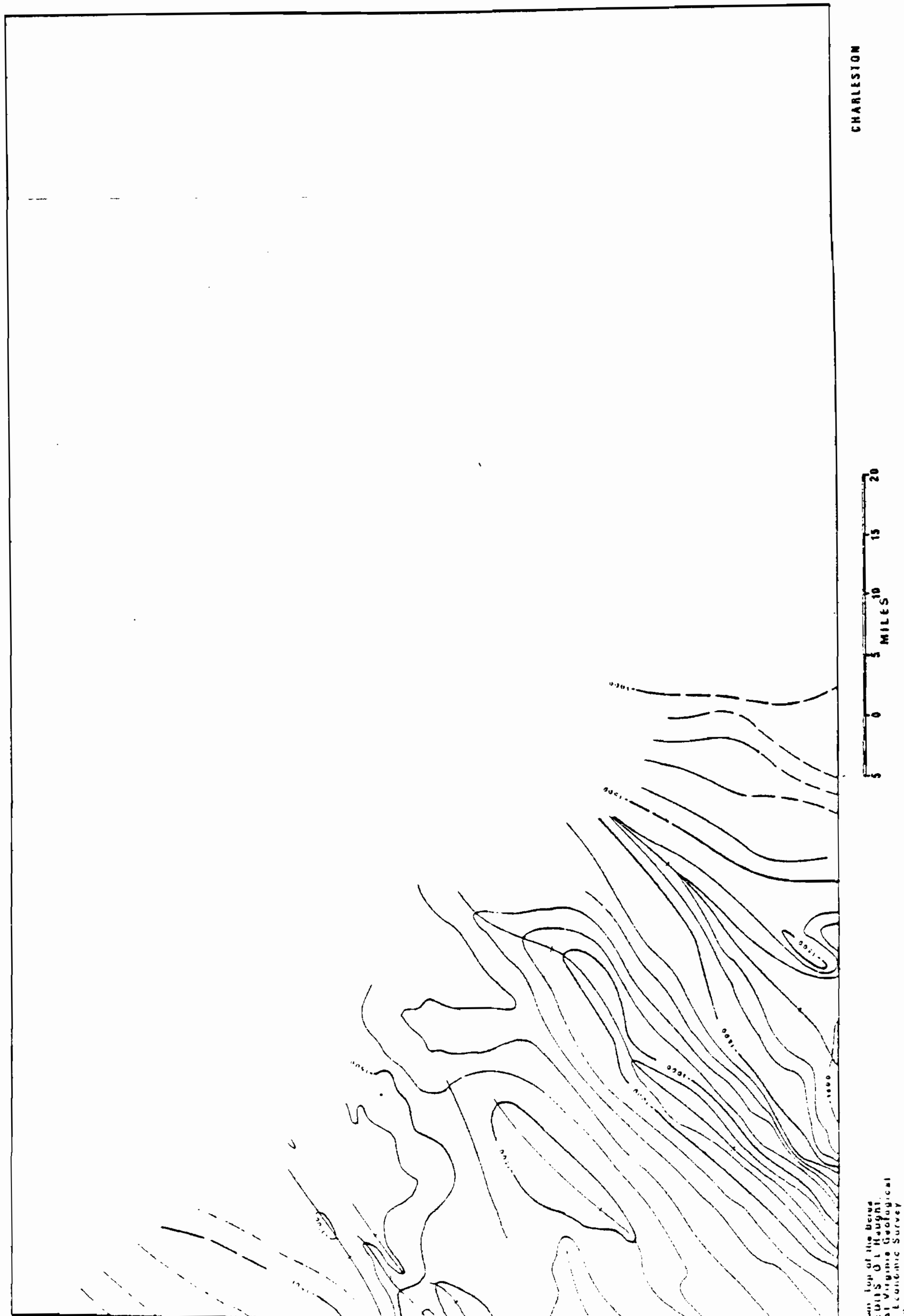
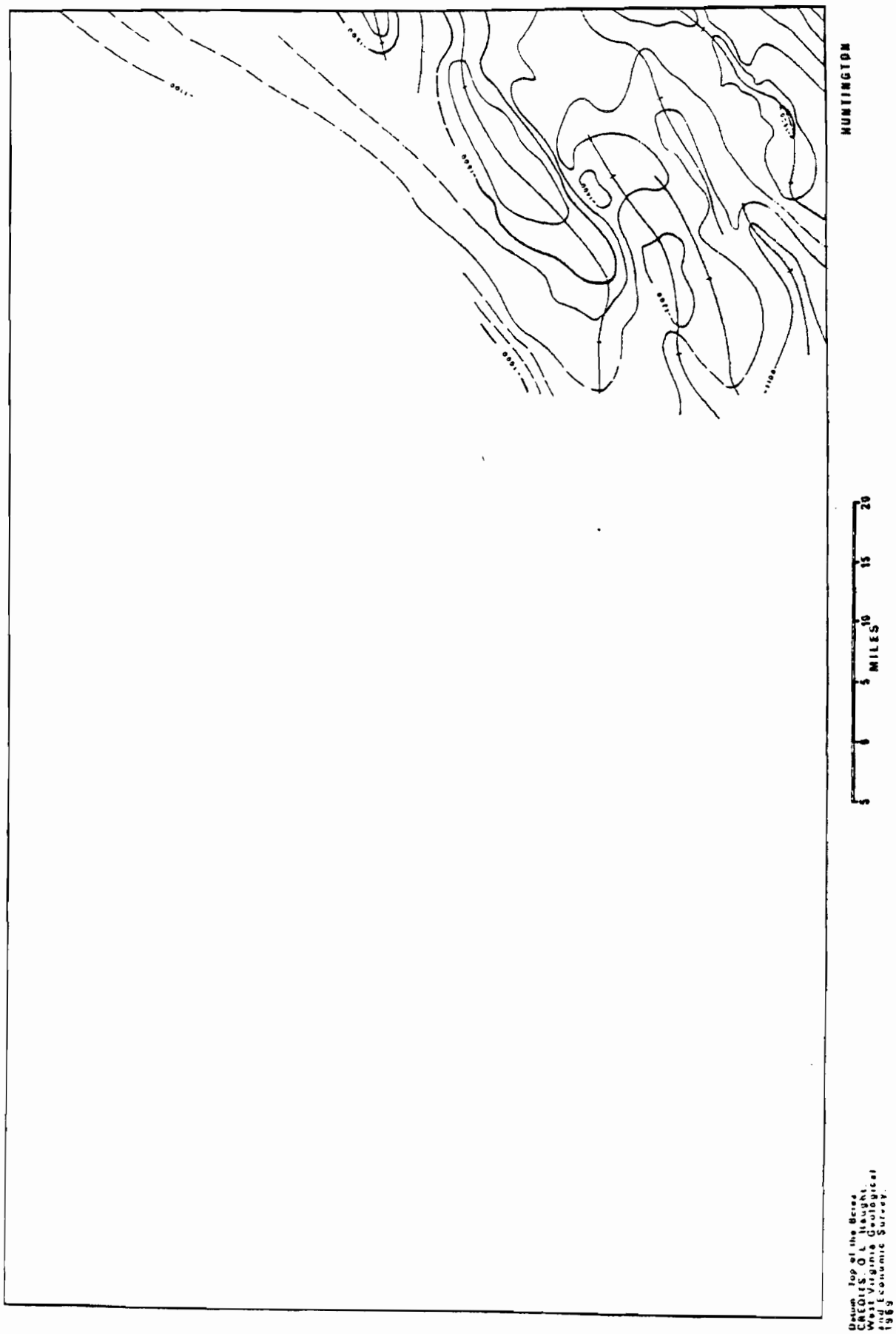
PRELIMINARY
BEREA STRUCTURE

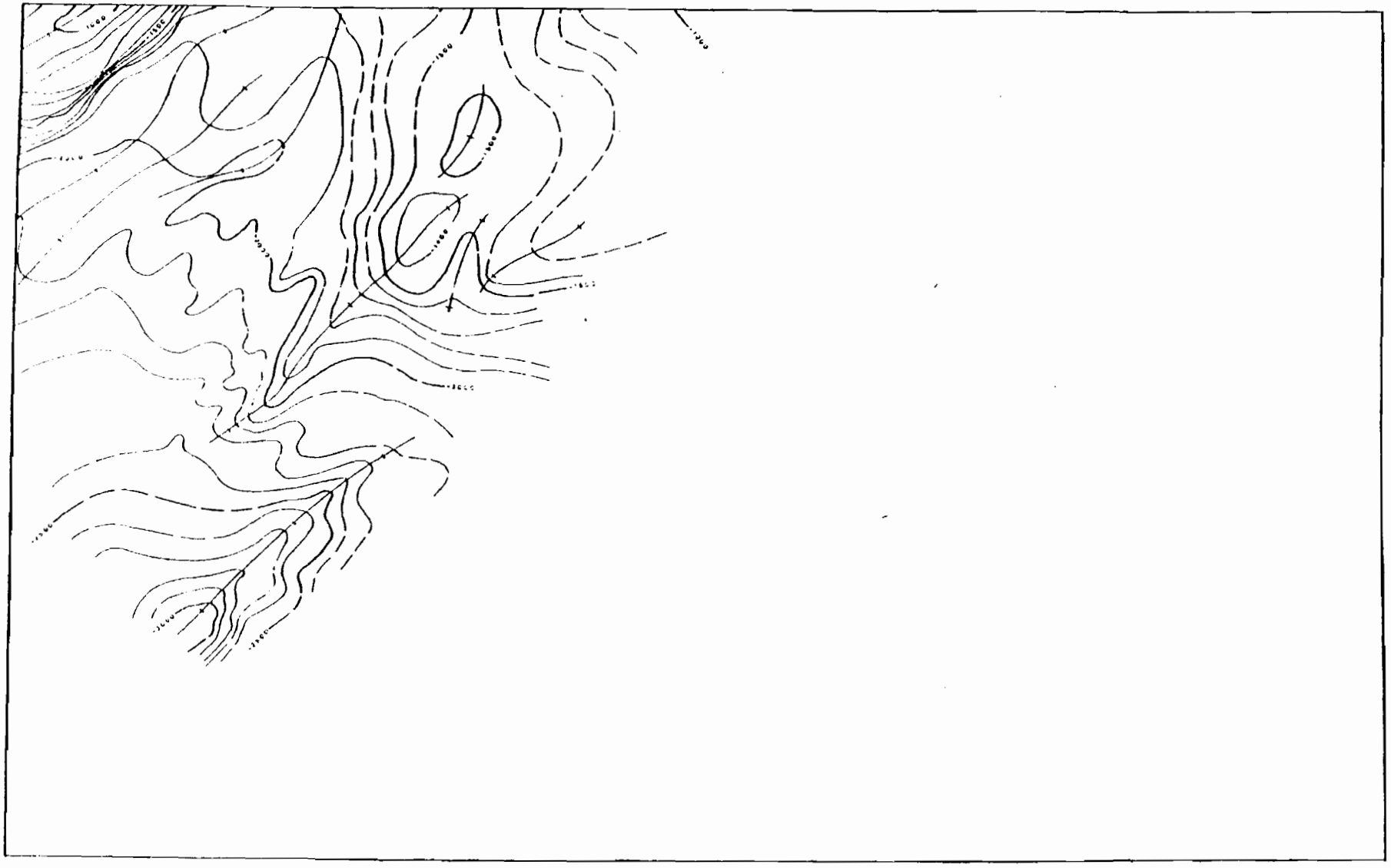


PRELIMINARY
BEREA STRUCTURE



PRELIMINARY

BEREA STRUCTURE



Datum: Top of the Berea
CREDITS: O. L. Haught
West Virginia Geological
and Economic Survey,
1959

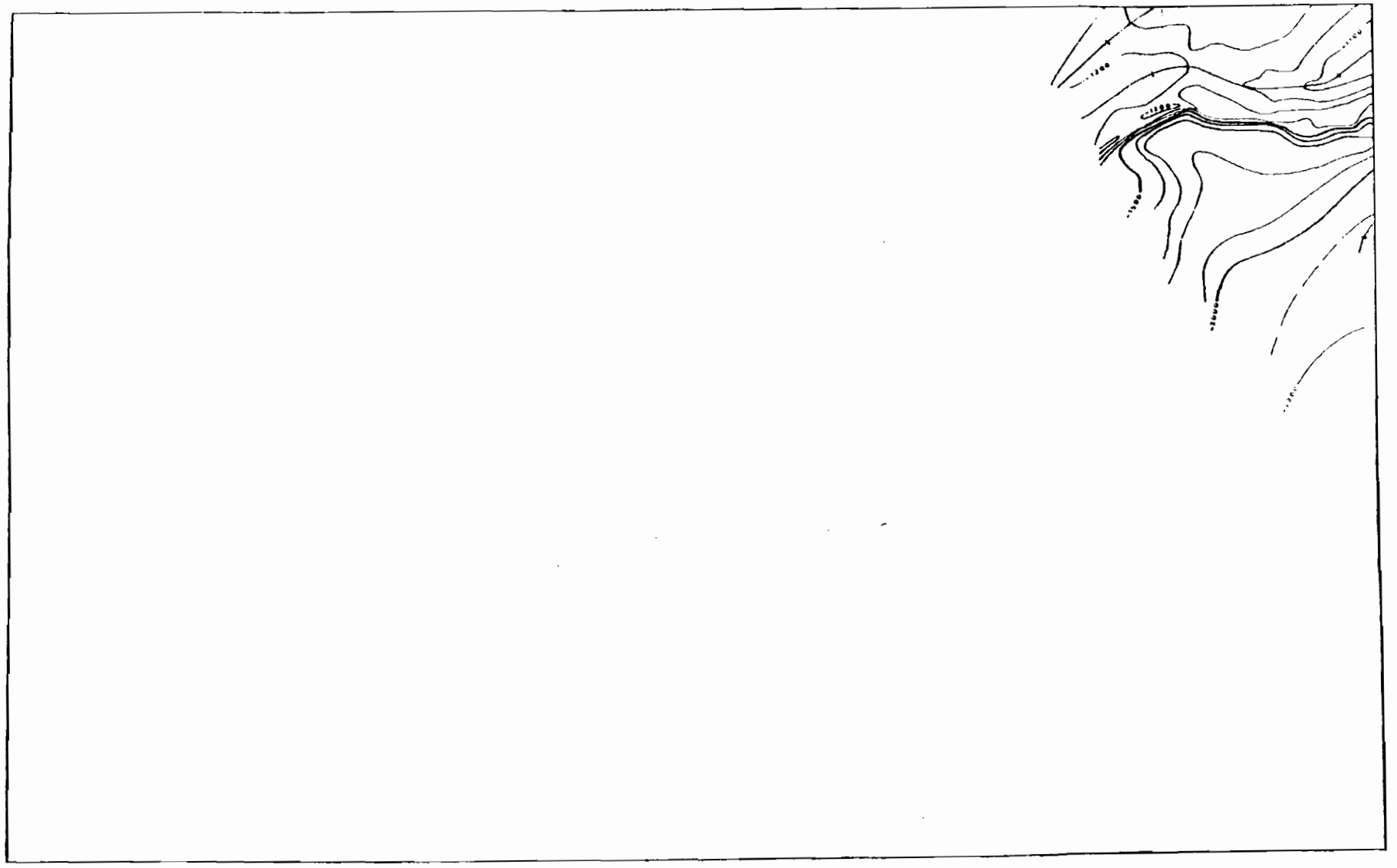
5 0 5 10 15 20
MILES

BLUEFIELD

Oct. 1977
W.Va.Univ. Dept. of Geology & Geography

PRELIMINARY

BEREA STRUCTURE



Datum: Top of the Berea
CREDITS: D. L. Haught, West Virginia Geological and Economic Survey, 1969

5 0 5 10 15 20
MILES

JENKINS

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PRELIMINARY MAP SERIES

STRUCTURE ON THE TOP OF THE ONONDAGA OR EQUIVALENT

West Virginia and eastern Kentucky (Incomplete)

West Virginia University ERDA Contract E 40 1 5194

LEGEND

Faults

Thrust Fault
(Sawteeth on upper plate)

Unclassified Fault
Upthrown side
Downthrown side

Probable Fault

Contours

(Solid where mapped, long dashed where approximated, short dashed where inferred)

100 ft

1500 500 ft

SCALE 1:250,000

CREDITS

D.H. Cardwell, West Virginia Geological and Economic Survey, 1973

UGR File #C048/1/A
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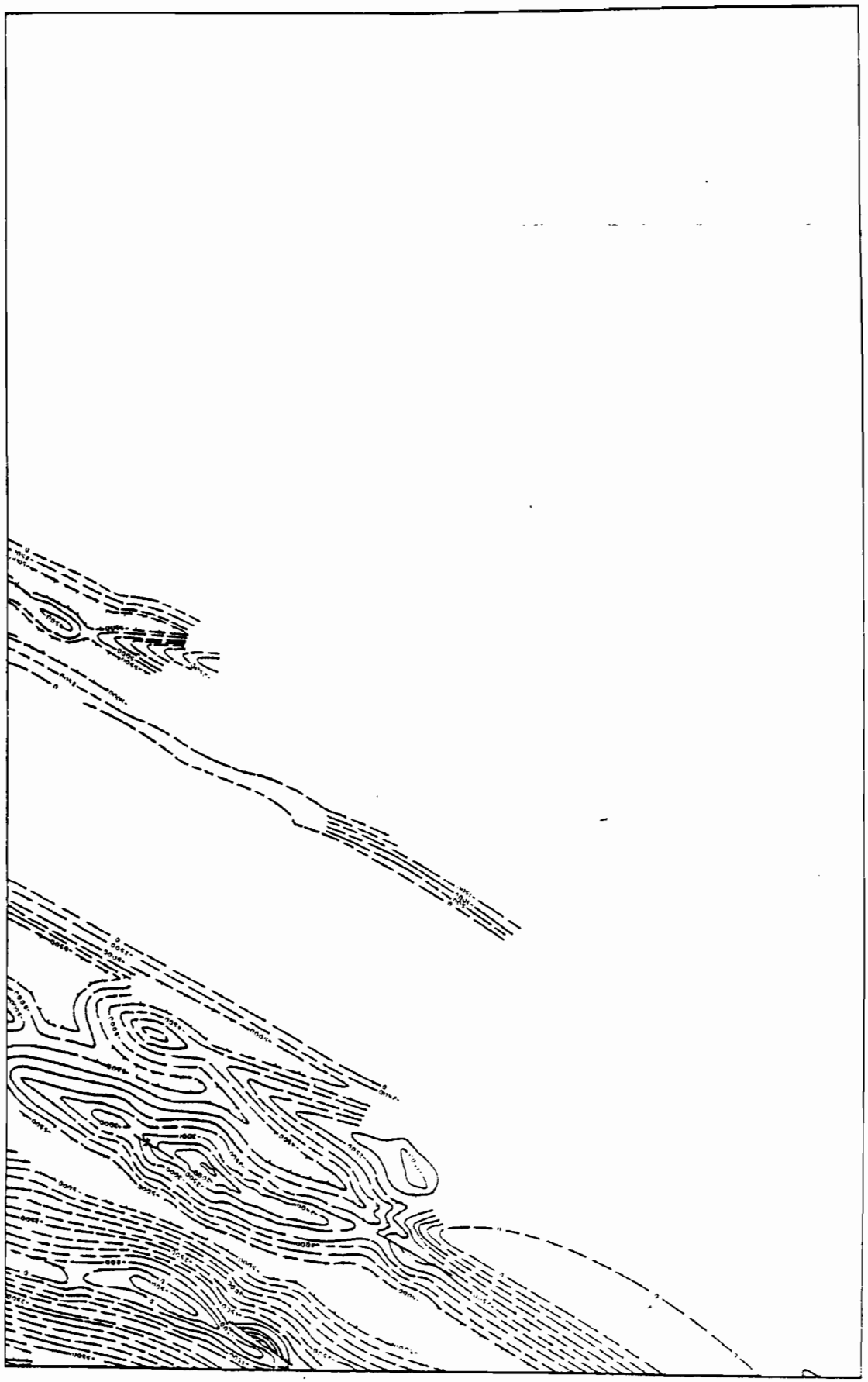
W.Va.Univ. Dept. of Geology & Geography

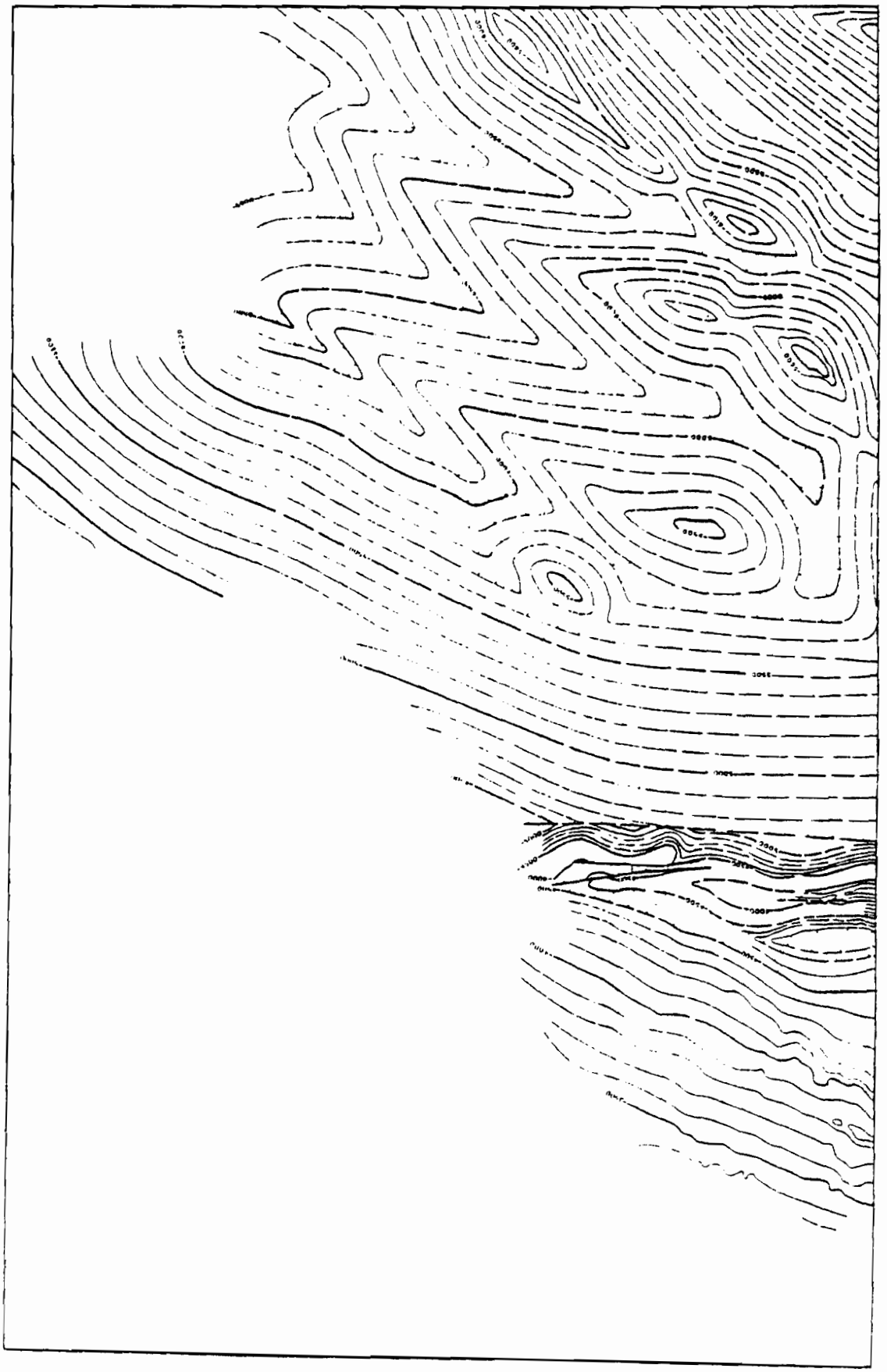
PRELIMINARY ONONDAGA STRUCTURE



Datum Top of the Onondaga or equivalent
CREDITS D. H. Cardwell, West Virginia Geological and Economic Survey, 1973

PRELIMINARY

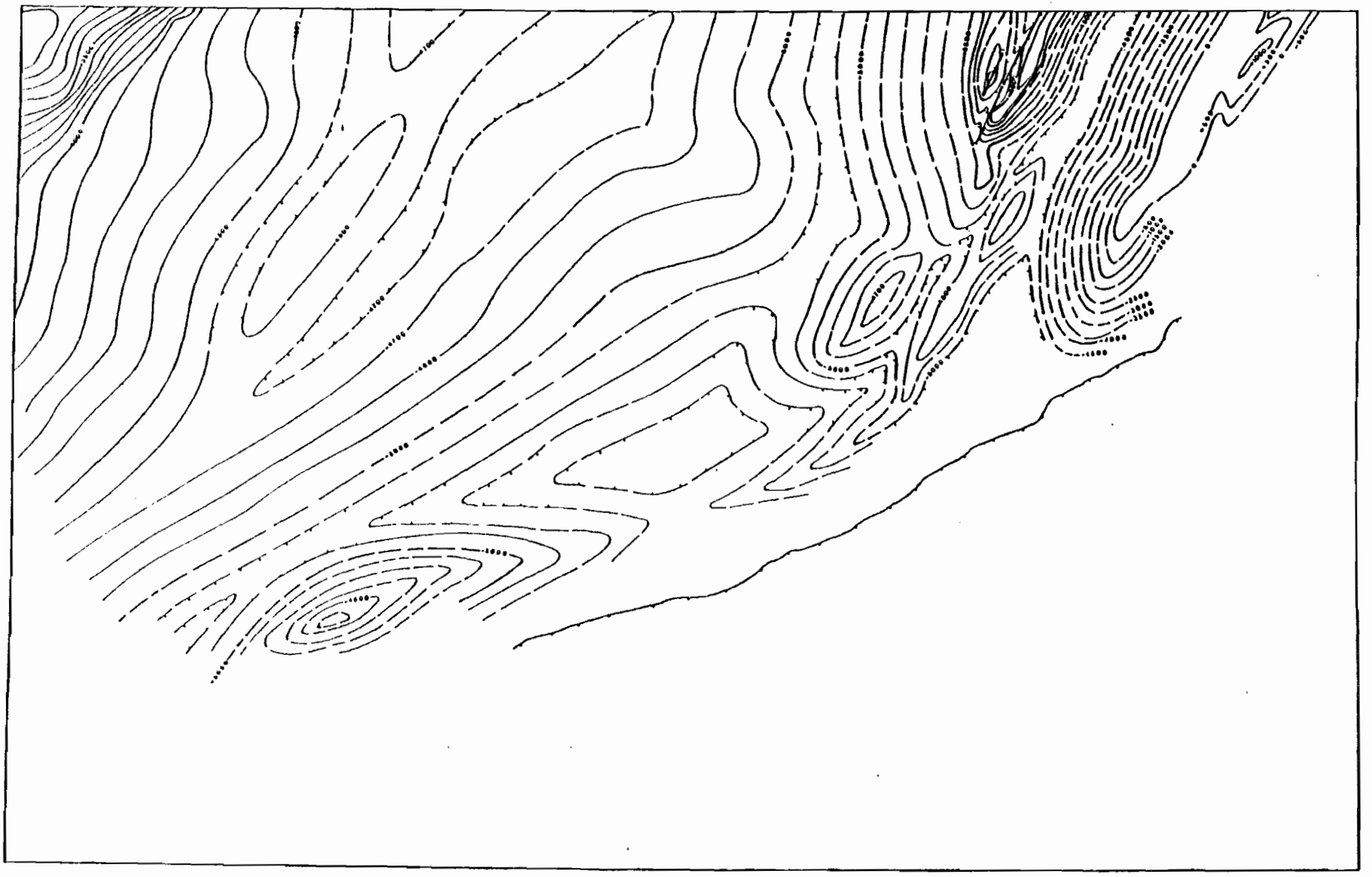
ONONDAGA STRUCTURE



Datum Top of the Onondaga
CREDITS: Dr. Kurt Lehrer
West Virginia Geological
and Economic Survey 1973

PRELIMINARY

ONONDAGA STRUCTURE



Datum Top of the Onondaga or equivalent
CREDITS D. H. Cardwell, West Virginia Geological and Economic Survey, 1973

5 0 5 10 15 20
MILES

BLUEFIELD

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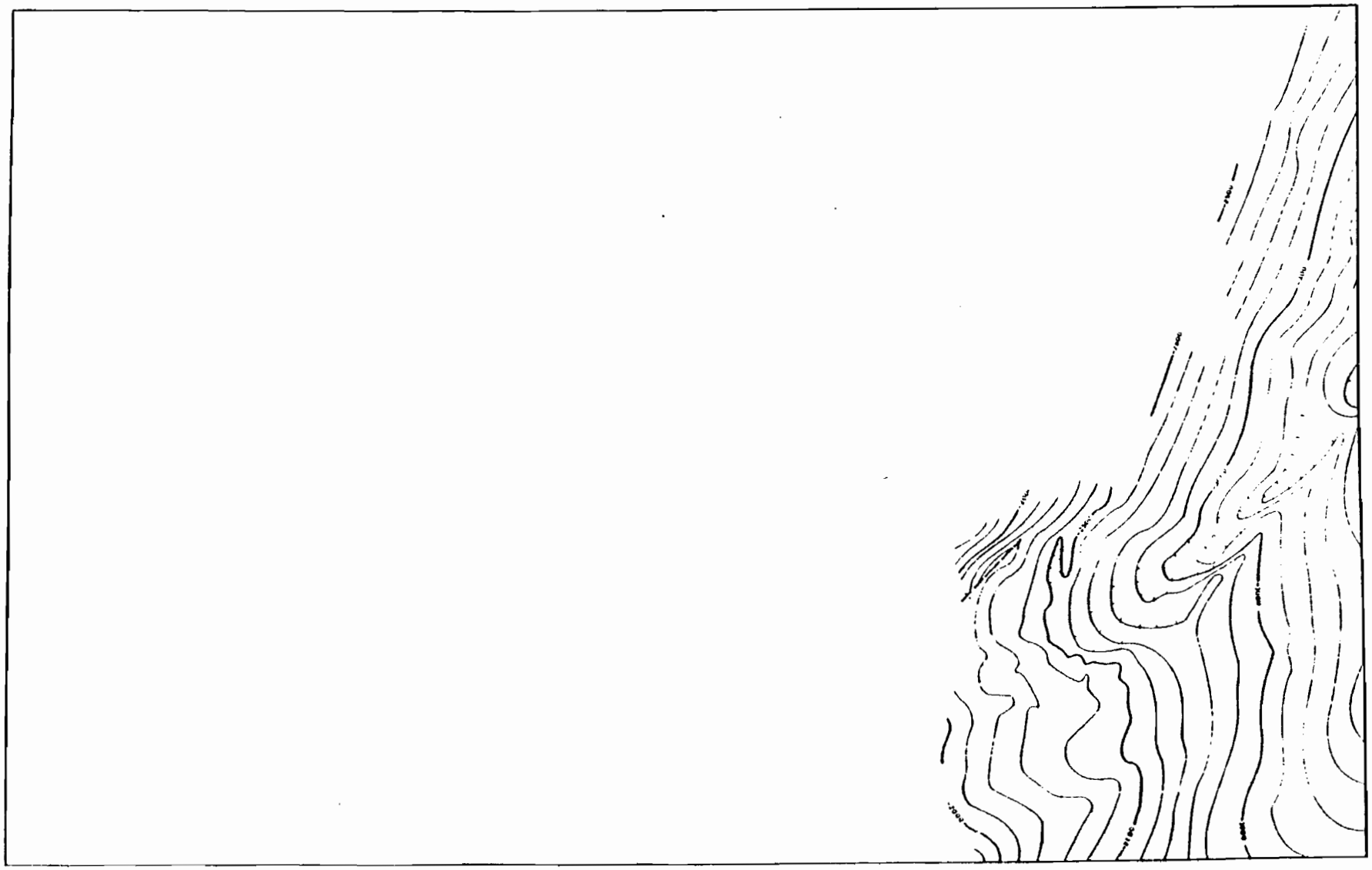
PRELIMINARY

ONONDAGA STRUCTURE



Datum Top of the Onondaga or equivalent
CREDITS D H Cardwell, West Virginia Geological and Economic Survey 1973

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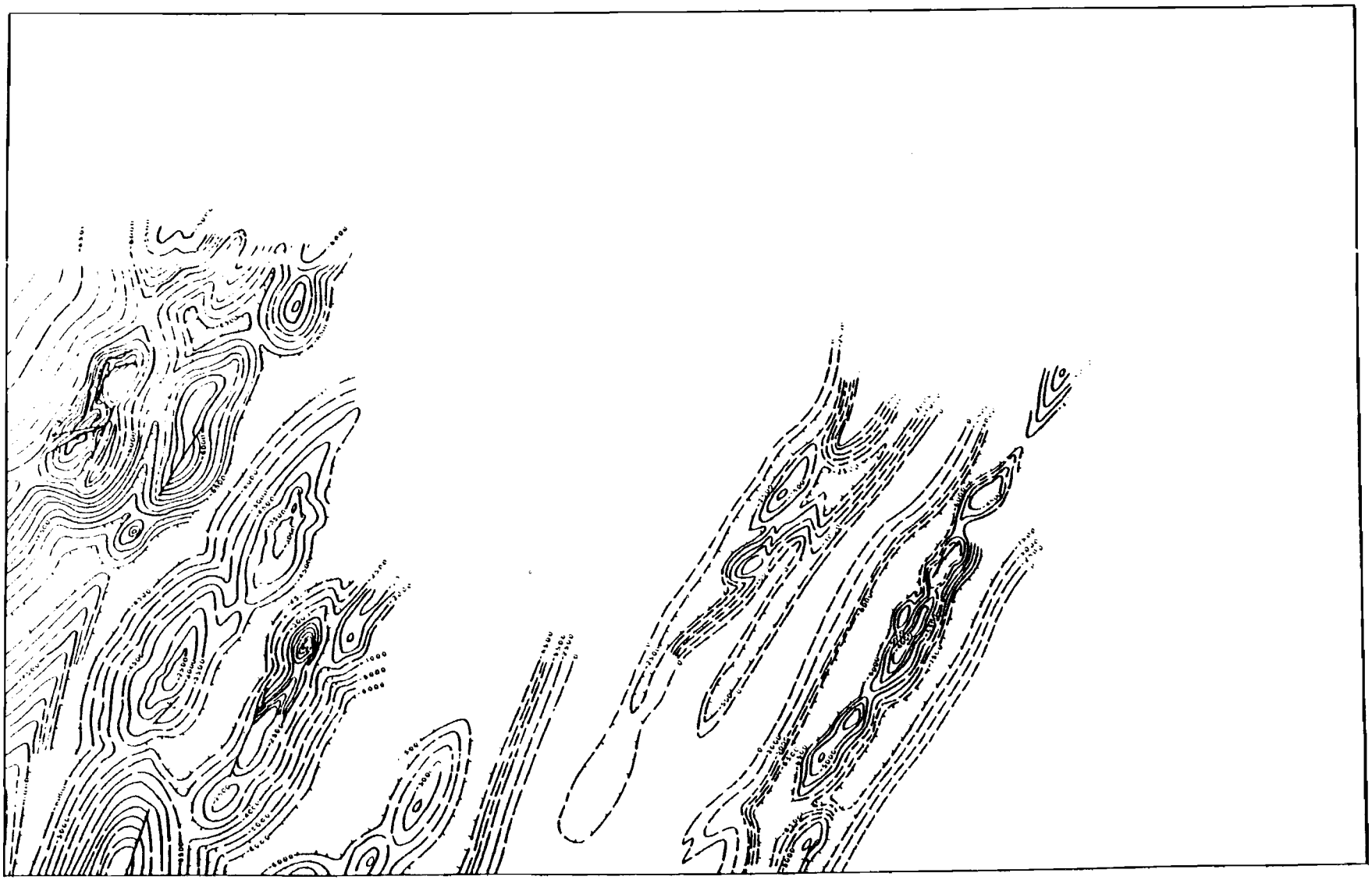
PRELIMINARY

ONONDAGA STRUCTURE



Datum Top of the Onondaga or equivalent
CREDITS D H Cardwell, West Virginia Geological and Economic Survey 1973

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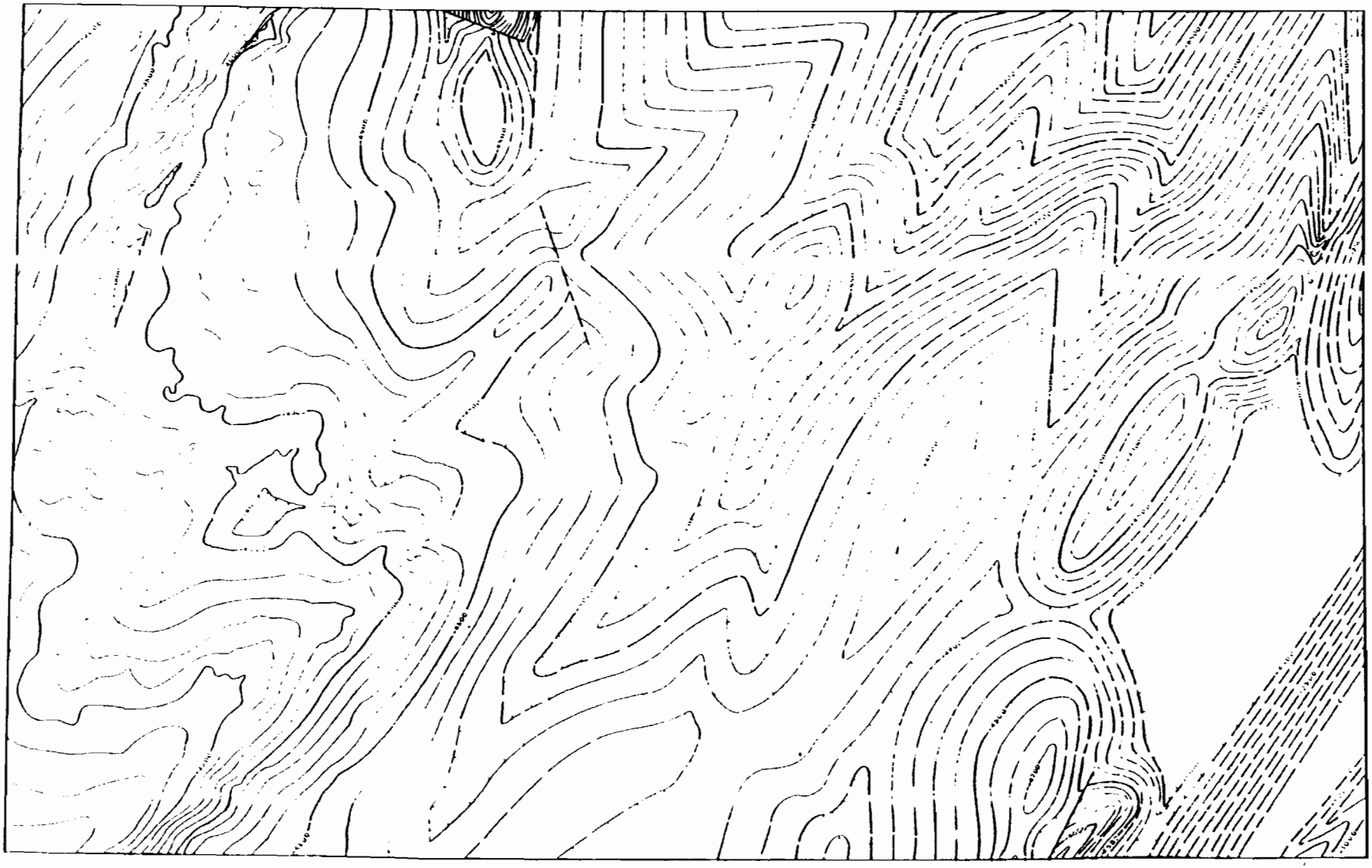
PRELIMINARY

ONONDAGA STRUCTURE



Datum: Top of the Onondaga or equivalent
CREDITS: D. H. Cardwell
West Virginia Geological and Economic Survey 1973

5 0 5 10 15 20
MILES

CHARLESTON

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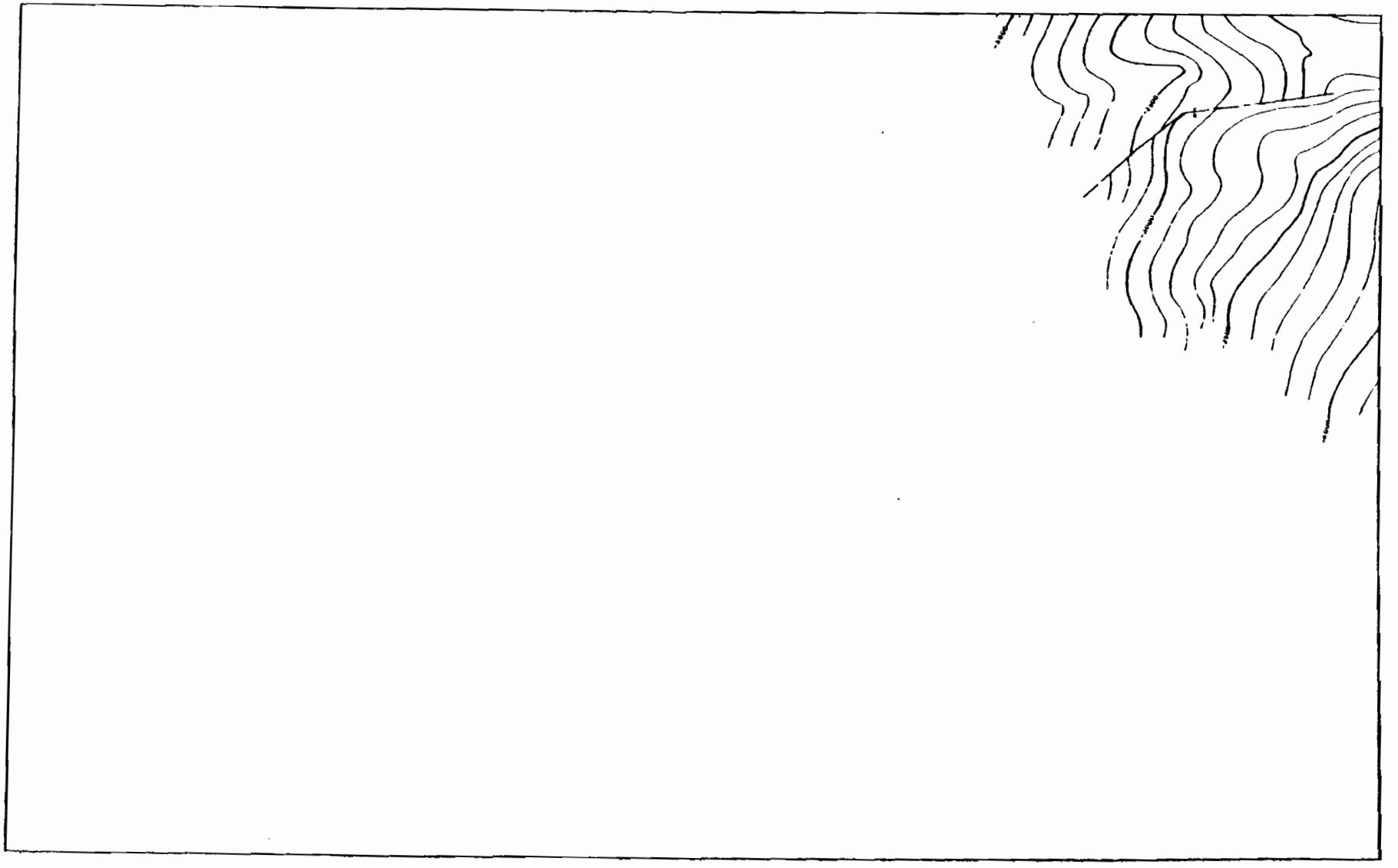
PRELIMINARY

ONONDAGA STRUCTURE



Datum Top of the Onondaga or equivalent
CREDITS D. H. Cardwell, West Virginia Geological and Economic Survey, 1973

5 0 5 10 15 20
MILES

JENKINS

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APPENDIX B

Kentucky Fracture Data

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TASK 5 DATA

The joint set data collected for task 5 has been arranged alphabetically by quadrangle. Locations within each quadrangle are presented as latitude and longitude in degrees, minutes and seconds. Columns under each latitude and longitude location include from left to right:

Column 1: Strike: positive values such as "56" should be read as N 56 E.
negative values such as "-56" should be read as N 56 W.

Column 2: Lithology: the following abbreviations have been used:
COL = coal
SST = sandstone
RSH = brown shale
BSH = black shale
GSH = grey shale
LST = limestone

Column 3: Bedding thickness: listed in feet

Column 4: Vertical dimension: listed in feet

Column 5: Horizontal dimension: listed in feet

Column 6: Frequency: distance between joints in feet. For example, "2.0" should be read as one joint every two feet.

Column 7: Roughness: listed as "R" is rough, "S" is smooth.

NOTES:

Information for Adams Quadrangle is available but has not been printed.

Blank columns indicate information that was not observable in the field.

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LAT	36	28	22				
LONG	2	52	14				
-78		COL	1.0	0.2	0.2		R
-87		COL	1.0	0.2	0.2		R
-77		COL	1.0	0.2	0.2		R
95		COL	1.0	1.0	0.3		
15		COL	1.0	1.0	0.3		
16		COL	1.0	1.0	0.3		
17		COL	1.0	1.0	0.3		
75		COL	1.0	0.5	0.2		R
95		COL	1.0	0.5	0.2		R
72		COL	1.0	0.5	0.2		R
-67		COL					
-66		COL					
-87		COL					
-98		COL					
15		COL					
-16		COL					
-25		COL					
-15		COL					
-75		COL					
LAT	46	28	22				
LONG	82	52	22				
5		SSH	2.0	4.0	0.2	1.0	
57		BSSH	2.0	4.0	0.2	1.0	R
62		BSSH	2.0	4.0	0.2	1.0	R
54		BSSH	2.0	4.0	0.2	1.0	R
45		BSSH	2.0	4.0	0.2	1.0	R
46		BSSH	2.0	4.0	0.2	1.0	R
43		BSSH	2.0	4.0	0.2	1.0	R
-87		BSSH	2.0	1.0	1.0	0.5	R
-82		BSSH	2.0	1.0	1.0	0.5	R
-73		BSSH	2.0	1.0	1.0	0.5	R
-42		BSSH	4.0	0.5	0.2	0.5	R
-59		BSSH	4.0	0.5	0.2	0.5	R
-37		BSSH					
42		RSSH	0.2	5.0	0.5	5.0	R
49		RSSH	0.2	5.0	0.5	5.0	R
42		RSSH	0.2	5.0	0.5	5.0	R
54		RSSH	0.2	5.0	0.5	5.0	R
55		RSSH	0.2	5.0	0.5	5.0	R
64		RSSH	0.2	5.0	0.5	5.0	R
53		RSSH	0.2	5.0	0.5	5.0	R
67		RSSH	0.2	5.0	0.5	5.0	R
-46		RSSH	0.1	5.0	0.5	2.0	R
-51		RSSH	0.1	5.0	0.5	2.0	R
-44		RSSH	0.1	5.0	0.5	2.0	R
-35		RSSH	0.1	5.0	0.5	2.0	R
-36		RSSH	0.1	5.0	0.5	2.0	R
-35		RSSH	0.1	5.0	0.5	2.0	R
-13		RSSH	0.1	2.0	2.0	5.0	R
0		RSSH	0.1	2.0	2.0	5.0	R
73		RSSH	0.1	4.0	3.0		R
8		RSSH	0.1	4.0	3.0		R
75		RSSH	0.1	4.0	3.0		R
55		RSSH	0.1	4.0	3.0		R
72		RSSH	0.1	4.0	3.0		R
74		RSSH	0.1	4.0	3.0		R
25		RSSH					
46		RSSH					
4		SSST	1.0	1.0	0.5	2.0	R
36		SSST	1.0	1.0	0.5	2.0	R
45		SSST	1.0	1.0	0.5	2.0	R
46		SSST	1.0	1.0	0.5	2.0	R
-40		SSST	1.0	1.0	1.0	0.5	R
-43		SSST	1.0	1.0	1.0	0.5	R
-55		SSST	1.0	1.0	1.0	0.5	R
-45		SSST	1.0	1.0	1.0	0.5	R
-55		SSST	1.0	1.0	1.0	0.5	R
55		SSST	1.0	1.0	2.0	1.5	R
57		SSST	1.0	1.0	2.0	1.5	R
52		SSST	1.0	1.0	2.0	1.5	R
54		SSST	1.0	1.0	2.0	1.5	R

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[illegible]		SST	6.0	6.0	20.0		[illegible]
[illegible]		SST	6.0	6.0	20.0		[illegible]
-[illegible]		SST	1.5	1.5	2.0	10.0	[illegible]
-[illegible]		SST	1.5	1.5	2.0	10.0	[illegible]
-17		SST	1.5	1.5	2.0	10.0	[illegible]
77		SST					

ASHLAND QUAD

LAT	38	27	00				
LONG	82	40	35				
-77		COOL	1.0	0.8	0.2	0.2	S
-84		COOL	1.0	0.8	0.2	0.2	S
-76		COOL	1.0	0.8	0.2	0.2	S
-72		COOL	1.0	0.8	0.2	0.2	S
-77		COOL	1.0	0.8	0.2	0.2	S
-82		COOL	1.0	0.8	0.2	0.2	S
-72		COOL	1.0	0.8	0.2	0.2	S
-74		COOL	1.0	0.8	0.2	0.2	S
-75		COOL	1.0	0.8	0.2	0.2	S
[illegible]		COOL	1.0	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		COOL	1.0	0.2	[illegible]	[illegible]	[illegible]
[illegible]		COOL	1.0	0.2	[illegible]	[illegible]	[illegible]
[illegible]		COOL	1.0	0.2	[illegible]	[illegible]	[illegible]
-54		COOL	1.0	0.2	[illegible]	[illegible]	[illegible]
-57		COOL	1.0	0.5	0.3	0.2	S
-59		COOL	1.0	0.5	0.3	0.2	S
-62		COOL	1.0	0.5	0.3	0.2	S
-62		COOL	1.0	0.5	0.3	0.2	S
32		COOL	1.0	0.3	0.2		R
30		COOL	1.0	0.3	0.2		R
37		COOL	1.0	0.3	0.2		R
42		COOL	1.0	0.3	0.2		R
42		COOL	1.0	0.3	0.2		R
-50		RSSH	3.0	0.2	0.2	0.2	R
-52		RSSH	3.0	0.2	0.2	0.2	R
-59		RSSH	3.0	0.2	0.2	0.2	R
14		RSSH	3.0	0.2	0.2	0.2	R
15		RSSH	3.0	0.2	0.2	0.2	R
[illegible]		RSSH	3.0	0.2	0.2	0.2	R
[illegible]		RSSH	3.0	0.2	0.2	0.2	R
-[illegible]		RSSH	3.0	0.2	0.2	0.2	R
17		RSSH	3.0	0.2	0.2	0.2	R
-62		RSSH	3.0	0.2	0.2	0.2	R
-76		RSSH	3.0	0.2	0.2	0.2	R

AULT QUAD

LAT	38	09	00				
LONG	83	11	35				
-37		SSST	1.0	1.0	0.5	2.0	R
-45		SSST	1.0	1.0	0.5	2.0	R
-53		SSST	1.0	1.0	0.5	2.0	R
-45		SSST	1.0	1.0	0.5	2.0	R
-43		SSST	1.0	1.0	0.5	2.0	R
53		SSST	1.0	0.5	0.5	1.0	R
64		SSST	1.0	0.5	0.5	1.0	R
47		SSST	1.0	0.5	0.5	1.0	R
52		SSST	1.0	0.5	0.5	1.0	R
47		SSST	1.0	0.5	0.5	1.0	R
46		SSST	1.0	0.5	0.5	1.0	R
[illegible]		SSST	1.0	0.5	0.5	1.0	R
[illegible]		SSST	1.0	0.5	0.5	1.0	R
45		SSST	1.0	0.5	0.5	1.0	R
30		SSST					
-10		RSSH	0.1	1.0	0.2	0.5	R
-1[illegible]		SSH	0.1	1.0	0.2	0.5	R
-1[illegible]		SSH	0.1	1.0	0.2	0.5	R
-1[illegible]		SSH	0.1	0.3	0.2		R
45		SSH	0.1	2.0	0.1	3.0	R
57		SSH	0.1	2.0	0.1	3.0	R
36		SSH	0.1	2.0	0.1	3.0	R
[illegible]		SSH	0.1	2.0	0.1	3.0	R
[illegible]		SSH	0.1	2.0	0.1	3.0	R
[illegible]		SSH	0.1	[illegible]	[illegible]	4.0	R
[illegible]		SSH	0.1	[illegible]	0.5	4.0	R
[illegible]		SSH	0.1	0.4	0.1	0.5	R
[illegible]		SSH	0.1	0.4	0.1	0.5	R

-07	BSH	0.1	0.4	0.1	0.5	R
-24	BSH					
-36	BSH					
-62	BSH					

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BALKAN QUAD

LAT 36 45 30
LONG 83 36 15

42	COL					
45	COL					
47	COL					
-45	COL					
-30	COL					
-43	COL					
-48	COL					
-23	BSH	0.1	8.0	4.0	5.0	R
-27	BSH	0.1	8.0	4.0	5.0	R
-33	BSH	0.1	8.0	4.0	5.0	R
-49	BSH	0.1	8.0	4.0	5.0	R
-49	BSH	0.1	8.0	4.0	5.0	R
-20	BSH	0.1	8.0	4.0	5.0	R
-37	BSH	0.1	8.0	4.0	5.0	R
51	BSH	0.1	3.0	2.0	2.0	R
52	BSH	0.1	3.0	2.0	2.0	R
67	BSH	0.1	3.0	2.0	2.0	R
53	BSH	0.1	3.0	2.0	2.0	R
-22	BSH					
-10	BSH					
-05	SST	1.0	5.0	7.0	2.0	R
-28	SST	1.0	5.0	7.0	2.0	R
-22	SST	1.0	5.0	7.0	2.0	R
57	SST	1.0	5.0	8.0	8.0	R
58	SST	1.0	5.0	8.0	8.0	R
72	SST	1.0	5.0	8.0	8.0	R
77	SST	1.0	5.0	8.0	8.0	R
72	SST	1.0	5.0	8.0	8.0	R

BANGOR QUAD

LAT 38 03
LONG 83 25 10

24	GSH	0.1	1.0	2.0	0.7	R
12	GSH	0.1	1.0	2.0	0.7	R
30	GSH	0.1	1.0	2.0	0.7	R
15	GSH	0.1	1.0	2.0	0.7	R
32	GSH	0.1	1.0	2.0	0.7	R
-42	GSH	0.1	1.5	0.5	2.0	R
-40	GSH	0.1	1.5	0.5	2.0	R
-55	GSH	0.1	1.5	0.5	2.0	R
-44	GSH	0.1	1.5	0.5	2.0	R
-61	GSH	0.1	1.5	0.5	2.0	R
-53	GSH	0.1	1.5	0.5	2.0	R
-65	GSH	0.1	1.5	0.5	2.0	R
86	GSH	0.1	0.2	0.1	0.3	R
-87	GSH	0.1	0.2	0.1	0.3	R
-82	GSH	0.1	0.2	0.1	0.3	R
25	SST	1.0	3.0	5.0	6.0	R
33	SST	1.0	3.0	5.0	6.0	R
32	SST	1.0	3.0	5.0	6.0	R
41	SST	1.0	3.0	5.0	6.0	R
15	SST	1.0	3.0	5.0	6.0	R
48	SST	1.0	3.0	5.0	6.0	R
30	SST	1.0	3.0	5.0	6.0	R
-35	SST	1.5	10.0	5.0	12.0	R
-66	SST	1.5	10.0	5.0	12.0	R
-52	SST	1.5	10.0	5.0	12.0	R
-52	SST	1.5	10.0	5.0	12.0	R
-65	SST	1.5	10.0	5.0	12.0	R
-54	SST	1.5	10.0	5.0	12.0	R
-66	SST	5.0	12.0	2.0	20.0	R
-55	SST	5.0	12.0	2.0	20.0	R
-72	SST	5.0	12.0	2.0	20.0	R
-78	SST	5.0	12.0	2.0	20.0	R
-71	SST	5.0	12.0	2.0	20.0	R

[illegible] QUAD

LAT 37 13 17
LONG 83 42 13

35	BSH	0.1	8.0	10.0		R

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45	BSH	0.1	8.0	10.0		R
37	BSH	0.1	8.0	10.0		R
37	BSH	0.1	8.0	10.0		R
-75	BSH	0.1	1.0	0.5	4.0	R
-67	BSH	0.1	1.0	0.5	4.0	R
-58	BSH	0.1	1.0	0.5	4.0	R
-56	BSH	0.1	1.0	0.5	4.0	R
-43	BSH	0.1	3.0	0.2	7.0	R
-54	BSH	0.1	3.0	0.2	7.0	R
-32	BSH	0.1	0.4	0.2	1.0	R
-20	BSH					
70	BSH	0.1	3.0	4.0		R
63	BSH	0.1	3.0	4.0		R

BEATTYVILLE QUAD

LAT	37	34	33			
LONG	83	40	12			
-45	COL					
-38	COL					
-43	COL					
47	COL					
48	COL					
54	COL					
11	COL					
13	COL					
25	COL					
12	COL					
67	BSH	0.1	3.0	4.0	2.0	R
85	BSH	0.1	3.0	4.0	2.0	R
60	BSH	0.1	3.0	4.0	2.0	R
75	BSH	0.1	3.0	4.0	2.0	R
80	BSH	0.1	3.0	4.0	2.0	R
-35	BSH	0.1	4.0	6.0	3.0	R
-30	BSH	0.1	4.0	6.0	3.0	R
-36	BSH	0.1	4.0	6.0	3.0	R
-32	BSH	0.1	4.0	6.0	3.0	R
-10	BSH	0.1	4.0	6.0	3.0	R
000	BSH	0.1	0.5	0.2		R
-68	BSH	0.1	0.3	0.7		R
-08	SST	0.3	0.3	0.4	2.0	R
-10	SST	0.3	0.3	0.4	2.0	R
-09	SST	0.3	0.3	0.4	2.0	R
82	SST	0.3	0.3	0.7	2.0	R
83	SST	0.3	0.3	0.7	2.0	R

BELFREY QUAD

LAT	37	36	50			
LONG	82	20	35			
-40	GSH	0.1	10.0	3.0	5.0	R
-36	GSH	0.1	10.0	3.0	5.0	R
-54	GSH	0.1	10.0	3.0	5.0	R
-39	GSH	0.1	10.0	3.0	5.0	R
-60	GSH	0.1	6.0	2.0	5.0	R
-70	GSH	0.1	6.0	2.0	5.0	R
-04	GSH	0.1	6.0	2.0	5.0	R
21	GSH	0.1	6.0	2.0	6.0	R
54	GSH	0.1	6.0	2.0	6.0	R
65	GSH	0.1	6.0	2.0	6.0	R
0	GSH	0.1	10.0	2.0	6.0	R
5	GSH	0.1	10.0	2.0	6.0	R

BEVERLY QUAD

LAT	36	56	22			
LONG	83	32	08			
33	COL					
32	COL					
47	COL					
43	COL					
-62	COL					
-59	COL					
-54	COL					
-62	COL					
-47	BSH	0.1	2.5	4.0		R
-37	BSH	0.1	2.5	4.0		R
-41	BSH	0.1	2.5	4.0		R
-35	BSH	0.1	2.5	4.0		R
-40	BSH	0.1	2.5	4.0		R
43	BSH	0.1	0.2	0.1		R

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42	BSH	0.1	0.2	0.1		R
35	BSH	0.1	0.2	0.1		R
62	BSH	0.1	0.2	0.1		R
28	BSH	0.1	2.0	3.0	3.0	R
25	BSH	0.1	2.0	3.0	3.0	R
-28	BSH	0.1	2.0	2.0	10.0	R
-72	BSH	0.1	2.0	2.0	10.0	R
-40	SST	4.0	4.0	12.0		S
-32	SST	4.0	4.0	12.0		S
52	SST	4.0	3.0	2.0		R
38	SST	4.0	3.0	2.0		R
35	SST					
80	SST					

BIG CREEK QUAD

LAT 37 09 37
LONG 83 34 14

73	GSH	0.1	8.0	2.0	12.0	R
82	GSH	0.1	8.0	2.0	12.0	R
87	GSH	0.1	8.0	2.0	12.0	R
77	GSH	0.1	8.0	2.0	12.0	R
74	GSH	0.1	8.0	2.0	12.0	R
-75	GSH	0.1	3.0	1.5		R
-77	GSH	0.1	3.0	1.5		R
-82	GSH	0.1	3.0	1.5		R
24	GSH	0.1	12.0	15.0	6.0	R
17	GSH	0.1	12.0	15.0	6.0	R
50	GSH	0.1	12.0	15.0	6.0	R
53	GSH	0.1	12.0	15.0	6.0	R
52	GSH	0.1	12.0	15.0	6.0	R
03	GSH					
05	GSH					
03	GSH					
34	SST	2.0	2.0	12.0		R
28	SST	2.0	2.0	12.0		R
53	SST	2.0	1.0	1.0		R
60	SST	2.0	1.0	1.0		R
54	SST	2.0	1.0	1.0		R

BLACKEY QUAD

LAT 37 12 13
LONG 82 55 04

76	COL					
77	COL					
80	COL					
78	COL					
79	COL					
-17	COL					
-16	COL					
-13	COL					
-43	COL					
-45	COL					
-32	COL					
-43	COL					
-75	BSH	0.1	2.0	1.0	12.0	R
-75	BSH	0.1	2.0	1.0	12.0	R
82	BSH	0.1	2.0	1.0	12.0	R
-35	BSH	0.1	3.0	3.0		R
-54	BSH	0.1	3.0	3.0		R
-57	BSH	0.1	3.0	3.0		R
37	BSH	0.1	3.0	1.0		R
30	BSH	0.1	3.0	1.0		R

BLAINE QUAD

LAT 38 02 27
LONG 82 48 31

-37	COL	1.3	0.5	0.1	0.1	R
-27	COL	1.3	0.5	0.1	0.1	R
-40	COL	1.3	0.5	0.1	0.1	R
-33	COL	1.3	0.5	0.1	0.1	R
-36	COL	1.3	0.5	0.1	0.1	R
54	COL	1.3	0.2	1.2	0.1	R
42	COL	1.3	0.2	1.2	0.1	R
57	COL	1.3	0.2	1.2	0.1	R
51	COL	1.3	0.2	1.2	0.1	R
54	COL	1.3	0.2	1.2	0.1	R
-53	SST	1.0	7.0	1.0	8.0	R
-61	SST	1.0	7.0	1.0	8.0	R

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-37		SST	0.3	5.0	2.0	12.0	R
27		SST	0.3	5.0	2.0	12.0	R
30		SST	0.3	5.0	2.0	12.0	R
37		SST	0.3	5.0	2.0	12.0	R
43		SST	0.3	5.0	2.0	12.0	R
22		SST	0.3	5.0	2.0	12.0	R
17		SST	0.3	5.0	2.0		R
19		SST	0.3	5.0	2.0		R
15		SST	0.3	5.0	2.0		R
-23		SST	0.3	5.0	2.0		R
-15		SST	0.3	5.0	2.0		R
10		SST	0.3	5.0	2.0		R
-20		SST	0.3	5.0	2.0		R
10		SST	0.3	5.0	2.0		R
83		SST					
-83		SST	3.0	4.0	12.0	5.0	R
-83		SST	3.0	4.0	12.0	5.0	R
-70		SST	3.0	4.0	12.0	5.0	R
-77		SST	3.0	4.0	12.0	5.0	R

BLEDSOE QUAD

LAT	36	53	57				
LONG	83	21	31				
73		BSH	0.1	1.5	1.0		S
74		BSH	0.1	1.5	1.0		S
72		BSH	0.1	1.5	1.0		S
14		BSH	0.1	0.3	0.2	0.4	R
14		BSH	0.1	0.3	0.2	0.4	R
08		BSH	0.1	0.3	0.2	0.4	R
03		BSH	0.1	0.3	0.2	0.4	R
04		BSH	0.1	0.3	0.2	0.4	R
52		BSH	0.1	0.5	1.0	2.0	S
38		BSH	0.1	0.5	1.0	2.0	S
63		BSH	0.1	0.5	1.0	2.0	S
-12		LST	1.5	2.0	1.5	1.0	R
-02		LST	1.5	2.0	1.5	1.0	R
-13		LST	1.5	2.0	1.5	1.0	R
81		LST	1.5	10.0	12.0	1.5	R
83		LST	1.5	10.0	12.0	1.5	R
80		LST	1.5	10.0	12.0	1.5	R
LAT	36	52	52				
LONG	83	18	35				
-25		BSH	0.1	0.1	0.1		R
77		BSH	0.1	1.0	1.0	0.3	R
58		BSH	0.1	1.0	1.0	0.3	R
65		BSH	0.1	0.2	0.1		R
50		BSH	0.1	0.2	0.1		R
63		BSH	0.1	0.2	0.1		R
60		BSH	0.1	0.2	0.1		R
-10		BSH	0.1	0.4	0.2	0.1	R
-03		SST					
-67		SST	2.0	5.0	6.0	3.0	R
-70		SST	2.0	5.0	6.0	3.0	R
73		SST					
50		SST					
31		SST					
-48		SST	1.0	0.5	0.6	10.0	R
-45		SST	1.0	0.5	0.6	10.0	R
LAT	36	53	22				
LONG	83	18	38				
-36		SST	2.0	6.0	5.0	1.0	R
-27		SST	2.0	6.0	5.0	1.0	R
75		SST	1.0	1.0	1.0		
-55		SST					
50		SST					
-38		GSH	0.1	2.0	5.0		R
65		GSH	0.1	1.0	1.0	2.0	R
57		BSH	0.1	0.2	0.2	0.2	R
-26		BSH	0.1	0.2	0.2	0.2	R
-43		BSH	0.1	0.5	0.5	3.0	R
-60		BSH	0.1	0.5	0.5	3.0	R

SCOTTSFORK QUAD

LAT	38	20	55				
LONG	83	42	31				
74		COL	1.5	0.2	0.1	0.1	C
33		COL	1.5	0.2	0.3	0.1	R
37		COL	1.5	0.2	0.3	0.1	R
41		COL	1.5	0.2	0.3	0.1	R

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42		CCL	1.5	0.2	0.3	0.1	R
41		CCL	1.5	0.2	0.3	0.1	R
-59		CCL	1.5	0.3	0.4	0.1	R
-67		CCL	1.5	0.3	0.4	0.1	R
-71		CCL	1.5	0.3	0.4	0.1	R
-63		CCL	1.5	0.3	0.4	0.1	R
-57		CCL	1.5	0.3	0.4	0.1	R
-58		CCL	1.5	0.3	0.4	0.1	R
-18		GGSH	0.1	2.0	0.1		R
-25		GGSH	0.1	2.0	0.1		R
-13		GGSH	0.1	2.0	0.1		R
000		GGSH	0.1	2.0	0.1		R
-08		GGSH	0.1	2.0	0.1		R
-06		GGSH	0.1	2.0	0.1		R
42		GGSH					
28		GGSH					
[illegible]		GGSH					
04		GGSH					
28		SST	1.0	1.0	2.0	3.0	R
3[illegible]		SST	1.0	1.0	2.0	3.0	R
[illegible]		SST					
8[illegible]		SST	1.0	1.0	2.		
[illegible]		SST	1.0	1.0	[illegible]		
-[illegible]		SST	1.0	1.0	[illegible]	2.5	[illegible]
-[illegible]		SST	1.0	1.0	[illegible]	2.5	R
-1[illegible]		SST	1.0	1.0	2.0	2.5	R
-1[illegible]		SST	1.0	1.0	2.0	2.5	R
[illegible]		SST	0.5	0.5	0.2		R
15		SST	0.5	0.5	0.2		R
16		SST	0.5	0.5	0.2		R
-37		SST					
-55		SST					
LAT	38 17 20						
LONG	82 42 24						
55		SST	1.0	1.5	1.0	6.0	R
48		SST	1.0	1.5	1.0	6.0	R
40		SST	1.0	1.5	1.0	6.0	R
41		SST	1.0	1.5	1.0	6.0	R
38		SST	1.0	1.5	1.0	6.0	R
51		SST	1.0	1.5	1.0	6.0	R
-50		SST	1.0	1.5	2.0		R
-40		SST	1.0	1.5	2.0		R
-48		SST	1.0	1.5	2.0		R
-52		SST	1.0	1.5	2.0		R
-62		SST	1.0	1.5	2.0		R
-00		SST	1.0	1.0	4.0	3.0	R
03		SST	1.0	1.0	4.0	3.0	R
-10		SST	1.0	1.0	4.0	3.0	R
-15		SST	1.0	1.0	4.0	3.0	R
-04		SST	1.0	1.0	4.0	3.0	R
04		SST	1.0	1.0	4.0	3.0	R
72		SST	1.0	3.0	1.0	12.0	R
90		SST	1.0	3.0	1.0	12.0	R
85		SST	1.0	3.0	1.0	12.0	R
-85		SST	1.0	3.0	1.0	12.0	R
70		SST	1.0	3.0	1.0	12.0	R
76		SST	1.0	3.0	1.0	12.0	R
-82		SST	1.0	3.0	1.0	12.0	R
-82		SST	1.0	3.0	1.0	12.0	R
78		SST	1.0	3.0	1.0	12.0	R
BONNEVILLE QUAD							
LAT	37 23 02						
LONG	83 41 15						
44		GGSH	0.1	3.0	2.0		R
42		GGSH	0.1	3.0	2.0		R
43		GGSH	0.1	3.0	2.0		R
45		GGSH	0.1	3.0	2.0		R
40		GGSH	0.1	3.0	2.0		R
28		GGSH	0.1	2.5	4.0		R
[illegible]		GGSH	0.1	2.5	4.0		R
-24		GGSH	0.1	2.5	2.0		R
72		GGSH	0.1	0.2	0.2		R
57		GGSH	0.1	0.2	0.2		R
45		GGSH	0.1	0.2	0.2		R
-77		GGSH	0.1	1.5	3.0		R
-71		GGSH	0.1	1.0	3.0		R
-68		GGSH	0.1	1.0	3.0		R

BROAD BOTTOM QUAD

LAT	37	32	24				
LONG	82	35	35				
78		GSH	0.1	8.0	20.0	4.0	R
68		GSH	0.1	8.0	20.0	4.0	R
65		GSH	0.1	8.0	20.0	4.0	R
54		GSH	0.1	8.0	20.0	4.0	R
48		GSH	0.1	8.0	20.0	4.0	R
-20		GSH	0.1	8.0	4.0	12.0	R
-21		GSH	0.1	8.0	4.0	12.0	R
-22		GSH	0.1	8.0	4.0	12.0	R
-31		GSH	0.1	8.0	4.0	12.0	R
-32		GSH	0.1	8.0	4.0	12.0	R
-30		GSH	0.1	8.0	4.0	12.0	R

PRLL QUAD

LAT	38	09	32				
LONG	83	[illegible]	[illegible]				
[illegible]		SST	5.0	5.0	6.0	6.0	S
-74		SST	5.0	5.0	6.0	6.0	S
-77		SST	5.0	5.0	6.0	6.0	S
25		SST	5.0	5.0	6.0	6.0	S
-[illegible]		SST	5.0	5.0	6.0	6.0	S
-70		SST	5.0	5.0	6.0	6.0	S
81		SST	5.0	5.0	6.0	6.0	S
60		SST	5.0	5.0	6.0	6.0	S
-11		SST	5.0	5.0	6.0	6.0	S
-60		RSH	0.5	1.0	0.5	0.5	R
-62		RSH	0.5	1.0	0.5	0.5	R
-58		RSH	0.5	1.0	0.5	0.5	R
-53		RSH	0.5	1.0	0.5	0.5	R
-54		RSH	0.5	1.0	0.5	0.5	R
-60		RSH	0.5	1.0	0.5	0.5	R
-85		RSH	1.0	5.0	1.0	5.0	R
-80		RSH	1.0	5.0	1.0	5.0	R
-74		RSH	1.0	5.0	1.0	5.0	R
-30		RSH	0.5	0.7	0.1	4.0	R
-15		RSH	0.5	0.7	0.1	4.0	R
-14		RSH	0.5	0.7	0.1	4.0	R
-25		RSH	0.5	0.7	0.1	4.0	R
-18		RSH	0.5	0.7	0.1	4.0	R
-27		RSH	0.5	0.7	0.1	4.0	R
-40		RSH	0.5	0.5	0.2	2.0	R
-45		RSH	0.5	0.5	0.2	2.0	R
-47		RSH	0.5	0.5	0.2	2.0	R
50		RSH	0.5	0.2	0.5	0.5	R
55		RSH	0.5	0.2	0.5	0.5	R
18		RSH					
10		RSH					

BRUSHART QUAD

LAT	38	31	37				
LONG	83	04	50				
08		SST	0.2	0.2	20.0	2.5	S
10		SST	0.2	0.2	20.0	2.5	S
13		SST	0.2	0.2	20.0	2.5	S
08		SST	0.2	0.2	20.0	2.5	S
00		SST	0.1	0.5	25.0	3.0	S
-01		SST	0.1	0.5	25.0	3.0	S
03		SST	0.1	0.5	25.0	3.0	S
04		SST	0.1	0.5	25.0	3.0	S
02		SST	0.1	0.5	25.0	3.0	S
03		SST	0.1	0.5	25.0	3.0	S
05		SST	0.1	0.5	25.0	3.0	S
50		SST	0.1	0.1	0.2	0.5	R
-80		SST	0.1	0.1	0.2	0.5	R
73		SST	0.1	0.1	0.2	0.5	R
-77		SST	0.1	0.1	0.2	0.5	R
70		SST	0.1	0.1	0.2	0.5	R

HUCKHORN QUAD

LAT	37	18	23	
LONG	83	26	20	
38		COL		
42		COL		
12		COL		

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-50		COL	
-45		COL	
-58		COL	
58		RSH	
-85		RSH	
45		RSH	
-25		RSH	
01		RSH	
-05		RSH	
-80		SST	
-85		SST	
15		SST	
05		SST	
30		SST	
65		SST	
70		SST	
-1[illegible]		SST	
-3[illegible]		SST	
-15		SST	
LAT	37	18	24
LONG	83	26	2[illegible]
-1[illegible]		COL	
-1[illegible]		COL	
-1[illegible]		COL	
-0[illegible]		COL	
5[illegible]		COL	
71		COL	
76		COL	
67		COL	
67		SST	
72		SST	
72		SST	
62		SST	
-22		SST	
00		SST	
-22		GSH	
87		GSH	
-5[illegible]		GSH	
35		GSH	
28		GSH	
22		GSH	
LAT	37	18	3[illegible]
LONG	83	25	23
-12		COL	
-06		COL	
64		COL	
53		COL	
58		COL	
-05		COL	
72		COL	
62		COL	
-18		COL	
-32		COL	
-32		COL	
-19		COL	
78		COL	
69		COL	
86		COL	
61		RSH	
77		RSH	
-2[illegible]		RSH	
-15		RSH	
65		RSH	
-2[illegible]		RSH	
6[illegible]		RSH	
-29		RSH	
-49		SST	
85		SST	
-6[illegible]		SST	
-52		SST	
-60		SST	
26		SST	
-75		SST	
LAT	37	19	12
LONG	83	25	27
-[illegible]		COL	
-1[illegible]		COL	
-0[illegible]		COL	
79		COL	
91		COL	

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[illegible]			GSH					
-36			GSH					
-57			GSH					
20			GSH					
52			GSH					
-2[illegible]			GSH					
-1[illegible]			GSH					
-40			SST					
-20			SST					
37			SST					
55			SST					
66			SST					
90			SST					
72			SST					

HURTONVILLE QUAD

LAT	38	24	28					
LONG	83	35	43					
49			BSH				0.5	R
47			BSH				0.5	R
45			BSH				0.5	R
45			BSH				0.5	R
46			BSH				0.5	R
50			BSH				0.5	R
47			BSH				0.5	R
47			BSH				0.5	R
46			BSH				0.5	R
48			BSH				0.5	R
-24			BSH				1.0	R
-22			BSH				1.0	R
-37			BSH				1.0	R
-42			BSH				10.0	R
-45			BSH				10.0	R
-43			BSH				10.0	R
-10			BSH					R
-20			BSH					R
-36			RSH				4.0	R
-40			RSH				4.0	R
LAT	38	27	52					
LONG	83	32	00					
47			BSH				1.5	R
51			BSH				1.5	R
45			BSH				1.5	R
49			BSH				1.5	R
45			BSH				1.5	R
47			BSH				1.5	R
48			BSH				1.5	R
45			BSH				1.5	R
43			BSH				1.5	R
45			BSH				1.5	R
40			BSH				1.5	R
42			BSH				1.5	R
42			BSH				1.5	R
35			BSH				1.0	R
37			BSH				1.0	R
23			BSH				1.0	R
28			BSH				1.0	R
5			BSH					R
10			BSH					R
-48			BSH				2.0	R
-42			BSH				2.0	R
-53			BSH				2.0	R
-44			BSH				2.0	R
-42			BSH				2.0	R
-12			BSH					R
-10			BSH					R

CAMPTON QUAD

LAT	37	44	26					
LONG	83	33	56					
-13			COL					
-70			COL					
-84			RSH	0.1	0.5	0.3	0.3	R
-85			RSH	0.1	0.5	0.3	0.3	R
[illegible]			RSH	0.1	0.5	0.3	0.3	R
[illegible]			RSH	0.1	0.5	0.5	1.0	R
[illegible]			RSH	0.1	0.5	0.5	1.0	R
[illegible]			BSH	0.1	0.3	0.2	1.0	R
-85			BSH	0.1	0.3	0.2	1.0	R

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66	BSH	0.1	0.3	0.2	1.0	R
21	BSH	0.1	0.3	0.2	4.0	R
22	BSH	0.1	0.3	0.2	4.0	R
15	BSH	0.1	0.3	0.1		R
85	GSH	0.1	2.0	1.0	7.0	R
-88	GSH	0.1	2.0	1.0	7.0	R
-89	GSH	0.1	2.0	1.0	7.0	R
77	GSH	0.1	2.0	1.0	7.0	R
76	SST	0.5	2.0	3.0	3.0	R
78	SST	0.5	2.0	3.0	3.0	R
82	SST	0.5	2.0	3.0	3.0	R
-28	SST	0.5	0.5	10.0		R
CCC	SST					

CANNEL CITY QUAD

LAT 37 52 08
LONG 83 19 41

-46	RSH	0.2	4.0	4.0	7.0	R
-42	RSH	0.2	4.0	4.0	7.0	R
-43	RSH	0.2	4.0	4.0	7.0	R
-47	RSH	0.2	4.0	4.0	7.0	R
65	RSH	0.2	0.4	5.0	7.0	R
72	RSH	0.2	0.4	5.0	7.0	R
70	RSH	0.2	0.4	5.0	7.0	R
-80	RSH	0.2	0.4	5.0	7.0	R
50	RSH	0.2	0.4	5.0	7.0	R
8	RSH	0.2	0.4	5.0	7.0	R
-18	RSH	0.2	0.4	5.0	7.0	R
28	RSH	0.2	0.4	5.0	7.0	R
-20	RSH	0.2	0.7	1.0	7.0	R
-22	RSH	0.2	0.7	1.0	7.0	R
-26	RSH	0.2	0.7	1.0	7.0	R
0	BSH	0.3	2.0	0.2	2.0	R
-06	BSH	0.3	2.0	0.2	2.0	R
-03	BSH	0.3	2.0	0.2	2.0	R
-01	BSH	0.3	2.0	0.2	2.0	R
-90	BSH	0.3	2.0	0.2	2.0	R
-72	BSH	0.3	2.0	0.2	2.0	R
-70	BSH	0.3	2.0	0.2	2.0	R
-50	BSH	0.3	2.0	0.2	2.0	R
-43	BSH	0.3	2.0	0.2	2.0	R
14	BSH	0.3	2.0	0.2	2.0	R
45	BSH	0.3	2.0	0.2	2.0	R

CANOE QUAD

LAT 37 28 05
LONG 83 28 47

30	COL					
32	COL					
33	COL					
17	COL					
04	COL					
-85	COL					
-80	COL					
-43	COL					
-48	COL					
-20	GSH	0.1	2.0	4.0	2.0	R
-24	GSH	0.1	2.0	4.0	2.0	R
-17	GSH	0.1	2.0	4.0	2.0	R
-22	GSH	0.1	2.0	4.0	2.0	R
36	GSH	0.1	1.5	0.2	3.0	R
33	GSH	0.1	1.5	0.2	3.0	R
40	GSH	0.1	1.5	0.2	3.0	R
39	GSH	0.1	1.5	0.2	3.0	R
38	GSH	0.1	1.5	0.2	3.0	R
74	GSH	0.1	0.6	0.3	2.5	R
64	GSH	0.1	0.6	0.3	2.5	R
58	GSH	0.1	0.6	0.3	2.5	R
60	GSH	0.1	0.6	0.3	2.5	R
-30	SST	4.0	8.0	12.0	5.0	R
-22	SST	4.0	8.0	12.0	5.0	R
-30	SST	4.0	8.0	12.0	5.0	R
59	SST	2.5	2.5	1.0	3.0	R
57	SST	2.5	2.5	1.0	3.0	R
[illegible]	SST	2.5	2.5	1.0	3.0	R
[illegible]	SST	2.5	2.5	1.0	3.0	R
36	SST	1.0	2.0	0.2		R
4[illegible]	SST	1.0	2.0	0.2		R

27	RSH	0.2				R
37	RSH	0.2				R
35	RSH	0.2				R
65	RSH	0.1			0.2	R
54	RSH	0.1			0.2	R
47	RSH	0.1			0.2	R

CELFAX QUAD

LAT 38 08 17
LONG 83 43 15

40	LST	0.3	0.3	0.1	0.2	R
43	LST	0.3	0.3	0.1	0.2	R
-42	LST	0.3	0.3	0.1	0.2	R
-48	LST	0.3	0.3	0.1	0.2	R
-28	LST	0.3	0.3	0.1	0.2	R
-[illegible]	LST	0.3	0.3	0.2	1.0	R
6	LST	0.3	0.3	0.2	1.0	R
1	LST	0.3	0.3	0.2	1.0	R
4	LST	0.3	0.3	0.2	1.0	R
14	LST	0.3	0.3	0.2	1.0	R
17	LST	0.3	0.3	0.2	1.0	R
8	LST	0.3	0.3	0.2	1.0	R
[illegible]	LST	0.3	0.3	0.2	1.0	R
[illegible]	LST	0.3	0.3	0.2	1.0	R
60	LST	0.3	0.3	0.2	2.5	R
77	LST	0.3	0.3	0.2	2.5	R
73	LST	0.3	0.3	0.2	2.5	R
8[illegible]	LST	0.3	0.3	0.2	2.5	R
64	LST	0.3	0.3	0.2	2.5	R
30	LST	0.4	0.4	0.5	1.5	R
20	LST	0.4	0.4	0.5	1.5	R
-73	LST	0.4	0.4	0.5	1.5	R
-82	LST	0.4	0.4	0.5	1.5	R
-80	LST	0.4	0.4	0.5	1.5	R
-78	LST	0.4	0.4	0.5	1.5	R

CCKCREEK QUAD

LAT 37 27 54
LONG 83 32 57

50	COL					
32	COL					
30	COL					
45	COL					
78	COL					
67	COL					
28	COL					
32	COL					
31	COL					
25	COL					
35	COL					
02	BSH	0.1	0.4	0.2	1.0	R
-05	BSH	0.1	0.4	0.2	1.0	R
-03	BSH	0.1	0.4	0.2	1.0	R
38	BSH	0.1	0.5	2.5	0.7	R
35	BSH	0.1	0.5	2.5	0.7	R
32	BSH	0.1	0.5	2.5	0.7	R
32	BSH	0.1	0.5	2.5	0.7	R
35	BSH	0.1	0.5	2.5	0.7	R
-50	BSH	0.1	0.5	0.5	2.0	R
-43	BSH	0.1	0.5	0.5	2.0	R
-46	BSH	0.1	0.5	0.5	2.0	R
-60	BSH	0.1	0.5	0.5	2.0	R
-42	BSH	0.1	0.5	0.5	2.0	R
-32	BSH	0.1	0.5	0.5	2.0	R

CRANSTON QUAD

LAT 38 17 00
LONG 83 24 34

-61	SST	0.6	0.6	0.3	0.3	R
-56	SST	0.6	0.6	0.3	0.3	R
-54	SST	0.6	0.6	0.3	0.3	R
-45	SST	0.6	0.6	0.3	0.3	R
-43	SST	0.6	0.6	0.3	0.3	R
-42	SST	0.6	0.6	0.3	0.3	R
27	SST	0.6	0.6	2.0	1.0	S
32	SST	0.6	0.6	2.0	1.0	S
38	SST	0.6	0.6	2.0	1.0	S
46	SST	0.6	0.6	2.0	1.0	S

-[illegible]	SST	0.3	0.5	2.0	3.0	R
-36	SST	0.3	0.5	2.0	3.0	R
-37	SST	0.3	0.5	2.0	3.0	R
-29	SST	0.3	0.5	2.0	3.0	R
-29	SST	0.3	0.5	2.0	3.0	R

CRLEKVILLE QUAD

LAT 37 05 37
LONG 83 33 26

22	COL					
35	COL					
35	COL					
34	COL					
-70	COL					
-70	COL					
-63	COL					
-58	COL					
58	BSH	0.1	5.0	1.0	5.0	R
6[illegible]	BSH	0.1	5.0	1.0	5.0	R
57	BSH	0.1	5.0	1.0	5.0	R
[illegible]	BSH	0.1	5.0	1.0	5.0	R
[illegible]7	BSH	0.1	5.0	10.0		R
[illegible]	BSH	0.1	5.0	10.0		R
-[illegible]	BSH	0.1	10.0	7.0		R
-32	BSH	0.1	10.0	7.0		R
-[illegible]	BSH	0.1	10.0	7.0		R
-74	BSH					
-[illegible]	SST	3.0	3.0	10.0		S
-[illegible]	SST	3.0	3.0	10.0		S
-35	SST	1.0	15.0	12.0	10.0	R
-32	SST	1.0	15.0	12.0	10.0	R
-40	SST	1.0	15.0	12.0	10.0	R
38	SST	1.5	2.0	4.0		S
52	SST	1.5	2.0	4.0		S

CUTSHIN QUAD

LAT 37 05 57
LONG 83 15 54

82	COL					
-79	COL					
87	COL					
-83	COL					
87	COL					
15	COL					
05	COL					
00	COL					
-32	COL					
-33	COL					
-08	COL					
32	SST	1.5	5.5	17.0		R
28	SST	1.5	5.5	17.0		R
-75	SST	2.0	2.0	3.0		R
55	GSH	0.1	2.0	10.0		R
-2[illegible]	GSH	0.1	2.0	2.0		R

DAVID QUAD

LAT 37 32 17
LONG 82 55 35

-78	COL	0.3	0.2	0.1	0.1	R
-74	COL	0.3	0.2	0.1	0.1	R
-73	COL	0.3	0.2	0.1	0.1	R
-65	COL	0.3	0.2	0.1	0.1	R
10	COL	0.3	0.2	0.1	0.1	R
2[illegible]	COL	0.3	0.2	0.1	0.1	R
29	COL	0.3	0.2	0.1	0.1	R
-44	SST	0.1	5.0	3.0	7.0	R
-57	SST	0.1	5.0	3.0	7.0	R
-85	SST	0.1	5.0	3.0	7.0	R
-75	SST	0.1	5.0	3.0	7.0	R
-64	SST	0.1	5.0	3.0	7.0	R
-32	SST	0.1	12.0	12.0		R
-25	SST	0.1	12.0	12.0		R
[illegible]	SST	0.1	5.0			R
[illegible]	SST	0.1	5.0			R
[illegible]	SST	0.1	5.0			R
[illegible]	SST	0.1	5.0			R
[illegible]	SST	0.1	5.0			R
0[illegible]	SST	0.1	12.0	1.0	12.0	R

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[illegible]	[illegible]	[illegible]	12.0	1.0	12.0	R
70	SST	0.1	12.0	1.0	12.0	R
66	SST	0.1	12.0	1.0	12.0	R
11	SST					
21	SST					
-05	SST					

DINGUS QUAD

LAT 37 55 27
LONG 83 03 22

-63	COL	1.0	1.0	0.2	0.1	R
-58	COL	1.0	1.0	0.2	0.1	R
-57	COL	1.0	1.0	0.2	0.1	R
-60	COL	1.0	1.0	0.2	0.1	R
27	COL	1.0	0.3	0.3	0.2	R
22	COL	1.0	0.3	0.3	0.2	R
30	COL	1.0	0.3	0.3	0.2	R
32	COL	1.0	0.3	0.3	0.2	R
-68	SST	1.5	6.0	15.0	1.0	R
-62	SST	1.5	6.0	15.0	1.0	R
-67	SST	1.5	6.0	15.0	1.0	R
5	SST	1.0	6.0	1.5	7.0	R
-14	SST	1.0	6.0	1.5	7.0	R
13	SST	1.0	6.0	1.5	7.0	R
-22	SST	1.0	6.0	1.5	7.0	R

DORTON QUAD

LAT 37 18 46
LONG 82 35 53

-12	GSH	0.1	12.0	0.5	5.0	R
-29	GSH	0.1	12.0	0.5	5.0	R
-26	GSH	0.1	12.0	0.5	5.0	R
-36	GSH	0.1	12.0	0.5	5.0	R
-37	GSH	0.1	12.0	0.5	5.0	R
-57	GSH	0.1	2.0	0.5	5.0	R
-76	GSH	0.1	2.0	0.5	5.0	R
-77	GSH	0.1	2.0	0.5	5.0	R
20	GSH	0.1	5.0	1.0	4.0	R
6	GSH	0.1	5.0	1.0	4.0	R
8	GSH	0.1	5.0	1.0	4.0	R
62	GSH	0.1	5.0	1.0	4.0	R
45	GSH	0.1	5.0	1.0	4.0	R
-05	GSH	3.0	12.0	2.0	4.0	R
-28	GSH	3.0	12.0	2.0	4.0	R
-23	GSH	3.0	12.0	2.0	4.0	R
-07	GSH	3.0	12.0	2.0	4.0	R
85	GSH	4.0	4.0	1.0	3.0	R
75	GSH	4.0	4.0	1.0	3.0	R
54	GSH	4.0	4.0	1.0	3.0	R
64	GSH	4.0	4.0	1.0	3.0	R

EVARTS QUAD

LAT 36 46 21
LONG 83 11 55

-43	GSH	0.1	0.5	0.4	1.0	S
-37	GSH	0.1	0.5	0.4	1.0	S
-47	GSH	0.1	0.5	0.4	1.0	S
-38	GSH	0.1	0.5	0.4	1.0	S
-45	GSH	0.1	0.5	0.4	1.0	S
-58	GSH	0.1	0.5	0.4	1.0	S
83	GSH	0.1	0.5	3.0	3.0	S
71	GSH	0.1	0.5	3.0	3.0	S
74	GSH	0.1	0.5	3.0	3.0	S
65	GSH	0.1	0.5	3.0	3.0	S
60	GSH	0.1	0.5	3.0	3.0	S
40	GSH	0.1	0.7	0.5		S
38	GSH	0.1	0.7	0.5		S
34	GSH	0.1	0.7	0.5		S
15	GSH					
-80	GSH	0.1	0.3	0.3		S

EZEL QUAD

LAT 37 52 27
LONG 83 26 15

10	ASH	0.1	0.2	0.1	1.0	R
5	ASH	0.1	0.2	0.1	1.0	R
-03	ASH	0.1	0.2	0.1	1.0	R

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11	RSH	0.1	0.2	0.1	1.0	R
29	RSH	0.1	0.1	0.1	1.0	R
27	RSH	0.1	0.1	0.1	1.0	R
-18	RSH	0.1	0.2	0.2	1.0	R
-20	RSH	0.1	0.2	0.2	1.0	R
-26	RSH	0.1	0.2	0.2	1.0	R
-23	RSH	0.1	0.2	0.2	1.0	R
-42	RSH	0.1	0.1	0.1	1.0	R
-32	RSH	0.1	0.1	0.1	1.0	R

FALLSBURG QUAD

LAT	38	12	37			
LONG	82	44	03			
-65	SST	0.5	1.5	3.0	1.0	R
-60	SST	0.5	1.5	3.0	1.0	R
-62	SST	0.5	1.5	3.0	1.0	R
-57	SST	0.5	1.5	3.0	1.0	R
-66	SST	0.5	1.5	3.0	1.0	R
-55	SST	0.5	1.5	3.0	1.0	R
-50	SST	0.5	1.5	3.0	1.0	R
-42	SST	0.5	1.5	3.0	1.0	R
78	SST	0.4	1.2	1.5		R
63	SST	0.4	1.2	1.5		R
31	SST	1.0	1.0	0.5	2.0	R
34	SST	1.0	1.0	0.5	2.0	R
42	SST	1.0	1.0	0.5	2.0	R
43	SST	1.0	1.0	0.5	2.0	R
44	SST	1.0	1.0	0.5	2.0	R
57	SST	0.5	0.5	0.3	2.0	R
52	SST	0.5	0.5	0.3	2.0	R
51	SST	0.5	0.5	0.3	2.0	R
-82	SST	2.5	4.0	5.0	8.0	R
-70	SST	2.5	4.0	5.0	8.0	R
LAT	38	11	06			
LONG	82	42	09			
-60	COL	1.0	0.2	0.1	0.2	R
-63	COL	1.0	0.2	0.1	0.2	R
-60	COL	1.0	0.2	0.1	0.2	R
-62	COL	1.0	0.2	0.1	0.2	R
-67	COL	1.0	0.2	0.1	0.2	R
29	COL	1.0	0.2	0.1	0.1	R
28	COL	1.0	0.2	0.1	0.1	R
33	COL	1.0	0.2	0.1	0.1	R
25	COL	1.0	0.2	0.1	0.1	R
22	COL	1.0	0.2	0.1	0.1	R
-10	SST	2.0	8.0	3.0		R
-12	SST	2.0	8.0	3.0		R
-28	SST	2.0	8.0	3.0		R
-25	SST	2.0	8.0	3.0		R
-07	SST	2.0	8.0	3.0		R
-13	SST	2.0	8.0	3.0		R
-34	SST	2.0	6.0	4.0	4.0	R
-37	SST	2.0	6.0	4.0	4.0	R
74	SST	3.0	4.0	10.0	4.0	R
77	SST	3.0	4.0	10.0	4.0	R
57	SST	3.0	4.0	10.0	4.0	R

FARMERS QUAD

LAT	38	09	52			
LONG	83	35	43			
54	BSH	0.5	3.0	12.0	1.0	S
53	BSH	0.5	3.0	12.0	1.0	S
54	BSH	0.5	3.0	12.0	1.0	S
42	BSH	0.5	3.0	12.0	1.0	S
41	BSH	0.5	3.0	12.0	1.0	S
43	BSH	0.5	3.0	12.0	1.0	S
40	BSH	0.5	3.0	12.0	1.0	S
-45	BSH	0.3	0.3	0.3	0.5	S
-42	BSH	0.3	0.3	0.3	0.5	S
-35	BSH	0.3	0.3	0.3	0.5	S
-39	BSH	0.3	0.3	0.3	0.5	S
-45	BSH	0.3	0.3	0.3	0.5	S
-75	BSH	0.3	3.0	2.0	5.0	R
-72	BSH	0.3	3.0	2.0	5.0	R
-65	BSH	0.3	3.0	2.0	5.0	R
-73	BSH	0.3	3.0	2.0	5.0	R
-47	BSH	0.3	3.0	2.0	5.0	R
-44	BSH	0.3	3.0	2.0	5.0	R

-65	BSH	0.3	3.0	2.0	5.0	R
22	BSH	0.3	2.5	10.0	3.0	S
33	BSH	0.3	2.5	10.0	3.0	S
34	BSH	0.3	2.5	10.0	3.0	S
35	BSH	0.3	2.5	10.0	3.0	S
76	BSH					
-25	BSH					

FLEMINGSBURG QUAD

LAT	38	24	50			
LONG	83	43	15			
-15	LST	0.4			0.5	R
-16	LST	0.4			0.5	R
-80	LST	1.0			2.0	R
-72	LST	1.0			2.0	R
-73	LST	1.0			2.0	R
-58	LST				4.0	R
-60	LST				4.0	R
5	LST	0.2			1.5	R
7	LST	0.2			1.5	R
1	LST	0.2			1.5	R
-55	LST	0.2			1.5	R
-5[illegible]	LST	0.2			1.5	R
[illegible]	LST	0.2				R
85	LST				2.0	R
9[illegible]	LST				2.0	R
LAT	38	27	08			
LONG	83	41	29			
74	LST				4.0	R
66	LST				4.0	R
75	LST				4.0	R
67	LST				4.0	R
-80	LST					R
-85	LST					R
-72	LST					R
-77	LST					R
-38	LST					R
-25	LST					R
-45	LST				0.2	R
-60	LST				0.2	R
-65	LST				0.2	R
-53	LST				0.2	R
-34	LST				0.2	R
10	LST					R
7	LST					R
5	LST					R
12	LST					R
22	LST					R
90	LST					R

FRENCHBURG QUAD

LAT	37	57	30			
LONG	83	40	52			
-80	LST	1.0	1.0	1.0	12.0	R
-85	LST	1.0	1.0	1.0	12.0	R
-88	LST	1.0	1.0	1.0	12.0	R
-06	LST	1.0	1.0	1.0	3.0	R
-03	LST	1.0	1.0	1.0	3.0	R
-12	LST	1.0	1.0	1.0	3.0	R
-59	LST	0.7	0.7	1.0	5.0	R
-48	LST	0.7	0.7	1.0	5.0	R
-57	LST	0.7	0.7	1.0	5.0	R
-25	SST	0.5	0.5	1.0		R
-24	SST	0.5	0.5	1.0		R
76	SST	0.5	0.5	1.2		R

FRIENDSHIP QUAD

LAT	39	38	08			
LONG	83	00	23			
-62	SST	0.3	2.0	0.5	11.0	R
-67	SST	0.3	2.0	0.5	11.0	R
-68	SST	0.3	2.0	0.5	11.0	R
-74	SST	0.3	2.0	0.5	11.0	R
-45	SST	0.3	2.0	0.5	11.0	R
-85	SST	0.3	2.0	0.5	11.0	R
-65	SST	0.3	2.0	0.5	11.0	R
-55	SST	0.3	2.0	0.5	11.0	R
-77	SST	0.3	2.0	0.5	11.0	R

[illegible]	SS[illegible]	0.5	0.5	2.5	[illegible]	R
36	SST	0.5	0.5	2.5	[illegible]	R
27	SST	0.5	0.5	2.5	[illegible]	R
24	SST	0.5	0.5	2.5	[illegible]	R
-22	SST	0.2	0.2	0.3	20.0	R
-43	SST	0.2	0.2	0.3	20.0	R
-44	SST	0.2	0.2	0.3	20.0	R
-42	SST	0.2	0.2	0.3	20.0	R

GARRISON QUAD

LAT 38 32 03
LONG 83 13 10

21	SST	1.0	2.0	1.0	10.0	R
29	SST	1.0	2.0	1.0	10.0	R
38	SST	1.0	2.0	1.0	10.0	R
41	SST	1.0	2.0	1.0	10.0	R
50	SST	1.0	2.0	1.0	10.0	R
52	SST	1.0	2.0	1.0	10.0	R
-24	SST	1.0	2.0	1.5		
-38	SST	1.0	2.0	1.5		
-17	SST	1.0	2.0	1.5		
-37	SST	1.0	2.0	1.5		
-38	SST	1.0	2.0	1.5		
-39	SST	1.0	2.0	1.5		
-73	SST	1.0	1.0	10.0		
-72	SST	1.0	1.0	10.0		
-74	SST	1.0	1.0	10.0		

LAT 38 35 15
LONG 83 11 32

22	SST	1.0	1.0	3.0	0.7	R
29	SST	1.0	1.0	3.0	0.7	R
26	SST	1.0	1.0	3.0	0.7	R
18	SST	1.0	1.0	3.0	0.7	R
22	SST	1.0	1.0	3.0	0.7	R
20	SST	1.0	1.0	3.0	0.7	R
25	SST	1.0	1.0	3.0	0.7	R
25	SST	1.0	1.0	3.0	0.7	R
-68	SST	1.0	1.0	1.0	3.0	R
-67	SST	1.0	1.0	1.0	3.0	R
-59	SST	1.0	1.0	1.0	3.0	R
-54	SST	1.0	1.0	1.0	3.0	R
-68	SST	1.0	1.0	1.0	3.0	R
-65	SST	1.0	1.0	1.0	3.0	R
-64	SST	1.0	1.0	1.0	3.0	R
-60	SST	1.0	1.0	1.0	3.0	R
-44	SST	2.0	2.0	1.0	5.0	R
-43	SST	2.0	2.0	1.0	5.0	R
-37	SST	2.0	2.0	1.0	5.0	R
-44	SST	2.0	2.0	1.0	5.0	R
24	SST	2.0	2.0	3.0	1.0	R
08	SST	2.0	2.0	3.0	1.0	R
-79	SST	2.0	2.0	1.0	10.0	R
82	SST	2.0	2.0	1.0	10.0	R
85	SST	2.0	2.0	1.0	10.0	R

GALGE QUAD

LAT 37 35 34
LONG 83 10 54

53	COL					
55	COL					
-47	COL					
-44	COL					
-52	COL					
80	BSH	0.1	2.0	2.0	0.2	R
55	BSH	0.1	2.0	2.0	0.2	R
-09	BSH	0.1	2.0	0.2		R
-35	BSH					
-16	BSH					
-22	BSH					
-37	SST	0.2	5.0	4.0	4.0	R
-46	SST	0.2	5.0	4.0	4.0	R
-25	SST	0.2	5.0	4.0	4.0	R
75	SST	0.4	0.4	8.0		S
53	SST	0.5	0.5	7.0		S
[illegible]	SS[illegible]					
-64						
-69	SST	0.2	1.5	1.0		R
13	SST	0.2	1.6	1.0		R

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GRAHN QUAD

LAT 38 19 25
LONG 83 04 08

-72	CCL	1.0	1.0	0.5	0.3	R
-71	CCL	1.0	1.0	0.5	0.3	R
-63	CCL	1.0	1.0	0.5	0.3	R
-67	CCL	1.0	1.0	0.5	0.3	R
-67	CCL	1.0	1.0	0.5	0.3	R
-74	CCL	1.0	1.0	0.5	0.3	R
22	CCL	1.0	0.5	0.4	0.2	R
37	CCL	1.0	0.5	0.4	0.2	R
27	CCL	1.0	0.5	0.4	0.2	R
3[illegible]	CCL	1.0	0.5	0.4	0.2	R
2[illegible]	CCL	1.0	0.5	0.4	0.2	R
0[illegible]	GSH	0.1	12.0	0.1	10.0	R
17	GSH	0.1	12.0	0.1	10.0	R
1[illegible]	GSH	0.1	12.0	0.1	10.0	R
11	GSH	0.1	12.0	0.1	10.0	R
2[illegible]	GSH	0.1	12.0	0.1	10.0	R
1[illegible]	GSH	0.1	12.0	0.1	10.0	R
16	GSH	0.1	12.0	0.1	10.0	R
1[illegible]	GSH	0.1	12.0	0.1	10.0	R
-1[illegible]	GSH	0.1	4.0	0.1	1.5	R
-87	GSH	0.1	4.0	0.1	1.5	R
-86	GSH	0.1	4.0	0.1	1.5	R
80	GSH	0.1	4.0	0.1	1.5	R
-76	GSH	0.1	4.0	0.1	1.5	R
-46	GSH					
-29	GSH					

GRAYSON QUAD

LAT 38 18 58
LONG 82 57 14

-54	BSH	0.2	0.2	0.3	0.5	S
-44	BSH	0.2	0.2	0.3	0.5	S
-62	BSH	0.2	0.2	0.3	0.5	S
-49	BSH	0.2	0.2	0.3	0.5	S
-44	BSH	0.2	0.2	0.3	0.5	S
88	BSH	0.2	0.2	0.3	0.5	R
65	BSH	0.2	0.2	0.3	0.5	R
65	BSH	0.2	0.2	0.3	0.5	R
67	BSH	0.2	0.2	0.3	0.5	R
20	BSH	0.2	4.0	1.0	10.0	S
25	BSH	0.2	4.0	1.0	10.0	S
18	BSH	0.2	4.0	1.0	10.0	S
-34	BSH	0.2	1.0	0.3	3.0	R
-37	BSH	0.2	1.0	0.3	3.0	R
-35	BSH	0.2	1.0	0.3	3.0	R
-42	BSH	0.2	1.0	0.3	3.0	R
04	BSH	0.2	0.5	0.5		S
05	BSH	0.2	0.5	0.5		S
04	BSH	0.2	0.5	0.5		S
06	BSH	0.2	0.5	0.5		S
07	BSH	0.2	0.5	0.5		S
-05	BSH					
-01	BSH					
52	BSH	0.2	0.3	0.5		
40	BSH	0.2	0.3	0.5		
43	BSH	0.2	0.3	0.5		
61	BSH	0.2	0.3	0.5		
76	SST	2.0	4.0	2.0	10.0	R
84	SST	2.0	4.0	2.0	10.0	R
77	SST	2.0	4.0	2.0	10.0	R
84	SST	2.0	4.0	2.0	10.0	R
26	SST	3.0	6.0	4.0		S
20	SST	3.0	6.0	4.0		S
23	SST	3.0	6.0	4.0		S
25	SST	3.0	6.0	4.0		S
20	SST	3.0	6.0	4.0		S
-66	SST	2.0	6.0	2.0	10.0	R
-57	SST	2.0	6.0	2.0	10.0	R
-6[illegible]	SST	2.0	6.0	2.0	10.0	R
-[illegible]	SST	2.0	6.0	2.0	10.0	R
-[illegible]	SST	2.0	6.0	2.0	10.0	R
-2[illegible]	SST	0.5	0.6	1.0	8.0	R
-15	SST	0.5	0.6	1.0	6.0	R
-17	SST	0.5	0.6	1.0	6.0	R

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-45	SS					
-85	SST	1.0	4.0	0.5	8.0	R
-80	SST	1.0	4.0	0.5	8.0	R
-82	SST	1.0	4.0	0.5	8.0	R
55	SST	1.0	4.0	0.5	8.0	R
54	SST					
-77	COL	0.7	0.7	0.2	0.2	R
-60	COL	0.7	0.7	0.2	0.2	R
-24	COL	0.7	0.7	0.2	0.2	R
-18	COL	0.7	0.7	0.2	0.2	R

GREENUP QUAD

LAT	38 33 55					
LONG	82 49 35					
31	BSH	0.1	0.1	1.0	0.1	R
34	BSH	0.1	0.1	1.0	0.1	R
34	BSH	0.1	0.1	1.0	0.1	R
40	BSH	0.1	0.1	1.0	0.1	R
30	BSH	0.1	0.1	1.0	0.1	R
46	BSH	0.1	0.1	1.0	0.1	R
-26	BSH	0.1	0.1	0.5	0.3	R
-15	BSH	0.1	0.1	0.5	0.3	R
-12	BSH	0.1	0.1	0.5	0.3	R
-20	BSH	0.1	0.1	0.5	0.3	R
-18	BSH	0.1	0.1	0.5	0.3	R
-82	BSH	0.1	3.0	1.0	2.0	R
-82	BSH	0.1	3.0	1.0	2.0	R
50	BSH	0.1	3.0	1.0	2.0	R
-78	BSH	0.1	3.0	1.0	2.0	R
-77	BSH	0.1	3.0	1.0	2.0	R
54	BSH	0.1	0.2	0.2	1.0	R
50	BSH	0.1	0.2	0.2	1.0	R
48	BSH	0.1	0.2	0.2	1.0	R
52	BSH	0.1	0.2	0.2	1.0	R
-65	BSH	0.1	4.5	4.0	8.0	R
-45	BSH	0.1	4.5	4.0	8.0	R
-43	BSH	0.1	4.5	4.0	8.0	R
-64	BSH	0.1	4.5	4.0	8.0	R

HADDIX QUAD

LAT	37 28 35					
LONG	83 17 36					
03	GSH	0.1	1.5	0.2		R
-10	GSH	0.1	1.5	0.2		R
12	GSH	0.1	1.5	0.2		R
20	GSH	0.1	1.5	0.2		R
83	GSH	0.1	0.3	0.2		R
86	GSH	0.1	0.3	0.2		R
-87	GSH	0.1	0.3	0.2		R
-87	GSH	0.1	0.3	0.2		R
-70	GSH	0.1	0.3	0.2	2.5	R
-77	GSH	0.1	0.3	0.2	2.5	R
-65	GSH	0.1	0.3	0.2	2.5	R
08	SST	2.0	3.0	12.0		S
-01	SST	2.0	3.0	12.0		S
-75	SST	2.0	3.0	4.5		R
-80	SST	2.0	3.0	4.5		R
-77	SST	2.0	3.0	4.5		R

HALDEMAN QUAD

LAT	38 11 13					
LONG	83 21 17					
69	SST	3.0	3.0	10.0	5.0	R
74	SST	3.0	3.0	10.0	5.0	R
75	SST	3.0	3.0	10.0	5.0	R
83	SST	3.0	3.0	10.0	5.0	R
50	SST					
-23	SST	1.0	7.0	5.0	6.0	R
-17	SST	1.0	7.0	5.0	6.0	R
-15	SST	1.0	7.0	5.0	6.0	R
-22	SST	1.0	7.0	5.0	6.0	R
-25	SST	1.0	7.0	5.0	6.0	R
-20	SST	1.0	7.0	5.0	6.0	R
-50	SST	1.0	7.0	5.0	6.0	R
-17	SST	1.0	7.0	5.0	6.0	R
-24	SST	1.0	7.0	5.0	6.0	R
-17	SST	1.0	7.0	5.0	6.0	R
40	SST	0.5	0.5	1.0	2.0	R

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45	SST	0.5	0.5	1.0	2.0	R
-62	SST	0.5	0.6	0.4	1.5	R
-51	SST	0.5	0.6	0.4	1.5	R

HANDSHOE QUAD

LAT 37 24 43
LONG 82 52 43

46	GSH	0.1	2.0	0.1	3.0	R
52	GSH	0.1	2.0	0.1	3.0	R
53	GSH	0.1	2.0	0.1	3.0	R
74	GSH	0.1	1.5	0.1	2.0	R
62	GSH	0.1	1.5	0.1	2.0	R
-37	GSH	0.1	1.5	0.1	2.0	R
-36	GSH	0.1	1.5	0.1	2.0	R
-46	GSH	0.1	0.3	0.2	5.0	R
-55	GSH	0.1	0.3	0.2	5.0	R
-55	GSH	0.1	0.3	0.2	5.0	R
20	GSH	0.1	0.3	0.1	5.0	R
29	GSH	0.1	0.3	0.1	5.0	R
15	GSH	0.1	0.3	0.1	5.0	R
28	GSH	0.1	0.3	0.1	5.0	R
26	GSH	0.1	0.3	0.1	5.0	R
14	GSH	0.1	0.3	0.1	5.0	R
-75	GSH	0.1	0.3	0.1	5.0	R
16	SST	0.5	0.5	2.0	3.0	R
14	SST	0.5	0.5	2.0	3.0	R
19	SST	0.5	0.5	2.0	3.0	R
14	SST	0.5	0.5	2.0	3.0	R
10	SST	0.5	0.5	2.0	3.0	R
78	SST	2.0	2.0	4.0	10.0	R
90	SST	2.0	2.0	4.0	10.0	R
87	SST	2.0	2.0	4.0	10.0	R
-78	SST	2.0	2.0	4.0	10.0	R
-20	SST	2.0	2.0	4.0	10.0	R

HARLAN QUAD

LAT 36 50 43
LONG 83 22 21

37	GSH	0.1	3.0	0.2		R
32	GSH	0.1	3.0	0.2		R
33	GSH	0.1	3.0	0.2		R
36	GSH	0.1	3.0	0.2		R
-40	GSH					
52	GSH	0.1	1.0	0.2		R
69	GSH	0.1	1.0	0.2		R
50	GSH	0.1	1.0	0.2		R
-12	GSH	0.1	0.5	0.3		R
-14	GSH	0.1	0.5	0.3		R
-04	GSH	0.1	0.5	0.3		R
-08	GSH	0.1	0.5	0.3		R
-63	GSH	0.1	1.3	1.0		R
-45	GSH	0.1	7.0	1.0	10.0	R
-43	GSH	0.1	7.0	1.0	10.0	R

HARCLD QUAD

LAT 37 33 28
LONG 82 38 30

-48	GSH	0.1	5.0	1.0	5.0	R
-47	GSH	0.1	5.0	1.0	5.0	R
-60	GSH	0.1	5.0	1.0	5.0	R
-64	GSH	0.1	5.0	1.0	5.0	R
-58	GSH	0.1	5.0	1.0	5.0	R
-51	GSH	0.1	5.0	1.0	5.0	R
40	GSH	0.1	4.0	1.0	5.0	R
41	GSH	0.1	4.0	1.0	5.0	R
30	GSH	0.1	4.0	1.0	5.0	R
53	GSH	0.1	4.0	1.0	5.0	R
34	GSH	0.1	4.0	1.0	5.0	R
17	GSH	0.1	4.0	1.0	5.0	R
16	GSH	0.1	4.0	1.0	5.0	R
15	GSH	0.1	4.0	1.0	5.0	R

HAZARD NORTH QUAD

LAT 37 18 29
LONG 83 12 35

-52	COL					
-65	COL					

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-67		COL						
-76		COL						
-52		COL						
10		COL						
27		COL						
31		COL						
26		COL						
0[illegible]		SST	0.5	3.0	10.0			R
-[illegible]8		SST	0.5	3.0	10.0			R
87		SST	0.2	1.5	1.0			R
78		SST	3.0	6.0	3.0			S
25		SST	2.0	3.0	4.0	5.0		S
31		SST	2.0	3.0	4.0	5.0		S
LAT	37	20	03					
LONG	83	23	00					
-40		GSH	0.1	2.0	0.1	10.0		R
-35		GSH	0.1	2.0	0.1	10.0		R
-35		GSH	0.1	2.0	0.1	10.0		R
-23		GSH	0.1	0.2	0.1			R
-22		GSH	0.1	0.2	0.1			R
81		GSH	0.1	1.0	4.0			R
-[illegible]		GSH	0.1	0.2	0.2			R
[illegible]		GSH	0.1	0.2	0.2			R
-1[illegible]		GSH	0.1	0.2	0.2			R
[illegible]		GSH	0.1	0.2	0.2			R
-65		GSH	0.1	0.2	0.2			R
-40		BSH	0.1	0.1	0.1	0.5		R
-41		BSH	0.1	0.1	0.1	0.5		R
-35		BSH	0.1	0.1	0.1	0.5		R
-1[illegible]		BSH	0.1	0.1	0.1			R
-85		BSH	0.1	0.2	0.2	0.1		R
-85		BSH	0.1	0.2	0.2	0.1		R
-55		BSH						

HAZARD SOUTH QUAD

LAT	37	13	33					
LONG	83	09	50					
72		COL						
62		COL						
69		COL						
7[illegible]		COL						
-14		COL						
-23		COL						
-40		COL						
-10		COL						
68		BSH	0.1	1.0	0.3			R
63		BSH	0.1	1.0	0.3			R
52		BSH	0.1	1.0	0.3			R
53		BSH	0.1	1.0	0.3			R
57		BSH	0.1	1.0	0.3			R
-13		BSH	0.1	1.0	0.2	0.6		R
-24		BSH	0.1	1.0	0.2	0.6		R
-50		BSH	0.1	1.0	0.2	0.6		R
-35		BSH	0.1	1.0	0.2	0.6		R
-26		BSH	0.1	1.0	0.2	0.6		R
-29		BSH	0.1	1.0	0.2	0.6		R
-36		BSH	0.1	1.0	0.2	0.6		R
-26		BSH	0.1	1.0	0.2	0.6		R
-20		SST	1.0	3.0	0.5			R
80		SST	2.0	2.0	1.0			R
42		SST	2.0	2.0	1.0			R
64		SST	2.0	2.0	1.0			R
-44		SST	1.0	1.0	1.0	2.0		R
-40		SST	1.0	1.0	1.0	2.0		R
-35		SST	1.0	1.0	1.0	2.0		R
-46		SST	1.0	1.0	1.0	2.0		R

HAZEL GREEN QUAD

LAT	37	51	46					
LONG	83	25	26					
2		GSH	0.1	1.0	2.0	5.0		R
3		GSH	0.1	1.0	2.0	5.0		R
6		GSH	0.1	1.0	2.0	5.0		R
-[illegible]		GSH	0.1	1.0	2.0	5.0		R
[illegible]		GSH	0.1	1.0	2.0	5.0		R
-[illegible]		GSH	0.1	1.0	2.0	5.0		R
[illegible]		GSH	0.1	2.0	0.2	7.0		R
72		GSH	0.1	2.0	0.2	7.0		R
74		GSH	0.1	2.0	0.2	7.0		R

86	GSH	0.1	2.0	0.2	7.0	R
86	GSH	0.1	2.0	0.2	7.0	R
-82	GSH	0.1	0.5	0.3	2.0	R
-83	GSH	0.1	0.5	0.3	2.0	R
-37	BSH	0.1	0.3	0.2	0.2	R
-30	BSH	0.1	0.3	0.2	0.2	R
-67	BSH	0.1	0.2	0.1	1.0	R
-60	BSH	0.1	0.2	0.1	1.0	R
10	BSH	0.1	0.2	0.1	1.0	R
22	BSH	0.1	0.2	0.1	1.0	R
50	BSH	0.1	0.3	0.1	0.5	R
53	BSH	0.1	0.3	0.1	0.5	R

HEAD OF GRASSY QUAD

LAT 38 25 39
LONG 83 16 58

-83	SST	1.0			1.0	R
-72	SST	1.0			1.0	R
-18	SST	0.5			2.0	R
-12	SST	0.5			2.0	R
-30	SST	0.4			2.0	R
-40	SST	0.4			2.0	R
-88	SST	3.0			1.0	R
-68	SST	3.0			1.0	R
74	SST	0.4			1.5	R
80	SST	0.4			1.5	R
86	SST	0.4			1.5	R
73	SST	0.4			1.5	R
81	SST	0.4			1.5	R
58	SST	0.3			1.0	R
58	SST	0.3			1.0	R
62	SST	0.3			1.0	R
CCC	SST	0.2			2.0	R
CCC	SST	0.2			2.0	R
CC1	SST	0.2			2.0	R
15	SST	0.4				S
90	SST	0.4				S
34	SST	2.5			1.5	R
47	SST	2.5			1.5	R
38	SST	2.5			1.5	R

HELLIER QUAD

LAT 37 21 22
LONG 82 25 27

-17	GSH	0.1	3.0	0.2	12.0	R
-65	GSH	0.1	3.0	6.0	12.0	R
-68	GSH	0.1	3.0	6.0	12.0	R
-63-	GSH	0.1	3.0	6.0	12.0	R
50-	GSH	0.1	3.0	12.0	7.5	R
54-	GSH	0.1	3.0	12.0	7.5	R
48-	GSH	0.1	3.0	12.0	7.5	R
45-	GSH	0.1	3.0	12.0	7.5	R
88-	GSH	0.1	1.0	1.0	7.5	R
-83-	GSH	0.1	1.0	1.0	7.5	R
-86-	GSH	0.1	1.0	1.0	7.5	R
48	SST	3.0	4.0	10.0	3.0	R
42	SST	3.0	4.0	10.0	3.0	R
38-	SST	3.0	4.0	10.0	3.0	R
50-	SST	3.0	4.0	10.0	3.0	R
48	SST	3.0	4.0	10.0	3.0	R
-48	SST	3.0	3.0	3.0	5.0	R
-54	SST	3.0	3.0	3.0	5.0	R
-62	SST	3.0	3.0	3.0	5.0	R
-51	SST	3.0	3.0	3.0	5.0	R

HELTON QUAD

LAT 36 59 08
LONG 83 23 42

-53	BSH	0.1	1.0	0.5	7.0	R
-65	BSH	0.1	1.0	0.5	7.0	R
-80	BSH	0.1	1.0	0.5	7.0	R
-04	BSH	0.1	0.3	0.2		R
-05	BSH	0.1	0.3	0.2		R
[illegible]	BSH					
[illegible]	BSH					
50	BSH					
-33	SST	0.5	0.5	0.2	6.0	R
-3[illegible]	SST	0.5	0.5	0.2	6.0	R

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32	SST	0.3	0.3	2.5	2.0	S
22	SST	0.3	0.3	2.5	2.0	S
20	SST	0.3	0.3	2.5	2.0	S
19	SST	0.3	0.3	2.5	2.0	S
-67	SST	0.3	0.3	2.0	2.0	R
-80	SST	0.3	0.3	2.0	2.0	R
-72	SST	0.3	0.3	2.0	2.0	R
62	SST	0.3	0.3	2.0	1.0	S
54	SST	0.3	0.3	2.0	1.0	S
48	SST	0.3	0.3	2.0	1.0	S

HINCMAN QUAD

LAT 37 19 27
LONG 82 58 06

-05	GSH	0.1	10.0	14.0	10.0	R
-16	GSH	0.1	10.0	14.0	10.0	R
-08	GSH	0.1	10.0	14.0	10.0	R
-15	GSH	0.1	10.0	14.0	10.0	R
67	GSH	0.1	10.0	5.0	12.0	R
65	GSH	0.1	10.0	5.0	12.0	R
57	GSH	0.1	10.0	5.0	12.0	R
74	GSH					
72	GSH					
82	GSH					
-58	GSH	0.1	1.5	1.0		R
-42	GSH	0.1	1.5	1.0		R
17	GSH	0.1	2.0	3.0		R
67	SST	3.0	15.0	5.0	12.0	R
72	SST	3.0	15.0	5.0	12.0	R
-16	SST	3.0	15.0	20.0	10.0	R
42	SST	2.0	2.0	2.0		R
32	SST	2.0	2.0	2.0		R
34	SST	2.0	2.0	2.0		R
-48	SST	2.0	2.0	2.0		R

HOSKINSTON QUAD

LAT 37 00 57
LONG 83 23 46

54	COL					
57	COL					
47	COL					
55	COL					
-25	COL					
-47	COL					
-24	COL					
-18	COL					
-68	GSH	0.1	1.0	0.5		R
-86	GSH	0.1	1.0	0.5		R
-67	GSH	0.1	1.0	0.5		R
03	GSH	0.1	1.0	1.0		R
06	GSH	0.1	1.0	1.0		R
07	GSH	0.1	1.0	1.0		R
83	GSH	0.1	0.3	0.3	1.0	R
77	GSH	0.1	0.3	0.3	1.0	R
87	GSH	0.1	0.3	0.3	1.0	R
17	SST	0.2	0.2	5.0	3.0	R
15	SST	0.2	0.2	5.0	3.0	R
53	SST	0.2	0.2	0.2	4.0	R
58	SST	0.2	0.2	0.2	4.0	R
56	SST	0.2	0.2	0.2	4.0	R
67	SST	0.2	0.2	0.2	4.0	R

LAT 37 05 44
LONG 83 23 49

-15	BSH	0.1	5.0	0.2		R
-28	BSH	0.1	5.0	0.2		R
-38	BSH	0.1	5.0	0.2		R
-86	BSH	0.1	1.0	3.0		R
-85	BSH	0.1	1.0	3.0		R
-68	BSH	0.1	1.0	3.0		R
-62	BSH	0.1	1.0	3.0		R
-57	BSH	0.1	1.0	3.0		R
-60	BSH	0.1	1.0	3.0		R
12	BSH	0.1	4.0	0.2		R
[illegible]	BSH	0.1	4.0	0.2		R
[illegible]	BSH	0.1	4.0	1.0		R
[illegible]	BSH	0.1	4.0	1.0		R
20	RSH	0.1	3.5	3.5		R
30	RSH	0.1	3.5	3.5		R
-6[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	R

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-63	RSH	0.1	2.0	1.0	7.0	R
-65	RSH	0.1	2.0	1.0	7.0	R
-33	RSH	0.1	4.0	2.0	8.0	R
-77	RSH	0.1	4.0	2.0	8.0	R

HYDEN EAST QUAD

LAT 37 09 17
LONG 83 22 08

50	COL					
62	COL					
-49	COL					
-27	COL					
-20	COL					
-70	COL					
24	COL					
15	COL					
58	COL					
43	COL					
34	COL					
-48	GSH	0.1	3.0	4.0		S
-33	GSH	0.1	3.0	4.0		S
28	GSH	0.1	0.5	0.2	2.0	R
17	GSH	0.1	0.5	0.2	2.0	R
15	GSH	0.1	0.5	0.2	2.0	R
50	GSH	0.1	3.0	0.2		R
50	GSH					
-85	GSH					
-15	GSH	0.1	2.0	1.0	3.0	S
-20	GSH	0.1	2.0	1.0	3.0	S
-06	GSH	0.1	2.0	1.0	3.0	S
-06	GSH	0.1	2.0	1.0	3.0	S
-10	SST	3.0	10.0	5.0		S
-04	SST	3.0	10.0	5.0		S
-03	SST	3.0	10.0	5.0		S
-19	SST	3.0	10.0	5.0		S
-67	SST	2.0	2.0	5.0		R
88	SST					
-47	SST	3.0	10.0	15.0		S
-28	SST	3.0	10.0	15.0		S

HYDEN WEST QUAD

LAT 37 08 47
LONG 83 25 02

12	GSH	0.1	0.5	4.0		R
-55	GSH					
-80	GSH					
-65	GSH					
-75	GSH					
27	GSH	0.1	0.3	0.2		R
42	GSH	0.1	0.3	0.2		R
85	GSH	0.1	0.3	0.2		R
82	GSH	0.1	0.3	0.2		R
60	GSH	0.1	0.3	0.2		R
-22	GSH					R
-23	GSH					R
-32	GSH					R
-05	GSH					
53	SST	0.5	3.0	2.0		R
37	SST	0.5	3.0	2.0		R
48	SST	0.5	3.0	2.0		R
-44	SST	0.5	2.5	3.0		R
-80	SST	0.5	2.5	3.0		R
-18	SST					

INEZ QUAD

LAT 37 52 06
LONG 82 31 55

-06	SST	1.0	3.0	2.0	6.0	R
4	SST	1.0	3.0	2.0	6.0	R
6	SST	1.0	3.0	2.0	6.0	R
0	SST	1.0	3.0	2.0	6.0	R
-04	SST	1.0	3.0	2.0	6.0	R
-07	SST	1.0	3.0	2.0	6.0	R
-12	SST	1.0	3.0	2.0	6.0	R
-04	SST	1.0	3.0	2.0	6.0	R
88	SST	2.5	2.5	5.0	6.0	R
-82	SST	2.5	2.5	5.0	6.0	R
51	SST	4.0	4.0	1.0	10.0	R

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68	SST	4.0	4.0	1.0	10.0	R
42	SST	4.0	4.0	1.0	10.0	R
65	SST	4.0	4.0	1.0	10.0	R
-63	SST	4.0	4.0	5.0	10.0	R
-57	SST	4.0	4.0	5.0	10.0	R
-54	SST	4.0	4.0	5.0	10.0	R

ISONVILLE QUAD

LAT 38 04 04
LONG 83 04 15

-57	COL	2.0	0.2	0.2	0.1	R
-58	COL	2.0	0.2	0.2	0.1	R
-57	COL	2.0	0.2	0.2	0.1	R
-58	COL	2.0	0.2	0.2	0.1	R
-61	COL	2.0	0.2	0.2	0.1	R
42	COL	2.0	0.2	0.2	0.2	R
36	COL	2.0	0.2	0.2	0.2	R
35	COL	2.0	0.2	0.2	0.2	R
26	COL	2.0	0.2	0.2	0.2	R
43	COL	2.0	0.2	0.2	0.2	R
82	SST	3.0	3.0	15.0	3.0	R
83	SST	3.0	3.0	15.0	3.0	R
75	SST	3.0	3.0	15.0	3.0	R
85	SST	3.0	3.0	15.0	3.0	R
79	SST	3.0	3.0	15.0	3.0	R
-12	SST	0.5	3.0	2.0	2.5	R
-11	SST	0.5	3.0	2.0	2.5	R
07	SST	2.0	5.0	2.0	2.0	R
03	SST	2.0	5.0	2.0	2.0	R
14	SST	2.0	5.0	2.0	2.0	R

IVYTON QUAD

LAT 37 39 43
LONG 82 51 24

-42	COL					
-43	COL					
-42	COL					
45	COL					
48	COL					
47	COL					
77	GSH	0.1	2.5	3.0	20.0	R
80	GSH	0.1	2.5	3.0	20.0	R
-85	GSH	0.1	2.5	3.0	20.0	R
68	GSH	0.1	2.5	3.0	20.0	R
90	GSH	0.1	2.5	3.0	20.0	R
-29	GSH	0.1	4.0	15.0		R
-13	GSH	0.1	4.0	15.0		R
-26	GSH	0.1	4.0	15.0		R
-30	GSH	0.1	4.0	15.0		R
-26	GSH	0.1	4.0	15.0		R
08	GSH					
41	GSH					
-25	SST	1.5	8.0	12.0	6.0	R
-27	SST	1.5	8.0	12.0	6.0	R
-30	SST	1.5	8.0	12.0	6.0	R
-31	SST	1.5	8.0	12.0	6.0	R
29	SST	0.5	3.0	0.5		R
28	SST	0.5	3.0	0.5		R
27	SST	0.5	3.0	0.5		R
70	SST	1.0	2.0	3.0		
75	SST	1.0	2.0	3.0		
64	SST	1.0	2.0	3.0		
05	SST	1.0	1.0	1.0	7.0	R
-04	SST	1.0	1.0	1.0	7.0	R

JACKSON QUAD

LAT 37 32 53
LONG 83 23 45

-37	COL					
-32	COL					
-33	COL					
-35	COL					
45	COL					
52	COL					
53	COL					
43	COL					
-09	RSH	0.1	4.0	0.4	8.0	R
-08	RSH	0.1	4.0	0.4	8.0	R

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03	RSH	0.1	4.0	0.4	8.0	R
05	RSH	0.1	4.0	0.4	8.0	R
07	RSH	0.1	4.0	0.4	8.0	R
-88	RSH	0.1	1.0	0.2		R
75	RSH	0.1	1.0	0.2		R
35	RSH	0.1	0.2	0.1	0.6	R
34	RSH	0.1	0.2	0.1	0.6	R
31	RSH	0.1	0.2	0.1	0.6	R
40	RSH	0.1	0.2	0.1	0.6	R
-60	RSH	0.2	3.0	2.5		R
-32	SST	0.3	0.3	0.5		R
-25	SST	0.3	0.3	0.5		R
-10	SST	0.2	0.3	0.2		R
83	SST	0.4	0.4	2.0		R
67	SST	0.4	0.4	2.0		R
85	SST	0.4	0.4	2.0		R
45	SST	0.5	1.0	0.7		R

KERMIT QUAD

LAT 37 49 50
LONG 82 27 07

-27	BSH	0.1	3.0	8.0	2.0	R
-33	BSH	0.1	3.0	8.0	2.0	R
-25	BSH	0.1	3.0	8.0	2.0	R
56	BSH	0.1	3.0	1.0	5.0	R
66	BSH	0.1	3.0	1.0	5.0	R
63	BSH	0.1	3.0	1.0	5.0	R
72	BSH	0.1	3.0	1.0	5.0	R
22	BSH	0.1	0.7	0.2	4.0	R
25	BSH	0.1	0.7	0.2	4.0	R
32	BSH	0.1	0.7	0.2	4.0	R
44	BSH	0.1	0.7	0.2	4.0	R
-75	BSH	0.1	0.5	0.1	3.0	R
-67	BSH	0.1	0.5	0.1	3.0	R
-46	SST	0.1	0.5	0.1	3.0	R
76	SST	0.1	0.5	0.1	3.0	R
74	SST	0.1	0.5	0.1	3.0	R
6	SST	0.1	0.5	0.1	3.0	R
-88	SST	0.1	0.5	0.1	3.0	R

KITE QUAD

LAT 37 16 05
LONG 82 45 01

87	COL					
88	COL					
85	COL					
86	COL					
-10	COL					
-04	COL					
-15	COL					
03	COL					
-45	BSH	0.1	0.4	0.2	1.0	R
-43	BSH	0.1	0.4	0.2	1.0	R
-70	BSH					
77	BSH	0.1	0.4	0.1	2.0	R
82	BSH	0.1	0.4	0.1	2.0	R
72	BSH	0.1	0.4	0.1	2.0	R
-88	BSH	0.1	0.4	0.1	2.0	R
-05	BSH	0.1	0.2	0.2	3.0	R
03	BSH	0.1	0.2	0.2	3.0	R
62	SST	1.0	1.5	1.0	3.0	R
74	SST	1.0	1.5	1.0	3.0	R
55	SST	1.0	1.5	1.0	3.0	R
73	SST	1.0	1.5	1.0	3.0	R
12	SST	1.0	1.0	10.0		R
08	SST	1.0	1.0	10.0		R
21	SST	1.0	1.0	10.0		R
-75	SST	1.0	1.5	0.1	5.0	R
-82	SST	1.0	1.5	0.1	5.0	R
-46	SST	1.5	1.5	3.0	1.7	R
-28	SST	1.5	1.5	3.0	1.7	R
-22	SST	1.5	1.5	3.0	1.7	R

KRYPTON QUAD

LAT 37 21 08
LONG 83 20 50

-33	SST	0.1	0.3	1.5	1.0	R
-33	SST	0.1	0.3	1.5	1.0	R

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83	SST	0.1	0.3	2.0		R
85	SST	0.1	0.3	2.0		R
-85	SST	0.1	0.3	2.0		R
-83	SST	0.1	0.3	2.0		R
000	SST	0.1	6.0	1.0	4.0	R
000	SST	0.1	6.0	1.0	4.0	R
12	SST	0.1	6.0	1.0	4.0	R
16	SST	0.1	6.0	1.0	4.0	R
16	SST	0.1	6.0	1.0	4.0	R
45	SST	0.1	0.3	1.0		R
48	SST	0.1	0.3	1.0		R
-09	SST	0.1	0.6	0.5		R
-71	SST					

LANCER QUAD

LAT 37 38 16
LONG 82 40 12

42	GSH	0.1	2.0	2.0	1.5	R
52	GSH	0.1	2.0	2.0	1.5	R
47	GSH	0.1	2.0	2.0	1.5	R
-32	GSH	0.1	1.0	0.5	3.0	R
-25	GSH	0.1	1.0	0.5	3.0	R
15	GSH	0.1	0.4	0.3	1.0	R
12	GSH	0.1	0.4	0.3	1.0	R
18	GSH	0.1	0.4	0.3	1.0	R
45	SST	2.0	2.0	5.0	4.0	S
42	SST	2.0	2.0	5.0	4.0	S
45	SST	2.0	2.0	5.0	4.0	S
-06	SST	2.0	2.0	5.0	4.0	S
11	SST	2.0	2.0	5.0	4.0	S
-84	SST	2.0	2.0	3.0	7.0	R
-67	SST	2.0	2.0	3.0	7.0	R
-77	SST	2.0	2.0	3.0	7.0	R
-52	SST	2.0	2.0	3.0	7.0	R
-47	SST	2.0	2.0	3.0	7.0	R
-29	SST	2.0	2.0	3.0	7.0	R
-58	SST	2.0	2.0	3.0	7.0	R

LANDSAW QUAD

LAT 37 39 06
LONG 83 28 30

-65	BSH	0.1	6.0	3.0	4.0	R
-71	BSH	0.1	6.0	3.0	4.0	R
-70	BSH	0.1	6.0	3.0	4.0	R
14	BSH	0.1	12.0	7.0		R
12	BSH	0.1	12.0	7.0		R
18	BSH	0.1	12.0	7.0		R
42	BSH	0.1	2.0	2.0		R
-80	BSH	0.1	0.2	0.5	0.2	S
-85	BSH	0.1	0.2	0.5	0.2	S
-72	BSH	0.1	0.2	0.5	0.2	S
35	BSH					
13	BSH					
20	BSH					
83	SST	3.0	4.0	7.0		S
14	SST	5.0	12.0	7.0		R
04	SST	5.0	12.0	7.0		R
-32	SST	6.0	13.0	15.0		S

LEATHERWOOD QUAD

LAT 37 02 23
LONG 83 10 14

000	COL					
-000	COL					
-000	COL					
85	COL					
75	COL					
85	COL					
75	SST	4.0	5.0	3.0	9.0	R
65	SST	4.0	5.0	3.0	9.0	R
55	SST	4.0	5.0	3.0	9.0	R
45	SST	4.0	5.0	3.0	9.0	R
65	SST	4.0	5.0	3.0	9.0	R
55	SST	4.0	5.0	3.0	9.0	R
45	SST	4.0	5.0	3.0	9.0	R
-15	SST	5.0	5.0	2.0		R
-15	SST	5.0	5.0	2.0		R
37	SST	5.0	6.0	5.0		R

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-64	SST	5.0	5.5	8.0		S
-62	SST	5.0	5.5	8.0		S
-38	SST	5.0	6.0	7.0		R
-29	SST	5.0	6.0	7.0		R
-14	SST	5.0	6.0	7.0		R

LEE CITY QUAD

LAT 37 40 32
LONG 83 21 17

25	COL					
29	COL					
23	COL					
18	COL					
-38	COL					
-39	COL					
-57	COL					
-62	COL					
-55	BSH	0.1	0.5	0.3		R
-50	BSH	0.1	0.5	0.3		R
68	BSH	0.1	0.5	0.5		R
75	BSH	0.1	0.5	0.5		R
72	BSH	0.1	0.5	0.5		R
-2[illegible]	BSH	0.1	0.6	1.0		R
-15	BSH	0.1	0.6	1.0		R
-16	BSH	0.1	0.6	1.0		R
-21	BSH	0.1	0.6	1.0		R
-38	RSH	0.1	2.5	0.1	4.0	R
-49	RSH	0.1	2.5	0.1	4.0	R
-29	RSH	0.1	2.5	0.1	4.0	R
-86	RSH	0.1	0.6	3.0		R
-84	RSH	0.1	0.6	3.0		R
33	RSH	0.1	0.3	0.5		R

LENOX QUAD

LAT 37 54 05
LONG 83 14 22

28	RSH	0.1	0.4	0.2	0.5	R
26	RSH	0.1	0.4	0.2	0.5	R
32	RSH	0.1	0.4	0.2	0.5	R
30	RSH	0.1	0.4	0.2	0.5	R
85	RSH	0.1	0.2	0.2	3.0	R
67	RSH	0.1	0.2	0.2	3.0	R
63	RSH	0.1	0.2	0.2	3.0	R
-64	RSH	0.1	0.2	0.2	3.0	R
-57	RSH	0.1	0.2	0.2	3.0	R
-66	RSH	0.1	0.2	0.2	3.0	R
-45	RSH	0.1	0.2	0.2	3.0	R
15	RSH	0.1	4.0	7.0	10.0	R
4	RSH	0.1	4.0	7.0	10.0	R
10	RSH	0.1	4.0	7.0	10.0	R
8	RSH	0.1	4.0	7.0	10.0	R
-82	RSH	0.1	3.0	2.0	8.0	R
-81	RSH	0.1	3.0	2.0	8.0	R
-72	RSH	0.1	3.0	2.0	8.0	R
-70	RSH	0.1	3.0	2.0	8.0	R
-74	RSH	0.1	3.0	2.0	8.0	R
-78	RSH	0.1	3.0	2.0	8.0	R

LOAD QUAD

LAT 38 31 55
LONG 82 57 55

-57	SST	1.0	1.0	2.0	4.0	R
-60	SST	1.0	1.0	2.0	4.0	R
-72	SST	1.0	1.0	2.0	4.0	R
-59	SST	1.0	1.0	2.0	4.0	R
-61	SST	1.0	1.0	2.0	4.0	R
-65	SST	1.0	1.0	2.0	4.0	R
-87	SST	0.5	0.5	1.0	2.0	R
-82	SST	0.5	0.5	1.0	2.0	R
-84	SST	0.5	0.5	1.0	2.0	R
-82	SST	0.5	0.5	1.0	2.0	R
-[illegible]	SST	1.0	1.0	4.0		R
[illegible]	SST	1.0	1.0	4.0		R
-[illegible]	SST	1.0	1.0	4.0		R
[illegible]	SST	1.0	1.0	2.0	10.0	R
2[illegible]	SST	1.0	1.0	2.0	10.0	R
3[illegible]	SST	1.0	1.0	2.0	10.0	R

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75	SST	0.3	2.0	2.0		

LOUISA QUAD

LAT	38	07	22			
LONG	82	37	23			
-57	COL	0.5	0.5	0.3	0.2	R
-56	COL	0.5	0.5	0.3	0.2	R
-53	COL	0.5	0.5	0.3	0.2	R
-54	COL	0.5	0.5	0.3	0.2	R
-58	COL	0.5	0.5	0.3	0.2	R
35	COL	0.5	0.5	0.2	0.2	R
28	COL	0.5	0.5	0.2	0.2	R
37	COL	0.5	0.5	0.2	0.2	R
17	COL	0.5	0.5	0.2	0.2	R
32	COL	0.5	0.5	0.2	0.2	R
-67	SST	1.0	1.0	1.5	3.0	R
-58	SST	1.0	1.0	1.5	3.0	R
-75	SST	1.0	1.0	1.5	3.0	R
-73	SST	1.0	1.0	1.5	3.0	R
-64	SST	1.0	1.0	1.5	3.0	R
-56	SST	1.0	1.0	1.5	3.0	R
-65	SST	1.0	1.0	1.5	3.0	R
45	SST	1.0	10.0	1.0	3.0	R
37	SST	1.0	10.0	1.0	3.0	R
36	SST	1.0	10.0	1.0	3.0	R
46	SST	1.0	10.0	1.0	3.0	R
30	SST	1.0	10.0	1.0	3.0	R
25	SST	1.0	10.0	1.0	3.0	R
17	SST	0.5	10.0	1.0	40.0	R
25	SST	0.5	10.0	1.0	40.0	R
32	SST	0.5	10.0	1.0	40.0	R
17	SST	0.5	10.0	1.0	40.0	R
-10	SST					
-11	SST					
-42	SST					
-37	SST					
73	SST					
84	SST					

MCCOWELL QUAD

LAT	37	29	00			
LONG	82	39	26			
-76	GSH	0.1	0.3	0.1	0.3	R
-75	GSH	0.1	0.3	0.1	0.3	R
-73	GSH	0.1	0.3	0.1	0.3	R
77	GSH	0.1	0.3	0.1	0.3	R
86	GSH	0.1	0.3	0.1	0.3	R
[illegible]	GSH	0.1	0.3	0.1	0.2	R
-03	GSH	0.1	0.3	0.1	0.2	R
-04	GSH	0.1	0.3	0.1	0.2	R
-12	GSH	0.1	0.3	0.1	0.2	R
14	GSH	0.1	0.3	0.1	0.2	R
[illegible]	GSH	0.1	0.3	0.1	0.2	R
12	GSH	0.1	0.3	0.1	0.2	R
54	GSH	0.1	0.3	0.1	0.5	R
56	GSH	0.1	0.3	0.1	0.5	R
-45	GSH	0.1	0.4	3.0	0.5	R
-41	GSH	0.1	0.4	3.0	0.5	R
-47	GSH	0.1	0.4	3.0	0.5	R
2	SST	0.1	0.4	3.0	0.5	R
-18	SST	0.1	0.4	3.0	0.5	R
19	SST	0.1	0.4	3.0	0.5	R
-82	SST	0.1	0.4	3.0	0.5	R
64	SST	0.1	0.4	3.0	0.5	R
70	SST	0.1	0.4	3.0	0.5	R
82	SST	0.1	0.4	3.0	0.5	R

MARTIN QUAD

LAT	37	32	10			
LONG	82	47	07			
62	SST					
55	SST					
[illegible]	SST					
[illegible]	SST					
[illegible]	GSH	0.1	0.3	0.2	2.0	R
-82	GSH	0.1	0.3	0.2	2.0	R
-73	GSH	0.1	0.3	0.2	2.0	R

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-84	GSH	0.1	0.3	0.2	2.0	R
-85	GSH	0.1	0.3	0.2	2.0	R
-86	GSH	0.1	0.3	0.2	2.0	R
-74	GSH	0.1	0.3	0.2	2.0	R
-02	GSH	0.1	0.2	0.2	0.3	R
-04	GSH	0.1	0.2	0.2	0.3	R
-12	GSH	0.1	0.2	0.2	0.3	R
04	GSH	0.1	0.2	0.2	0.3	R
33	GSH	0.1	0.4	0.1	2.0	R
37	GSH	0.1	0.4	0.1	2.0	R
41	GSH	0.1	0.4	0.1	2.0	R
38	GSH	0.1	0.4	0.1	2.0	R
65	GSH	0.1	1.0	0.5	2.0	R
68	GSH	0.1	1.0	0.5	2.0	R
-30	GSH					
-42	GSH					
-55	GSH					
-78	SST					
-74	SST					
-45	SST					
37	SST					
25	SST					

MAYKING QUAD

LAT 37 13 25
LONG 82 49 00

00	COL					
-12	COL					
13	COL					
-20	COL					
68	COL					
62	COL					
72	COL					
78	COL					
17	GSH	0.1	5.0	3.0		R
37	GSH	0.1	5.0	3.0		R
34	GSH	0.1	5.0	3.0		R
47	GSH	0.1	5.0	3.0		R
30	GSH	0.1	5.0	3.0		R
46	GSH	0.1	5.0	3.0		R
52	GSH	0.1	5.0	3.0		R
-38	GSH	0.1	5.0	2.5		R
-23	GSH	0.1	5.0	2.5		R
-53	GSH	0.1	5.0	2.5		R
87	GSH	0.1				
-68	GSH	0.1				
-87	GSH	0.1				
55	SST	0.5	0.5	1.5	2.0	S
53	SST	0.5	0.5	1.5	2.0	S
51	SST	0.5	0.5	1.5	2.0	S
-67	SST	0.5	0.5	1.0	3.0	S
-75	SST	0.5	0.5	1.0	3.0	S
-10	SST	0.2	0.2	0.3		R
-05	SST	0.2	0.2	0.3		R

MAZIE QUAD

LAT 38 00 50
LONG 82 55 07

-64	SST	0.2	2.0	1.0	3.0	R
-68	SST	0.2	2.0	1.0	3.0	R
-65	SST	0.2	2.0	1.0	3.0	R
-73	SST	0.2	2.0	1.0	3.0	R
-65	SST	0.2	2.0	1.0	3.0	R
-55	SST	0.2	2.0	1.0	3.0	R
77	SST	0.5	2.0	1.0	7.0	R
88	SST	0.5	2.0	1.0	7.0	R
72	SST	0.5	2.0	1.0	7.0	R
90	SST	0.5	2.0	1.0	7.0	R
83	SST	0.5	2.0	1.0	7.0	R
-84	SST	0.5	2.0	1.0	7.0	R
70	SST	0.5	2.0	1.0	7.0	R
-90	SST	0.5	2.0	1.0	7.0	R
16	SST					
35	SST					
07	SST	0.6	2.0	2.0	10.0	R
18	SST	0.6	2.0	2.0	10.0	R
41	SST	0.6	2.0	2.0	10.0	R
48	SST	0.6	2.0	2.0	10.0	R
-20	SST	1.0	1.0	3.0	2.0	R

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-24	SS	0.0	0.0	3.0	2.0	R

META QUAD

LAT	37	31	22			
LONG	82	28	21			
42	GSH	0.1	3.0	2.0	3.5	R
42	GSH	0.1	3.0	2.0	3.5	R
48	GSH	0.1	3.0	2.0	3.5	R
45	GSH	0.1	3.0	2.0	3.5	R
28	GSH	0.1	3.0	2.0	3.5	R
-50	GSH	0.1	3.0	2.0	3.5	R
-90	GSH	0.1	3.0	2.0	3.5	R
-82	GSH	0.1	3.0	2.0	3.5	R
10	GSH	0.1	3.0	2.0	3.5	R
[illegible]	GSH	0.1	3.0	2.0	3.5	R
-41	GSH	0.1	3.0	2.0	3.5	R
-42	GSH	0.1	3.0	2.0	3.5	R
-28	GSH	0.1	3.0	2.0	3.5	R
-45	GSH	0.1	3.0	2.0	3.5	R
-63	GSH	0.1	3.0	2.0	3.5	R
-68	GSH	0.1	3.0	2.0	3.5	R
-60	GSH	0.1	3.0	2.0	3.5	R

MILLARD QUAD

LAT	37	24	27			
LONG	82	26	24			
-65	GSH	0.1	5.0	2.0	10.0	R
-55	GSH	0.1	5.0	2.0	10.0	R
-53	GSH	0.1	5.0	2.0	10.0	R
-52	GSH	0.1	5.0	2.0	10.0	R
-12	GSH	0.1	5.0	2.0	10.0	R
-13	GSH	0.1	5.0	2.0	10.0	R
-26	GSH	0.1	5.0	2.0	10.0	R
-27	GSH	0.1	5.0	2.0	10.0	R
-10	GSH	0.1	5.0	2.0	10.0	R
4	GSH	0.1	5.0	2.0	10.0	R
85	GSH	0.1	4.0	2.0	10.0	R
75	GSH	0.1	4.0	2.0	10.0	R
-30	GSH	0.1	6.0	5.0	10.0	R
-34	GSH	0.1	6.0	5.0	10.0	R
-41	GSH	0.1	6.0	5.0	10.0	R
56	SST	0.1	20.0	10.0	30.0	R
55	SST	0.1	20.0	10.0	30.0	R
57	SST	0.1	25.0	25.0	30.0	R

MILO QUAD

LAT	37	55	30			
LONG	82	32	18			
88	GSH	0.2	0.7	0.5	2.0	R
54	GSH	0.2	0.7	0.5	2.0	R
42	GSH	0.2	0.7	0.5	2.0	R
58	GSH	0.2	0.7	0.5	2.0	R
32	GSH	0.2	0.7	0.5	2.0	R
56	GSH	0.2	0.7	0.5	2.0	R
68	GSH	0.2	0.7	0.5	2.0	R
-22	GSH	0.2	0.5	0.1	0.5	R
-38	GSH	0.2	0.5	0.1	0.5	R
-42	GSH	0.2	0.5	0.1	0.5	R
-40	GSH	0.2	0.5	0.1	0.5	R
-28	GSH	0.2	0.5	0.1	0.5	R
10	GSH	0.2	0.5	0.1	0.5	R

MOREHEAD QUAD

LAT	38	10	50			
LONG	83	28	00			
17	SST	0.1	5.0	0.1	2.0	R
23	SST	0.1	5.0	0.1	2.0	R
17	SST	0.1	5.0	0.1	2.0	R
11	SST	0.1	5.0	0.1	2.0	R
-68	SST	0.1	5.0	0.1	2.0	R
-51	SST	0.1	5.0	0.1	2.0	R
-42	SST	0.5	0.5	0.5	6.0	R
-42	SST	0.5	0.5	0.5	6.0	R
-20	SST	0.5	0.5	0.5	6.0	R
-33	SST	0.5	0.5	0.5	6.0	R
-26	SST	0.5	0.5	0.5	6.0	R

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62	SST	1.0	12.0	1.0	12.0	R
77	SST	1.0	12.0	1.0	12.0	R
82	SST	1.0	12.0	1.0	12.0	R
87	SST	1.0	12.0	1.0	12.0	R
64	SST	1.0	12.0	1.0	12.0	R
66	SST	1.0	12.0	1.0	12.0	R
32	SST	0.3	4.0	1.0	5.0	R
42	SST	0.3	4.0	1.0	5.0	R
46	SST	0.3	4.0	1.0	5.0	R
-10	SST	0.1	0.3	0.1	0.4	R
-05	SST	0.1	0.3	0.1	0.4	R
-04	SST	0.1	0.3	0.1	0.4	R
-16	SST	0.1	0.3	0.1	0.4	R

NOBLE QUAD

LAT	37 24 01					
LONG	83 12 20					
-45	GSH	0.1	2.5	0.1		R
-[illegible]	GSH	0.1	0.1	0.1	0.2	R
-1[illegible]	GSH	0.1	0.1	0.1	0.2	R
-[illegible]	GSH	0.1	0.1	0.1	0.2	R
-[illegible]62	GSH	0.1	0.1	0.1	0.2	R
-52	GSH	0.1	0.1	0.1	0.1	R
78	GSH	0.1	0.2	0.2		R
-43	SST	0.5	2.5	1.0	2.0	R
-35	SST	0.5	2.5	1.0	2.0	R
-40	SST	0.5	2.5	1.0	2.0	R
-18	SST	1.0	1.0	0.3		R
55	SST	1.0	1.0	1.0		R

CFFUTT QUAD

LAT	37 50 18					
LONG	82 42 37					
-52	GSH	0.1	1.0	1.0	0.2	R
-40	GSH	0.1	1.0	1.0	0.2	R
-71	GSH	0.1	0.2	0.1	0.2	R
-77	GSH	0.1	0.2	0.1	0.2	R
-82	GSH	0.1	0.2	0.1	0.2	R
-24	GSH	0.1	0.2	0.1	0.2	R
81	GSH	0.1	0.2	0.1	0.2	R
87	GSH	0.1	0.2	0.1	0.2	R
85	GSH	0.1	0.2	0.1	0.2	R
50	GSH	0.1	0.2	0.1	0.2	R
33	GSH	0.1	0.2	0.1	0.2	R
27	GSH	0.1	0.2	0.1	0.2	R
34	GSH	0.1	0.2	0.1	0.2	R
[illegible]	SST	0.5	0.5	3.0	0.2	R
[illegible]	SST	0.5	0.5	3.0	0.2	R
[illegible]8	SST	0.5	0.5	3.0	0.2	R
5	SST	0.5	0.5	3.0	0.2	R
-02	SST	0.5	0.5	3.0	0.2	R
-10	SST	0.5	0.5	3.0	0.2	R
-57	SST	0.5	2.0	1.5	0.2	R
-62	SST	0.5	2.0	1.5	0.2	R
-80	SST	0.5	2.0	1.5	0.2	R
-77	SST	0.5	2.0	1.5	0.2	R
28	SST	0.5	2.0	1.5	0.2	R
38	SST	0.5	2.0	1.5	0.2	R
-37	SST	0.5	2.0	1.5	0.2	R
82	SST	2.0	2.0	2.0	10.0	S
70	SST	2.0	2.0	2.0	10.0	S
78	SST	2.0	2.0	2.0	10.0	S
54	SST	2.0	2.0	2.0	10.0	S
LAT	37 50 34					
LONG	82 40 10					
78	SST	2.0	2.0	10.0	3.0	R
76	SST	2.0	2.0	10.0	3.0	R
78	SST	2.0	2.0	10.0	3.0	R
74	SST	2.0	2.0	10.0	3.0	R
72	SST	2.0	6.0	25.0	3.0	R
22	SST	2.0	2.0	2.5	10.0	R
37	SST	2.0	2.0	2.5	10.0	R
[illegible]	SST	0.3	0.3	1.0	2.0	R
-12	SST	0.3	0.3	1.0	2.0	R
-30	SST	0.3	0.3	1.0	2.0	R

COLE QUAD

LAT	38	24	34				
LONG	83	40	03				
-43		COL					
-39		COL					
-38		COL					
34		COL					
34		COL					
28		COL					
-26		GSH	0.1	5.0	0.1		R
-33		GSH	0.1	5.0	0.1		R
-65		GSH	0.1	5.0	0.1		R
37		GSH					
45		GSH					
-82		GSH	0.1	2.0	1.0	3.0	R
-71		GSH	0.1	2.0	1.0	3.0	R
-68		GSH	0.1	2.0	1.0	3.0	R
-69		GSH	0.1	2.0	1.0	3.0	R
72		GSH					
83		GSH					
-07		SST					
37		SST					
-09		SST					
-07		SST					
02		SST					
92		SST	1.0	2.5	2.0	2.0	R
87		SST	1.0	2.5	2.0	2.0	R
90		SST	1.0	2.5	2.0	2.0	R
90		SST	1.0	2.5	2.0	2.0	R
13		SST					
67		SST					

CIL SPRINGS QUAD

LAT	37	49	28				
LONG	82	56	40				
-27		COL	0.7	0.7	0.2	0.2	R
-24		COL	0.7	0.7	0.2	0.2	R
-20		COL	0.7	0.7	0.2	0.2	R
-25		COL	0.7	0.7	0.2	0.2	R
82		COL	0.7	0.7	0.2	0.2	R
83		COL	0.7	0.7	0.2	0.2	R
90		COL	0.7	0.7	0.2	0.2	R
75		COL	0.7	0.7	0.2	0.2	R
85		COL	0.7	0.7	0.2	0.2	R
-26		GSH	0.1	2.0	1.0	20.0	R
-10		GSH	0.1	2.0	1.0	20.0	R
-20		GSH	0.1	2.0	1.0	20.0	R
-84		GSH	0.1	2.0	1.0	20.0	R
-85		GSH	0.1	2.0	1.0	20.0	R
-55		GSH	0.1	1.0	1.0	20.0	R
-45		GSH	0.1	1.0	1.0	20.0	R
-35		GSH	0.1	1.0	1.0	20.0	R
10		GSH	0.1	3.0	0.5	3.0	R
17		GSH	0.1	3.0	0.5	3.0	R
8		GSH	0.1	3.0	0.5	3.0	R
24		GSH	0.1	3.0	0.5	3.0	R
30		GSH	0.1	3.0	0.5	3.0	R
70		GSH	0.1	2.0	1.0	3.0	R
74		GSH	0.1	2.0	1.0	3.0	R
55		GSH	0.1	2.0	1.0	3.0	R
70		GSH	0.1	2.0	1.0	3.0	R

CLOTOWN QUAD

LAT	38	26	00				
LONG	82	53	56				
-19		SST	2.0	3.0	5.0	1.0	R
-15		SST	2.0	3.0	5.0	1.0	R
-16		SST	2.0	3.0	5.0	1.0	R
-12		SST	2.0	3.0	5.0	1.0	R
29		SST					
56		SST	3.0	10.0	2.0	10.0	R
55		SST	3.0	10.0	2.0	10.0	R
45		SST	3.0	10.0	2.0	10.0	R
56		SST	3.0	10.0	2.0	10.0	R
62		SST	3.0	10.0	2.0	10.0	R
-07		SST					
-62		SST	2.0	2.0	3.0	2.0	R
-68		SST	2.0	2.0	3.0	2.0	R
-61		SST	2.0	2.0	3.0	2.0	R
-53		SST	2.0	2.0	3.0	2.0	R

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-67	SST	2.0	2.0	3.0	2.0	R
-68	SST	2.0	2.0	3.0	2.0	R
[illegible]	SST	1.0	1.0	1.0	4.0	R
[illegible]	SST	1.0	1.0	1.0	4.0	R
65	GSH	1.0	0.1	0.1		R
67	GSH	1.0	0.1	0.1		R
[illegible]	GSH	1.0	0.1	0.1		R
-29	GSH	1.0	0.1	0.1		R

CLIVE HILL QUAD

LAT 38 17 33
LONG 83 11 20

-92	LST	0.6	0.6	1.5	2.0	R
-87	LST	0.6	0.6	1.5	2.0	R
-83	LST	0.6	0.6	1.5	2.0	R
-92	LST	0.6	0.6	1.5	2.0	R
-84	LST	0.6	0.6	1.5	2.0	R
-77	LST	0.6	0.6	1.5	2.0	R
-81	LST	0.6	0.6	1.5	2.0	R
09	LST	0.5	0.5	0.3	7.0	R
14	LST	0.5	0.5	0.3	7.0	R
[illegible]	LST	0.5	0.5	0.3	7.0	R
35	LST	0.3	0.3	1.5	1.2	R
32	LST	0.3	0.3	1.5	1.2	R
43	LST	0.3	0.3	1.5	1.2	R
42	LST	0.3	0.3	1.5	1.2	R
34	LST	0.3	0.3	1.5	1.2	R
32	LST	0.3	0.3	1.5	1.2	R
36	LST	0.3	0.3	1.5	1.2	R
-10	LST	0.3	0.3	0.2	0.5	R
-14	LST	0.3	0.3	0.2	0.5	R
-11	LST	0.3	0.3	0.2	0.5	R
63	LST	1.0	2.0	5.0		R
74	LST	1.0	2.0	5.0		R
82	LST	1.0	2.0	5.0		R
78	LST	1.0	2.0	5.0		R
-60	LST					
-62	LST					
-46	LST					

CLYMPIA QUAD

LAT 38 03 47
LONG 83 40 33

-88	BSH	0.1	3.0	1.0	2.0	R
-75	BSH	0.1	3.0	1.0	2.0	R
-71	BSH	0.1	3.0	1.0	2.0	R
-90	BSH	0.1	3.0	1.0	2.0	R
-75	BSH	0.1	3.0	1.0	2.0	R
-78	BSH	0.1	3.0	1.0	2.0	R
-69	BSH	0.1	3.0	1.0	2.0	R
-87	BSH	0.1	5.0	0.3	2.0	R
-88	BSH	0.1	5.0	0.3	2.0	R
-65	BSH	0.1	5.0	0.3	2.0	R
-50	BSH	0.1	5.0	0.3	2.0	R
-55	BSH	0.1	5.0	0.3	2.0	R
-15	BSH	0.1	0.2	0.2	1.0	R
-08	BSH	0.1	0.2	0.2	1.0	R
-05	BSH	0.1	0.2	0.2	1.0	R
-06	BSH	0.1	0.2	0.2	1.0	R
70	BSH	0.1	0.3	0.2	3.0	R
72	BSH	0.1	0.3	0.2	3.0	R
92	BSH	0.1	0.3	0.2	3.0	R
-33	BSH	0.1	0.5	4.0	2.0	R
-22	BSH	0.1	0.5	4.0	2.0	R
-46	BSH	0.1	0.5	4.0	2.0	R
-30	BSH	0.1	0.5	4.0	2.0	R
-30	BSH	0.1	0.5	4.0	2.0	R
-20	BSH	0.1	0.5	4.0	2.0	R

ONEIDA QUAD

LAT 37 19 00
LONG 83 41 15

-49	COL
-33	COL
-33	COL
34	COL
39	COL
52	COL

[illegible]	BSH	0.1	5.0	4.0		R
65	BSH	0.1	5.0	4.0		R
70	BSH	0.1	5.0	4.0		R
-44	BSH	0.1	5.0	7.0	3.0	R
-43	BSH	0.1	5.0	7.0	3.0	R
-43	BSH	0.1	5.0	7.0	3.0	R
-42	BSH	0.1	5.0	7.0	3.0	R
-29	BSH	0.1	1.5	7.0		
-83	BSH	0.1	1.5	7.0		
09	BSH	0.1	2.0	5.0		R
40	BSH					
27	BSH					
20	SST					
32	SST					
45	SST					
-22	SST	1.0	1.0	4.0	2.0	R
-42	SST	1.0	1.0	4.0	2.0	R
-43	SST	1.0	1.0	4.0	2.0	R
57	SST					
-92	SST					

MANCEBURG QUA

LAT	39	32	43			
LONG	83	41	44			
-15	LST	0.1			2.0	R
-15	LST	0.1			2.0	R
-35	LST	0.1			1.5	R
-27	LST	0.1			1.5	R
-27	LST	0.1			1.5	R
-58	LST	0.1			1.5	R
-50	LST	0.1			1.5	R
-42	LST	0.1			1.5	R
-49	LST	0.1			1.5	R
-48	LST	0.1			1.5	R
-04	LST	0.1			0.2	R
-05	LST	0.1			0.2	R
-06	LST	0.1			0.2	R
10	LST	0.1			1.0	R
6	LST	0.1			1.0	R
40	LST	0.1			1.0	R
44	LST	0.1			1.0	R
34	LST	0.1			1.0	R
80	LST	0.1				R
LAT	38	36	50			
LONG	83	41	42			
-26	LST	0.2			1.0	R
-20	LST	0.2			1.0	R
-53	LST	0.2			0.2	R
-55	LST	0.2			0.2	R
-02	LST	0.2			1.0	R
-08	LST	0.2			1.0	R
-72	LST	0.2			0.7	R
-66	LST	0.2			0.7	R
-65	LST	0.2			0.7	R
-63	LST	0.2			0.7	R
-12	LST	0.2				R
45	LST	0.2			3.0	R
47	LST	0.2			3.0	R
48	LST	0.2			3.0	R
45	LST	0.2			3.0	R
50	LST	0.2			3.0	R
42	LST	0.2			3.0	R
44	LST	0.2			3.0	R
36	LST	0.2			3.0	R
48	LST	0.2			3.0	R
38	LST	0.2			3.0	R
[illegible]	LST	0.2				R
90	LST	0.1				R
90	LST	0.1				R
85	LST	0.1				R
21	LST	0.2				R

PAINTSVILLE QUAD

LAT	37	49	18			
LONG	82	49	40			
-[illegible]	BSH	0.1	5.0	0.5	6.0	R
-75	BSH	0.1	5.0	0.5	6.0	R
-8[illegible]	BSH	0.1	5.0	0.5	6.0	R
-70	BSH	0.1	5.0	0.5	6.0	R

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55	LST	0.1	1.0	1.0	0.4	R
-44	LST	0.1	0.2	0.2	0.2	R
-45	LST	0.1	0.2	0.2	0.2	R
-46	LST	0.1	0.2	0.2	0.2	R
-38	LST	0.1	0.2	0.2	0.2	R
-56	LST	0.1	0.2	0.2	0.2	R
-48	LST	0.1	0.2	0.2	0.2	R
-52	LST	0.1	0.2	0.2	0.2	R
-50	LST	0.1	0.2	0.2	0.2	R
-50	LST	0.1	0.2	0.2	0.2	R
21	LST	0.1	0.1	0.5	0.3	R
26	LST	0.1	0.1	0.5	0.3	R
18	LST	0.1	0.1	0.5	0.3	R
-70	LST	0.1	0.3	0.4	0.5	R
-65	LST	0.1	0.3	0.4	0.5	R
-68	LST	0.1	0.3	0.4	0.5	R
-72	LST	0.1	0.3	0.4	0.5	R
75	LST	0.1	0.3	0.4	0.5	R

POMERCYTON QUAD

LAT 37 49 14
LONG 83 34 56

-52	LST	4.0	12.0	6.0	5.0	R
-54	LST	4.0	12.0	6.0	5.0	R
-53	LST	4.0	12.0	6.0	5.0	R
42	LST	4.0	12.0	5.0	6.0	R
47	LST	4.0	12.0	5.0	6.0	R
58	LST	2.0	10.0	3.0		R
63	LST	2.0	10.0	3.0		R
08	LST	1.0	7.0	2.0		R
18	LST	1.0	7.0	2.0		R
13	LST	1.0	7.0	2.0		R
-27	LST	3.0	3.0	6.0		R
-78	LST	3.0	3.0	6.0		R
-85	LST	3.0	3.0	6.0		R
88	LST	3.0	3.0	6.0		R

PORTSMOUTH QUAD

LAT 38 42 50
LONG 82 57 20

16	SST	0.3	0.3	2.0	3.0	R
17	SST	0.3	0.3	2.0	3.0	R
20	SST	0.3	0.3	2.0	3.0	R
77	SST	0.1	2.0	1.0	1.0	R
70	SST	0.1	2.0	1.0	1.0	R
70	SST	0.1	2.0	1.0	1.0	R
75	SST	0.1	2.0	1.0	1.0	R
70	SST	0.1	2.0	1.0	1.0	R
75	SST	0.1	2.0	1.0	1.0	R
65	SST	0.2	0.2	0.5	10.0	R
64	SST	0.2	0.2	0.5	10.0	R
60	SST	0.2	0.2	0.5	10.0	R
61	SST	0.2	0.2	0.5	10.0	R
65	SST	0.2	0.2	0.5	10.0	R
60	SST	0.2	0.2	0.5	10.0	R
-72	SST					
43	SST					
00	SST					
45	SST					
50	SST					
-32	SST	0.2	0.2	10.0	1.0	R
-25	SST	0.2	0.2	10.0	1.0	R
-29	SST	0.2	0.2	10.0	1.0	R
-27	SST	0.2	0.2	10.0	1.0	R
-55	SST	0.2	0.2	10.0	1.0	R

PRESTONSBURG QUAD

LAT 37 41 25
LONG 82 46 32

-31	COL					
-32	COL					
-36	COL					
-33	COL					
[illegible]	COL					
[illegible]	COL					
[illegible]	COL					
[illegible]	GSH	0.1	8.0	12.0	6.0	R
[illegible]	GSH	0.1	8.0	12.0	6.0	R

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90	BSH	0.1	5.0	0.5	6.0	R
-95	BSH	0.1	5.0	0.5	6.0	R
-26	BSH	0.1	0.6	4.0		R
-11	BSH	0.1	0.6	4.0		R
-29	BSH	0.1	0.6	4.0		R
8	BSH					
15	BSH					
23	BSH					
74	BSH	0.1	2.0	0.5	1.5	R
56	BSH	0.1	2.0	0.5	1.5	R
54	BSH	0.1	2.0	0.5	1.5	R
60	BSH	0.1	2.0	0.5	1.5	R
70	BSH	0.1	2.0	0.5	1.5	R
72	BSH	0.1	2.0	0.5	1.5	R
-58	BSH	0.1	10.0	0.8		R
-66	BSH	0.1	10.0	0.8		R
-63	BSH	0.1	10.0	0.8		R
-66	BSH	0.1	10.0	0.8		R
18	BSH					
-36	SST	2.0	6.0	20.0		R
52	SST	2.0	6.0	20.0		
40	SST	2.0	6.0	20.0		
8	SST	2.0	6.0	20.0		R
57	CCL					
56	CCL					
54	CCL					
-46	CCL					
-52	CCL					
-54	CCL					

PIKEVILLE QUAD

LAT 37 27 57
LONG 82 31 40

-64	SST	0.1	12.0	15.0	25.0	R
-70	SST	0.1	12.0	30.0	25.0	R
-75	SST	0.1	12.0	30.0	25.0	R
30	SST	0.1	7.0	5.0	25.0	R
28	SST	0.1	7.0	5.0	25.0	R
25	SST	0.1	7.0	5.0	25.0	R
9	SST	0.1	12.0	0.5	15.0	R
12	SST	0.1	12.0	0.5	15.0	R
17	SST	0.1	12.0	0.5	15.0	R
5	SST	0.1	12.0	0.5	15.0	R

PINEVILLE QUAD

LAT 36 47 45
LONG 83 39 56

-52	SST	0.5	3.0	0.1	1.0	R
-45	SST	0.5	3.0	0.1	1.0	R
-35	SST	0.5	3.0	0.1	1.0	R
-47	SST	0.5	3.0	0.1	1.0	R
-49	SST	0.5	3.0	0.1	1.0	R
-52	SST	0.5	3.0	0.1	1.0	R
-63	SST	0.5	3.0	0.1	1.0	R
-59	SST	0.5	3.0	0.1	1.0	R
-62	SST	0.5	3.0	0.1	1.0	R
48	SST	0.3	1.0	3.0		R
33	SST	0.3	1.0	3.0		R
32	SST	0.3	1.0	3.0		R
90	SST	0.3	0.5	1.0	1.5	R
86	SST	0.3	0.5	1.0	1.5	R
67	SST	0.3	0.5	1.0	1.5	R
82	SST	0.3	0.5	1.0	1.5	R
87	SST	0.3	0.5	1.0	1.5	R
-25	SST	0.3	0.5	0.1	1.0	R
-15	SST	0.3	0.5	0.1	1.0	R
05	SST					

PLUMMERS LANDING QUAD

LAT 38 21 37
LONG 83 36 58

36	LST	0.1	1.0	1.0	0.4	R
37	LST	0.1	1.0	1.0	0.4	R
38	LST	0.1	1.0	1.0	0.4	R
46	LST	0.1	1.0	1.0	0.4	R
49	LST	0.1	1.0	1.0	0.4	R
43	LST	0.1	1.0	1.0	0.4	R
53	LST	0.1	1.0	1.0	0.4	R

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12	GSH	0.1	8.0	12.0	6.0	R
16	GSH	0.1	8.0	12.0	6.0	R
-71	GSH	0.1	7.0	6.0	4.0	R
-61	GSH	0.1	7.0	6.0	4.0	R
-66	GSH	0.1	7.0	6.0	4.0	R
-73	GSH	0.1	7.0	6.0	4.0	R
-74	GSH	0.1	7.0	6.0	4.0	R
-72	GSH	0.1	7.0	6.0	4.0	R
-24	SST	3.0	3.0	15.0		S
11	SST	3.0	3.0	15.0		S
08	SST	3.0	3.0	15.0		S
12	SST	3.0	3.0	15.0		S
-81	SST	3.0	3.0	4.0		S
83	SST	3.0	3.0	4.0		S
86	SST	3.0	3.0	4.0		
7[illegible]	SST	3.0	3.0	4.0		R

GLICKSAND QUAD

LAT 37 32 51
LONG 83 2[illegible] 45

-24	CCL					
-29	CCL					
-2[illegible]	CCL					
44	CCL					
51	CCL					
4[illegible]	CCL					
-43	GSH	0.1	5.0	6.0	8.0	R
-42	GSH	0.1	5.0	6.0	8.0	R
-2[illegible]	GSH	0.1	5.0	6.0	8.0	R
-3[illegible]	GSH	0.1	5.0	6.0	8.0	R
-37	GSH	0.1	5.0	6.0	8.0	R
-30	GSH	0.1	5.0	6.0	8.0	R
57	GSH	0.1	5.0	4.0		
48	GSH	0.1	5.0	4.0		
52	GSH	0.1	5.0	4.0		
77	GSH	0.1	4.0	1.0	10.0	R
75	GSH	0.1	4.0	1.0	10.0	R
-77	GSH	0.1	1.0	0.1		R
-85	GSH	0.1	1.0	0.1		R
-25	SST	6.0	6.0	25.0	3.0	S
-22	SST	6.0	6.0	25.0	3.0	S
37	SST	4.0	4.0	5.0		R
-38	SST	3.0	3.0	3.0	4.0	R
-36	SST	3.0	3.0	3.0	4.0	R

REDBUSH QUAD

LAT 37 56 50
LONG 82 59 03

-75	BSH	0.1	0.1	0.3	0.3	R
-62	BSH	0.1	0.1	0.3	0.3	R
-70	BSH	0.1	0.1	0.3	0.3	R
-65	BSH	0.1	0.1	0.3	0.3	R
39	BSH	0.1	0.1	0.1	0.2	R
40	BSH	0.1	0.1	0.1	0.2	R
32	BSH	0.1	0.1	0.1	0.2	R
33	BSH	0.1	0.1	0.1	0.2	R
12	BSH	0.1	0.1	0.1	0.2	R
13	BSH	0.1	0.1	0.1	0.2	R
5	BSH	0.1	0.1	0.1	0.2	R
6	BSH	0.1	0.1	0.1	0.2	R
-06	BSH	0.1	0.1	0.1	0.2	R
-10	SST	1.5	1.5	2.0	4.0	R
1[illegible]	SST	1.5	1.5	2.0	4.0	R
-32	SST	1.5	1.5	2.0	4.0	R
19	SST	1.5	1.5	2.0	4.0	R
-12	SST	1.5	1.5	2.0	4.0	R
-04	SST	1.5	1.5	2.0	4.0	R
-23	SST	1.5	1.5	2.0	4.0	R
0	SST	1.5	1.5	2.0	4.0	R
88	SST	2.0	2.0	3.0	2.0	R
86	SST	2.0	2.0	3.0	2.0	R
65	SST	2.0	2.0	3.0	2.0	R
83	SST	2.0	2.0	3.0	2.0	R
7[illegible]	SST	2.0	2.0	3.0	2.0	R
[illegible]	SST	2.0	2.0	3.0	2.0	R
-67	SST	3.0	3.0	8.0	2.0	R
-65	SST	3.0	3.0	8.0	2.0	R

RICHARDSON QUAD

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LAT	37	57	30				
LONG	82	40	03				
-67		BSH	0.1	0.4	0.3	0.3	R
-55		BSH	0.1	0.4	0.3	0.3	R
-35		BSH	0.1	0.4	0.3	0.3	R
-45		BSH	0.1	0.4	0.3	0.3	R
45		BSH	0.1	0.5	1.0	0.3	R
20		BSH	0.1	0.5	1.0	0.3	R
34		BSH	0.1	0.5	1.0	0.3	R
18		BSH	0.1	0.5	1.0	0.3	R
-03		BSH	0.1	1.0	1.0	0.2	R
-00		BSH	0.1	1.0	1.0	0.2	R
54		BSH	0.1	1.0	0.2	1.0	R
53		BSH	0.1	1.0	0.2	1.0	R
0		GSH	0.1	0.5	0.3	1.0	R
11		GSH	0.1	0.5	0.3	1.0	R
4		GSH	0.1	0.5	0.3	1.0	R
8		GSH	0.1	0.5	0.3	1.0	R
85		GSH	0.1	0.3	0.1	1.0	R
-66		GSH	0.1	0.3	0.1	1.0	R
41		SST	2.0	2.0	1.0	25.0	R
53		SST	2.0	2.0	1.0	25.0	R
37		SST	2.0	2.0	1.0	25.0	R
-33		SST	5.0	4.0	2.0	25.0	R
-55		SST	5.0	4.0	2.0	25.0	R

RUSH QUAD

LAT	38	20	43				
LONG	82	50	40				
58		SST	1.5	1.5	5.0	10.0	R
63		SST	1.5	1.5	5.0	10.0	R
53		SST	1.5	1.5	5.0	10.0	R
40		SST	1.5	1.5	5.0	10.0	R
-32		SST	0.7	0.5	0.3	2.0	R
-30		SST	0.7	0.5	0.3	2.0	R
-41		SST	0.7	0.5	0.3	2.0	R
-84		SST	1.5	1.5	2.0	1.0	R
-64		SST	1.5	1.5	2.0	1.0	R
-88		SST	1.5	1.5	2.0	1.0	R
-75		SST	1.5	1.5	2.0	1.0	R
-07		SST	1.5	3.5	0.2	5.0	R
-11		SST	1.5	3.5	0.2	5.0	R
-14		SST	1.5	3.5	0.2	5.0	R
-15		SST	1.5	3.5	0.2	5.0	R
57		COL	0.2	0.2	0.1	0.2	R
48		COL	0.2	0.2	0.1	0.2	R
48		COL	0.2	0.2	0.1	0.2	R
51		COL	0.2	0.2	0.1	0.2	R
53		COL	0.2	0.2	0.1	0.2	R
-44		COL	0.2	0.2	0.1	0.1	R
-53		COL	0.2	0.2	0.1	0.1	R
-30		COL	0.2	0.2	0.1	0.1	R
-30		COL	0.2	0.2	0.1	0.1	R
-33		COL	0.2	0.2	0.1	0.1	R
08		GSH	0.1	0.3	0.1	0.5	R
13		GSH	0.1	0.3	0.1	0.5	R
05		GSH	0.1	0.3	0.1	0.5	R
16		GSH	0.1	0.3	0.1	0.5	R
17		GSH	0.1	0.3	0.1	0.5	R
-01		GSH	0.1	0.3	0.1	0.5	R
-77		GSH	0.1	0.3	0.1		R
-59		GSH	0.1	0.3	0.1		R
-53		GSH	0.1	0.3	0.1		R
-40		GSH					
72		GSH	0.1	1.5	1.0	6.0	R
71		GSH	0.1	1.5	1.0	6.0	R
57		GSH	0.1	1.5	1.0	6.0	R
LAT	38	18	27				
LONG	82	46	47				
40		SST	0.2	0.2	0.3	0.2	R
42		SST	0.2	0.2	0.3	0.2	R
46		SST	0.2	0.2	0.3	0.2	R
35		SST	0.2	0.2	0.3	0.2	R
37		SST	0.2	0.2	0.3	0.2	R
-37		SST	0.2	0.2	0.3	0.5	R
-43		SST	0.2	0.2	0.3	0.5	R
-49		SST	0.2	0.2	0.3	0.5	R
-62		SST	0.2	0.2	0.3	0.5	R
-4		SST	0.2	0.2	0.3	0.5	R

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42	GSH	0.1	4.0	3.0	5.0	R
28	GSH	0.1	4.0	3.0	5.0	R
20	GSH	0.1	4.0	3.0	5.0	R
21	GSH	0.1	4.0	3.0	5.0	R
25	GSH	0.1	4.0	3.0	5.0	R
26	GSH	0.1	4.0	3.0	5.0	R
20	GSH	0.1	4.0	3.0	5.0	R
41	GSH	0.1	4.0	3.0	5.0	R
34	GSH	0.1	4.0	3.0	5.0	R
85	GSH	0.1	0.5	0.3	0.5	R
83	GSH	0.1	0.5	0.3	0.5	R
65	GSH	0.1	0.5	0.3	0.5	R
90	GSH	0.1	0.5	0.3	0.5	R
62	GSH	0.1	0.5	0.3	0.5	R
74	GSH	0.1	0.5	0.3	0.5	R
85	GSH	0.1	0.5	0.3	0.5	R
-73	GSH	0.1	1.0	0.1	10.0	R
-78	GSH	0.1	1.0	0.1	10.0	R
-70	GSH	0.1	1.0	0.1	10.0	R
-63	GSH	0.1	1.0	0.1	10.0	R
-93	GSH	0.1	1.0	0.1	10.0	R
-35	GSH	0.1	0.4	1.0	0.5	R
-29	GSH	0.1	0.4	1.0	0.5	R

SALT LICK QUAD

LAT 38 07 18
LONG 83 32 23

-79	RSH	0.1	0.3	0.2	1.0	R
-73	RSH	0.1	0.3	0.2	1.0	R
-82	RSH	0.1	0.3	0.2	1.0	R
-67	RSH	0.1	0.3	0.2	1.0	R
-75	RSH	0.1	0.3	0.2	1.0	R
-72	RSH	0.1	0.3	0.2	1.0	R
-60	RSH	0.1	0.3	0.2	1.0	R
-04	RSH					
13	RSH	0.2	0.3	1.0	0.5	R
20	RSH	0.2	0.3	1.0	0.5	R
21	RSH	0.2	0.3	1.0	0.5	R
17	RSH	0.2	0.3	1.0	0.5	R
15	RSH	0.2	0.3	1.0	0.5	R
18	RSH	0.2	0.3	1.0	0.5	R
14	RSH	0.2	0.3	1.0	0.5	R
-20	RSH	0.1	0.1	0.2	1.5	R
-25	RSH	0.1	0.1	0.2	1.5	R
-21	RSH	0.1	0.1	0.2	1.5	R
75	RSH	0.1	3.0	0.5	6.0	R
82	RSH	0.1	3.0	0.5	6.0	R
90	RSH	0.1	3.0	0.5	6.0	R
46	RSH	0.2	2.5	50.0	3.0	S
50	RSH	0.2	2.5	50.0	3.0	S
42	RSH	0.2	2.5	50.0	3.0	S
51	RSH	0.2	2.5	50.0	3.0	S
43	RSH	0.2	2.5	50.0	3.0	S

SALYERSVILLE NORTH QUAD

LAT 37 46 50
LONG 83 05 32

32	SST	0.1	1.5	0.1	3.5	R
28	SST	0.1	1.5	0.1	3.5	R
33	SST	0.1	1.5	0.1	3.5	R
-14	SST	0.1	5.0	3.0	3.5	R
-04	SST	0.1	5.0	3.0	3.5	R
-84	SST	0.1	2.5	6.0	3.5	R
-81	SST	0.1	2.5	6.0	3.5	R
[illegible]	GSH	0.1	5.0	0.1	1.0	R
-06	GSH	0.1	5.0	0.1	1.0	R
-03	GSH	0.1	5.0	0.1	1.0	R
88	GSH	0.1	0.2	0.5	0.5	R
82	GSH	0.1	0.2	0.5	0.5	R
67	GSH	0.1	0.2	0.5	0.5	R
63	GSH	0.1	0.2	0.5	0.5	R
40	GSH	0.1	0.2	0.5	0.5	R
58	GSH	0.1	0.2	0.5	0.5	R

SALYERSVILLE SOUTH QUAD

LAT 37 44 59
LONG 83 04 03

-03	GSH	0.1	8.0	3.0	10.0	R

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-69	BSH	0.1	8.0	3.0	10.0	R
-19	BSH	0.1	8.0	3.0	10.0	R
4	BSH	0.1	8.0	3.0	10.0	R
15	BSH	0.1	8.0	3.0	10.0	R
11	BSH	0.1	8.0	3.0	10.0	R
6	BSH	0.1	8.0	3.0	10.0	R
22	BSH	0.1	8.0	3.0	10.0	R
61	BSH	0.1	8.0	3.0	10.0	R
66	BSH	0.1	8.0	3.0	10.0	R
-80	BSH	0.1	15.0	3.0	10.0	R
42	BSH	0.1	2.0	0.7	20.0	R
41	BSH	0.1	2.0	0.7	20.0	R
25	BSH	0.1	2.0	0.7	20.0	R
48	BSH	0.1	2.0	0.7	20.0	R
33	BSH	0.1	2.0	0.7	20.0	R
-40	BSH	0.1	15.0	1.0	20.0	R
-45	BSH	0.1	15.0	1.0	20.0	R
-47	BSH	0.1	15.0	1.0	20.0	R
-57	BSH	0.1	15.0	1.0	20.0	R

SANDY RIDGE QUAD

LAT	38	01	57			
LONG	83	10	46			
-77	COL	1.0	0.2	0.1	0.2	R
-75	COL	1.0	0.2	0.1	0.2	R
-67	COL	1.0	0.2	0.1	0.2	R
-56	COL	1.0	0.2	0.1	0.2	R
-56	COL	1.0	0.2	0.1	0.2	R
-57	COL	1.0	0.2	0.1	0.2	R
-20	COL	1.0	0.2	0.1	0.2	R
-18	COL	1.0	0.2	0.1	0.2	R
-37	COL	1.0	0.2	0.1	0.2	R
10	COL	1.0	0.2	0.1	0.2	R
58	RSH	0.2	3.0	4.0	3.0	R
65	RSH	0.2	3.0	4.0	3.0	R
64	RSH	0.2	3.0	4.0	3.0	R
-34	RSH	0.2	2.5	2.0	4.0	R
-38	RSH	0.2	2.5	2.0	4.0	R
LAT	38	06	35			
LONG	83	14	08			
45	GSH	0.2	3.0	1.0	4.0	R
55	GSH	0.2	3.0	1.0	4.0	R
50	GSH	0.2	3.0	1.0	4.0	R
56	GSH	0.2	3.0	1.0	4.0	R
60	GSH	0.2	3.0	1.0	4.0	R
44	GSH	0.2	3.0	1.0	4.0	R
62	GSH	0.2	3.0	1.0	4.0	R
14	GSH	0.2	2.0	1.0	5.0	R
08	GSH	0.2	2.0	1.0	5.0	R
14	GSH	0.2	2.0	1.0	5.0	R
23	GSH	0.2	0.5	0.5	2.0	R
25	GSH	0.2	0.5	0.5	2.0	R
38	GSH	0.2	0.5	0.5	2.0	R
28	GSH	0.2	0.5	0.5	2.0	R
-68	GSH	0.1	0.5	0.5	3.0	R
-59	GSH	0.1	0.5	0.5	3.0	R
80	GSH	0.1	0.4	0.2	1.0	R
79	GSH	0.1	0.4	0.2	1.0	R
72	GSH	0.1	0.4	0.2	1.0	R
73	GSH	0.1	0.4	0.2	1.0	R

SCRANTON QUAD

LAT	37	54	50			
LONG	83	32	35			
-13	GSH	0.1	0.4	0.1	1.0	R
6	GSH	0.1	0.4	0.1	1.0	R
-02	GSH	0.1	0.4	0.1	1.0	R
2	GSH	0.1	0.4	0.1	1.0	R
8	GSH	0.1	0.4	0.1	1.0	R
-67	GSH	0.1	0.1	0.1	1.0	R
-65	GSH	0.1	0.1	0.1	1.0	R
-58	GSH	0.1	0.1	0.1	1.0	R
-71	GSH	0.1	0.1	0.1	1.0	R
-86	GSH	0.1	0.1	0.1	1.0	R
85	GSH	0.1	0.1	0.1	1.0	R
30	GSH	0.1	0.3	0.2	4.0	R
32	GSH	0.1	0.3	0.2	4.0	R
33	GSH	0.1	0.3	0.2	4.0	R

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25	GSH	0.1	0.3	0.2	4.0	R
41	GSH	0.1	0.3	0.2	4.0	R
-39	GSH	0.1	0.3	0.2	4.0	R
-30	GSH	0.1	0.3	0.2	4.0	R
-18	SST	1.0	1.2	1.0	3.0	S
-14	SST	1.0	1.2	1.0	3.0	S
-24	SST	1.0	1.2	1.0	3.0	S
-10	SST	1.0	1.2	1.0	3.0	S
-03	SST	1.0	1.2	1.0	3.0	S
-56	SST	1.0	1.2	1.0	3.0	S
16	SST	0.5	0.5	0.2	3.0	R
15	SST	0.5	0.5	0.2	3.0	R
23	SST	0.5	0.5	0.2	3.0	R
42	SST	0.5	0.5	0.2	3.0	R

SEITZ QUAD

LAT 37 38 33
LONG 83 09 40

-39	CCL					
-35	CCL					
-43	CCL					
42	CCL					
26	CCL					
69	CCL					
77	CCL					
64	CCL					
-67	SST	0.4	1.0	1.5		R
28	SST	0.4	0.4	2.0		R
-16	SST	0.3	3.0	2.0		R
-32	SST	0.3	0.3	2.0		R

SITKA QUAD

LAT 37 54 04
LONG 82 46 18

45	GSH	0.1	0.4	1.0	12.0	R
68	GSH	0.1	0.4	1.0	12.0	R
52	GSH	0.1	0.4	1.0	12.0	R
62	GSH	0.1	0.4	1.0	12.0	R
-65	GSH	0.1	0.3	0.2	12.0	R
-89	GSH	0.1	0.3	0.2	12.0	R
-70	GSH	0.1	0.3	0.2	12.0	R
-32	GSH	0.1	0.3	0.2	12.0	R
-28	GSH	0.1	0.3	0.2	12.0	R
84	GSH	0.1	0.3	0.2	12.0	R
-85	GSH	0.1	0.3	0.2	12.0	R
-87	GSH	0.1	0.3	0.2	12.0	R
88	GSH	0.1	0.3	0.2	12.0	R
87	SST	8.0	8.0	1.0	12.0	R
76	SST	8.0	8.0	1.0	12.0	R
83	SST	8.0	8.0	1.0	12.0	R
-86	SST	8.0	8.0	1.0	12.0	R
-85	SST	8.0	8.0	1.0	12.0	R
-43	SST	8.0	8.0	1.0	12.0	R
-48	SST	8.0	8.0	1.0	12.0	R
-59	SST	8.0	8.0	1.0	12.0	R
-08	SST	8.0	8.0	1.0	12.0	R

SOLDIER QUAD

LAT 38 06 14
LONG 83 19 25

54	SST	0.1	0.3	2.0	1.0	R
40	SST	0.1	0.3	2.0	1.0	R
36	SST	0.1	0.3	2.0	1.0	R
52	SST	0.1	0.3	2.0	1.0	R
53	SST	0.1	0.3	2.0	1.0	R
50	SST	0.1	0.3	2.0	1.0	R
52	SST	0.1	0.3	2.0	1.0	R
-53	SST	0.2	0.3	1.0	1.0	R
-57	SST	0.2	0.3	1.0	1.0	R
-56	SST	0.2	0.3	1.0	1.0	R
-50	SST	0.2	0.3	1.0	1.0	R
54	SST	0.3	0.3	1.0	1.0	R
66	SST	0.3	0.3	1.0	1.0	R
57	SST	0.3	0.3	1.0	1.0	R
75	SST	0.3	0.3	1.0	1.0	R
[illegible]	SST	0.1	0.1	0.2	1.0	R
-05	SST	0.1	0.1	0.2	1.0	R

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STRICKLETT QUAD

LAT	38	25	51				
LONG	83	25	43				
-56		LST	0.1			2.5	R
-59		LST	0.1			2.5	R
-17		LST	0.1				R
-75		LST	0.2			2.0	R
-70		LST	0.2			2.0	R
-70		LST	0.2			2.0	R
-67		LST	0.2			2.0	R
33		LST	0.1			1.0	R
28		LST	0.1			1.0	R
25		LST	0.1			1.0	R
30		LST	0.1			1.0	R
35		LST	0.1			1.0	R
36		LST	0.1			1.0	R
34		LST	0.1			1.0	R
15		LST	0.2			4.0	R
10		LST	0.2			4.0	R
15		LST	0.2			4.0	R
[illegible]		LST	0.2			4.0	R
7[illegible]		LST	0.1				R
-46		BSH	0.7			2.0	R
-31		BSH	0.7			2.0	R
-35		BSH	0.7			2.0	R
-4[illegible]		BSH	0.7			2.0	R
-10		BSH	3.0				R
-58		BSH	1.0				R

TALLEGA QUAD

LAT	37	34	23				
LONG	83	36	53				
35		BSH	0.1	1.5	0.5		R
30		BSH	0.1	1.5	0.5		R
-82		BSH	0.1	1.5	1.0		R
-67		BSH	0.1	1.5	1.0		R
90		BSH	0.1	1.5	1.0		R
88		BSH	0.1	1.5	1.0		R
-28		BSH	0.1	0.7	0.5		R
07		BSH	0.1	0.4	0.3		R
08		BSH	0.1	0.4	0.3		R
18		BSH	0.1	0.4	0.3		R

THOMAS QUAD

LAT	37	40	59				
LONG	82	35	57				
79		SST	5.0	5.0	5.0	6.0	R
90		SST	5.0	5.0	5.0	6.0	R
64		SST	5.0	5.0	5.0	6.0	R
71		SST	5.0	5.0	5.0	6.0	R
-55		SST	3.0	3.0	3.0	2.5	R
-62		SST	3.0	3.0	3.0	2.5	R
-53		SST	3.0	3.0	3.0	2.5	R
-61		SST	3.0	3.0	3.0	2.5	R
-54		SST	3.0	3.0	3.0	2.5	R
-78		SST	2.0	5.0	8.0	2.5	R
[illegible]		SST	3.0	4.0	1.0	10.0	R
2		SST	3.0	4.0	1.0	10.0	R
22		SST	3.0	4.0	1.0	10.0	R
33		SST	3.0	4.0	1.0	10.0	R
-37		SST	3.0	6.0	1.0	10.0	R
-34		SST	3.0	6.0	1.0	10.0	R
-33		SST	3.0	6.0	1.0	10.0	R
-25		SST	3.0	6.0	1.0	10.0	R
-17		SST	3.0	6.0	1.0	10.0	R
32		SST	3.0	6.0	1.0	10.0	R

TILFORD QUAD

LAT	37	05	05	
LONG	83	06	28	
64		COOL		
62		COOL		
75		COOL		
4[illegible]		COOL		
-1[illegible]		COOL		
-1[illegible]		COOL		
-1[illegible]		COOL		

19	SSH	0.1	10.0	10.0			R
17	GSH	0.1	10.0	10.0			R
23	GSH	0.1	10.0	10.0			R
-03	GSH	0.1	2.0	2.0			R
45	GSH	0.1	1.0	1.0			R
-64	GSH	0.1	0.2	0.1	0.2		R
-67	GSH	0.1	0.2	0.1	0.2		R
-77	GSH	0.1	0.2	0.1	0.2		R
-77	GSH	0.1	0.2	0.1	0.2		R
46	SST	1.5	12.0	6.0			R
56	SST	1.5	12.0	6.0			R
56	SST	1.5	12.0	6.0			R
-20	SST	0.3	1.0	2.0	1.5		R
-31	SST	0.3	1.0	2.0	1.5		R
-37	SST	0.3	1.0	2.0	1.5		R
-43	SST	0.3	1.0	2.0	1.5		R
-52	SST	0.3	1.0	2.0	1.5		R
-88	SST						
-72	SST						
-85	SST						
20	SST	2.0	10.0	10.0			R
19	SST	2.0	10.0	10.0			R

TOLLESBORO QUAD

LAT 38 33 57
LONG 83 32 25

-25	LST				5.0		R
-21	LST				5.0		R
-22	LST				5.0		R
-22	LST				5.0		R
-20	LST				5.0		R
-60	LST				3.0		R
-72	LST				3.0		R
-75	LST				3.0		R
-75	LST				3.0		R
-70	LST				3.0		R
-75	LST				3.0		R
-41	LST				1.5		R
-35	LST				1.5		R
-45	LST				1.5		R
-35	LST				1.5		R
-35	LST				1.5		R
-38	LST				1.5		R
-12	LST						R
-05	LST						R
-80	LST						R
-65	LST						R
42	LST				2.0		R
40	LST				2.0		R

TYGARTS VALLEY QUAD

LAT 38 27 21
LONG 83 04 17

-55	SST	3.0	3.0	1.0	8.0		
-45	SST	3.0	3.0	1.0	8.0		
-38	SST	3.0	3.0	1.0	8.0		
30	SST	3.0	4.0	5.0	5.0		R
31	SST	3.0	4.0	5.0	5.0		R
35	SST	3.0	4.0	5.0	5.0		R
20	SST	3.0	4.0	5.0	5.0		R
36	SST	3.0	7.0	10.0	5.0		R
70	SST	3.0	10.0	25.0	3.0		R
65	SST	3.0	10.0	25.0	3.0		R
53	SST	3.0	10.0	25.0	3.0		R
50	SST	3.0	10.0	25.0	3.0		R
48	SST	3.0	10.0	25.0	3.0		R
41	SST	3.0	10.0	25.0	3.0		R
-10	SST	3.0	15.0	3.0			
-10	SST	3.0	15.0	3.0			
-62	SST	3.0	3.0	0.5			
-40	SST	3.7					
-40	SST	3.0	14.0	2.0	10.0		
-38	SST	3.0	14.0	2.0	10.0		
-37	SST	3.0	14.0	2.0	10.0		
-37	SST	3.0	14.0	2.0	10.0		
-02	SST						
-52	SST						
-75	SST						

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LAT	38	24	41					
LONG	83	04	26					
-43		LST		0.2	4.0	1.5	6.0	R
-37		LST		0.2	4.0	1.5	6.0	R
-36		LST		0.2	4.0	1.5	6.0	R
-39		LST		0.2	4.0	1.5	6.0	R
-40		LST		0.2	4.0	1.5	6.0	R
-46		LST		0.2	4.0	1.5	6.0	R
31		LST		0.3	4.0	3.0	2.0	R
28		LST		0.3	4.0	3.0	2.0	R
39		LST		0.3	4.0	3.0	2.0	R
41		LST		0.3	4.0	3.0	2.0	R
43		LST		0.3	4.0	3.0	2.0	R
26		LST		0.3	4.0	3.0	2.0	R
-10		LST		0.2	3.0	1.0	10.0	
-[illegible]		LST		0.2	3.0	1.0	10.0	
-[illegible]		LST		0.2	3.0	1.0	10.0	
04		LST		0.2	3.0	1.0	10.0	
-14		LST		0.2	3.0	1.0	10.0	
17		LST		0.4	3.0	1.0	1.0	R
17		LST		0.4	3.0	1.0	1.0	R
15		LST		0.4	3.0	1.0	1.0	R
75		LST						

VANCEBURG QUAD

LAT	38	35	52					
LONG	83	19	35					
-76		BSH		0.1				R
-72		BSH		0.1				R
-74		BSH		0.1				R
-15		BSH		0.2				R
-18		BSH		0.2				R
-17		BSH		0.2				R
-20		BSH		0.2				R
-21		BSH		0.2				R
-37		BSH		0.3			0.5	R
-30		BSH		0.3			0.5	R
40		BSH		0.1				R
52		BSH		0.1				R
50		BSH		0.1				R
000	BSH			0.1				R
10	BSH			0.1				R
21	BSH			0.1				R
22	BSH			0.1				R
33	BSH			0.1				R
35	BSH			0.1				R
-15		RSH		1.0				R
-08		RSH		1.0				R
-46		RSH		2.5				R
-33		RSH		2.5				R
57		RSH		1.7			6.0	R
52		RSH		1.7			6.0	R
LAT	38	30	53					
LONG	83	21	12					
-60		SST		2.0				R
-80		SST		1.0			3.0	R
-80		SST		1.0			3.0	R
-76		SST		1.0			3.0	R
-05		SST		1.0			6.0	R
-14		SST		1.0			6.0	R
86		SST		1.0			2.0	R
75		SST		1.0			2.0	R
86		SST		1.0			2.0	R
42		SST		1.5			1.0	R
57		SST		1.5			1.0	R
70		SST		1.0			2.0	R
68		SST		1.0			2.0	R
76		SST		1.0			2.0	R
61		SST		1.0			2.0	R
35		SST		1.0			0.2	R
22		SST		1.0			0.2	R
23		SST		1.0			0.2	R
26		SST		1.0			0.2	R

VICCO QUAD

LAT	37	12	17					
LONG	83	36	21					
32		CCC						
32		CCC						

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65	COL					
64	COL					
-18	COL					
-32	COL					
-27	COL					
-35	COL					
66	COL					
78	COL					
5[illegible]	COL					
59	COL					
-5[illegible]	COL					
-55	COL					
-55	COL					
-06	BSH	0.1	2.0	1.0	5.0	R
-12	BSH	0.1	2.0	1.0	5.0	R
-30	BSH	0.1	2.0	1.0	5.0	R
84	BSH	0.1	2.5	2.0	3.0	R
-87	BSH	0.1	2.5	2.0	3.0	R
-[illegible]	BSH	0.1	2.5	2.0	3.0	R
-86	BSH	0.1	2.5	2.0	3.0	R
47	BSH	0.1	0.6	0.5		R
45	BSH	0.1	0.6	0.5		R
4[illegible]	BSH	0.1	0.6	0.5		R
[illegible]	BSH					
12	BSH					
68	SST	4.0	4.0	1.5	10.0	R
72	SST	4.0	4.0	1.5	10.0	R
78	SST	4.0	4.0	1.5	10.0	R
-32	SST	4.0	4.0	8.0	10.0	R
-28	SST	4.0	4.0	8.0	10.0	R
-28	SST	4.0	4.0	8.0	10.0	R
00[illegible]	SST					

WALLINS CREEK QUAD

LAT 36 49 00
LONG 83 29 39

58	COL					
62	COL					
64	COL					
-32	COL					
-28	COL					
-26	COL					
5[illegible]	SST	1.0	7.0	0.2	10.0	R
68	SST	1.0	7.0	0.2	10.0	R
45	SST	1.0	7.0	0.2	10.0	R
-36	SST	0.5	3.0	5.0	7.0	R
-36	SST	0.5	3.0	5.0	7.0	R
-35	SST	0.5	3.0	5.0	7.0	R
-20	BSH	0.1	15.0	40.0	5.0	S
-18	BSH	0.1	15.0	40.0	5.0	S
-16	BSH	0.1	15.0	40.0	5.0	S
65	BSH					
37	BSH	0.1	8.0	1.0	3.0	R
34	BSH	0.1	8.0	1.0	3.0	R
-3[illegible]	BSH					
-23	BSH					
-22	BSH					
13	BSH					
23	BSH					

WAYLAND QUAD

LAT 37 36 37
LONG 82 50 07

-72	COL	2.5	1.0	0.5	0.2	R
-77	COL	2.5	1.0	0.5	0.2	R
-67	COL	2.5	1.0	0.5	0.2	R
2[illegible]	COL	2.5	0.3	0.2	0.5	R
15	COL	2.5	0.3	0.2	0.5	R
26	COL	2.5	0.3	0.2	0.5	R
27	COL	2.5	0.3	0.2	0.5	R
7[illegible]	SST	15.0	15.0	12.0	25.0	S
[illegible]	SST	15.0	15.0	12.0	25.0	S
[illegible]	SST	15.0	15.0	12.0	25.0	S
[illegible]	SST	15.0	15.0	12.0	25.0	S
[illegible]	SST	15.0	15.0	12.0	25.0	S
-15	SST	15.0	15.0	15.0	15.0	R
-17	SST	15.0	15.0	15.0	15.0	R
-2[illegible]	SST	15.0	15.0	15.0	15.0	R

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005		SST	1				
42		SST	15.0	15.0	2.0	40.0	R
41		SST	15.0	15.0	2.0	40.0	R
34		SST	15.0	15.0	2.0	40.0	R
42		SST	15.0	15.0	2.0	40.0	R
42		SST	15.0	15.0	2.0	40.0	R
-65		SST	1				

WEEBVILLE QUAD

LAT	38	09	34				
LONG	82	47	19				
26		SST	5.0	4.0	6.0	12.0	S
27		SST	5.0	4.0	6.0	12.0	S
14		SST	5.0	4.0	6.0	12.0	S
-53		SST	5.0	5.0	2.0	15.0	S
-43		SST	5.0	5.0	2.0	15.0	S
-45		SST	5.0	5.0	2.0	15.0	S
-47		SST	5.0	5.0	2.0	15.0	S
-51		SST	5.0	5.0	2.0	15.0	S
-42		SST	5.0	5.0	2.0	15.0	S
-73		SST	2.0	3.0	1.0	10.0	S
-52		SST	2.0	3.0	1.0	10.0	S
-73		SST	2.0	3.0	1.0	10.0	S
-[illegible]		SST					
41		SST	3.0	3.0	5.0	6.0	S
52		SST	3.0	3.0	5.0	6.0	S
-56		GSH	0.1	5.0	3.0	3.0	R
-43		GSH	0.1	5.0	3.0	3.0	R
-35		GSH	0.1	5.0	3.0	3.0	R
67		GSH	0.1	3.0	4.0	10.0	R
57		GSH	0.1	3.0	4.0	10.0	R
54		GSH	0.1	3.0	4.0	10.0	R
60		GSH	0.1	3.0	4.0	10.0	R
-11		GSH	0.1	6.0	0.5	12.0	R
-19		GSH	0.1	6.0	0.5	12.0	R
-11		GSH	0.1	6.0	0.5	12.0	R
-28		GSH	0.1	6.0	0.5	12.0	R
-75		GSH					

WESLEYVILLE QUAD

LAT	38	27	21				
LONG	83	11	55				
-68		SST	0.3			0.5	R
-76		SST	0.3			0.5	R
-73		SST	0.3			0.5	R
-68		SST	0.3			0.5	R
-65		SST	0.3			0.5	R
-63		SST	0.3			0.5	R
-70		SST	0.3			0.5	R
-3[illegible]		SST	0.1				R
-48		SST	0.3				R
-54		SST	0.3				R
24		SST	0.2			2.0	R
28		SST	0.2			2.0	R
27		SST	0.2			2.0	R
28		SST	0.2			2.0	R
28		SST	0.2			2.0	R
34		SST	0.2			2.0	R
24		SST	0.2			2.0	R
21		SST	0.2			2.0	R
44		SST	0.5				R
76		SST	0.2				R
15		SST	0.4			1.5	R
17		SST	0.4			1.5	R
18		SST	0.4			1.5	R
21		SST	0.4			1.5	R
18		SST	0.4			1.5	R
LAT	38	24	04				
LONG	83	09	25				
-43		LST	2.0	4.0	15.0	3.0	R
-45		LST	2.0	4.0	15.0	3.0	R
17		LST	2.0	4.0	2.0	25.0	R
18		LST	2.0	4.0	2.0	25.0	R
13		LST	2.0	4.0	2.0	25.0	R
[illegible]		LST	2.0	4.0	2.0	25.0	R
[illegible]		LST	2.0	4.0	2.0	25.0	R
12		LST	2.0	4.0	2.0	25.0	R
19		LST	2.0	4.0	2.0	25.0	R
17		LST	2.0	4.0	2.0	25.0	R

12	LST	2.0	4.0	2.0	25.0	R
35	LST	2.0	10.0	3.0		R
44	LST	2.0	10.0	3.0		R
52	LST	1.0	4.0	1.0	7.0	R
62	LST	1.0	4.0	1.0	7.0	R
57	LST	1.0	4.0	1.0	7.0	R
63	LST	1.0	4.0	1.0	7.0	R
56	LST	1.0	4.0	1.0	7.0	R
-67	LST	1.0	6.0	5.0	12.0	R
-56	LST	1.0	6.0	5.0	12.0	R

WEST LIBERTY QUAD

LAT 37 56 32
LONG 83 16 56

64	GSH	0.1	0.3	0.1	2.0	R
47	GSH	0.1	0.3	0.1	2.0	R
58	GSH	0.1	0.3	0.1	2.0	R
67	GSH	0.1	0.3	0.1	2.0	R
22	GSH	0.1	0.3	0.1	2.0	R
4	GSH	0.1	0.3	0.1	2.0	R
11	GSH	0.1	0.3	0.1	2.0	R
3	GSH	0.3	0.3	0.2	0.5	R
2	GSH	0.3	0.3	0.2	0.5	R
11	GSH	0.3	0.3	0.2	0.5	R
7	GSH	0.3	0.3	0.2	0.5	R
-73	GSH	0.1	1.0	1.5	0.5	R
-77	GSH	0.1	1.0	1.5	0.5	R
-82	GSH	0.1	1.0	1.5	0.5	R
-63	GSH	0.1	1.0	1.5	0.5	R
-48	GSH	0.1	1.0	1.5	0.5	R
83	GSH	0.1	1.0	1.5	0.5	R
87	GSH	0.1	1.0	1.5	0.5	R
86	GSH	0.1	1.0	1.5	0.5	R
-21	GSH	0.2	2.0	1.0	20.0	R
-22	GSH	0.2	2.0	1.0	20.0	R
-28	GSH	0.2	2.0	1.0	20.0	R

LAT 37 54 47
LONG 83 15 55

-73	COL	1.0	0.2	0.2	0.3	R
-61	COL	1.0	0.2	0.2	0.3	R
-62	COL	1.0	0.2	0.2	0.3	R
-64	COL	1.0	0.2	0.2	0.3	R
21	COL	1.0	0.2	0.3	0.3	R
18	COL	1.0	0.2	0.3	0.3	R
25	COL	1.0	0.2	0.3	0.3	R
24	COL	1.0	0.2	0.3	0.3	R
-62	BSH	0.1	0.2	0.2	1.0	R
-63	BSH	0.1	0.2	0.2	1.0	R
-65	BSH	0.1	0.2	0.2	1.0	R
-61	BSH	0.1	0.2	0.2	1.0	R
-57	BSH	0.1	0.2	0.2	1.0	R
72	BSH	0.1	0.2	0.2	1.0	R
77	BSH	0.1	0.2	0.2	1.0	R
4	BSH	0.1	0.2	0.2	1.0	R
-10	BSH	0.1	0.3	0.2	1.0	R
-24	BSH	0.1	0.3	0.2	1.0	R
-20	BSH	0.1	0.3	0.2	1.0	R
35	SST	1.2	3.0	12.0	20.0	S
42	SST	1.2	3.0	12.0	20.0	S
-37	SST	1.2	1.2	2.0	20.0	S

WHEELWRIGHT QUAD

LAT 37 21 03
LONG 82 41 40

-74	GSH	0.1	2.0	0.1	3.0	R
-68	GSH	0.1	2.0	0.1	3.0	R
-65	GSH	0.1	2.0	0.1	3.0	R
-73	GSH	0.1	2.0	0.1	3.0	R
54	GSH	0.1	0.3	0.2	3.0	R
45	GSH	0.1	0.3	0.2	3.0	R
45	GSH	0.1	0.3	0.2	3.0	R
54	GSH	0.1	0.3	0.2	3.0	R
22	GSH	0.1	0.5	2.0	3.0	R
12	GSH	0.1	0.5	2.0	3.0	R
7	GSH	0.1	0.3	2.0	3.0	R
-46	GSH	0.1	0.3	1.0	3.0	R
-54	GSH	0.1	0.3	1.0	3.0	R
-55	GSH	0.1	0.3	1.0	3.0	R
-54	GSH	0.1	0.3	1.0	3.0	R

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-15		GSH	0.1	0.2	0.3	3.0	R
-23		GSH	0.1	0.2	0.3	3.0	R
-12		GSH	0.1	0.2	0.3	3.0	R
-22		GSH	0.1	0.2	0.3	3.0	R
45		GSH	4.0	6.0	12.0	3.0	R
-8[illegible]		SST	1.0	1.0	1.0	3.0	R
[illegible]4		SST	1.0	1.0	1.0	3.0	R
-2[illegible]		SST	1.0	1.0	1.0	3.0	R

WHITE OAK QUAD

LAT	37	49	58				
LONG	83	10	37				
-32		GSH	0.5	1.5	2.5	5.0	R
-57		GSH	0.5	1.5	2.5	5.0	R
54		GSH	0.5	1.5	3.0	5.0	R
51		GSH	0.5	1.5	3.0	5.0	R
35		GSH	0.5	1.5	3.0	5.0	R
42		GSH	0.5	1.5	3.0	5.0	R
50		GSH	0.5	1.5	3.0	5.0	R
1[illegible]		GSH	0.5	1.5	3.0	5.0	R
[illegible]		GSH	0.5	1.5	3.0	5.0	R
-11		GSH	0.5	1.5	3.0	5.0	R
-34		SST	3.0	7.0	7.0	8.0	R
-32		SST	3.0	7.0	7.0	8.0	R
57		SST	3.0	7.0	7.0	8.0	R
[illegible]		SST	3.0	7.0	7.0	8.0	R
[illegible]		SST	3.0	7.0	7.0	8.0	R
45		SST	3.0	7.0	7.0	8.0	R
-8[illegible]		COL	0.4	0.3	0.2	0.1	R
-62		COL	0.4	0.3	0.2	0.1	R
-63		COL	0.4	0.3	0.2	0.1	R
-59		COL	0.4	0.3	0.2	0.1	R
29		COL	0.4	0.3	0.1	0.1	R
30		COL	0.4	0.3	0.1	0.1	R
32		COL	0.4	0.3	0.1	0.1	R

WILLARD QUAD

LAT	38	12	13				
LONG	82	53	33				
57		SST	2.0	4.0	2.0	2.5	R
56		SST	2.0	4.0	2.0	2.5	R
53		SST	2.0	4.0	2.0	2.5	R
48		SST	2.0	4.0	2.0	2.5	R
63		SST	2.0	4.0	2.0	2.5	R
45		SST	2.0	4.0	2.0	2.5	R
54		SST	2.0	4.0	2.0	2.5	R
-38		COL	1.0	1.0	0.1	0.2	R
-42		COL	1.0	1.0	0.1	0.2	R
-40		SST	2.0	3.0	2.0	3.5	R
-38		SST	2.0	3.0	2.0	3.5	R
-42		SST	2.0	3.0	2.0	3.5	R
-36		SST	2.0	3.0	2.0	3.5	R
-85		SST	1.0	2.0	0.5	1.5	R
72		SST	1.0	2.0	0.5	1.5	R
90		SST	1.0	2.0	0.5	1.5	R
73		SST	1.0	2.0	0.5	1.5	R
90		SST	1.0	2.0	0.5	1.5	R
35		SST	2.0	3.0	2.0	4.0	R
2[illegible]		SST	2.0	3.0	2.0	4.0	R
25		SST	2.0	3.0	2.0	4.0	R
36		SST	2.0	3.0	2.0	4.0	R
-58		SST	3.0	3.0	1.0	2.0	R
-53		SST	3.0	3.0	1.0	2.0	R
-56		SST	3.0	3.0	1.0	2.0	R
-62		SST	3.0	3.0	1.0	2.0	R
LAT	38	09	28				
LONG	82	55	47				
3[illegible]		SST	5.0				
34		SST	5.0	7.0	3.0	40.0	R
5[illegible]		SST	5.0	7.0	3.0	40.0	R
47		SST	5.0	7.0	3.0	40.0	R
[illegible]		SST	5.0	7.0	3.0	40.0	R
[illegible]		SST	5.0	7.0	3.0	40.0	R
-42		SST	5.0	10.0	4.0	30.0	R
[illegible]		SST	5.0	10.0	4.0	30.0	R
[illegible]		SST	5.0	10.0	4.0	30.0	R
[illegible]		SST	5.0	10.0	4.0	30.0	R
[illegible]		SST	5.0	10.0	4.0	30.0	R

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-34	SST	5.0	6.0	1.0	4.0	R
-11	SST	5.0	6.0	1.0	4.0	R
-67	SST	5.0	15.0	4.0	15.0	R
-56	SST	5.0	15.0	4.0	15.0	R
-67	SST	5.0	15.0	4.0	15.0	R
82	SST	5.0	2.0	1.0	2.0	R
-85	SST	5.0	2.0	1.0	2.0	R

WILLIAMSON QUAD

LAT 37 43 28
LONG 82 21 02

-35	GSH	0.1	15.0	15.0	6.0	R
-40	GSH	0.1	15.0	15.0	6.0	R
-77	GSH	0.1	15.0	15.0	6.0	R
-68	GSH	0.1	15.0	15.0	6.0	R
30	GSH	0.1	5.0	2.0	6.0	R
35	GSH	0.1	5.0	2.0	6.0	R
32	GSH	0.1	5.0	2.0	6.0	R
36	GSH	0.1	5.0	2.0	6.0	R
35	GSH	0.1	5.0	2.0	6.0	R
62	GSH	0.1	4.0	2.0	6.0	R
-14	GSH	0.1	20.0	1.0	6.0	R
-24	GSH	0.1	20.0	1.0	6.0	R

WRIGLEY QUAD

LAT 38 02 02
LONG 83 18 00

-72	GSH	0.1	1.0	1.0	1.0	R
-76	GSH	0.1	1.0	1.0	1.0	R
-85	GSH	0.1	1.0	1.0	1.0	R
-77	GSH	0.1	1.0	1.0	1.0	R
-79	GSH	0.1	1.0	1.0	1.0	R
[illegible]	GSH					
-25	GSH					
-03	GSH					
85	GSH	0.1	2.0	1.0	5.0	R
72	GSH	0.1	2.0	1.0	5.0	R
75	GSH	0.1	2.0	1.0	5.0	R
[illegible]	GSH	0.2	0.2	0.1	0.2	R
[illegible]	GSH	0.2	0.2	0.1	0.2	R
-32	SST	0.2	0.2	1.0	1.0	R
-32	SST	0.2	0.2	1.0	1.0	R
-31	SST	0.2	0.2	1.0	1.0	R
-21	SST	0.2	0.2	1.0	1.0	R
-25	SST	0.2	0.2	1.0	1.0	R
-22	SST	0.2	0.2	1.0	1.0	R
-42	SST	0.2	0.2	1.0	1.0	R
62	SST	0.2	0.2	1.0	1.5	R
65	SST	0.2	0.2	1.0	1.5	R
54	SST	0.2	0.2	1.0	1.5	R
36	SST	0.2	0.2	1.0		R
35	SST	0.2	0.2	1.0		R
-77	SST	0.2	0.2	1.0	3.0	R
-60	SST	0.2	0.2	1.0	3.0	R
-73	SST	0.2	0.2	1.0	3.0	R
-62	SST	0.2	0.2	1.0	3.0	R
-67	SST	0.2	0.2	1.0	3.0	R

ZACHARIAH QUAD

LAT 37 41 22
LONG 83 41 08

71	GSH	0.1	0.3	0.1		R
44	GSH	0.1	0.1	0.1		R
48	GSH	0.1	0.1	0.1		R
54	GSH	0.1	0.1	0.1		R
25	GSH	0.1	0.2	0.1		R
-36	GSH	0.1	0.1	0.1		R
-79	GSH	0.1	0.1	0.1		R
-82	SST	1.0	1.0	1.5	2.0	R
-77	SST	1.0	1.0	1.5	2.0	R
-67	SST	1.0	1.0	1.5	2.0	R
-74	SST	1.0	1.0	1.5	2.0	R
[illegible]	SST	1.0	1.0	1.5	[illegible]	R
[illegible]	SST	1.0	1.0	2.0		R
72	SST	1.0	1.0	0.5		R
63	SST	1.0	1.0	0.5		R

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[illegible] QUAD

LAT	37	20	07					
LONG	83	02	37					
[illegible]		GSSH		0.1	0.5	1.0	1.5	[illegible]
[illegible]		GSSH		0.1	0.5	1.0	1.5	R
[illegible]		GSSH		0.1	0.5	1.0	1.5	R
[illegible]		GSSH		0.1	0.5	1.0	1.5	R
[illegible]		GSSH		0.1	0.5	1.0	1.5	R
-44		GSSH		0.1	1.0	0.3	1.5	R
-42		GSSH		0.1	1.0	0.3	1.5	R
-36		GSSH		0.1	1.0	0.3	1.5	R
-43		GSSH		0.1	1.0	0.3	1.5	R
-65		GSSH		0.1	1.0	0.3	1.5	R
-05		GSSH		0.1	0.3	0.2	2.0	R
-1[illegible]		GSSH		0.1	0.3	0.2	2.0	R
[illegible]		SSST		2.0	2.0	4.0	2.0	S
72		SSST		2.0	2.0	4.0	2.0	S
35		SSST		2.0	2.0	4.0	2.0	S
4[illegible]		SSST		2.0	2.0	4.0	2.0	S
14		SSST		2.0	2.0	4.0	3.0	[illegible]
-[illegible]		SSST		1.5	1.0	0.3	4.0	[illegible]
-1[illegible]		SSST		1.5	1.5	0.3	4.0	[illegible]
-1[illegible]		SSST		1.5	1.5	0.3	4.0	R
-[illegible]		SSST		1.5	1.5	0.3	4.0	R
-2[illegible]		SSST		1.0	1.0	2.0	7.0	R
-1[illegible]		SSST		1.0	1.0	2.0	7.0	R
-2[illegible]		SSST		1.0	1.0	2.0	7.0	R
-3[illegible]		SSST		1.0	1.0	2.0	7.0	R
-4[illegible]		SSST		1.0	1.0	2.0	7.0	R

CHARTERS QUAD

LAT	38	34	00					
LONG	83	27	00					
-52		LSST		1.0			2.0	R
-53		LSST		1.0			2.0	R
-65		LSST		1.0			2.0	R
-55		LSST		1.0			2.0	R
-56		LSST		1.0			2.0	R
-56		LSST		1.0			2.0	R
-57		LSST		1.0			2.0	R
-[illegible]		LSST		1.0			2.0	R
-57		LSST		1.0			2.0	R
-52		LSST		1.0			2.0	R
-43		LSST		1.0			2.0	R
92		LSST		0.5			7.0	R
84		LSST		0.5			7.0	R
58		LSST		1.0			6.0	R
42		LSST		1.0			6.0	R
57		LSST		1.0			6.0	R
43		LSST		1.0			6.0	R
49		LSST		1.0			6.0	R
56		LSST		1.0			6.0	R
42		LSST		1.0			6.0	R
51		LSST		1.0			6.0	R
46		LSST		1.0			6.0	R
3[illegible]		LSST		2.0			4.0	R
23		LSST		2.0			4.0	R
24		LSST		2.0			4.0	R
LAT	38	34	40					
LONG	83	26	00					
-42		RSSH		0.1			0.1	R
-42		RSSH		0.1			0.1	R
-47		RSSH		0.1			0.1	R
-4[illegible]		RSSH		0.1			0.1	R
-42		RSSH		0.1			0.1	R
-81		RSSH		0.1			0.1	R
-75		RSSH		0.1			0.1	R
-6[illegible]		RSSH		0.1			0.1	R
-68		RSSH		0.1			0.1	R
-70		RSSH		0.1			0.1	R
-[illegible]		RSSH		0.1				R
-[illegible]		RSSH		0.1				R
-[illegible]		RSSH		0.1				R
-[illegible]		RSSH		0.1				R
[illegible]		RSSH		0.2				R
[illegible]		RSSH		0.2				R
[illegible]		RSSH		0.2				R
[illegible]		RSSH		0.2				R

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APPENDIX C

Groundwater Data Tables

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TABLE 1

PHYSICAL WELL DATA

Well No.	Topographic Setting	Well Use	Well Depth(ft)	Well Diameter(in)	Elevation of Well Top(ft)	Depth to Static Water Level(ft)	Depth of Well Casing	Well Yield(g
Co-1	S	D	110	5	600	30	80	2.5
Co-2	H	D	155	6	720	100	80	4.0
Co-3	S	D	160	6	580	40	50	0.3
Co-4	H	D	170	6	700	42	160	1.7
Co-5	V	D	38	6	560	8	38	10.0
Co-6	H	D	120	6	700	30	65	0.7
Co-7	S	D	112	6	620	32	70	1.0
Co-8	V	D	185	6	620	75	185	12
Co-9	V	D	137	6	640	27		71.7
CO-10	H	D	150	4	700	27	150	1.7
Ra-1	H	A-D	112	5	620	30	50	1.0
Ra-2	H	A-D	90	6	640			1.0
Ra-3	H	D	160	6	610	60	160	1.5
Ra-4	S	D	84	6	600	30	84	80
Ra-5	V	D	97	6	620	35	97	80
Ra-6	H	D	225	6	680	80-125	225	3.3
Ra-7	S	D,S	100	9	640	20	100	100
Ra-8	S	D	72	6	580	32	70	15
Ra-9	V	D	75	4	630	74	60	10
Ra-10	V	D	50	6	740	25	23	3.0
Ra-11	S	D	90	6	640	10	90	1.0
Ra-12	V	D	326	8	810	231	280	8.3
Ra-13	H	D	155	4	760	45	155	3.0
Ra-14	S	D	150	6	610	50	150	0.5
Ra-15	H	D	335	6	800		335	3.0
Ra-16	H	D	365	6	810		365	10
Rp-1	S	D	165	6	660	15-20	165	1.7
Rp-2	V	D	90	6	620		90	2.5
Rp-3	V	D	255	6	640	40	255	1.7
Rp-4	S	D	175	6	660		175	3.0
Rp-5	H	D	210	6	700	100	210	2.0
Rp-6	H	D	435	4	860	335	375	6.7
Rp-7	H	D	323	4	770	100	230	1.7
Rp-8	V	D	80		740			
Rp-9	H	D	372	4	780	150	285	1.7
Rp-10	H	D	160	6	800	20	160	11
Rp-11	S	D	330	4	820	150	330	5.8
Rp-12	S	D	330	4	800	150	330	5.8
Rp-13	H	D	454	6	920	300	454	2.5

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PHYSICAL WELL DATA

Well No.	Topographic Setting	Well Use	Well Depth(ft)	Well Diameter(in)	Elevation of Well Top(ft)	Depth to Static Water Level(ft)	Depth of Well Casing	Well Yield(
Rp-14	H	D	480	6	890	355	400	3.0
Rp-15	H	D	119	6	820		56	3.0
Rp-16	H	D	482	6	900	357	400	3.0
Rp-17	S	D	200		680			
Rp-18	H	D	300	6	700	175-200	264	2.0
Rp-19	V	D	245	6	670	140	245	3.0
Sa-1	V	D	236	6	610	70	236	1.0-2.0
Sa-2	V	D	482	6	640	33	482	3.0
Sa-5	V	D	110	6	590	60	110	5.0
Sa-4	V	D	215	6	620	200	215	3.0
Sa-6	S	A-D	227	6	680	5	227	105
Sa-7	V	D			620			
Sa-8	V	D	138	6	620	87	138	16
Sa-9	S	D(PS)			620			
Sa-10	H	D	253	6	600	80	253	
Sa-11	V	D	210	6	640	90	210	3.3
Sa-12	H	D	255	6	750	60	255	3.0
K-1	V	D	185	4	760	80	185	2.5
K-2	H	D	175	6	730	75	175	1.0
K-3	S	D	80		730	70		
K-4	V	D	100	5	750	50	100	0.5
K-5	V	D	165	6	800	20	20	16
K-6	V	D	70	6	860	12	20	1.0
K-7	V	D	36	6	760	30	8	3
K-8	V	D	35	6	720	10	15	5-10
K-9	V	D	80	6	660	20-25		3
K-10	V	D	117	6	680	15	60	1.7
K-11	H	D	175	6	700		40	3.0
K-12	V	D	80	6	720	25	12	8.3
K-13	V	D	177	4	700	80	125	71.7

S = Hillslope Well; H = Hilltop well; V = Valley Well
D = Domestic well; A = Abandoned Well; S = Stock Well; PS = Public Supply Well

Well locations are in general indicated by:
Co = Cottageville 7 1/2 minute quadrangle
Ra = Ravenswood 7 1/2 minute quadrangle
Rp = Ripley 7 1/2 minute quadrangle
Sa = Sandyville 7 1/2 minute quadrangle
K = Kenna 7 1/2 minute quadrangle

UGR File #C048/77A
Oct. 1977
W.V.U.Dept. of
Geology &
Geography

TABLE 2

CHEMICAL WATER WELL DATA

ell No.	Temp (C°)	Specific Conductance	Nitrate (mg/l)	Total Iron (mg/l)	Sulfate (mg/l)	Chloride (mg/l)	Hardness (as mg/l $CaCO_3$)	Ca Hardness (as mg/l $CaCO_3$)	Sodium (mg/l)	HCO_3 (mg/l)	pH
Co-1	14°	705	0.0	0.01	46.6	23.6	230	207	180	413	7.9
Co-2	15°	803	1.3	0.00	42.0	47.8	103	63.6	400	577	7.8
Co-3	14°	949	0.2	0.00	36.8	28.8	6.8	3.2	700	517	8.5
Co-4	15°	851	0.0	0.00	42.6	7.6	4.8	4.0	400	530	8.5
Co-5	16°	1338	15.8	0.06	42.0	18.0	501	365	270	511	7.6
Co-6	18°	827	0.0	0.00	43.1	20.2	29.6	22.4	500	514	8.4
Co-7	17°	555	0.0	0.00	0.1	1.8	19.6	12.4	320	407	8.0
Co-8	15°	1022	0.0	0.00	56.8	38.0	6.0	4.8	460	569	8.3
Co-9	16°	560	0.0	0.00	18.0	10.0	38.0	30.4	290	334	7.9
Ra-2	15°	1070	16.3	0.11	78.6	67.2	573	429	730	569	8.0
Ra-3	15°	1630	0.7	2.40	73.6	10.4	783	568	240	552	7.6
Ra-4	18°	730	0.0	0.03	60.3	43.2	126	120	245	339	7.7
Ra-6	16°	973	0.0	0.00	30.0	3.6	5.6	5.2		569	8.4
Ra-7	17°	701	12.7	0.00	34.0	16.8	258	218	60.7	424	7.7
Ra-8	15°	555	8.3	0.00	69.4	6.8	174	164	37.0	309	7.6
Ra-9	16°	691	0.0	0.00	7.1	10.6	42.8	32.0		470	7.9
Ra-10	17°	525	0.4	0.01	35.1	9.2	152	97.6	67.0	335	7.6
Ra-11	20°	448	0.2	0.01	0.8	4.6	142	101	85.0	298	8.1
Ra-12	18°	1946	0.0	0.00	27.1	322	13.6	11.2	900	16	8.1
Ra-13	17°	691	0.0	0.02	30.5	36.0	25.2	24.8	370	335	7.8
Ra-14	17°	530	0.2	0.01	15.7	40.0	88.4	74.0	210	341	7.6
Ra-15	15.5°	1168	0.0	0.00	48.8	39.0	6.0	5.6	600	650	8.3
Ra-16	19°	1387	0.2	0.00	43.1	107	9.6	8.0	800	650	8.2
Rp-1	16.5°	1362	0.7	0.01	99.1	4.8	419	213	650	836	7.7
Rp-2	16°	681	0.0	0.01	20.3	48.4	9.6	8.8	650	347	8.2
Rp-3	15.5°	1362	0.0	0.00	47.7	84.8	9.6	6.4	460	697	8.3
Rp-4	18°	856	0.2	0.00	38.6	35.2	6.0	4.0	500	500	8.7
Rp-5	15°	866	0.0	0.00	12.3	16.4	124	65.6	500	500	7.8
Rp-6	16°	1070	0.0	0.00	50.0	63.0	4.8	4.4	700	484	8.3
Rp-7	17°	973	0.0	0.00	43.1	47.0	6.4	5.2	700	524	8.3
Rp-8	16°	778	0.0	0.01	20.3	27.0	8.4	5.2		438	8.1
Rp-10	15°	730	17.0	0.01	27.1	14.0	303	200	7.8	453	7.8
Rp-11	16°	973	0.0	0.00	54.6	50.0	4.4	4.0	495	495	8.4
Rp-12	17°	1241	2.0	0.03	24.8	90.0	8.4	7.2	600	605	8.3
Rp-13	19°	798	0.0	0.02	16.8	4.0	8.4	3.2	340	476	8.6
Rp-14	16°	788	0.0	0.02	22.5	2.0	4.0	3.6	400	484	8.5
Rp-15	19°	681	5.5	0.01		2.0	28.4	6.0	800	405	2.8
Rp-16	16°	788									
Rp-9	15°	1022	0.2	0.00	46.6	23.0	5.2	2.4		534	8.

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Oct. 1977
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CHEMICAL WATER WELL DATA

Well No.	Temp (C°)	Specific Conductance	Nitrate (mg/l)	Total Iron (mg/l)	Sulfate (mg/l)	Chloride (mg/l)	Hardness (as mg/l $CaCO_3$)	Ca Hardness (as mg/l $CaCO_3$)	Sodium (mg/l)	HCO_3 (mg/l)	pH
Rp-17	18°	1129	0.4	0.02	32.8	8.0	18.0	12.4	500	452	7
Rp-18	20°	973	0.0	0.00	27.1	5.0	5.2	2.8	460	528	8
Rp-19	17°	1070	0.0	0.00	38.6	5.0	4.8	4.8	480	551	8
Sa-1	16°	3162	0.0	0.00	16.8	78.0	22.4	20.8	1200	589	8
Sa-2	15°	1703	0.0	0.04	7.0	16.0	40.0	25.6	850	863	7
Sa-3	15°	1460									
Sa-4	16°	817	0.0	0.01	44.3	119.0	12.8	6.4	600	585	8
Sa-5	16°	691	0.0	0.00	19.1	20.0	8.0	5.6		533	8
Sa-6	25°	876	9.1	0.00	38.6	55.0	156	105.0	450	840	7
Sa-7	15.5°	428	0.0	0.00	16.8	9.0	35.6	30.4	220	257	7
Sa-8	16°	1605	0.0	0.00	42.0	178.0	10.4	9.6	800	634	7
Sa-9	16°	2433	0.0	0.02	0.8	32.0	22.8	10.0	970	856	8
Sa-10	17°	1265	0.4	0.00	42.0	78.0	.0	7.2	650	708	7
Sa-11	17°	1265	0.0	0.00	54.6	130.0	6.40	5.6	650	511	8
Sa-12	15°	827	2.0	0.00	34.0	60.0	48.0	37.2	270	413	7
K-1	21°	730	0.2	0.01	13.4	8.0	4.4	2.5	650	455	8
K-2	17°	788	0.2	0.02	19.1	15.0	8.0	4.0	400	501	8
K-3	25°	681	0.0	0.04		20.0	157	116.0	225	420	7
K-4	16°	487	0.0	0.14	4.3	15.0	10.4	7.6	290	262	7
K-5	20°	788	0.0	0.02	16.8	44.0	156	88.4	280	432	7
K-6	20°	1090	0.0	0.12	12.3	109.0	297	28.4	140	517	7
K-7	17°	681	0.0	0.15	10.0	76.0	222	174.0	140	281	7
K-8	15°	379	1.7	0.12	13.4	13.0	67.2	59.2	171	181	7
K-9	16°	379	2.0	2.03		10.0	116	95.6	55.0	185	7
K-10	18°	360	2.0	2.42	7.0	3.0	156	118.0	19.5	229	7
K-11	19°	350	0.0	0.02	13.4	3.0	45.6	36.4	170	235	7
K-12	16°	584	0.0	0.01	12.3	14.0	198	114.0	94	368	7
K-13	16°	730	0.0	0.01		10.0	3.2	2.0	800	422	8

See explanation at bottom of Table 1 for the letter abbreviation definitions.

APPENDIX D

Production Data Tables

Oct. 1977
W.V.U.Dept. of
Geology &
Geography

COTTAGEVILLE GAS FIELD
MASON COUNTY

Permit #	Commenced Drilling	Natural Open Flow (Mcf)	After Stimulation (Mcf)	Initial Rock Pressure (lbs/psi)
1	11-09-29	4.6	213	860
3	06-20-30	0	350	885
38	12-08-47	0	103	800
39	12-15-47	84	84	860
40	12-27-47	0	39.5	860
41	12-18-47	0	0	NT
42	07-06-48	0	29.8	NT
44	07-23-48	39.4	21	300
45	10-13-48	0	0	NT
46	10-18-48	0	0	NT
47	10-28-48	34.9	60	810
51	05-08-49	?	660	625
52	09-16-50	0	18	NT
53	10-02-50	0	25	NT
125	08-19-74	0	189	NT
134	07-15-75	0	158	360
138	05-24-76	10	72	295
TOTAL:		172.9(16)	2028.3(17)	6655(10)
AVERAGE:		10.170	119.3	665.5

NT = Not Taken

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UGR File #C048/7/A
Oct. 1977
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COTTAGEVILLE GAS FIELD
JACKSON COUNTY

Permit #	Commenced Drilling	Natural Open Flow (Mcf)	After Stimulation (Mcf)	Initial Rock Pressure (lbs/psi)
10	01-31-31		830	875
586	04-05-48	445		700
597	04-24-48	0	14.9	NT
613	06-29-48	51.6	133	800
621	08-03-48	0	133	860
654	01-25-49	88	1309	790
657	01-17-49	79	736	800
676	08-03-49	539	NS	750
682	09-22-49	852	NS	817
687	11-10-49	?	582	800
691	12-12-49	?	231	800
693	12-08-49	133	381	790
694	01-50-50	36	1852	775
696	04-12-50	?	582	760
697	12-19-49	?	560	805
698	01-30-50	5	822	765
699	04-08-50	?	152	NT
700	02-28-50	?	200	780
701	04-21-50	?	700	735
702	02-28-50	?	460	780
703	03-03-50	.8	582	650
704	02-15-50	?	348	775
705	06-20-50	900	NS	715
706	02-16-50	36	1981	770
707	04-07-50	?	50	750
709	02-15-50	215	381	690
715	04-19-50	17	267	680
716	05-11-50	40	283	588
717	05-12-50	?	1100	740
721	03-23-51	9	412	675
722	04-26-50	15	528	740
723	05-29-50	0	0	NT
724	05-17-50	25	582	740
727	07- -50	?	140	1000
728	09-20-50	629	959	460
729	06-19-50	746	NS	680
731	06-29-50	14	762	865
732	07-13-50	?	539	680
733	06-14-50	5	198	685
	SUB-TOTAL:	4915.7(26)	19362.9(35)	27740(37)

NS = Not Stimulated
NT = Not Taken

JACKSON COUNTY continued

Oct. 1977
W.V.U.Dept. of
Geology & Geography

Permit #	Commenced Drilling	Natural Open Flow (Mcf)	After Stimulation (Mcf)	Initial Rock Pressure (Psig)
742	07-12-50	.9	337	690
743	07-06-50	163	823	660
745	12-15-50	0	283	350
746	09-11-50	823	NS	520
747	08-25-50	23	728	755
750	08-10-50	49	365	565
752	08-16-50	?	133	NT
755	12-09-50	?	0	NT
757	08-1850	61	660	625
758	08-07-50	18	762	685
759	09-06-50	0	63	NT
760	09-15-50	15	15	NT
761	09-21-50	21	152	NT
762	08-16-50	28	539	645
763	09-20-50	3110	640	NT
764	06-16-50	33	413	500
765	09-02-50	4	246	610
766	09-29-50	4.6	0	NT
767	10-18-50	0	4	NT
768	09-19-50	4	38	NT
772	10-04-50	2	269	465
774	09-29-50	12	321	375
775	09-28-50	1.8	203	375
776	10-28-50	0	184	380
777	10-26-50	38	440	667
778	01-06-51	3480	405	NT
779	10-31-50	30	377	505
780	12-26-50	0	179	385
783	12-26-50	140	376	430
784	03-31-51	4	33	NT
785	12-15-50	0	71	430
787	11-25-50	728	NS	435
789	11-04-50	15	311	NT
790	11-11-50	6	286	NT
792	01-25-51	2	622	615
793	12-12-50	158	337	665
800	03-31-51	112	207	480
935	07-09-57	?	0	NT
1202	04-14-70	33	100	NT
1365	03-14-74	?	273	151
SUB-TOTAL		9119.3(36)	10150(34)	14008(27)

JACKSON COUNTY continued

Permit #	Commenced Drilling	Natural Open Flow (Mcf)	After Stimulation (Mcf)	Initial Rock Pressure (lbs/psi)
1369	06-24-75	1007	NS	190
1371	11-11-75	0	111	424
1373	05-12-76	29	298	230
SUB-TOTAL:		1036(3)	409(2)	844(3)
GRAND TOTAL: (Jackson Co.)		15071.0(65)	29921.9(73)	42592(67)
GRAND TOTAL MASON and JACKSON COUNTIES:		152439(81)	31950.2(90)	49247(77)
AVERAGE		188.196	355.00	693.57

QUARTERLY PROGRESS REPORT
ERDA CONTRACT NO. E(40-1)-5194

April 1 - June 30, 1977

submitted by:

Department of Geology and Geography
West Virginia University

R.C. Shumaker Project Director

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MORGANTOWN, WV

Plans for the upcoming quarter include writing reports for several ERDA meetings and the preparation of illustrations for these meetings. If time permits, we will start structure maps on base of the Knox and the top of the Ordovician.

Fracture Mapping

This phase of our program was initiated during mid-May with the hiring of a geologist to accumulate, compile, and analyze fracture data for the contract area. In June we started to collect fracture data in the northeastern Kentucky area. This area was selected because of its importance in Devonian shale production and the paucity of published fracture data for that area. Data is being collected, where feasible, on at least a one station per 7.5' topographic quadrangle basis. Fracture patterns from coal, shale, and limestone are being collected wherever possible. Thus far data has been collected from outcrops in at least fifteen quadrangles from northeastern Kentucky (see Fig. 1, contract area of eastern Kentucky).
Plans for the upcoming quarter include continued field work to collect fracture pattern data in the Big Sandy Devonian shale gas field area of eastern Kentucky. Preparation of data for computer storage and plotting will be initiated during the latter part of the upcoming quarter.

Groundwater Investigations

This program was initiated during mid-May with the hiring of a geologist to accumulate, compile, and analyze groundwater data for the Mount Alto (Cottageville) Devonian shale gas field. Plans for the upcoming quarter include continued investigations compilation of data in a format and map scale that facilitates comparison of water production data with gas production data.

Production Studies

During this report period construction of structural, isopach and base maps for the Cottageville field was modified from hand plotting of data to a computer plot program. This was due to the construction of a more detail and accurate base map of Jackson County, West Virginia being generated by the West Virginia Geological Survey. The Cottageville gas field lies mainly within Jackson County, WV (80%) with the remaining portion in Mason County. The computer base map will have locations (by UTM coordinates) of all wells that penetrated the Devonian Shale section. Projected completion of this map is in mid-July.

Data collection for individual wells within the gas field continues and is now approximately 60% complete. We are completing a data sheet for eash well with the following type of data collected:

(1) Permit number and company number
(2) Date drilled and operator
(3) Ground elevations, and accurate location
(4) Formation Tops for the Greenbrier Limestone, Berea Sandstone, Organic shales, and Onondaga Limestone.

Quarterly Progress Report
ERDA Contract No. E(40-1)-5194

April 1 - June 31, 1977

Objectives

Collect, compile and analyze geological data and prepare geological structure maps for eastern Kentucky and western West Virginia.

Determine if structural types and styles and surface lineations for productive areas of the Black Shales differ from those in nonproductive areas.

Identify and define along with other contractors those geologic parameters that control gas production from the shales.

Determine the feasibility of using shallow penetration resistivity and seismic surveys to detect near surface faults and fractures and demonstrate their relationship to lineations observed on airborne imagery.

Determine if a relationship exists between ground water movement and shale gas productivity.

Develop a method for selecting areas for drilling shale wells that have a potential for gas production.

Regional Structure Maps

The status of the regional structure map program (scale 1:250,000) is indicated in Figure 2. All of the maps listed should be considered to be preliminary because they are completed with the data on hand during the start of the project. Some of the data is very complete, but other data is not. As the Eastern Gas Shale Program develops and as additional data becomes available, these maps will be revised and expanded into areas of incomplete coverage. We trust that other workers will notify us if we have missed data or have incorrectly interpreted data, and that pertinent work not included for West Virginia and eastern Kentucky will be brought to our attention.

During the last quarter several structural maps of the scale of 1:250,000 have been completed for all or part of the contract area. These include a preliminary structure map on the top of the Basement for the entire contract area, a preliminary strucuure map on the base of the Onondaga for West Virginia, a preliminary structure map on the top of the Big Lime for West Virginia, and a preliminary structure on the top of the Berea for southwestern West Virginia.

(5) Thickness of each organic shale zone
(6) Gas and oil shows throughout the Devonian shale section
(7) Detail yearly production histories
(8) Rock pressure tests
(9) Electrical logs
(10) Types of stimulation (amount and zones stimulated)
(11) Natural open flows and flow after stimulation

From this data, the following maps will be generated:

(1) Structure maps on the top of the Berea Formation, Organic shale Zones and Onondaga Formation
(2) Isopach maps of the Organic Shale Zones
(3) Natural open flows
(4) Cumulative production
(5) Isopressure
(6) Isotime map of drilling operations.

In addition to these maps we intend to compare and illustrate production declines for individual wells, compare natural production and production before and after stimulation vs. production graphs. Diagrams illustrating shale sections that were stimulated and where gas shows occured are being prepared for the annual review in October. From Consolidated Gas Supply Corporation, Columbia Gas and Cities Service detail production data was obtained for all company wells drilled in the Cottageville area. Additional production data from Cabot Corporation, Spartin Gas Company, Star Gas Company, Union Gas Company, Patrick Petroleum and the Carl E. Smith Company are still to be obtained.

Plans for the upcoming year call for expanding detailed production studies into other producing field areas within West Virginia and/or eastern Kentucky. The areas selected for such detailed analysis will largely be determined on the basis of the availability of well production data from gas company records.

Geophysics Section

In the third quarter most of the geophysical equipment put out for bid during the second quarter was received. The delivery of the field vehicle has been delayed by a strike at the manufacturing plant, and it is not scheduled to arrive until the first week of July. The delay will place us three months behind in our operation.

Much of the work in the third quarter has been devoted to testing the newly purchased seismic and resistivity equipment. A special switching box has been designed and built for the resistivity meter to fascilitate rapid switching between various electrode arrays.

The bread-board single channel seismic filter and amplifier has been assembled and extensively tested. As a result of problems encountered during tests, some redesign of the circitry for this instrument was necessary. Analysis of data printout showed that excessive noise interfered with the real high frequency seismic response. We determined that the noise was related to "high line" interference and its associated harmonics. The problems has been substantially reduced by shielding the geophone cables.

Laboratory experiments were run during the third quarter in an attempt to simulate and to define the frequency output of the seismic "thumper" we have designed. Spectrum analysis was performed, and results suggest that frequencies of upwards to 500 hz can be generated with the thumper. The higher frequencies, however, have a relatively low amplitude.

Tests were also performed using small explosive charges as an energy source. It was determined, by spectrum analysis, that high frequencies of relatively high amplitude are readily achievable with this type of energy source.

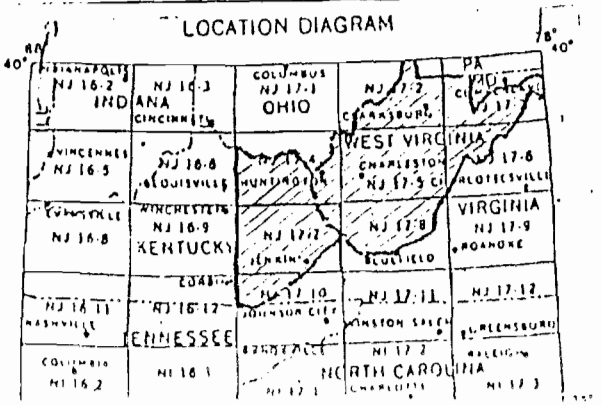
The use of a PDP-11 micro data processor has been obtained in order to reformat the data from the seismic digital recorder and make it compatable with the University computer. The software package for this micro-processor is still under development.

The advertisements placed in Geotimes and Geophysics to recruit an experienced geophysicist have resulted in several applications for this position. Screening and interviews have taken place, but, thus far, a suitable candidate has not been found. Screening and interviewing will continue during the fourth quarter with hopes of putting someone "on board" during the first quarter of 1978 fiscal year.

Plans for the upcoming quarter include assembly of the field model of the multi-channel seismic filter and amplifier by mid-July in time to allow installation into the equipment truck.

Because of the unexpected delay in receiving delivery on the field vehicle the first part of the fourth quarter will be spent assembling and integrating the field equipment into a concise and efficient package. It is expected that the first full scale test runs of the entire system will be spent assembling and integrating the field equipment into a concise and efficient package. It is expected that the first full scale test runs of the entire system will begin in mid-August or early September.

	Dev oil/g	Linear	Joints	Draina	Surfac Form 1	Surfac Tecton	Green-brie	Berea	Dev. shale	Shale Outcro	Penetr tion S	Tully	Ononda	Precam bria	Newber
Clarksburg NJ 17-2	P			C	R	C	R				PI		P	P	R
Cumberland NJ 17-3	N				R		R				PI		P	P	R
Huntington NJ 17-4	P		C	R	R	C	R	P			PI		P	P	R
Charleston NJ 17-5	P			R	R	C	R	P			PI		P	P	R
Charlottesville NJ 17-6	N						R						P		R
Jenkins NJ 17-7	P		C			C	R	P			PI		P	P	R
Bluefield NJ 17-8	P			R	R	C	R	P			PI		P	P	R
Louisville NJ 16-6					R*	C*									
Winchester NJ 16-9					R*	C*									
Corbin NJ 16-12					R*	C*									
Johnson City NJ 17-10					R	C									



Regional Structure
MAP STATUS
scale 1:250,000

R.C. Shumaker (304) 293-5603

Figure 1

N = Formation or Production not present
C = Compiling data
R = Rough copy completed
P = Preliminary map completed
X = Final draft completed
* = Not within area of responsibility but available upon request
PI = Petroleum information map on hand

UGR File C048/77Q4
WVU Dept. of Geog.
& Geogr.
April-June 1977

GR File #C048/78Q1
WVU Dept. of Geology and Geography
Oct.-Dec. 1977

West Virginia University

OPEN FILE # 048 Q1 78

QUARTERLY PROGRESS REPORT
ERDA Contract No. EY-76-C-05-5194

October - December 1977

submitted by:

Department of Geology and Geography
West Virginia University

Robert C. Shumaker, Project Director

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UGR File #C048/7801
WVU Dept. of Geology and Geography
Oct.-Dec. 1977

QUARTERLY REPORT: ERDA CONTRACT EY-76-C-05-5194

October - December 1977

Objectives

Collect, compile and analyze geological data and prepare geological structure maps for eastern Kentucky and western West Virginia (fig. 1).

Determine if structural types and styles and surface lineations for productive areas of the Black Shales differ from those in non-productive areas.

Identify and define along with other contractors those geologic parameters that control gas production from the shales.

Determine the feasibility of using shallow penetration resistivity and seismic surveys to detect near surface faults and fractures and demonstrate their relationship to lineations observed on airborne imagery.

Determine if a relationship exists between ground water movement and shale gas productivity.

Develop a method for selecting areas for drilling shale wells that have a potential for gas production.

Summary of Progress

During the first quarter three separate reports summarizing work or integrating results of our work with that of others were prepared in rough draft form for submission to DOE-MERC. One report, by J.N. DeWys and R.C. Shumaker, summarizes the results of a pilot study that utilized analytical techniques applied to production data from the Cottageville (fig. 1) (Mount Alto) field. The major emphasis of this report is on the techniques used in analyses of production data, but it also introduces several inovative techniques that are useful in comparative analyses of production and geologic data or interpretations. The second report, by R.C. Shumaker, summarizes the fracture data from several descriptive reports concerning EGS project cored wells. The report introduces and describes the concept of a "porous fracture facies" that is important to shale gas production, and in it the author briefly discusses the implication of such blanket-like fracturing to production, exploration and of the direction of the Eastern Gas Shale program. A third report, prepared jointly for our program and that of another agency by D. Scott Jones, summarizes the results of his field work and data analyses, and how it relates ground water productivity studies to air photo linears mapped in the Cottageville (Mount Alto) field area.

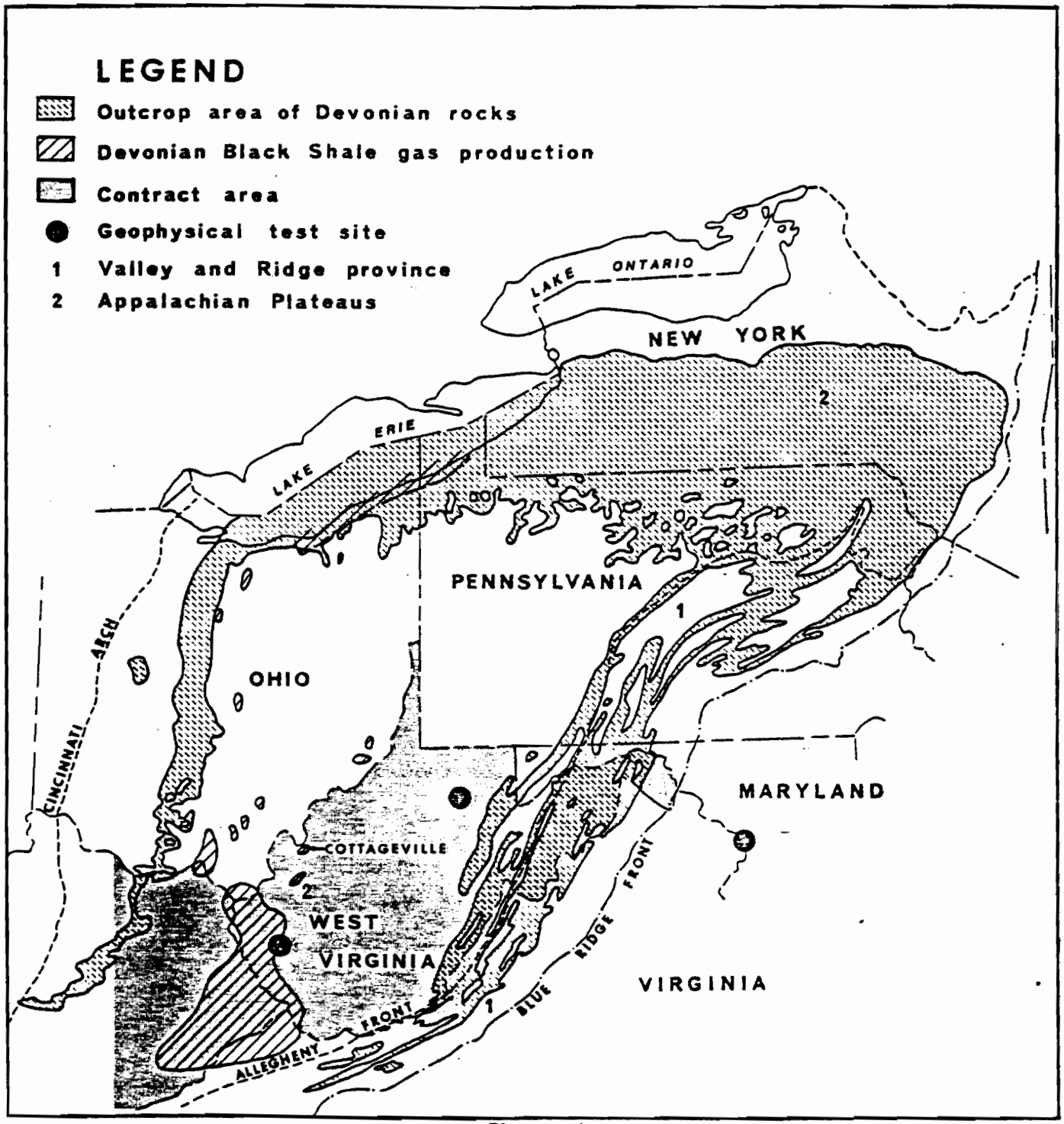
LEGEND
Outcrop area of Devonian rocks
Devonian Black Shale gas production
Contract area
Geophysical test site
1 Valley and Ridge province
2 Appalachian Plateaus
LAKE ONTARIO
NEW YORK
LAKE ERIE
PENNSYLVANIA
OHIO
CINCINNATI ARCH
MARYLAND
COTTAGEVILLE
WEST VIRGINIA
VIRGINIA
BLUE RIDGE FRONT
ALLEGHENY FRONT
1
2

Figure 1

Even though our contractual tasks do not include fracture analyses of shale cores, we studied certain cores from West Virginia, Virginia, and Kentucky in order to supplement published descriptions prepared by DOE and West Virginia Geological Survey personnel. We considered this diversion from our planned program necessary for a better definition and understanding of the interrelationships of fractures and gas production. The work on these wells included statistical presentation and analyses of all structual data including fractures, slickensides, and mineralized zones within the shale of the lower productive zone.

The geophysical equipment assembled during October and November, was field tested at the first test site located outside Washington, D.C., (fig. 1) during December. The system worked well, but road traffic noise at the site limited the effectiveness of recording seismic data.

Comprehensive geologic analyses of structural, stratigraphic and production data for the Cottageville Field continues. A preliminary week long visit was to the Kentucky - West Virginia Gas Company in Prestonsburg, Kentucky to arrange for a comprehensive study of the Kentucky portion of the Big Sandy Field. This working relationship with Kentucky - West Virginia Gas is of fundamental importance to a study of data from the heart of the Devonian Shale producing area.

Surface fracture analyses of eastern Kentucky centered first on encoding of fracture data collected during last summer, and then on preliminary computer analyses of that data. We have started the tedious job of grid locating data points which is required for computer display of analyses.

Personnel

Recruiting for a third structural geologist for the surface structure tasks of our program, and a second geophysicist for the geophysical tasks was initiated this past quarter. The recruiting for a geologist to undertake the task of a geologic analyses of the unconformity near or at the base of the Devonian shale has been postponed pending delineation of the availability of pertinent geologic data for eastern Kentucky.

Our secretary-bookkeeper resigned as of December 30, 1977. We are now interviewing perspective employees to fill that position.

Travel

Travel by contract personnel beyond the normal field work included a trip to Toronto, Canada to pick up the Winky Drill Rig, two trips to Washington, D.C. to cover geophysical investigations of the test site (see below), a recent visit to Prestonsburg for discussions with Kentucky - West Virginia personnel leading to the study of the Big Sandy Field (see below), and a trip to Lexington, Kentucky to the Kentucky Geological Survey to undertake a microstructural study of the Hazard and Martin County shale cores.

Publications

Three papers were published in the proceedings volume of the First Eastern Gas Shales Symposium:

1. Kirk, Keith G.; Geophysical Methods Used to Locate Zones of Secondary Porosity.

2. Nuckols, E.B.; Production Characteristics of Devonian Organic Shales in the Cottageville Field Near Ripley, West Virginia.

3. Shumaker, R.C., Kirk, Keith G., Nuckols, E.B., Long, B.R.; Analyses of Structural Geologic Parameters that Influence Gas Production from the Devonian Shale of the Appalachian Basin.

There are three manuscripts (noted above) in preparation for submittal to DOE-MERC this coming quarter.

Finances

A separate report will be submitted by the Comptroller of West Virginia University concerning the exact status of our finances.

In studying our expenditures through the first quarter, it was found that we have underestimated the cost of supplies used in preparation of reports, and more specifically in reproduction of illustrations to be included in these reports. Our projected increase in this budget item for the upcoming year is $1000 to cover these additional costs.

Secondarily, the project director underestimated the amount of typing and the personnel required to clear this typing during peak load times. For instance, next year it will be impossible for our secretary and our draftsmen to prepare the annual report for 8 to 10 project personnel in the time between their return from the field and when the work is due October 1, 1978. We expect that we will increase this category of our budget by $750 to hire temporary help for assistance in typing and drafting during peak load periods.

A third financial problem which must be resolved during the upcoming quarter is the unexpected high bid cost for modification of the University aircraft for multispectral aerial camera. The low bid for this job was $6000 whereas our estimation some two years ago, based on incomplete data, was that the cost would be from $500 to $1000. Either we must receive additional funds for this job or divert funds set aside for other equipment. A separate but less agreeable alternative would be to cancel this program entirely. We intend to place this job out for bids again if other companies can be located that would bid on this work. A final decision on this matter will be made in conjunction with the TPO during the next quarter.

I. STATUS OF RESOURCE INVENTORY TASKS

1. REGIONAL STRUCTURE - R. C. Shumaker (Project Director)

Most of the Directors time was spent in administrating the Contract.

A comparison of published descriptions of shale cores taken in the contract area show a general coincidence of mineralization, slickensides, fractures of a unique origin, and gas production. This coincidence led the director to gradually develope the concept that a "porous fracture facies" within the lower organic shales is critical to gas production from the shales of southern West Virginia and eastern Kentucky. The evidence on which this concept is based is presented in a brief report written at the end of the quarter. In this manuscript, a hypothesis is developed that minor thrust movement or differential shortening across the shale created much of the fracturing found associated with production.

The drilling of a cored well through the Pine Mountain Thrust (see Tom Wilson's report, below) seemed to be a rare opportunity to compare the deformation associated with proven thrust movement in the shale with the porous fractures found in the cores collected in the foreland and postulated to be created by minor thrust movement or differential shortening.

Because of the importance that these findings might have on the Eastern Gas Shale Program, the decision was made to divert a portion of our effort to describe and analyze the structural features found in the shale cores of our project area even though such work is not a part of our original task description. Two project investigators from our surface structures task confirmed and amplified the published descriptions of the Wise County, Virginia, and the Lincoln County and Collegeville, West Virginia cores. (see below Jan Dixon.)

Work will be completed with a thorough description and analysis of the structural features found in these cores, and the preliminary manuscript concerning the origin of the "porous fracture facies" will be submitted during the upcoming quarter.

Some progress was made during the past quarter by the project director in spotting tops of the Conasauga for construction of a structural contour map on that horizon for the project area. It is my intention to complete these maps during the upcoming quarter.

2. STRUCTURE TYPES - Jeanette M. Dixon

A structural cross-section (one to one scale) was drawn from the Hazard North quadrangle, Perry Co., Kentucky southeast through the Keokee quadrangle, Harlan Co., Kentucky and Lee Co., Virginia for the purpose of determining the structural setting of the Big Sandy gas field. Information was obtained by the following: (1) USGS-Kentucky state geologic maps were used for topography and outcrop location information,

(2) geologic maps and well logs were used for formation thicknesses, and (3) logs from wells near the line of section were used for formation depths.

Preliminary studies of slickensides of two Lincoln County well cores and two Cottageville well cores were made. The Cottageville wells studied were almost void of slickensides. The #11940 well had only five slickensides and the #12041 well had no slicks. The poor condition of the cores prevented measurement of orientations of the slicks. Twenty-one slickensides were found in the Lincoln County well #20402. These slicks showed preferred orientations of N40-50 W and N20 E. The #20403 well had twenty-eight slickensides with a preferred orientation of N0-20 W.

Detailed studies of the nature of movement and characteristics of the slickensides in the Lincoln County wells and the new Mason County well cores will be made in the month of January. Analysis and computer work for these wells will be done in February.

Thomas H. Wilson

An investigation of the distribution and orientations of slickensides and natural fractures commonly observed in cores through the Devonian shales has been undertaken. The ultimate aim of this work is to determine the tectonics producing these structures and to predict their occurrence.

Survey personnel have described in detail the occurrance of fractures and slickensides in the Wise, Martin and Marietta wells. Kulander, Dean and Barton, 1977 described in detail the characteristics and occurrence of induced and natural fractures and slickensides in the Nicholas Combs No. 7239 Well, Hazard, Kentucky.

This investigator has examined the Wise County core available at MERC and has recently been to the core library of the University of Kentucky in Lexington to make observations of the Nicholas Combs No. 7239 core and Martin County core.

Approximately 4000 natural and induced fracture orientations logged by survey personnel at the MERC core lab have been keypunched onto computer cards. Using the computer, sperical projections of poles to fracture surfaces were then Mellis contoured on an equal area net. The data is separated on the basis of depth and natural or induced fracture characteristics for the purpose of comparison. Specifically, changes in the orientation of natural and induced fracture surfaces with depth are investigated. Initially, the core data is broken into equally

spaced intervals which are later grouped together on the basis of similarity in orientation. All slickensided surfaces are plotted separately.

Some statistical tests have been done on changes of strike with depth for the induced fractures. The distributions of strikes for the induced fracture surfaces are commonly unimodal with small standard deviations so that the nonparametric Mann-Whitney U test is employed to determine statistical differences in the mean strike of these surfaces.

Results of this work are as follows:

1. Wise County Well - The strikes of the induced fractures from this well generally range from N40W to N60W. Frequency distributions of induced fracture surfaces for each 50 foot interval of the core show significant changes in the mean strike, and thus significant changes in the residual stress in the rock (Overbey, 1969; Komar et. al., 1973) between the intervals at 4820 to 4870 and 4870 to 4920. The induced fracture surfaces have bimodal dip distributions with peaks at roughly 45NW and 45SE. Figure 2 shows the general pattern formed by the poles to induced fracture surfaces. The two clusters result from the bimodal plunges of the uniformly trending poles. In the interval 5312 to 5337 the strike distribution becomes bimodal and a polymodal clustering of poles to these surfaces can be seen (see figure 3).

In the interval 5355 to 5435 the intensity of induced fracturing decreases rapidly with a simultaneous increase in the intensity of natural fracturing. The induced fracturing again increases in intensity below this interval.

This division of the ocre on the basis of induced and natural fracture intensity was used to examine whether there are any systematic changes in the clustering of the poles to natural fracture surfaces projected onto the equal area net. Mellis contoured spherical projections of the poles to natural fractures in these three divisions are shown in figures 4, 6 and 8.

In figure 4 (4870-5355) two clusters of poles with trends roughly NØ5E (a cluster of 4) and N85 (a cluster of 9) correspond to planes striking N85W and NØ5W respectively. The acute angle of intersection between these two planes is bisected by a line trending N45W which corresponds roughly to the trend of sigma 1 which produced the Pine Mountain thrust. Such fractures forming an acute angle with sigma 1 are shear or diagonal joints. However, it should be noted that slickensides were not logged for these surfaces and that confidence limits were not calculated for the separation angle between these two clusters, they may in fact be tensional joint sets. Also, poles to slickensided surfaces (see figure 5) do not show clusters in these areas of the net.

In figure 4, another cluster of 5 poles can be seen at the center of the net representing horizontal fractures. Their surfaces were not slickensided, but were mineralized and may represent fractures developed during conditions of high fluid overpressure, when sigma 3 is vertical. The occurrence of horizontal slickensided surfaces in this interval

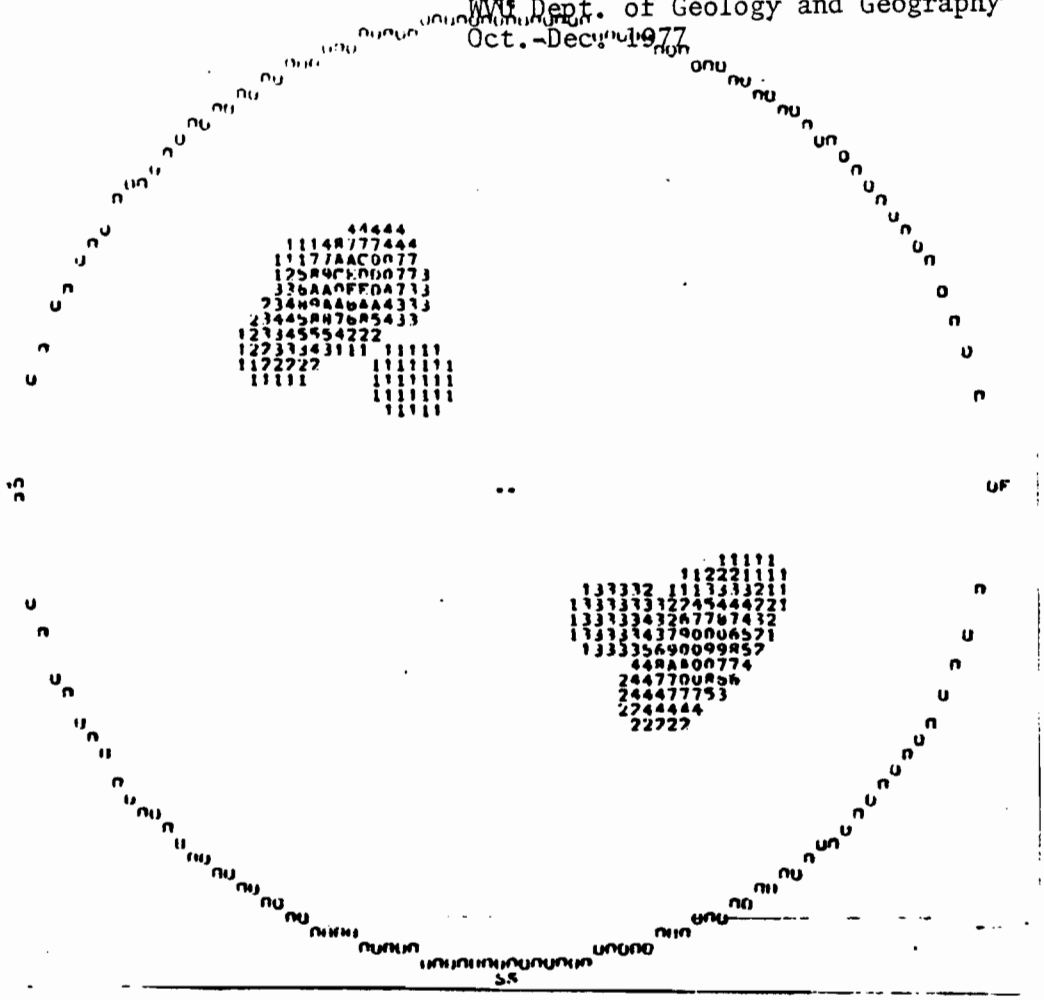

Figure 2

These plots represent lower hemisphere spherical projections of poles onto an equal area net. Each pole is represented by a 1 cm diameter circle, circumscribed about that poles location. This circle is outlined in approximate form by printing 1's at each printing location within this circle. Where circles overlap, the number of overlapping circles is printed at those printing within the area of overlap. This is known as the Mellis contouring method. 1 through 0 represent one to ten overlapping circles, then the letters of the alphabet are used to indicate greater than 10 overlapping circles, for instance, A=11, B=12, etc.

In this figure we see concentrations of poles to induced frature surfaces in the NW and SE octants of the lower hemisphere. These poles represent fracture surfaces that strike roughly N4SE with dips 45SE and 4S NW respectively.

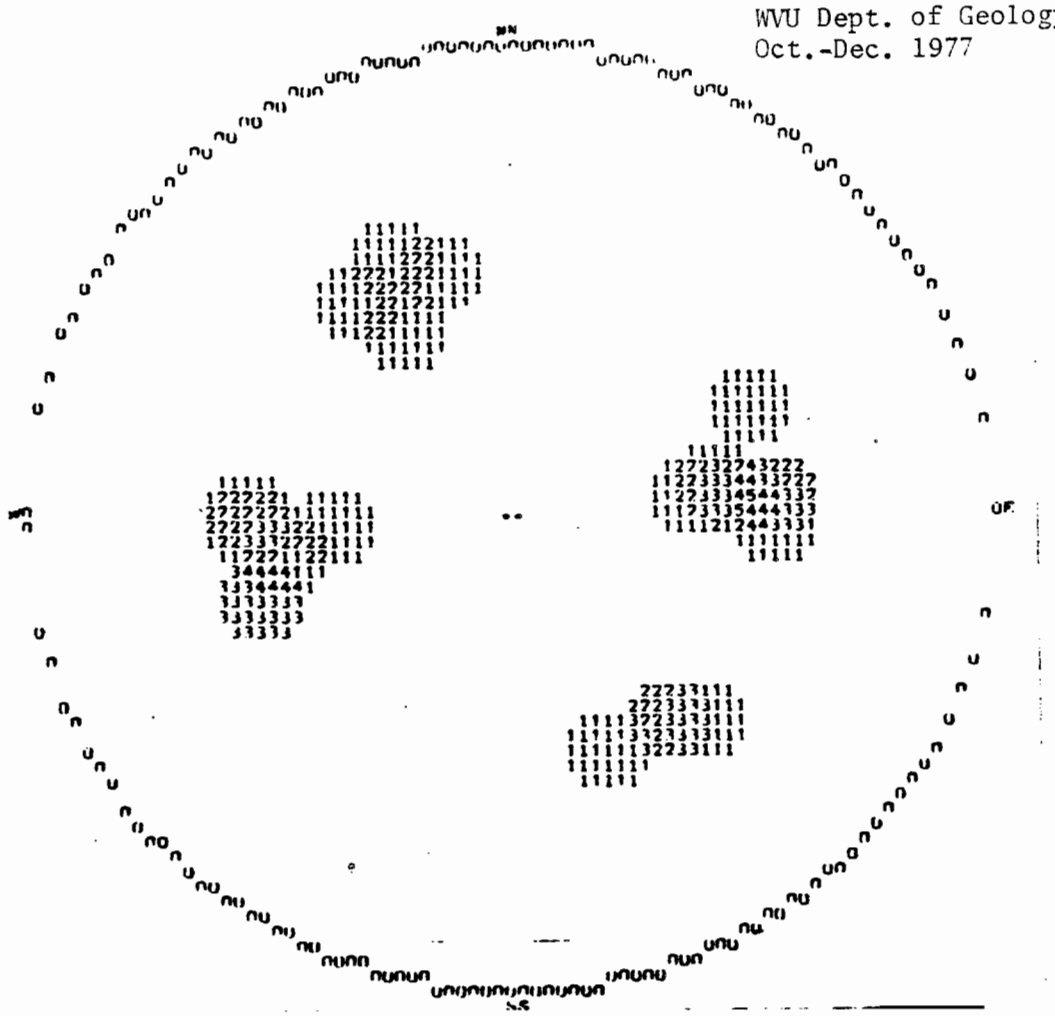

Figure 3

In this plot four clusters of poles can be seen. In the NW octant, there are four poles with a maximum of two overlappings, and in the SE octant there are five poles with a maximum of three overlappings. Both cluster represent poles trending roughly N30W and belong to induced fracture surfaces striking N60E. The other two clusters of poles in the SW and NE octants belong to induced fracture surfaces striking approximately N10W and dipping NE and SW respectively.

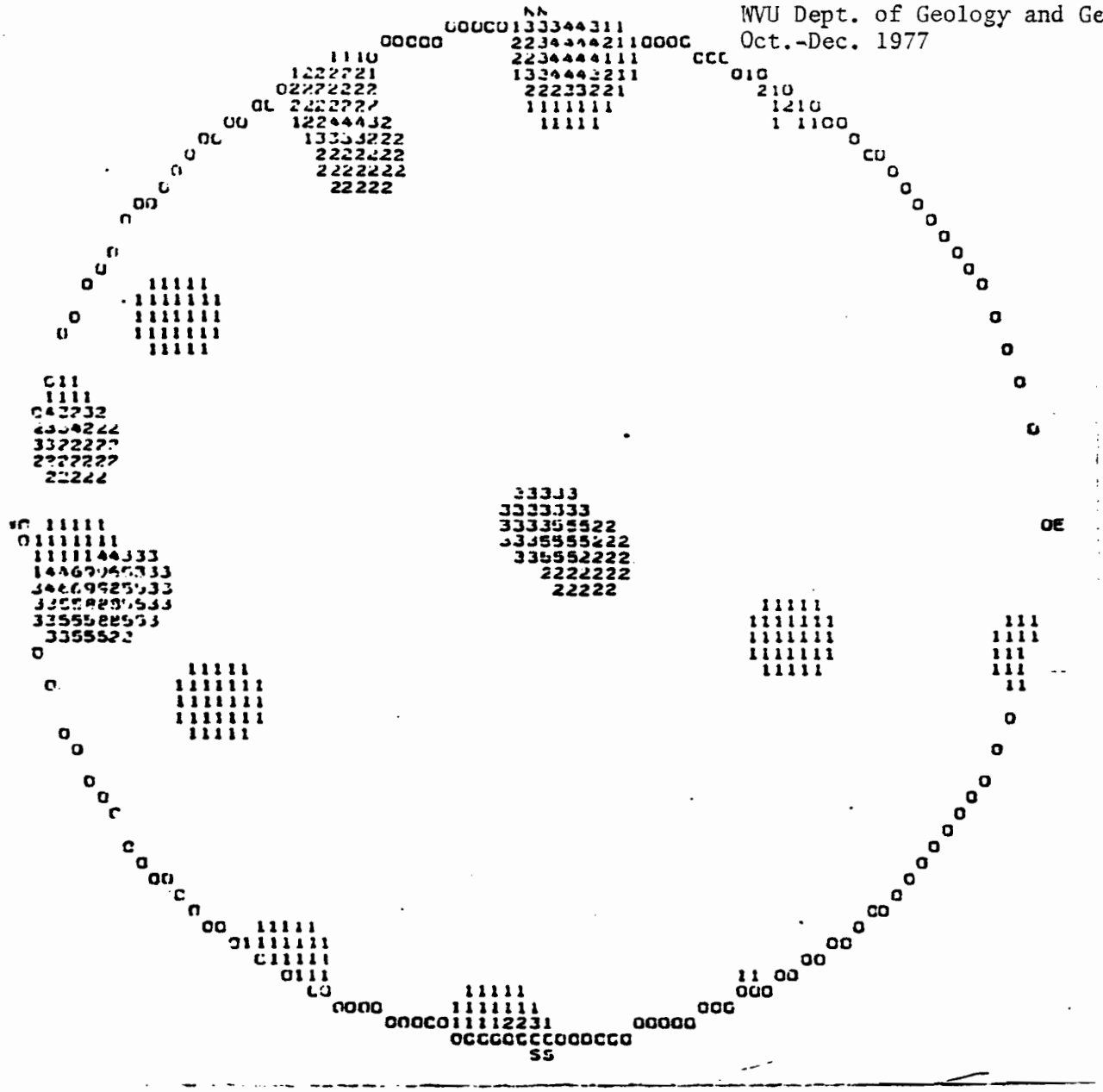

Figure 4

This figure illustrates the orientations of poles to natural fractures logged from a depth of 4870 feet to 5356 feet where the interval 4984-5225 was not cored.

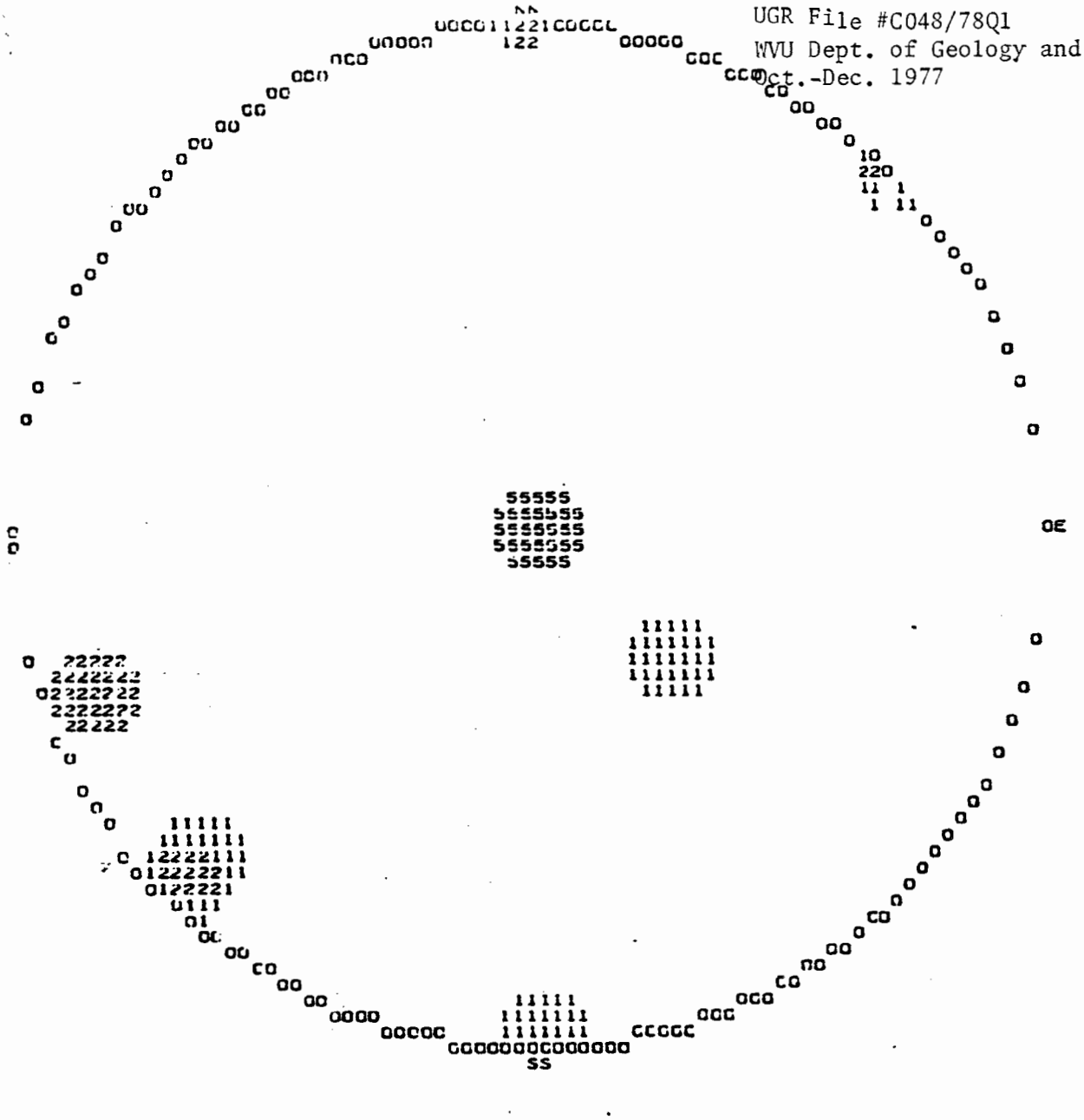

Figure 5

Poles to slickensided surfaces occurring between 4870 feet and 5356 feet, are contoured where the interval 4984-5225 was not cored.

(see figure 5) indicate that conditions of high fluid over pressure were local in nature. Also, the horizontal fractures occurred in groups of 2 and 3 which were widely separated in space. One final aspect of this upper division is that the intensity of fracturing is very low with only 30 natural fractures occurring in 344 feet of core.

In the zone from 5355 feet to 5435 feet, natural fracturing is most intense. The poles to the fractures (see figure 6) form a belt across the equal area net. This pattern of natural fractures is identical to the model 2 proposed by William K. Overbey Jr. for fractures generated by low-angle thrust faulting (see figure 10, Overbey, 1976). In this model it can be seen that a large number of fractures have poles plunging NW, and that the majority of fractures will be oriented parallel to the thrust sheet in agreement with the sperical projections of the poles to natural fractures in this division. Whether the significant proportion of fractures having poles plunging to the SE is inconsistant with this model is not known. Poles to slickensided surfaces (figure 7) lie in a belt, identical in orientation to that of the natural fractures, which is clustered in the same relative proportions. On the basis of the intensity and orientation of natural fractures and slickensided, it is suggested that the interval between 5355 feet to 5435 feet is the décolement in the Pine Mountain Thrust sheet. This zone corresponds to an 80 foot interval within the 176 feet of Brown shales which begin at 5300 feet (personnal communication, J. Schwietering). It should be noted that the interval below 5475 (the base of the Brown shales) to the top of the Onondago at 5676 feet (as inferred from the gamma ray log) was not cored, so that similar zones of fracturing may be present in this interval of 203 feet.

The natural fracturing in the remaining 40 feet of the core (below 5435 feet) shown in figure 8 exhibits no preferred trend. The orientations of poles to these surfaces indicate with few exceptions that these fractures are highly inclined to vertical and may have developed in response to tension resulting from dewatering along the surface of detatchment. The poles to slickensided surfaces (figure 7) occur in a 1 foot interval from 5435 - 5436 feet and should have been included in the division above.

This investigator has measured the trends of slickensides from the Wise County core finding the average trend to be N45W in rough agreement with the direction of movement for the Pine Mountain thrust sheet.

A reexamination of the slickensided surfaces is planned for this core. Trend and plunge of slickensides will be measured, along with the strike and dip of the slickensided surfaces providing the slicks do not trend perpendicular to the strike of the surface. Also, attempts will be made to determine the relative direction of movement along these surfaces.

2. Nicholas Combs No. 7239 and Martin Cores - Data collected at the core library of the University of Kentucky in Lexington has not yet been examined in detail. In the interval 2623 - 2647 feet from the Nicholas Combs core, the slickensides trending NE, noted by Kulander, Dean and Barton, 1977 were observed. The slicks plunge NE and SW with trends perpendicular to the strike of the fault surfaces. Where relative movement indicators were observed they indicated, with one exception,

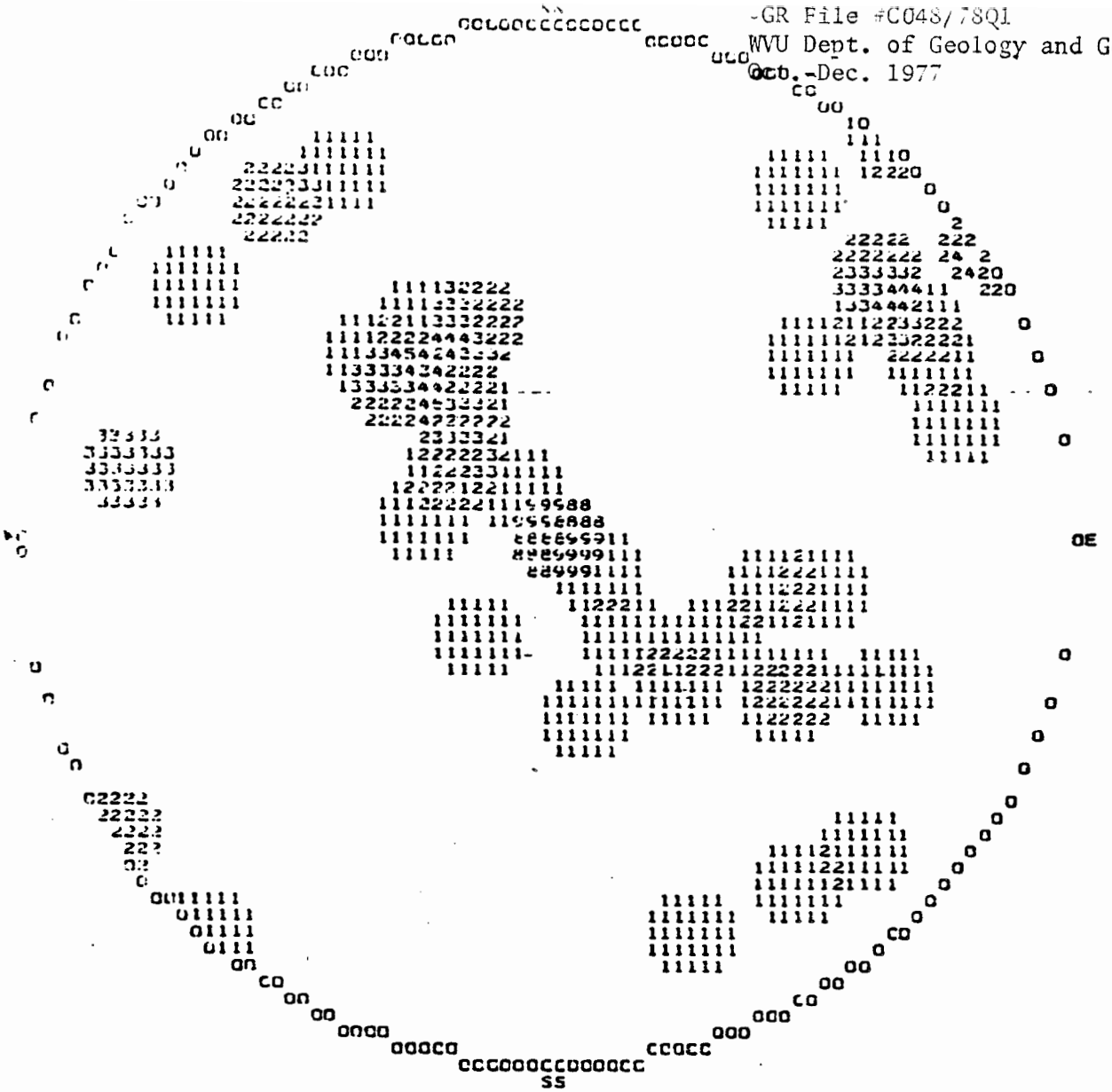

Figure 6

This is a contour of the poles to natural fractures occurring in the interval 5356-5435 feet.

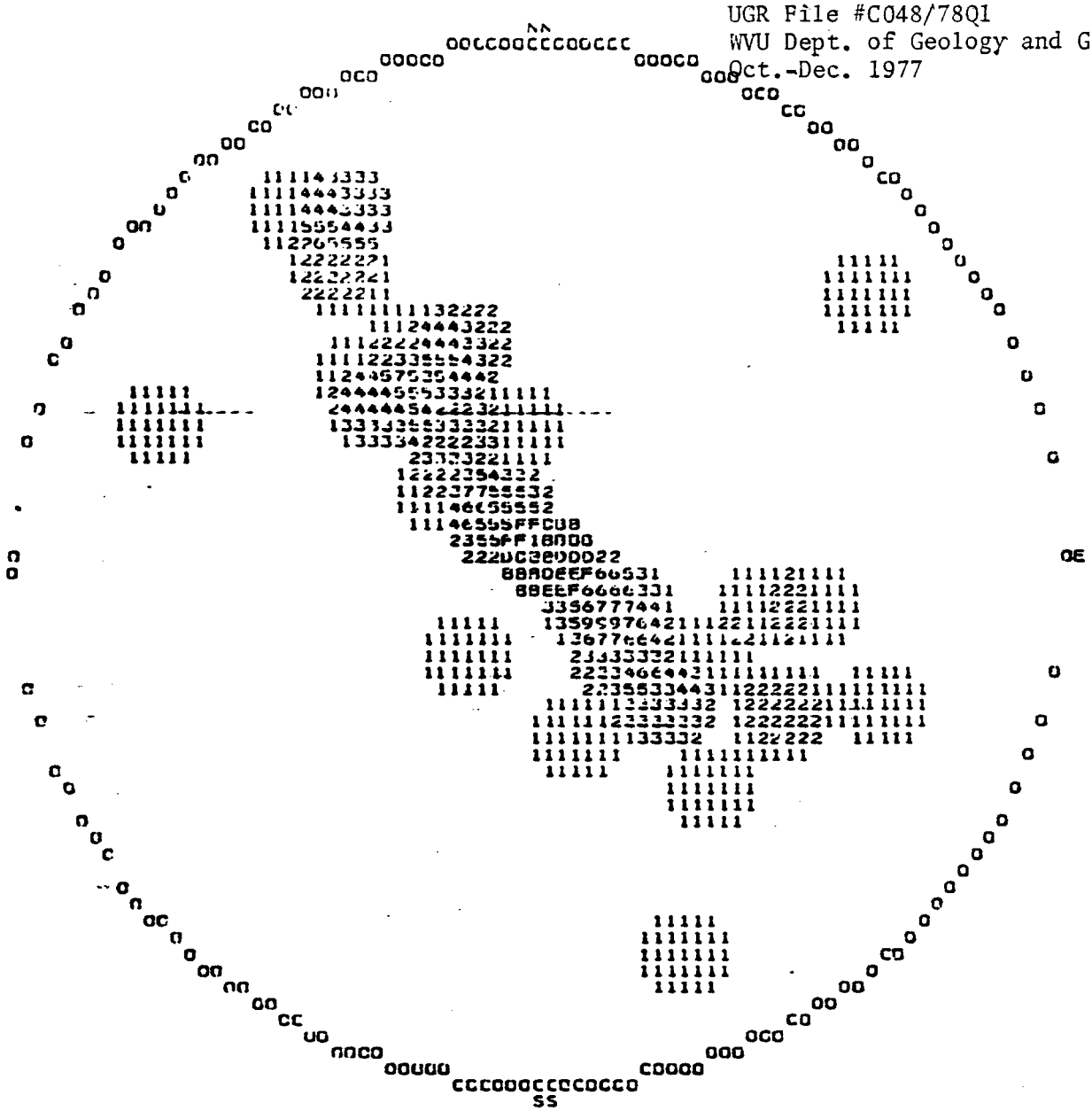

Figure 7

This figure is a contour of the poles to slickensided surfaced in the interval from 5356 feet to 5435 feet.

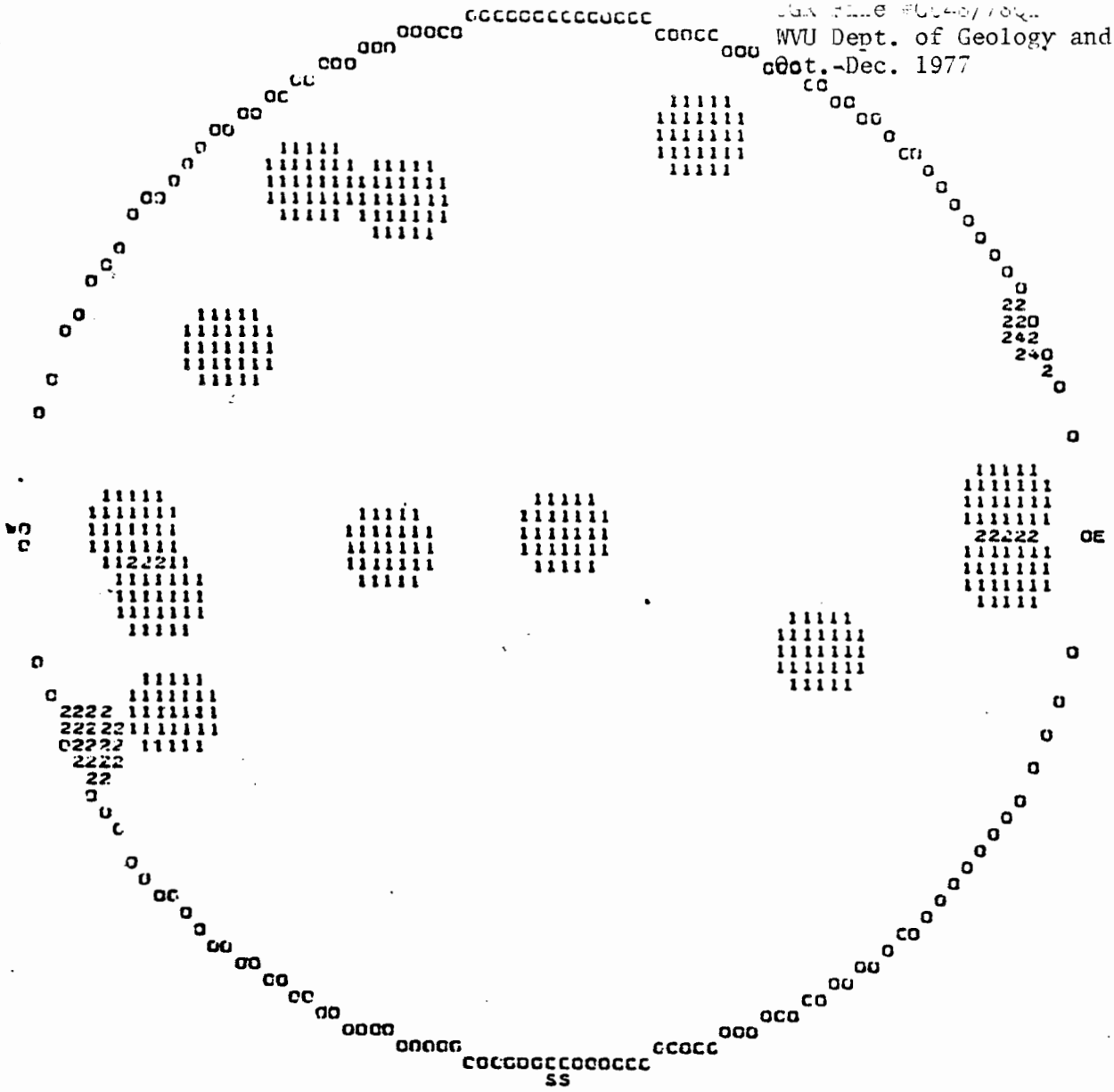

Figure 8

Poles to natural fractures occurring from 5435 feet to the bottom of the core at 5475 feet are contoured.

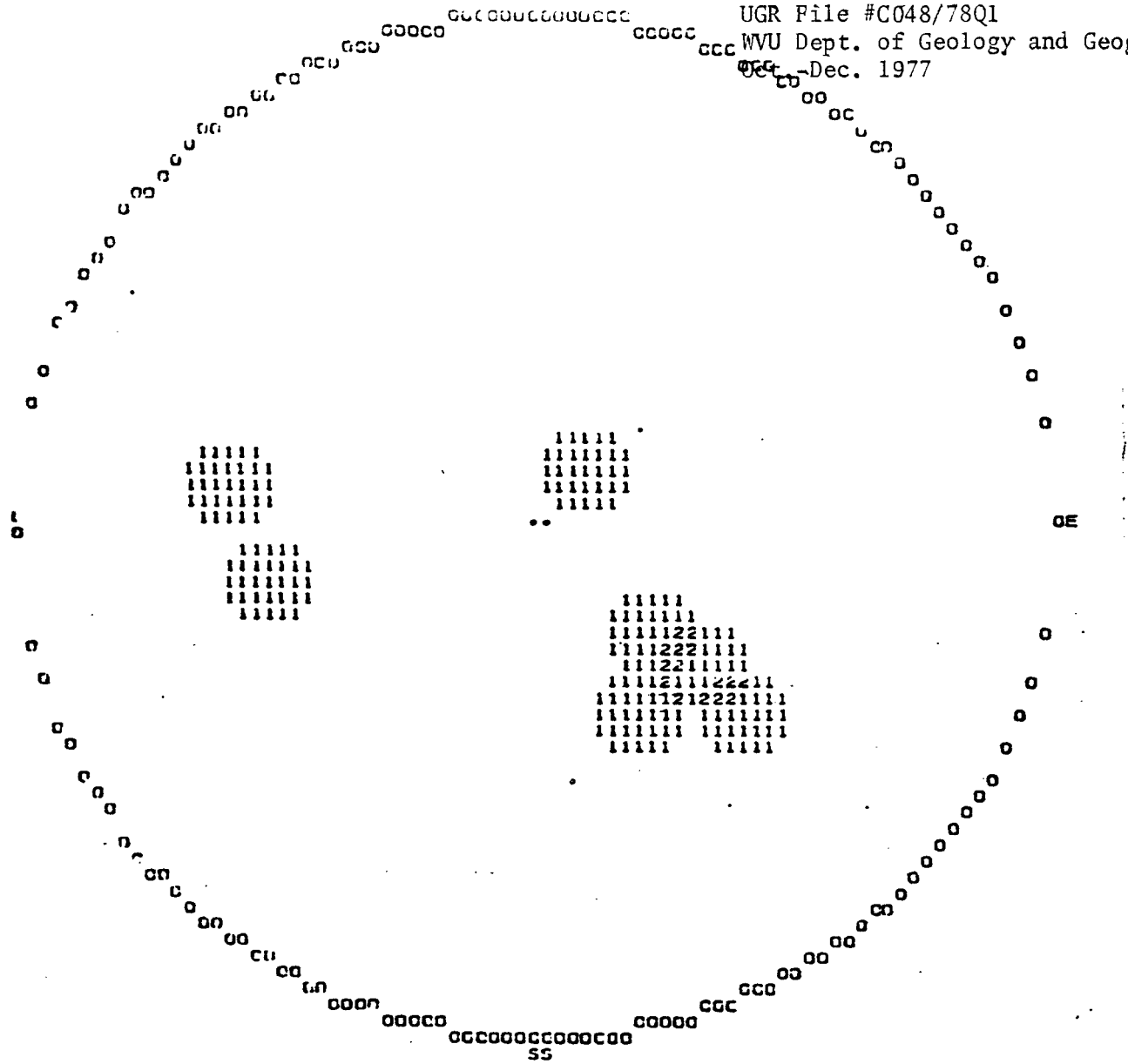

Figure 9

This is a contour of poles to slickensided surfaces occurring in a one foot interval 5435 feet to 5436 feet. The orientations of the slickensides and the class near to the above interval indicate that they should be included with those slickensides occurring between 5356 and 5435 feet.

downward movement of the hanging wall. This suggests that the movement is the result of compaction from loading associated with a local depositional irregularity.

The Nicholas Combs and Martin cores are in poor condition for examination, and much of the cores have been removed by various observers for more extensive analysis, making adequate data collection difficult.

The fracture logs provided by the survey for the Martin County cores are presently being examined.

3. Marietta Core - Spherical projections of poles to fracture surfaces were plotted for each 10 feet of this core. The survey's fracture log of this core did not differentiate between induced and natural fractures or slickensided surfaces, so that little can be said about these structures. It was noted in an earlier report that the poles to natural fractures have a more scattered appearance on the equal area net than to poles to induced fractures. However, some irregularity is also observed in the induced fractures and thus it is not reliable to conclude that those fractures whose poles fall outside clusters typical of the induced fractures are natural. As an example, a spherical projection of induced fractures in a ten foot interval from the Wise County well is included to illustrate this scatter (figure 10).

Future Work wil be as follows:

1. As mentioned earlier, the Wise County core will be reexamined measuring trend and plunge of slickensides as was done for the Nicholas Combs and Martin County cores.

2. Samples of horizontal natural fractures containing fibers will be thin sectioned and examined under the petrographic microscope for effects of high pore fluid pressure.

3. Spherical projections of the fractures in the Martin County core will be completed and examined.

4. Core induced fractures showing considerable scatter, as mentioned in the discussion of the Marietta Well, will be plotted separately to determine if they form clusters and whether these clusters have any tectonic significance.

5. Of ultimate concern to this work is the relationship between fracturing and petroleum production. The characteristics of fracturing in the Brown shale is of major interest in itself. Since the Brown shale is the main reservoir in 27 named fields in southwestern West Virginia (Patchen, 1977), it is hoped that fracture logs from the Brown shale gas fields can be obtained so that an examination and comparison of the characteristics of fracturing and faulting in this shale, and their cause, can lead to a more efficient and complete extraction of petroleum from the Brown shales.

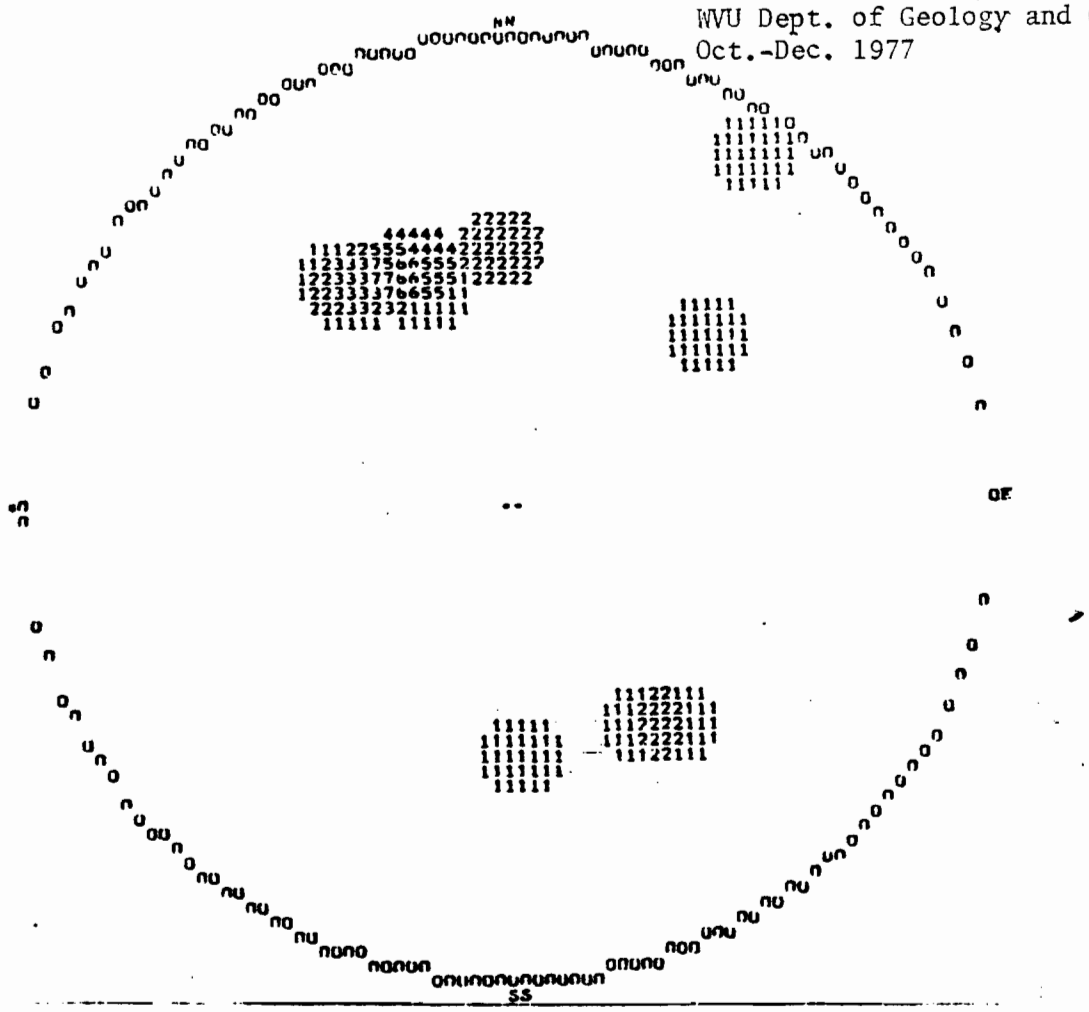

Figure 10

This contour of poles to induced fracture surfaces illustrates the scatter in orientation which is occasionally seen.

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3. PRODUCTION STUDIES - E. B. Nuckols

Continued production studies of the Cottageville Gas Field near Ripley, West Virginia, were concentrated in two major areas: (1) geologic map preparation (structure and isopach maps) and (2) computer analysis of gas production characteristics. Of these two areas of concentration, the major area of study was on geologic map preparation.

The following preliminary geological structure isopach and production maps have been delivered to the Morgantown Energy and Research Center:

1. Base Map showing location of all Devonian shale gas wells in the Cottageville Gas Field

2. Structure on the top of the Mississippian Berea sandstone

3. Structure on the bottom of the Middle Devonian Huron shale member of the Ohio Shale

4. Structure on the top of the Middle Devonian Onondaga Formation

5. Isopach of the upper organic shale zone (Zone III) in the lower portion of the Huron shale

6. Isopach of the lower organic shale zone (Zone II) in the lower portion of the Huron shale

7. Isocontour of initial reservoir pressure (rock pressure) after completion of shale well

8. Isocontour of initial gas test flow rate after completion of drilling

9. Isocontour of final gas test flow rate after stimulation or natural flow

In addition to the above maps, three additional maps have been completed but have not been submitted to MERC for inspection. These maps are: (1) Isopach of total Devonian shale section, (2) Isopach of the lower portion of the Huron shale member (portion of the shale section that produces gas) of the Ohio Shale and (3) Base Map with the location of all gas wells in the Cottageville study area.

In early December, Mr. Jerry Craig of MERC was contacted to see if a computer study of production characteristics could be accomplished. Upon receiving a go-ahead from him, production data from 62 wells in the Cottageville Field was submitted. The following computer analysis studies are now being performed:

1. Production decline curve analysis with exponential curve fit (43 wells)

2. Production decline (exponential curve fit) to economic limit (2400 MCF/year) for potential gas reserves.

3. Statistical analysis of reservoir pressure squared vs. cumulative production

4. Statistical summary of production decline, grouping gas wells according to initial gas flow rates and gas flow rates after stimulation

5. Slope characteristics of production decline curves at five year increments

These computer studies are due to be completed by the end of January and will be integrated into the overall gas field analysis.

In the upcoming second quarter of FY 78 the following areas of investigation will be investigated:

1. Map showing production status of Devonian shale gas wells

2. Gas show maps - indication map of what shale horizon is producing

3. Penetration map showing shale zones penetrated and total depth drilled

4. Isocontour map of production decline curve characteristics

5. Graphical representation of initial pressure vs. time (wells with production data only)

6. Stratigraphic cross section along the length of the gas field

7. Stratigraphic cross section normal to gas field trend

In addition to the above studies, geophysical work by Geophysical Service Inc. (under contract by Consolidated Gas Supply Corporation and MERC) in the Cottageville Field will be integrated into the field analysis. The availability of new data recently released by Devon Corporation and a somewhat more comprehensive study of production characteristics has delayed integration of production and geologic data for an analysis of their interrelationship. By the end of the second quarter the analysis should be complete and writing of the final report should be underway.

J. Negus de Wys

A paper entitled "Pilot Study of Gas Production Analysis Methods Applied to Cottageville Field," comprising 44 pages, 6 tables, 26 figures, and 12 transparencies, is in final stages of completion. This report will be submitted to MERC for publication in the orange cover report series. The report is authored by J. Negus de Wys and R. C. Shumaker.

A week-long visit to Kentucky - West Virginia Gas Company in Prestonsburg, Kentucky was extremely productive. The company was most cooperative in supplying assistance and data.

Three hundred wells logged through the Devonian have been plotted on a base map covering 10 counties in Eastern Kentucky. Electric logs (Gamma Ray, Neutron, Density, etc) have been pulled for all wells and are presently being correlated. Stratigraphic picks will include tops and bottoms of the Bedford, Cleveland, Three Lick, Huron, and Olentangy.

Information on the Big Lime will be included where possible. Isopach maps will then be prepared and compared with those of Linda Provo.

Additional wells will be obtained from Ashland and Columbia, who are also cooperating in this study.

Production data and drillers logs for Letcher County are being studied. This will be the basis for the proposed production study of the field, as far as how the data will be represented.

A proposal is being drawn up for logging of wells already in existence in areas of the eastern Kentucky field where electric flogs are scarce or nonexistent. Such additional information will greatly enhance the value of this study.

Well samples have been requested for all counties for microscopic examination. Lithologic descriptions will be compared with drillers logs and existing descriptions in the literature.

4. SUB-CROP MAPS

This task is not scheduled to commence until August 1978.

5. FRACTURE ANALYSIS - Brian R. Long

The task 5 Fracture Study involves the compilation and analysis of surface fracture trends in the eastern Kentucky area. Field data has been arranged into computer data sets for the plotting of fracture trends as individual Rose diagrams or as Rose diagrams plotted on variable map scales. Data point locations were converted from latitude - longitude to Universal Transverse Mercator grid coordinates for compatibility with computer mapping programs. A limited number of data points were plotted by quadrangle as individual Rose diagrams and included fracture trends of all lithologies.

During the next quarter existing computer programs will be used to plot fracture Rose diagrams individually or on a map of any scale. Maps or individual Roses will be plotted in relation to lithology, bed thickness, joint dimensions, and frequency of jointing. Correlation of fracture trends with locations of existing gas and oil pools will also begin during the next quarter.

II. STATUS OF SHALE CHARACTERIZATION TASKS

1. GEOPHYSICAL STUDIES - Keith Kirk

Research has continued to progress on the geophysical tasks. This progress has been somewhat slower than anticipated because of unexpected equipment difficulties with the final interfacing of the many pieces of equipment that, in total, make up the geophysical research vehicle. Also, the second geophysicist position has yet to be filled. Additional recruiting has taken place during the first quarter, and several applicants are presently being reviewed for the vacant position. It is anticipated that a decision will be made during the second quarter, and the second geophysicist will be on board by the third quarter.

The first field testing of the total system was skedualed for early fall. Because of equipment interfacing difficulties, testing was pushed back until late November. This testing uncovered additional interfacing problems that have just recently been solved.

September was spent designing and building two special purpose heavy duty bumpers for the geophysical research vehicle (GRV). The heavy duty front bumper was designed to hold the hydraulic impacter which is used as the seismic energy source to generate the shock impulse for the seismograph. The heavy duty rear bumper was designed so that the portable drill rig could be mounted on the rear of the GRV. The portable rig arrived and was installed in late September. Learning to properly operate this rig occupied the first two weeks of October.

During the third week of October the hydraulic impacter was removed from its temporary installation on the testing apparatus and remounted on the GRV. Once this was done the seismograph, analog filter, digital recorder and chart recorder were installed in the GRV, and the initial testing of the total system started.

As testing began it was discovered that there was a electrical noise problem that severely limited detection of high frequency signals. Further testing indicated that this electrical noise was generated primarily from two sources. These were: the noise associated with the engines electrical system in the GRV, and noise associated with the harmonics of 60 cycle A.C. power lines. These sources of noise were enhanced by the 128 decibel gain of the seismic amplifier. The answer to this noise problem involved a two stage solution.

A new power supply was designed and built to power the geophysical instruments. The power supply was highly filtered to eliminate the problem of the elctrical noise generated from the GRV electrical system.

In order to eliminate the problem of the 60 cycle harmonics much of the geophysical instruments had to be rewired with shielded electrical cable. This rewiring included rewiring the geophones and geophone leads, the electronics of the hydraulic impacter, and the connections between all of the geophysical instruments. After these problems were solved testing again began in late November.

As testing of the total system progressed into early December it was discovered that the rechargeable batteries which supply power to a portion of the system were sensitive to temperatures below freezing. This problem again necessitated the refurbishing of a portion of the power supply and the installation of a heater in the GRV.

After these problems were solved testing of the total system resumed. Initial results in sedimentary terrains show reflections are obtainable from depths up to 3000 feet with frequencies as high as 150 hz.

It has been noted that impacting of the ground in loosely compacted soils does not permit the transmission of high frequency impulses to pass into the subsurface. In fact, testing of the system at the first test site (figure 1) on metamorphic rocks in Maryland, where a thick saprolite exists, has shown that only frequencies less than 28 hz could be effectively transmitted into the ground with the hydraulic impacter.

It has been discovered that this problem can be circumvented in two ways. If the loose soil is saturated, high frequency waves can be transmitted. This however is not a viable solution since all field work cannot be scheduled to follow a hard rain. Another solution is to use the drill rig to auger a hole to bedrock, and then impact a steel post against the bedrock with the hydraulic impacter. This solution is only viable in areas of thin over burden.

Even though the hydraulic impacter is a relatively effecient and safe means of inputting energy into the ground several problems have developed in regard to its use. Extensive use of the impacter has caused the loosening of many of the mechanical parts on the GRV and has greatly reduced the effeciency and reliability of the GRV's front suspension system. This unexpected problem will necessitate the rebuilding the suspension system with extra heavy duty parts. It is expected that additional funds will be requested as funds were not budgeted to install a heavy duty suspension system into the GRV. We intend to evaluate this problem as a different type of energy source, such as a down hole sparker or accetalene "popper", may be a more suitable energy source for the system.

At this time it is difficult to make exact work plans for the second quarter of fiscal 1978. This is true because the field work involved with the geophysical evaluation is dependant on the weather during the winter months. Weather permitting, field testing will continue at the next two sites (figure 1).

During the expected inclement weather the problem of an alternative energy source for hydraulic impacter will be evaluated and the soft ware necessary to display the collected field data will be studied. If time permits the rough design of the acetalene "popper" will be made, and if money permits a "popper" will be built to determine if it is less costly alternative to rebuilding the front suspension system of the GRV.

We will be interviewing geophysicists during the second quarter this can fill the vacant position. It is hoped that this postion can be filled to assist in the many tasks involved in the program.

UGR File #C048/78Q2
Jan.-Mar. 1978
WVU Dept. of Geology and Geography

QUARTERLY PROGRESS REPORT

U. S. Department of Energy Contract No. EY-76-C-05-5194

January - March 1978

submitted by:

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West Virginia University

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Brian R. Long, Thomas H. Wilson,
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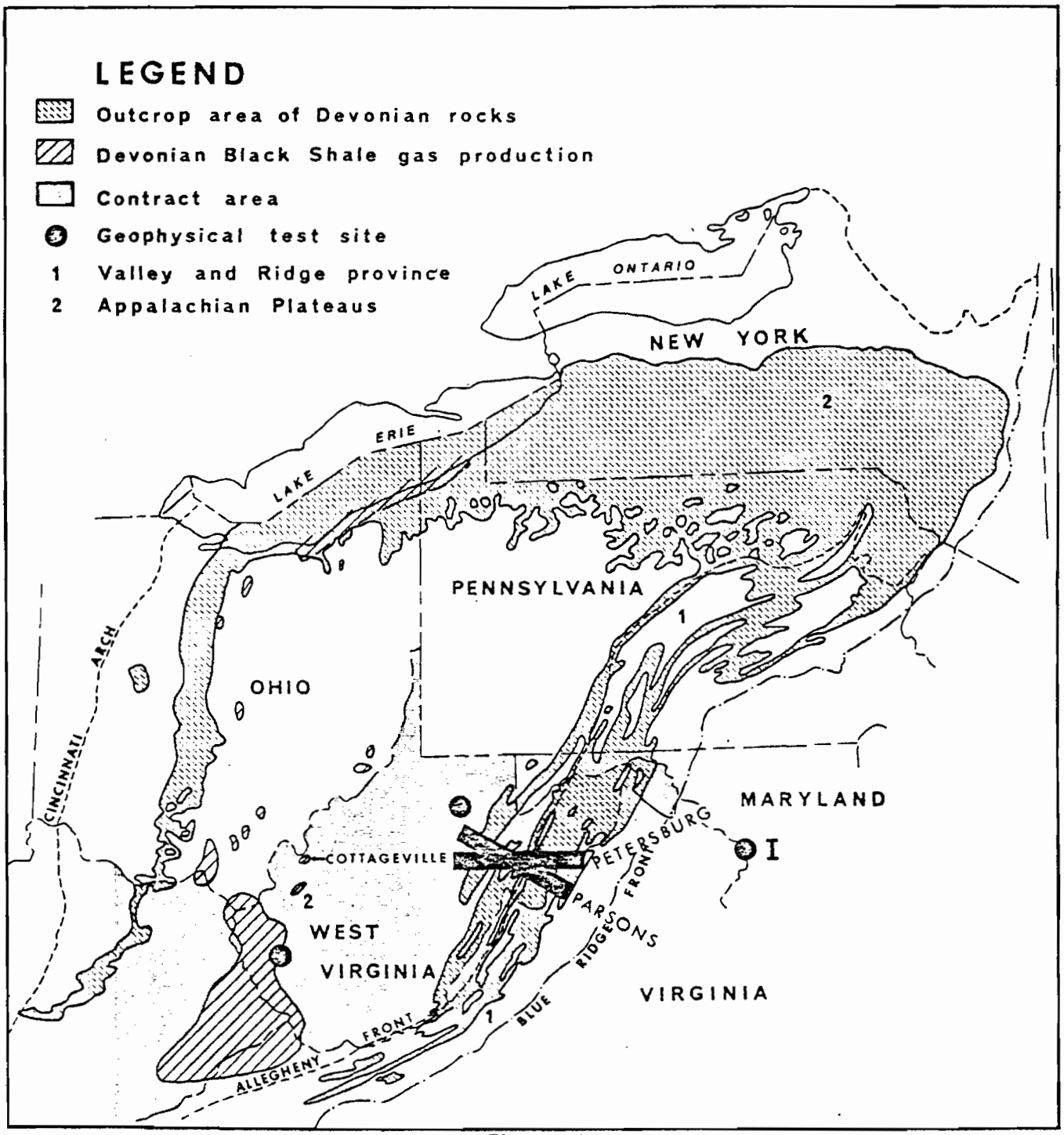
LEGEND
Outcrop area of Devonian rocks
Devonian Black Shale gas production
Contract area
Geophysical test site
1 Valley and Ridge province
2 Appalachian Plateaus
LAKE ONTARIO
NEW YORK
LAKE ERIE
PENNSYLVANIA
OHIO
CINCINNATI ARCH
MARYLAND
COTTAGEVILLE
PETERSBURG
PARSONS
BLUE RIDGE FRONT
WEST VIRGINIA
VIRGINIA
ALLEGHENY FRONT
I

Figure 1

QUARTERLY REPORT: ERDA CONTRACT EY-76-C-05-5194

January - March 1978

Objectives

Collect, compile and analyze geological data and prepare geological structure maps for eastern Kentucky and western West Virginia (fig. 1).

Determine if structural types and styles and surface lineations for productive areas of the Black Shales differ from those in non-productive areas.

Identify and define along with other contractors those geologic parameters that control gas production from the shales.

Determine the feasibility of using shallow penetration resistivity and seismic surveys to detect near surface faults and fractures and demonstrate their relationship to lineations observed on airborne imagery.

Determine if a relationship exists between ground water movement and shale gas productivity.

Develop a method for selecting areas for drilling shale wells that have a potential for gas production.

Organization

In order to attain the stated objectives, we have designed several tasks which have been organized into five study groups. Four of these groups - regional structure studies, fracture studies, structural type studies, and production studies - are carried under the U. S. Department of Energy Resource Inventory Task. One group - geophysical studies - is carried under Shale Characterization Task.

Summary of Progress

Results of our efforts during the winter months came to fruition in the completion of the reports (see publication section below).

The report by de Wys and Shumaker describes an innovative approach to analysis of shale gas production from the Cottageville Field of Jackson County, West Virginia. The reports by Shumaker, Wilson, et al. cover analysis of slickensides found in the shale cores collected during the first two years of the Eastern Gas Shales program in our contract area. Slickensides were generally considered to be compaction features, but our analysis clearly shows that most are related to regional tectonics. Regional analyses and possible ramifications of this discovery to the Eastern Gas Shales program are discussed in the second report by R. C.

Shumaker. Wilson, Dixon and Shumaker give detailed results of our structural analyses for each core. The report by Kirk presents the results of geophysical tests run at the first test site.

During this quarter, the Governor of West Virginia, Jay Rockefeller, froze all contract purchases and hiring for all grants. This action was taken because of the United Mine Workers' strike. Special requests and justifications for exemptions were prepared and submitted to the State to cover the hiring of three individuals under this contract to fill the vacancies in the geophysical and the structural tasks. We are awaiting State reaction to these requests.

Requisitions to install the multispectral camera and to purchase a density slice and edge enhancing viewer have been delayed until the freeze is lifted. Thus far, the effect of the strike has been to make progress more difficult, but it has not materially delayed our program. Should the freeze continue through the third quarter, it could materially affect the program since this is a time of field work and data acquisition.

Personnel

Recruiting for a third structural geologist carried under Structural Type Studies was completed and an offer made to a qualified individual. A second geophysicist for Geophysical Studies has been hired and, if approved by the State, should be working by June. During the quarter, we, in conjunction with the Technical Progress Officer, decided to intensify our study of fractures found in the shale. This effort is an outgrowth of our recognition of the "porous fracture facies" described in the reports listed below. This intensification required assigning one geologist from the Structural Types Task and one from the Unconformity Task to the Fracture Studies Task.

Through our efforts, additional geologic and production data will be available for eastern Kentucky gas production; so we intend to expand our program in that area (see production task below).

Travel

Travel by contract personnel beyond normal field work included a trip to Washington D. C. to report results of our geophysical investigation of site 1 (figure 1) to the Department of Transportation. The report covering our investigation of that site is included below (see Geophysical Task). We also visited the Mining Enforcement and Safety Administration Office in Pittsburgh to inspect and evaluate the optical analysis system they use to evaluate remote sensing data.

Publications

Five papers have been prepared for publication.

For the proceedings volume of the Geological Society of America, Southeastern Section Symposium entitled: Western Limits of Detachment and Related Structure in the Appalachian Foreland:

Shumaker, R. C., 1978, Porous Fracture Facies in Devonian Shales of Eastern Kentucky and West Virginia

Wheeler, R. L., 1978, Cross-strike Structural Discontinuities: Possible Exploration Tool in Detached Forelands

Wilson, T. H., Dixon, J. M., Shumaker, R. C., 1978, Fracture Patterns From Oriented Cores of the Devonian Shale in the Appalachian Basin

For publication in the DOE-MERC orange series:

de Wys, J. Negus and Shumaker, R. C., 1978, Pilot Study of Gas Production Analysis Methods Applied to Cottageville Field

For publication in the proceedings volume of the Department of Highway Conference on geophysical evaluation of the Forest Glen metro site:

Kirk, Keith G., 1978, High Resolution Seismic Survey at Forest Glen, 11 p.

Finances

A separate report will be submitted by the Comptroller through the West Virginia University Grants and Contracts Office concerning the exact status of our finances.

The minor problems concerning finances outlined in our last quarterly report were discussed and resolved in concert with our Technical Progress Officer.

I. STATUS OF RESOURCE INVENTORY TASKS

1. REGIONAL STRUCTURE - R. C. Shumaker (Project Director)

As noted in the previous quarterly report, we diverted a major part of our effort from structural type studies into an area that needed study; detailed structural analysis of oriented shale cores. The results of these efforts are detailed in two reports written this quarter:

1. Shumaker, R. C., 1978, Porous Fracture Facies in the Devonian Shales of Eastern Kentucky and West Virginia

2. Wilson, T. H., Dixon, J. M., Shumaker, R. C., 1978, Fracture Patterns From Oriented Cores of the Devonian Shale in the Appalachian Basin

The essence of results of these studies indicates that slickensides are not random as thought by many workers in the project, but they occur on oriented fractures within the productive porous facies of the highly organic portions of the shale. These fractures may provide the key for determining the origin of all fractures within the productive zone. More work is required to establish the interrelationships of fractures in the porous zone. During the upcoming summer data will be collected from cores, field work in the Devonian shales of Kentucky, Ohio, and Virginia to determine the extent and nature of fractures within the productive portions of the Devonian shale section. Interrelationships of mineralized vertical fractures and slickensided shear fractures of the porous fracture facies will be studied in more detail.

Tops for all wells penetrating the base of the Cambrian Knox dolomite were spotted on the 1:250,000 base maps and interpretive contouring was started this past quarter. Contour interpretation will be completed during the upcoming quarter on this structural map.

2. STRUCTURAL TYPE STUDIES - T. H. Wilson

Analysis of fracture and slickenside data provided by the West Virginia Geological Survey from several cored wells in the Devonian shale has been completed. The results of this analysis have been prepared as a manuscript to be included in the proceedings volume of the Southeastern Section Symposium of the Geological Society of America on Western Limits of Detachment and Related Structure in the Appalachian Foreland. The paper, entitled: Fracture Patterns From Oriented Cores of the Devonian Shale in the Appalachian Basin, is authored by T. H. Wilson J. M. Dixon, and R. C. Shumaker.

A detailed statistical analysis of bedding orientation data collected from the Middle Mountain syncline has been completed. Several maps constructed from this data will be used to examine the internal structures of the syncline, and to define the width of the Parsons structural lineament in this area (figure 1). Work has begun on a manuscript which will discuss the use and interpretation of bedding orientation data. This manuscript will not be completed until additional information can be gathered from the Middle Mountain area.

The Ph.D. dissertation, covering the work I am to accomplish under the contract was presented orally to the committee members for their consideration. The proposal was accepted.

Jeanette M. Dixon

The analysis of slickensides found in the cores from Cottageville wells #11940 and 12041, Lincoln County wells #20402 and 20403, and Mason County well D.K. #3 has been completed. Detailed results will be made available in the Report by Wilson, T. H., Dixon, J. M., and Shumaker, R. C.

Preliminary field work has been done in preparation for the fracture study in the Parsons area. This study will begin full time in May, 1978. Methods for measuring joint frequency and operator variability are being tested.

3. FRACTURE STUDIES - Brian R. Long

The fracture study has progressed during the last quarter in the visual and statistical display of joint data collected in the study area of eastern Kentucky. Visually the joint strike data has been plotted by computer as rose diagrams on the 1:250,000 base map scale. Separate map plots have been completed for coal, limestone, sandstone, and shale lithologies within the study area. In addition, designations of systematic and cross jointing sets have been added to the plots where available. During the next quarter comparisons of the joint strike roses and structural features will begin.

Statistically the data has been subdivided into lithologic groups and several tests to determine possible relationships between bedding thickness, joint frequency and strike direction have been attempted. First, scatter plots and contingency tables were made to better visualize these possible relationships. Second, linear and nonlinear regression has been run to test the relationships. Results are far from conclusive due to the need for further data set corrections and further testing. To date, little correlation between bedding thickness and frequency has been found in shale. The limestones and sandstones have shown approximately 50% correlation between bed thickness and frequency. No correlation has yet been found between frequency and joint strike direction; however, testing in this area is not complete. During the next quarter these and other tests will be continued.

4. PRODUCTION STUDIES - E. B. Nuckols III

Production analysis of the Cottageville Gas Field near Ripley, West Virginia, was concerned with computer analysis of production data and the final gathering of all readily available well and production data. Early in the quarter, Mr. Alan Cevtnick of MERC was asked to run certain production analysis tests on production data obtained from Consolidated Gas Supply Corporation, Columbia Gas, and Cities Service. The following type of production analysis was completed:

1. Production decline: declines for 41 wells with extrapolation to economic limits and potential gas reserves.

2. Decline curve analysis was grouped into summary form.

3. Decline curve slopes were computed for five year intervals.

In addition to the production analysis, a well status map of shale wells was completed along with a graphical representation of pressure decline for shale wells in the gas field.

A final compilation of data was made during this quarter, with the obtaining of drilling, completion, and other drilling particulars from the Devon Corporation. With this additional data acquisition, there will be a termination of data collection. All existing data on hand will now be analyzed and be organized into a final report. During the upcoming quarter, all analysis will be made and a rough draft of the final report will be completed.

J. Negus de Wys

Cottageville Production Study - The final copy of "Pilot Study of Gas Production Analysis Methods Applied to Cottageville Field" was submitted to MERC.

Eastern Kentucky Gas Field - Maps from a trend study have been obtained. Maps showing 1) total wells in the field, 2) gas wells with > 2 MMcf initial open flow, 3) gas wells with > 1 MMcf initial open flow, and 4) gas wells with > 500 Mcf initial open flow are included.

Release by five companies of a seismic basement structure map is being negotiated.

Samples from one well in each of ten counties in the study area have been located and are being shipped to West Virginia University. Microscopic lithologic examinations, examination of the Foerstia zone in Middle Huron, and geochemical analysis will be performed on these samples.

Arrangements have been made with Dr. Renton for the elemental and mineralic identifications using XRF and XRD.

Geophysical logs are being correlated. A base map with a grid of cross sections has been completed. The first cross section running NW-SE on the eastern edge of the field is nearing completion.

Arrangements have been made with the West Virginia Geological Survey for digitization of the nearly 5000 gas producing wells in the field. This is preliminary to computer analysis of production and geological geochemical data. A computer card data input sequence is being developed by a computer programmer.

A library computer search strategy has been developed with the main sets being Paleoecology, Geochemistry, and Devonian Shales. This search will be run by the University of Utah facility and cover all search bases from 1965 to the present in foreign and U. S. literature. Titles and abstracts are being requested.

Request has been made for personnel assistance commencing in June for proper coverage of a task which has gone from 300 to 5000 data points. This increased data base will insure higher integrity of results.

II. STATUS OF SHALE CHARACTERIZATION TASKS

GEOPHYSICAL STUDIES - Keith G. Kirk

The second quarter of 1978 was spent performing initial field testing on the High Resolution Seismic (HRS) system, analyzing the results of these tests, developing seismic modeling programs and designing and constructing a new seismic energy source.

The field testing took place at a Department of Transportation test site in Forest Glen, Maryland. The system was tested under extremely adverse conditions that included high noise and excessive earth attenuation problems. In order to properly analyze this data, seismic modeling programs were set up and the data was analyzed. A report briefly summarizing the results of the initial testing is appended to this quarterly report.

Experience at the test site led to the development of a new energy source that more efficiently transmits the high frequency seismic waves to the subsurface. The energy source is an acetylene canon that is placed down a shallow bore hole and fired electrically six times per minute. This instrument has been constructed and will be tested very early in the third quarter.

The majority of the third quarter will be spent collecting the field data and analyzing same.

UGR File #C048/78Q2
Jan.-Mar. 1978
WVU Dept. of Geology and Geography

HIGH RESOLUTION SEISMIC SURVEY AT FOREST GLEN

Submitted to;

United States Department of Transportation
Federal Highway Administration

Submitted by:

Keith G. Kirk
Department of Geology and Geography
West Virginia University
Morgantown WV. 26505

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INTRODUCTION

This research was funded by contract to the Department of Energy-MERC. The field work from which this report follows was performed from December 15 to December 20, 1977 under a separate contract to the Department of Transportation.

A shallow high resolution reflection seismic system developed at West Virginia University was used in order to evaluate its usefulness as a geotechnical site exploration tool. The high resolution seismics (HRS) as used in this investigation is a surface technique. Energy is imparted to the subsurface by impacting the ground with a hydraulically driven ram that strikes the ground with 30,000 lbs. of force. This energy source is capable of generating frequencies upwards to 350 Hz.

The energy once imparted to the subsurface travels down until it encounters a velocity boundary. At this boundary the energy is partitioned and a portion of the energy is reflected back to the surface where it is detected; a portion passes through this velocity boundary to be partitioned and reflected off of the next velocity contrast and so forth.

The time from which the energy is imparted into the ground until it returns to the detectors at the surface is the critical parameter that is measured to determine the depths to the various velocity boundaries. These velocity boundaries correspond to material boundaries in the subsurface.

The accuracy which is achievable by the HRS method of subsurface investigation is largely dependent on the frequency of the energy that is imparted into the ground. Figure 1 illustrates the relationship between velocity, frequency, and obtainable resolution. Velocity is an uncontrollable variable and varies from site to site. It can be readily seen that the smallest resolvable bed is inversely dependent upon the frequency. That is to say, the higher the frequency that can be transmitted through the ground and detected, the more reliable is the depth determination to the various earth layers. This is also, of course, dependent on an accurate determination of the velocity distribution within the subsurface. This factor will be addressed later in this report.

There are several problems inherent in transmitting and detecting high frequency seismic waves within the earth. Before these problems are discussed, one must first define what is meant by high frequency seismic waves. Generally, frequencies over 100 Hz are considered high frequency in terms of seismic exploration.

The first problem with using high frequency waves as an exploration tool is that the earth acts as a natural filter for these frequencies. Figure 2 illustrates a generalized graphical display of the attenuation caused by average earth conditions as a function of frequency. It can be seen from this diagram that earth attenuation has an exponential dependence on frequency. This relationship presents problems in the detection of high frequency signals. It follows that given an energy source that transmits energy equally over a given range of frequencies that, at the detector, the low frequency arrivals will be received at a

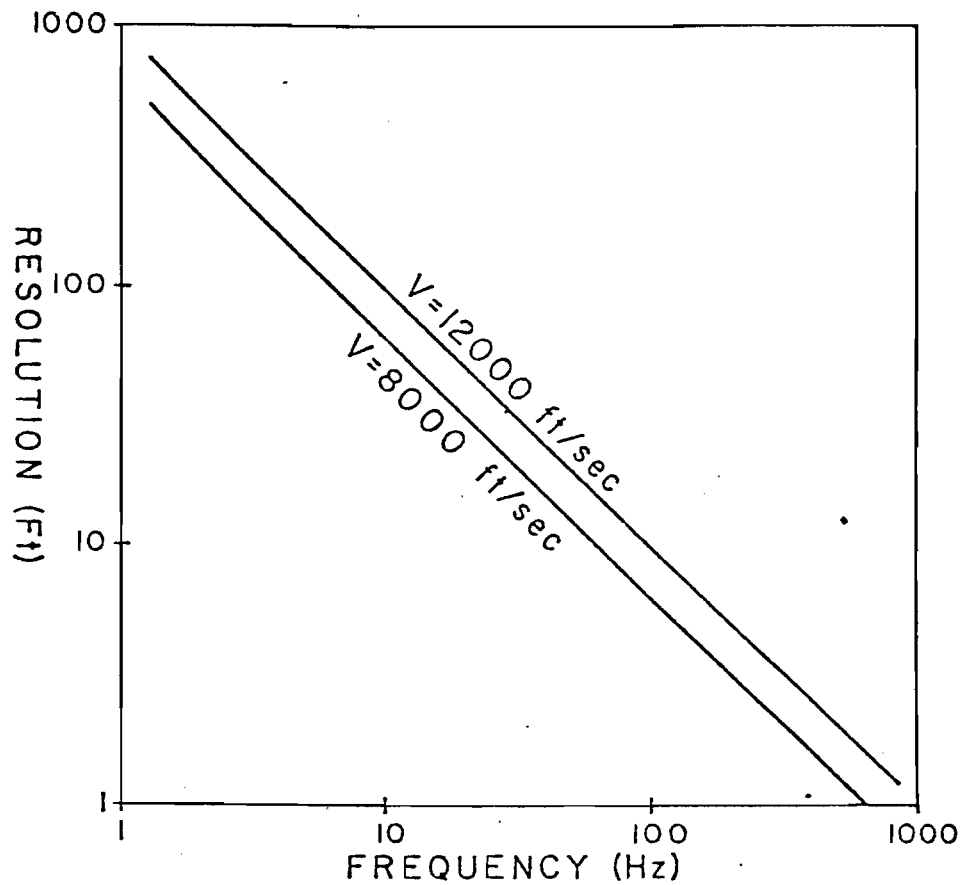

Figure 1 Resolution as a function of frequency for velocities common to the Forest Glen site.

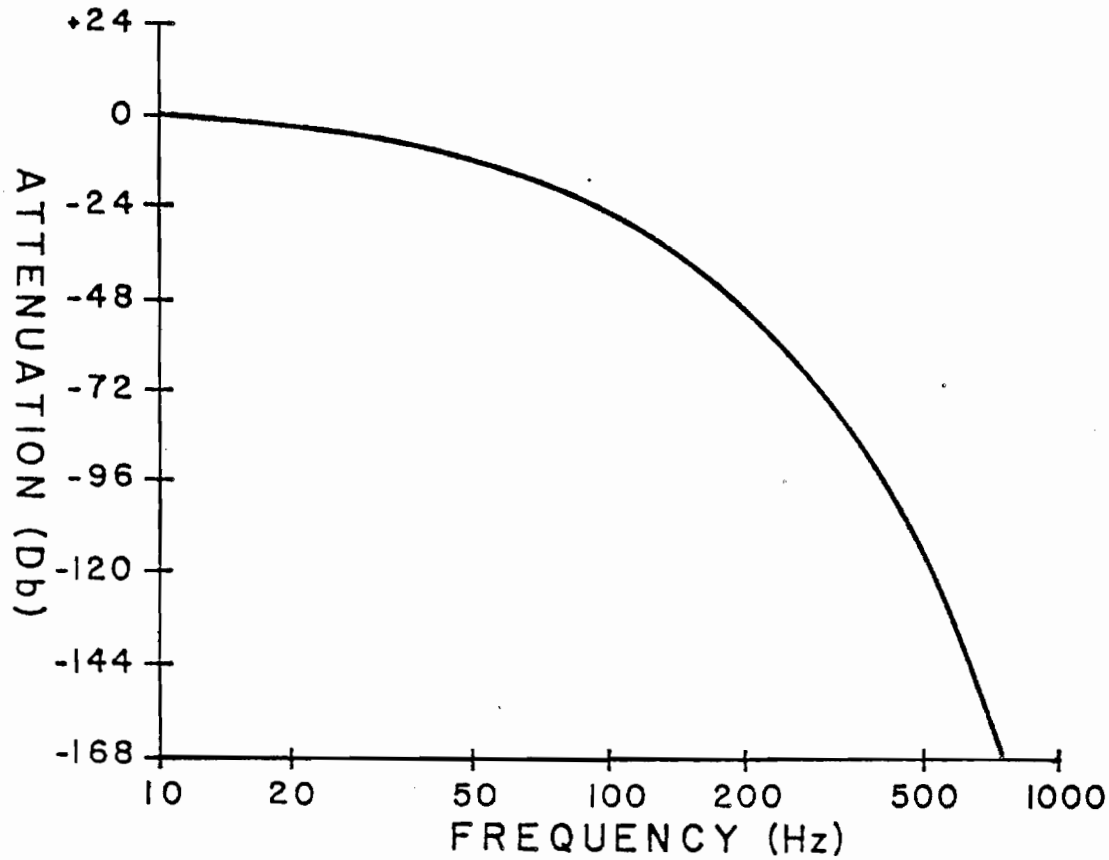

Figure 2 Generalized earth attenuation curve

much higher amplitude than the high frequency waves. This usually means that the high frequency signals are lost amongst the low frequency waves.

In order to alleviate this problem a combination analog filter and amplifier is used whose filter and amplification function can be adjusted to approximate the inverse of the earth attenuation function shown in Figure 2. The response of this filter at one of its available gain settings is shown in Figure 3.

Signals are detected with special purpose sensors or geophones that are designed specifically to detect high frequency waves. The response of one of these sensors is shown in Figure 4. Note that the sensors in and of themselves discriminate against the low frequency waves because of their unique response curves.

Once the signals are detected by the sensors another problem exists. This problem is that these high frequency signals are often of very low amplitude. Analog methods of signal amplification are not applicable here because the large degree of amplification required introduces too much noise into the system, and further the amplified background noise often masks the high frequency signals. For this reason an in-field digital stacking procedure is used to enhance the low amplitude high frequency signals and at the same time discriminate against random background noise.

In order to accomplish this, each channel of the seismograph that receives a signal from a sensor has associated with it an active digital memory.

This digital memory is used as follows to enhance or amplify the signal received from the sensors. Each time the ground is impacted and the resultant signal is received at the sensor the signal is stored in the active digital memory. Multiple impacts of the ground at the same point permit the signal from each of these impacts to be added together digitally within the active memory. This in effect allows the random background noise that often exists at many sites to be discriminated against and at the same time enhance the desired signals. A simplified example of this signal enhancement process is shown in Figure 5. Note that after the initial impact, the reflection is not readily discernible from the background noise but as the impacts are added together the reflection becomes much more apparent.

Once the signals from each channel of the seismograph are enhanced to an easily recognizable form they are played onto a digital recorder for later processing back at the computer center at West Virginia University. This data is then processed as any other seismic data.

In order to obtain an accurate determination of depth to the various boundaries of the different earth materials it is crucial that an accurate determination of the velocity distribution in the subsurface is known. Often it is difficult to obtain accurate velocity information at small construction sites where space constraints limit the length of the geophone spread. For this reason at such sites it is necessary that the velocity data be obtained by down hole velocity logging techniques.

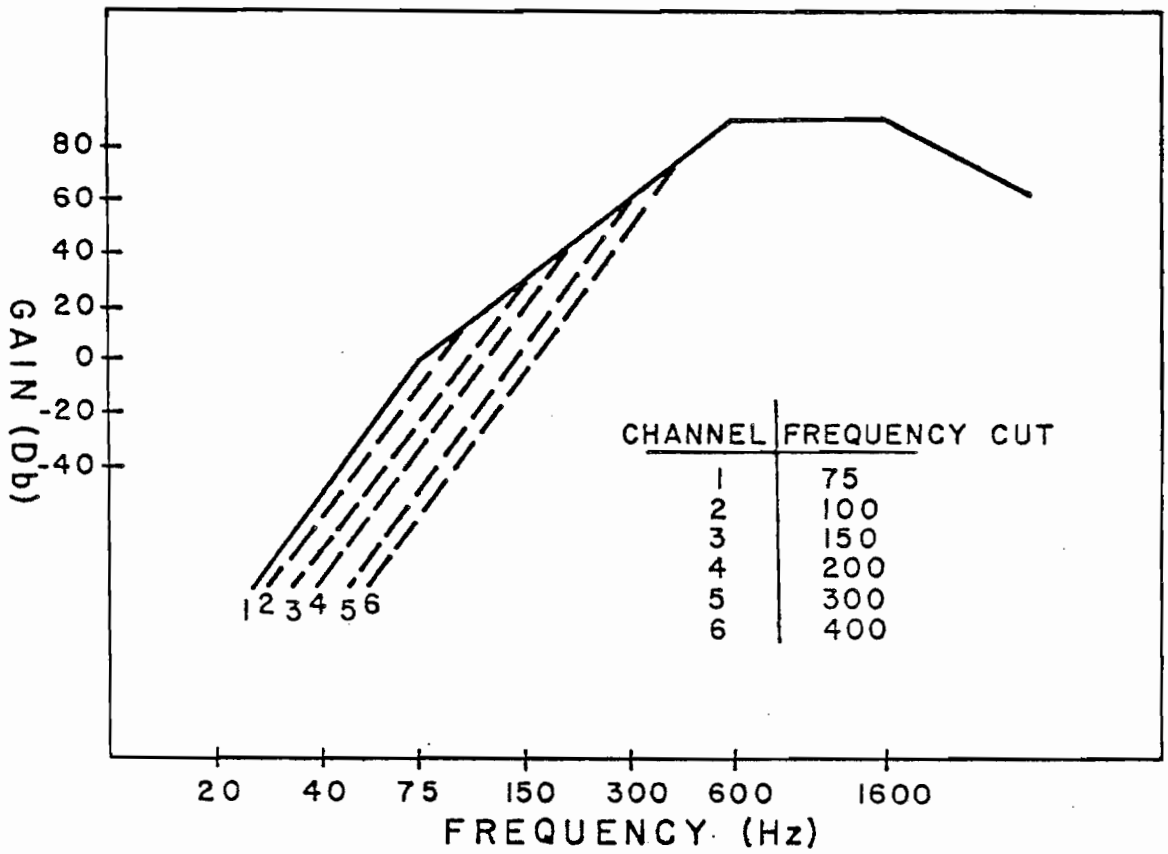

Figure 3. Amplifier response curve for a given gain setting.

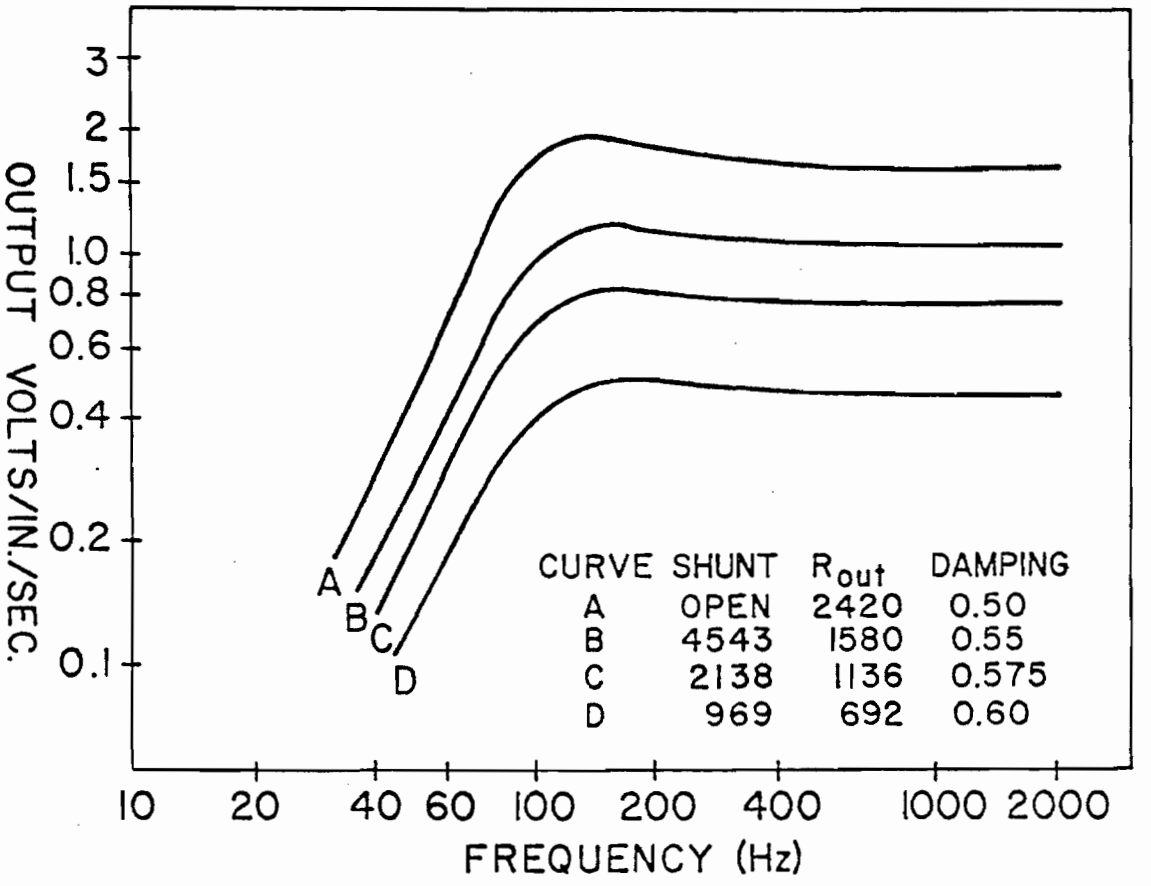

Figure 4 Geophone response curve

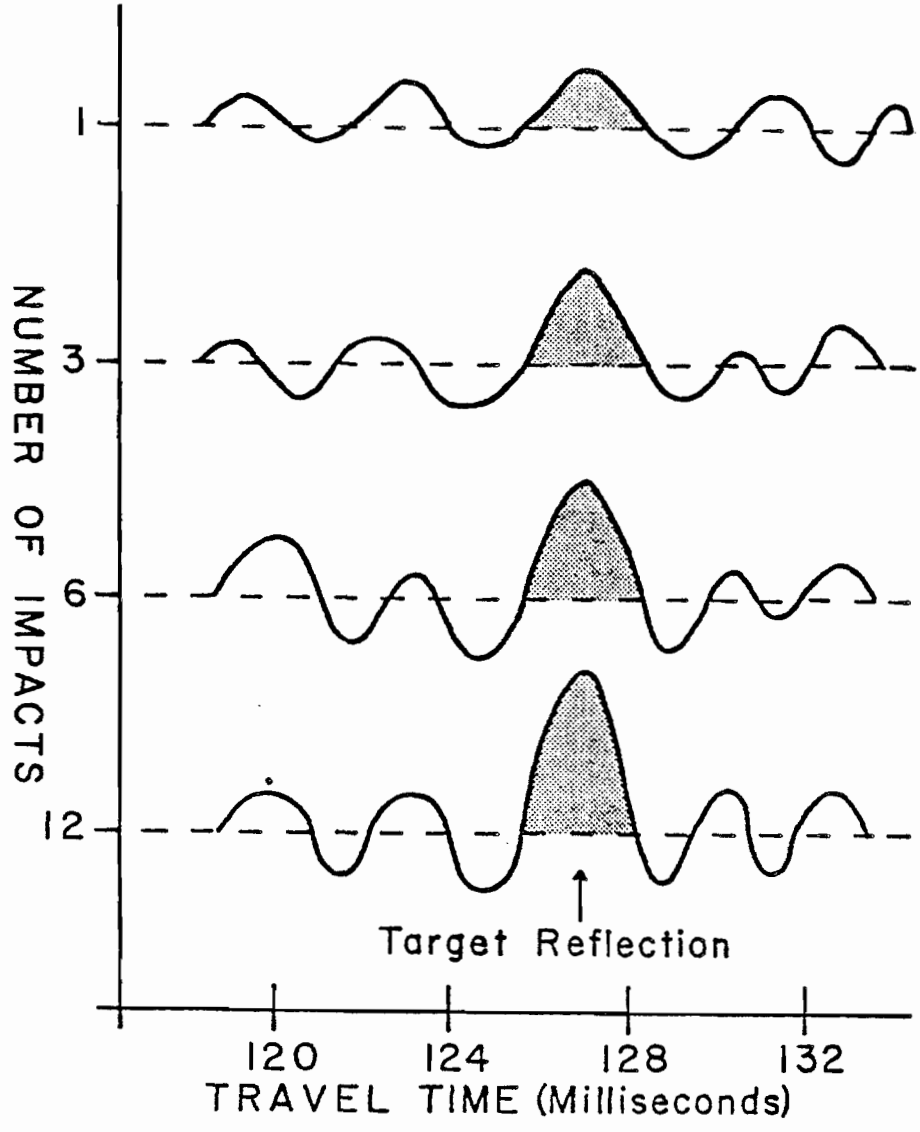

Figure 5 Simplified example of signal enhancement process. As the number of impacts increase the target reflection becomes more apparent.

At the Forest Glen site this velocity logging was performed by Birdwell. It is this velocity data that was used to interpret and model the seismic reflection data in this report.

DESCRIPTION OF FIELD WORK

The field work from which this report follows was performed on December 15 thru December 20. The Forest Glen site presented some difficult problems with regard to obtaining useful seismic data. The two biggest problems were the large amount of background noise and the large attenuation of high frequency seismic waves.

The interfering background noise at the Forest Glen site was extremely severe because of the close proximity of the site to Georgia Avenue and to a lesser degree the Washington Beltway (U.S. Route 495). After one day of unsuccessful data collection due to this background noise, it was decided that the only plausible solution to this noise problem was to work in the evening. We found that the traffic was reduced to an acceptable level between the hours of 1:00 AM and 6:00 AM provided that tests were performed during interludes in passing vehicles. The first evening's work uncovered another noise problem that has been noted by other seismic investigations in urban areas. A high frequency (approximately 2000 Hz) signal was observed when the geophones were placed in close proximity to Georgia Avenue. It is not completely certain what the source of this high frequency noise was; however, past experience has shown that this type of noise is often associated with a leaking water main, the high frequency noise being generated at the leak. This necessitated keeping the geophones as far away from Georgia Avenue as possible.

The second major problem associated with the Forest Glen site is that the unconsolidated material, in this case a saprolite overlying the bedrock strongly attenuated the high frequency components transmission to the subsurface. The first evening's work was only able to detect frequencies less than 37 Hz which is far too low for high resolution work. Another inconvenience was a continuous rain throughout the entire field program. This inconvenience actually aided in the transmission of the high frequency waves.

During the fourth evening of field work the ground apparently became saturated to the point where high frequency waves could be transmitted. At this time, frequencies up to 154 Hz were transmitted and received by the HRS system. This frequency (154 Hz) was the highest frequency that the earth materials transmitted successfully at the Forest Glen site. One hundred fifty-four Hz was a much lower frequency than what was originally anticipated that could be used at the site. It had been anticipated that 350 Hz could be used here but this estimate was incorrect.

Because of space constraints and obstructions such as trees and trailers along with the high frequency noise problem associated with Georgia Avenue, the only successful seismic line was that line that ran from the southeast corner of the site to the northwest corner.

ANALYSIS OF FIELD DATA

The first step in the analysis of this data involved modeling the velocity data obtained from the Birdwell logging services that were performed at the site. This modeling procedure was complicated by the fact that the Birdwell velocity data did not include velocity information for depths less than 100 feet in the case of hole T-3. A preliminary refraction survey by West Virginia University resulted in near surface (less than 30 feet) velocity information; a data gap of approximately 60 feet exists. For this reason an accurate determination of the depth to the reflection horizon is impossible. However, a reasonable determination of the depth to the reflecting horizon was possible based on the comparison between the modeled data and field data. It was assumed, based on the logging data and the refraction data that the average velocity for the first 100 feet of unconsolidated material was 4500 feet/second. This would result in a two way travel time of 44 milliseconds.

The field data showed the strongest reflection at a two way travel time of 57 ms. A reflection also occurred at 167 ms. A synthetic seismogram was prepared for well T-3. Programs developed at the Morgantown Energy Research Center were utilized for this purpose. The synthetic seismogram is shown in Figure 6. The major reflection occurs at approximately 53 to 60 ms. This reflection is caused by the high reflection coefficient that occurs at 119 feet depth on the modeled test hole T-3. This reflection coefficient corresponds with the reflection coefficients at 47 ms on Figure 6. This 119 foot depth appears to correlate with the transition point in the gamma-gamma density logs provided by the Tennessee Valley Authority for T-3. It should be noted that T-3 is a deviated hole and the true depth to this zone is less than 119 feet. However, the significant factor is that the density contrast at this point was detectable at shallow depth by the HRS system even under the extremely adverse conditions encountered at the Forest Glen site.

The 53 ms reflection horizon appears to deepen as one moves along the seismic line from the northwest corner of the site to the southeast corner. Correcting for normal moveout the reflected horizon arrives 7 ms later at the southeast corner of the site than at the northeast corner. From examining the available boring data, it appears as if this reflection horizon is caused by the physical transition between the weathered rock and the highly jointed rock as indicated on drawing F-G-82B.

The reflection at 167 ms occurs below the depth of investigation and since there is no available velocity data at this time interval a depth determination cannot be made.

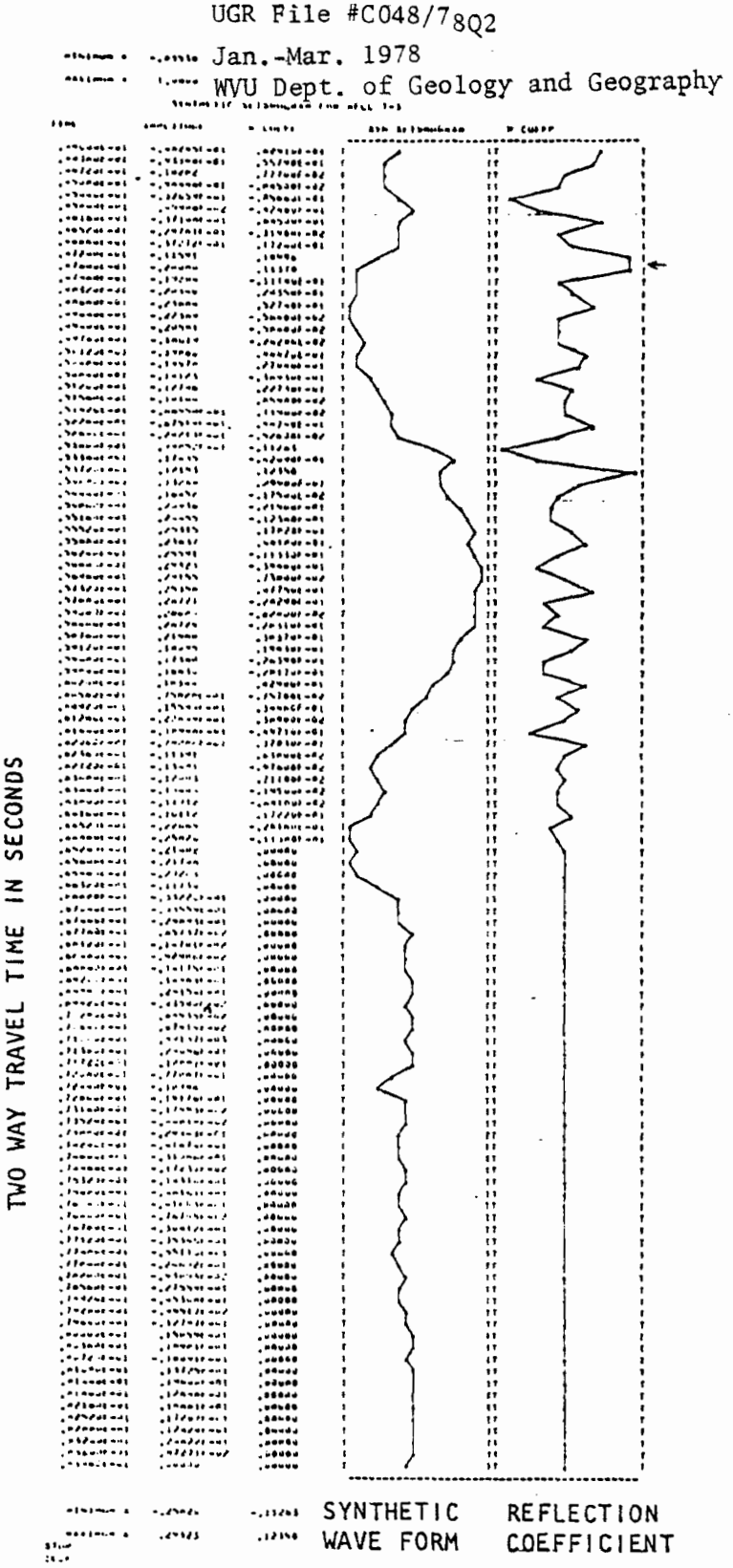

Figure 6 Synthetic seismogram taken from velocity data from test hole T-3. The synthetic wave form and reflection coefficient are plotted against two way travel time.

SUMMARY

The HRS survey performed at the Forest Glen test site was not extremely successful in detailing the subsurface. Primarily this was for two reasons, the large quantity of noise at the site and the unconsolidated materials' large attenuation of the high frequencies that are required for the high resolution work. The maximum detectable frequency was 154 Hz. It had been expected that at least 350 Hz could be used at the site. The 154 Hz frequency limited the resolution of the survey.

The noise at the test site prevented all but one successful seismic line. This line showed a strong reflection at 53 milliseconds. The reflection corresponds to a depth of approximately 120 feet based on a synthetic seismogram generated from the velocity data of deviated bore hole T-3. An accurate determination of the depth to this reflection is not possible since there is a 60 foot gap in the available velocity data.

The reflecting horizon associated with the 53 ms reflection deepens from the northwest corner of the site towards the southeast corner.

It would appear that from this test data that the HRS system, that has proved so effective in the sedimentary terrain of West Virginia, has limited application in igneous terrains due to the occurrence of thick saprolites that attenuate the high frequency waves to a large degree.

Seismic surveys can be successfully performed in urban areas provided the data is collected late at night to minimize the effects of noise created by traffic.

EASTERN GAS SHALES PROJECT OPEN FILES

DOCUMENT TRANSMITTAL FORM

TITLE: Quarterly Progress Report - West Virginia University Department of Geology and Geography., Robert C. Shumaker, Project Director. 27pp.

DATE: July 1978

OPEN FILE NO. UGR - 048/7803

ORGANIZATION PERFORMING WORK:

WVU Department of Geology and Gepgrap-y

TYPE OF DOCUMENT:

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MAP ____

CHART ____

LOG ____

UNPUBLISHED MANUSCRIPT ____

OTHER DATA XX

Quarterly Report

PREPRINT ____

SUGGESTED CROSS REFERENCES:

TITLE

WVU - Dept. of Geology and Geography

U.S. Dept. of Energy -

Contract #EY-76-C-05-5194

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Department of Geology and Geography

College of Arts and Sciences
Morgantown, West Virginia
26506

West Virginia
University

July, 1978

Department of Energy
Contract Division
RCP & R Branch
P. O. Box E
Oak Ridge, TN 37830

Gentlemen:

Enclosed please find the Quarterly Progress Report for Contract No. EY-76-C-05-5194 for the months April, May, and June, 1978, submitted by West Virginia University, Department of Geology and Geography, Robert C. Shumaker, Project Director.

RCS/jt

EGSP
OPEN FILE #048/78Q3

QUARTERLY PROGRESS REPORT

U. S. Department of Energy Contract No. EY-76-C-05-5194

April - June 1978

submitted by:

Department of Geology and Geography
West Virginia University

Robert C. Shumaker, Project Director

co-authored by:

Keith G. Kirk, E. B. Nuckols III,
Brian R. Long, Henry W. Rauch,
Thomas H. Wilson, Jeanette M. Dixon,
Mark Evans, J. Negus de Wys

Principal Investigators

1.0 EXECUTIVE SUMMARY

QUARTERLY REPORT: ERDA CONTRACT EY-76-C-05-5194

April - June 1978

1.0 EXECUTIVE SUMMARY

The following are significant events which occurred during the third quarter of the contract year, 1977-1978.

Regional structure - All regional structure maps (Table 1) for which data is readily available and as listed in our contract have been completed in rough draft or preliminary map form. We are making arrangements through DOE-MERC for the printing of the Preliminary Map Series to be distributed to EGSP contractors. The complete series will have 32 different map quads covering our contract area (Figure 1) published at 1:250,000 scale. Publication of these maps will, for the first time, make all regional structure data available at the scale of the USGS base for comparison with other shale parameters being posted at the same scale.

Production studies - Our production study of the Cottageville gas field is drawing to a close. We have submitted to DOE-MERC one manuscript (de Wys and Shumaker, in publication), and a second more comprehensive study (Nuckols, in preparation) will be complete early next quarter. After review and approval, it will be submitted to DOE-MERC for publication.

Attached is a copy of a completed report by Jones and Rauch on ground-water quality and productivity in the Cottageville area. Correlations between low-altitude photolineaments and water well productivity has been established in that area. Preliminary results which show relationships among certain well parameters, short lineaments, and shale gas productivity are being further investigated, and results will be reported at the EGSP October meeting. Progress is encouraging in this area of our program, and it warrants an expanded effort next year. Thus far, no coincidence is apparent between lineaments as mapped on high-altitude or satellite imagery and the northeast trending line of highly productive wells located along the axis of the field. During the quarter a second field, the Midway-Extra shale gas field was selected for study, and data will be collected there during the upcoming quarter.

During the next quarter, we will be moving our high-resolution experimental seismic equipment into Cottageville field to investigate shallow structure adjacent to certain of the highly productive gas wells.

With the completion of this seismic study, we will have documented the relationships of production and geology within the field.

It would seem to be an appropriate time to plan for a work conference of contractor scientists who have studied the field to appraise and to integrate the results of the several individual studies. This group should assess if further research is warranted or if drilling additional wells in or adjacent to the field is advisable.

Emphasis in our production studies is now shifting to collecting geologic and open-flow production data in the large Eastern Kentucky shale gas field. Our analysis of this field, clearly the foremost of its kind in the United States, if not the world, is fundamental to resource evaluation goals of the EGSP program. The availability of data from Kentucky-West Virginia Gas Company will form the basis for understanding the origin and nature of gas occurrence and production for this unknown giant. The level of funding for this study may determine the level of our understanding of shale gas production. The study plan will parallel and enlarge on that established for Cottageville, but clearly the field is very different from Cottageville if for no other reason than its size, over 100 times the size of Cottageville. We expect that Eastern Kentucky will hold many surprises concerning inter-relationships of stratigraphy, structure, geochemistry, and gas occurrence and production.

Geophysical studies - Progress on this program has been delayed by a number of mechanical malfunctions and certain design problems associated with our experimental system. Inasmuch as this research and development program involves newly designed equipment, such delays, while frustrating, must be expected. The delays have centered primarily on (1) modification of equipment and (2) testing of the reliability of an effective high-frequency seismic energy source. We expect to have problems associated with our newly designed acetylene "popper" resolved. However, if the problems persist we will revert to dynamite shooting for the field program this summer. We are presently shooting our second test site to evaluate the resolution capabilities of the system and to locate fractures at test site II (Figure 1). This test area is the DOE-MERC underground coal gasification site in Wetzel County, West Virginia. As digitally recorded seismic data is received from the field site, we must reformat that data and develop programs to display the results in typical cross section form. Upon completion of shooting the second site, we will move to the Warfield test site (Figure 1, Site III) and then to the Cottageville Field area for the most critical test of the system. As indicated above, we will shoot across the trend of highly productive wells to determine if subsurface fractures can be directly detected.

Fracture studies - During the past quarter, results of our preliminary study of fractures found in oriented cores were submitted to DOE-MERC for publication (Shumaker, and Wilson, et al.). The essence of these preliminary results is that shale gas production from eastern Kentucky and southern West Virginia comes, not from the entire shale section, but from zones or layers of more intense fracturing which are generally found associated with the lower shales and most often the organic rich portions of the shale. The association of mineralized fractures, slickensides, and more numerous natural fractures in a "fracture facies" suggest that the facies developed as a result of differential shortening across over-pressured organic-rich beds within the Devonian shales. Our efforts now center on further documentation and analysis of fractures as they are found both in cores and in the field. It is our intent to integrate the fracture analysis of each core with local shale gas production and geology, and then integrate those results into the broader structural framework to test the validity of the fracture facies-differential shortening interpretation presented above or to develop a better interpretation; or perhaps even to delineate the areas where a particular type of fracture porosity occurs. At the present time, we are studying the Devonian shale outcrops in eastern Kentucky, and we will be studying the Pine Mountain Thrust area in the beginning of next quarter to determine if the same types of fractures occur in those areas as were found within the cores last winter (Shumaker, and Wilson, et al.). In addition, we should complete reports on the fractures logged in the Mason County, West Virginia, core and the DOE-MERC core. All of these reports will go on open file, and they will be summarized for the EGSP meeting at Morgantown in October.

Surface studies - Intensive geologic analysis of selected surface structures that might have productive subsurface analogues started during this contract year. This past quarter field work was initiated for studies in three topical areas: (1) deformation of rocks equivalent to Devonian shale in the Middle Mountain syncline of the Valley and Ridge province, (2) testing approaches to the analysis of fracture density in the Plateau portion of West Virginia across the Parsons lineament, and (3) late stage deformation of folds which creates open fractures within fold limbs within the Plateau and Valley and Ridge provinces.

REFERENCES CITED

de Wys, J. Nègus and Shumaker, R. C., 1978, Pilot Study of Gas Production Analysis Methods Applied to Cottageville Field

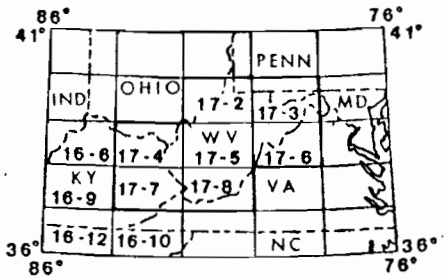
Nuckols III, E. B., 1978, Exploration Parameters Derived from Historical Devonian Shale Production in Western West Virginia

REFERENCES CITED - continued

Shumaker, R. C., 1978, Porous Fracture Facies in Devonian Shales of Eastern Kentucky and West Virginia; for the proceedings volume of the Geological Society of America, Southeastern Section Symposium entitled: Western Limits of Detachment and Related Structure in the Appalachian Foreland.

Wilson, T. H., Dixon, J. M., Shumaker, R. C., 1978, Fracture Patterns from Oriented Cores of the Devonian Shale in the Appalachian Basin; for the proceedings volume of the Geological Society of America, Southeastern Section Symposium entitled: Western Limits of Detachment and Related Structure in the Appalachian Foreland.

		PreCambrian	Base of Knox	Top of Ordovician	Newburg	Onondaga	Devonian Shale			Tully	Berea	Greenbrier	Surface Form	Surface Tectonic	Shale Outcrop	Joints	Linears	Drainage	Devonian Oil & Gas		
CONTRACT AREA	CLARKSBURG 17-2	◕	◑	◕	◕	◕				NO DATA		◕	◑	◔			U.S.G.S.	◑	◕		
	CUMBERLAND 17-3	◕		◑	◑	◕						◕	◑						○		
	HUNTINGTON 17-4	◕	◑	◕	◑	◕	◔				◕	◕	◑	◔	◑	◑		◑	◕		
	CHARLESTON 17-5	◕	◑	◕	◕	◕					◕	◕	◑	◔				◑	◕		
	CHARLOTTESVILLE 17-6	◕				◕						◕							○		
	JENKINS 17-7	◕	◑	◑	◑	◕	◔				◕	◕		◔		◑			◕		
	BLUEFIELD 17-8	◕	◑	◕	◕	◕					◕	◕	◑	◔				◑	◕		
	LOUISVILLE 16-6												◑	◔							
	WINCHESTER 16-9												◑	◔							
	CORBIN 16-12												◑	◔							
	JOHNSON CITY 17-10												◑	◔							



REGIONAL STRUCTURE MAP STATUS

R. C. SHUMAKER

SCALE 1:250,000

- ○ Formation or production not present
- ◔ Compiling data
- ◑ Rough copy completed
- ◕ Preliminary draft completed
- ● Final map completed

Table 1.

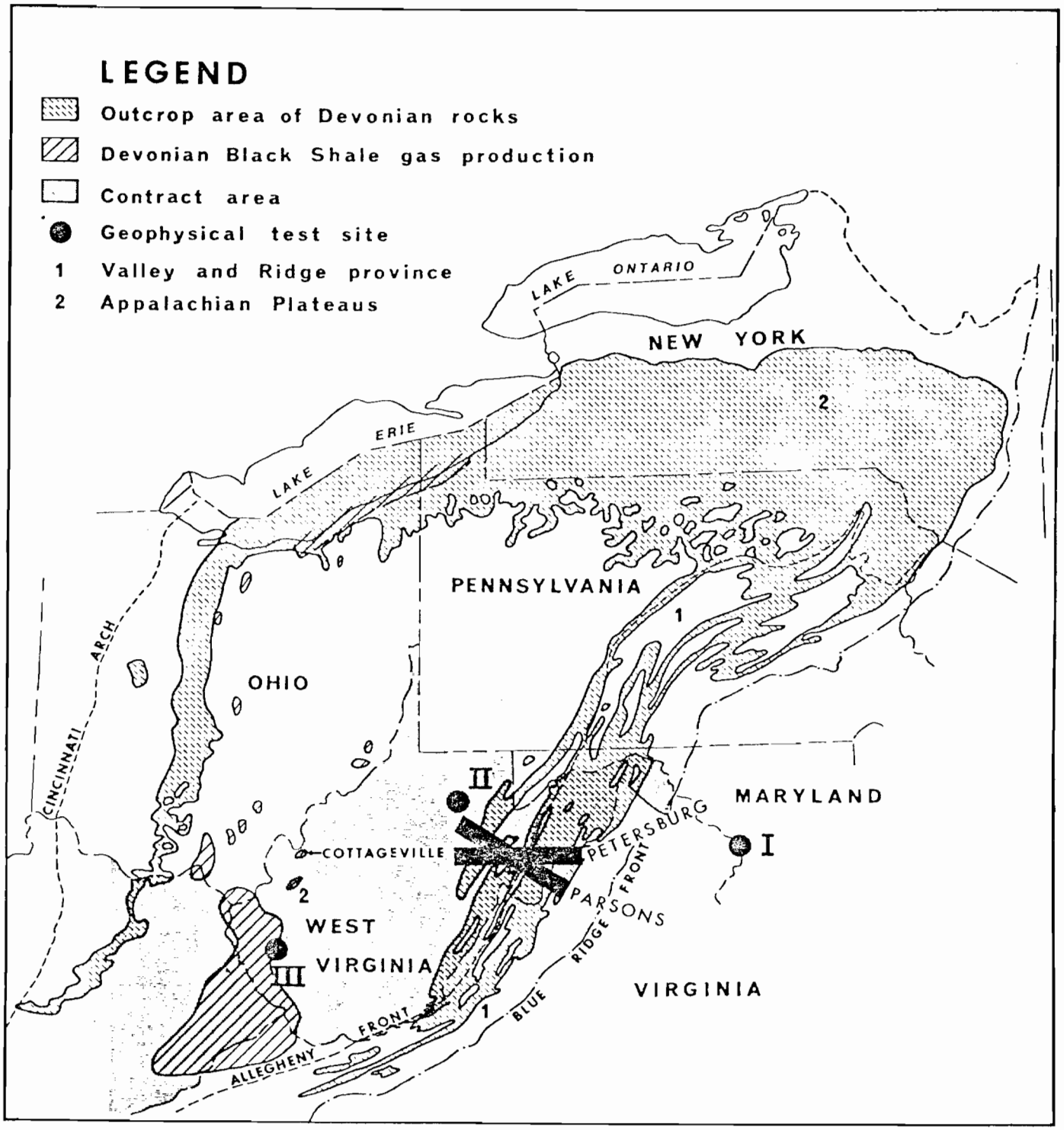

LEGEND
Outcrop area of Devonian rocks
Devonian Black Shale gas production
Contract area
Geophysical test site
1 Valley and Ridge province
2 Appalachian Plateaus
LAKE ONTARIO
NEW YORK
LAKE ERIE
PENNSYLVANIA
OHIO
CINCINNATI ARCH
MARYLAND
COTTAGEVILLE
PETERSBURG
PARSONS
BLUE RIDGE FRONT
WEST VIRGINIA
VIRGINIA
ALLEGHENY FRONT
I
II
III
1
2

Figure 1.

2.0 CONTRACT OBJECTIVES

2.0 CONTRACT OBJECTIVES

Collect, compile and analyze geological data and prepare geological structure maps for eastern Kentucky and western West Virginia.

Determine if structural types and styles and surface lineations for productive areas of the Black Shales differ from those in non-productive areas.

Identify and define along with other contractors those geologic parameters that control gas production from the shales.

Determine the feasibility of using shallow penetration resistivity and seismic surveys to detect near surface faults and fractures and demonstrate their relationship to lineations observed on airborne imagery.

Determine if a relationship exists between ground water movement and shale gas productivity.

In conjunction with other contractors develop a method for selecting areas for drilling shale wells that have a potential for gas production.

3.0 TECHNICAL PROGRESS

3.1 Work Package 2100-2-1 STRUCTURE CONTOUR MAPS — Robert C. Shumaker

3.1.1 Current status of work and scheduled deliverables

We are to complete preliminary structure maps as listed in the contract. We have completed all maps for which data are available and they are ready for printing.

3.1.2 Problem areas and suggested improvements

None

3.1.3 Work plan for next quarter

We are awaiting details for printing, and when notified, we will send the preliminary structure maps for printing.

3.1 Work Package 2100-2-2 STRUCTURE STUDIES — Jeanette M. Dixon

3.1.1 Current status of work and scheduled deliverables

Field work for the development and application of measuring systematic-joint intensity has been initiated. The Parsons lineament in western Tucker County is being investigated. About 90% of the data has been collected. There are no scheduled deliverables.

3.1.2 Problem areas and suggested improvements

A field assistant for obtaining and recording data would be valuable for this type of project.

3.1.3 Work plan for next quarter

Field work will be completed and analysis of data will be initiated for the next quarter.

* * * * * * *

3.1 Work Package 2100-2-2 STRUCTURE STUDIES — Thomas H. Wilson

3.1.1 Current status and deliverables

Field mapping and the collection of bedding orientation data within the lower Middle Devonian shales of the Middle Mountain syncline have been completed.

Work has begun on a manuscript titled "Bedding Orientation Contours--their Use and Interpretation," authored by T. H. Wilson and R. L. Wheeler.

3.1.2 Problem areas and suggested improvements

Car troubles forced a week's vacation in June or 6 lost days of field work.

3.1.3 Work plan for next quarter

Additional observations of internal structures within the Middle Mountain syncline will be made in conjunction with the ongoing fracture studies. A geologic and structure map of the area are scheduled for completion in September.

It is hoped that the manuscript on bedding orientation contours will be completed this quarter.

* * * * * *

3.1 Work Package 2100-1-2 FRACTURE DENSITY AND ORIENTATION Thomas H. Wilson

3.1.1 Current status and deliverables

The manuscript "Fracture Patterns in the Appalachian Basin" authored by T. H. Wilson, J. M. Dixon, R. C. Shumaker, and R. L. Wheeler has been completed. Only minor changes are expected at this point. The manuscript will be published in the Proceedings volume of the Geological Society of America's Southeastern Section Meeting on Western Limits.

An examination of space relationships and geometry of fractures found in the lower Middle Devonian shales within the Middle Mountain syncline has begun. This study should lead to a better understanding of the relationships between fracturing and major cross-strike structural discontinuities and be of benefit to the future exploration and extraction of petroleum. With this project still in the design stage, no reliable estimate of completion date can be given at this time.

3.1.2 Problem areas and suggested improvements

None

3.1.3 Work plan for next quarter

As indicated, only minor changes in the "Fracture Patterns in the Appalachian Basin" manuscript are expected.

During this coming quarter, I am planning to make detailed fracture studies along four 3-4 mile long cross sections through the Middle Mountain syncline, where lower Middle Devonian shales are exposed and intersected by the Parsons structural lineament. The cross sections will be arranged one northeast of the lineament, two within, and one southeast of the lineament. It may not be possible to do the cross section southeast of the lineament since the shales appear to plunge out within the lineament and fracture patterns in the underlying Devonian Oriskany exposed southeast of the lineament may be of no comparative value--on the basis of structural complexity and lithology. This could take 8-10 field weeks and thus is not scheduled for completion until next summer, or possibly, during this fall, 1978. However, this project is at best in the exploratory and design phase. An alternate

plan being considered is to examine fracture patterns along the flanks of the syncline which expose the Needmore through Mahantango Formations. This approach, would for the most part ignore the internal structural complexity within the syncline--internal structure which in part define the lineament. Some compromise will end up being made; but in any event, the project will be time consuming, and predictions of a completion date unrealistic at this time.

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3.1 Work Package: 2200-1-2 FRACTURE STUDIES — Brian R. Long

The fracture analysis has been concerned with the statistical comparisons of possible fracture domains in eastern Kentucky shale. Maps showing visually determined major joint sets and their residuals have both been completed. Statistical tests comparing the shale rose composite diagram to a uniform distribution have also been completed. During the next quarter work will begin to separate the fractures into formational age groups. These groups will be used to determine differences in fracture orientation due to age and rock properties.

Field work has begun to gather fracture data in the Devonian shales specifically. During the next quarter this work, gathering of data for fracture domain boundary determination and a possible detailed study of production areas, will be completed.

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3.1 Work Package: 2200-1-2 FRACTURE DENSITY AND ORIENTATION Mark Evans

3.1.1 Current status and deliverables

Work is ~10% complete. There are no scheduled deliverables for this quarter.

- o Mason County core fractures and MERC #1 core fractures have been logged, described, and photographed.
- o Rose plots and stereographic projections have been completed for both cores.
- o Work has begun on a fracture report for the Mason County core.

3.1.2 Problem areas and suggested improvements

The $100.00 per month limit on computer use may not be sufficient. $125.00 per month would be better.

3.1.3 Work plan for next quarter

3.1.3.1 Complete Mason County fracture report.

3.1.3.2 Continue statistical analysis on MERC # 1 fracture report.

3.1.3.3 Complete MERC # 1 fracture report.

3.1.3.4 Start fracture study on two Lincoln County cores.

3.1.3.5 Take a closer look at the mineralization in the fractures of the cores being studied.

* * * * * * *

3.1 Work Package 3200-5-1 PRODUCTION STUDIES — E. B. Nuckols III

Production characterization of Devonian Shale in the Cottageville Gas Field has been completed. A final report has been initiated and will be delivered to MERC approximately August 1, 1978. Upon completion of this report and some details following it, I will be terminating my University involvement with the Eastern Gas Shales Program (approximately mid-August).

Some difficulty is being experienced in completing all the necessary drafting for the final report. This problem may cause a delay in the arrival of final drafted maps until sometime later in August.

During the last quarter all structure maps and structural cross sections were completed. Close examination of structure maps and cross sections with production maps has shown a strong correlation between structural changes and gas production. Maximum gas production in the Cottageville Field falls along a flexure arm found on Berea, Huron and Onondaga structure maps. It is my belief that fracturing above these flexure areas has been the producing mechanism for Devonian shale gas in the Cottageville Gas Field.

* * * * * * *

J. Negus de Wys

3.1 Work Package: 2100-1-1 CROSS SECTIONS

3.1.1 Current status of work: ~20% completed

Scheduled deliverables: none

- Log correlation: 40 logs
- Data posting and compilation from correlated logs completed.
- Three preliminary cross sections in two modes completed and reviewed by Kentucky-West Virginia Gas and Kentucky Geological Survey.
- Drafting of preliminary cross sections in progress.
- Well samples from 10 wells obtained and prepared for lithologic and geochemical study.
- Martin County and Perry County cores examined and sampled in Lexington for comparison with well cuttings.
- *Protosalvinia* zone identified in Martin County and Perry County cores.
- Meetings attended per monthly reports.

3.1.2 Problem areas and suggested improvements

3.1.2.1 I could use a better microscope, light source, and camera setup to great advantage!

3.1.3. Work plan for next quarter

3.1.3.1 Correlate more logs! (300 in all to be correlated)

3.1.3.2 Complete 4 more cross sections.

3.1.3.3 Meet with U.S.G.S. for review of cross sections.

3.1.3.4 Draft cross sections.

3.1.3.5 Initiate lithology study on well cuttings.

3.1.3.6 Initiate API unit counts per unit for facies maps.

* * * * * * *

J. Negus de Wys

3.2 Work Package: 2100-1-2 ISOPACH MAPS

3.2.1 Current status of work: ~10% completed

Scheduled deliverables: none

- Log correlation, data tabulation, and calculations on 40 logs completed. (300 total)
- Base maps drawn and blue-line working copies reproduced.

3.2.2 Problem areas and suggested improvements

3.2.2.1 The separation of the Cleveland Black Shale from the gray shale facies appears rather difficult to justify in the northeastern part of the field. The gray, in my opinion, could be undifferentiated Chagrin and more similar to the Three Lick below. A geochemical approach may help in the solution of this problem. For the present I suggest that I map the Cleveland (Black)-"Undifferentiated Chagrin" (gray) as one unit. The Chagrin Three Lick would also be mapped separately and not included in the unit suggested above. The rationale behind this suggestion is that there is a rather large area of the field where the intertonguing is sufficiently great as to cause any "top" pick for the gray to be rather arbitrary.

A separation could be done at a later date when further analysis has been completed.

3.2.3 Work plan for next quarter

3.2.3.1 Continue log correlation, data tabulations, calculations.

3.2.3.2 Plot data on maps.

* * * * * * *

J. Negus de Wys

3.3 Work Package: 2100-2-1 STRUCTURE CONTOUR MAPS

3.3.1 Current status of work: ~20% completed

Scheduled deliverables: none

- Three preliminary structure maps completed and have been reviewed by Kentucky-West Virginia Gas and Kentucky Geological Survey. Drafting is in progress.
- A three-dimensional stratigraphic-structural model is being constructed.

3.3.2 Problem areas and suggested improvements

3.3.2.1 Release of basement seismic map being negotiated. Still lack one company's release.

3.3.2.2 A study of top of the Sunbury has been suggested by Ernie Jenkins. This study could be done from drillers' logs on almost 5000 wells, and would give a fair indication of area structure. The present study is using 300 electric logs and the top of the Berea.

3.3.3 Work plan for next quarter

3.3.3.1 Correlate additional logs required for four more cross sections.

3.3.3.2 Construct cross sections.

3.3.3.3 Construct fence diagram of all sections completed.

3.3.3.4 Construct three-dimensional model.

* * * * * * *

J. Negus de Wys

3.4 Work Package: 3200-4-1 OIL AND GAS MAPS

3.4.1 Current status of work: 15% completed

Scheduled deliverables: none

- o Two pattern recognition maps completed at 4 level breakdown of initial open flow data and 2 level breakdown on ~5000 wells.
- o Drafting of same in progress.
- o Nearest neighbor trend analysis initiated on four-level breakdown.
- o ~5000 points (wells) digitized by location by West Virginia Geological Survey.
- o Initial open flow data for ~5000 wells punched on cards.
- o Checking of data in progress.
- o Programmer working with SYMAP program for computerized map print out. Trial map run successful.
- o Gas occurrence noted on 60 temperature logs. To be included on cross sections.

3.4.2 Problem areas

150 wells in the field have been treated. Kentucky-West Virginia Gas will supply a list of wells. These will be removed from program.

3.4.3 Work plan for next quarter

3.4.3.1 Continue trend analysis.

3.4.3.2 Obtain first SYMAP computer map printout of contoured initial open flow data.

3.4.3.3 Adjust map program as deemed necessary for desirable results.

3.4.3.4 Initiate hand contouring of data.

3.4.3.5 Attend Sclumberger log interpretation school.

* * * * * * *

J. Negus de Wys

ABSTRACTS AND REPORTS THIS QUARTER

- o Abstract and Report on Pilot Study of Cottageville Production for Tulsa DOE meetings in August
- o Abstract and Report on Eastern Kentucky Gas Field(s) for Tulsa DOE meetings in August
- o Oral Report on Pilot Study of Cottageville Production given at MERC Stimulation Symposium
- o Abstract and Final Draft of Pilot Study of Cottageville Production to MERC for Technical Series publication
- o Abstract of study and conclusions on Pilot Study of Cottageville Production for Eastern Devonian Gas Shales Symposium to be held at Lakeview in October
- o Abstract of study of Eastern Kentucky Gas Field(s) for Eastern Devonian Gas Shales Symposium to be held at Lakeview in October

NEXT QUARTER

1. Slide preparation for Cottageville production paper in Tulsa in August
2. Slide preparation for Eastern Kentucky paper in Tulsa in August
3. Report and slide preparation for paper on Cottageville at Lakeview in October
4. Report and slide preparation for paper on Eastern Kentucky at Lakeview in October

* * * * * * *

3.1 Work Package 2100-1-1 SEISMIC — Keith Kirk

3.1.1 Current status and deliverables

The third quarter of 1978 was spent testing the new acetylene energy source, performing site preparation tasks at one of the test sites and collecting data at that test site. Near the end of the third quarter the second geophysicist position was finally filled. So work now is progressing on this task at a faster rate.

The preparation and data collection took place at the test site in Wetzel County, West Virginia. The data collected at this site will be analyzed during the fourth quarter.

3.1.2 Problem areas and suggested improvements

Several equipment problems developed during the third quarter. The acetylene cannon energy source that was developed and built during the last part of the second quarter was tested and two problems were discovered. The first problem is associated with the electronics of the cannon. In order to fire the cannon an electrical high voltage coil is energized prior to cannon detonation. After detonation a high voltage oscillation occurs through the common ground to the equipment. This causes an artificial wave form to be introduced into the seismic record that is difficult to distinguish from a reflected arrival. This problem has been partially solved by extensive shielding and capacitive filtering of the energy source.

The second problem associated with the acetylene cannon is that when the cannon fires in a water filled hole, the vacuum that is created shortly after the gas mixture is ignited causes a rapid influx of fluid into the firing chamber. This in turn causes the cannon to misfire. Several approaches have been tried in order to solve this problem; none of them have been successful in solving it. This leads to a third problem and that is the absence of an effective energy source. Temporarily this problem has been solved by using explosives as the primary energy source until the problems with the acetylene cannon can be solved.

Keith Kirk

3.1.3 Work plan for next quarter

Now that the second geophysicist position is filled and the geophysicist is on line, two phases of work will progress during the fourth quarter. These are the data collection phase and data analysis and display phase.

The data collection phase using an explosive energy source will take place at the remaining two test sites. This data collection will be in conjunction with Task 3200-2-3 (Surface Resistivity).

The data analysis and display phase has already started taking place. Software programs will continue to be developed to analyze the seismic data and programs will be developed to plot the data so that it is presentable in a usable display form.

* * * * * * *

3.1 Work Package 3200-2-3 SURFACE RESISTIVITY — Keith Kirk

3.1.1 Current status and scheduled deliverables

Work is on schedule, surveys have been completed over select areas of the groundwater study area (Task 3200-1-2). This data is being analyzed as part of the groundwater task. There are no deliverables scheduled for this quarter.

3.1.2 Problem areas and suggested improvements

None

3.1.3 Work plan for next quarter

Next quarter will be spent collecting data over selected sites in Logan County, West Virginia, and in the Cottageville Gas Field.

* * * * * * *

3.1 Work Package 3200-1-2 SUBSURFACE GEOLOGY — Henry Rauch

Subtask - Identify 3 areas in which to conduct ground water studies.

3.1.1 Current status of work and scheduled deliverables

A ground water study has been completed in the Cottageville study area, and a second such study has been organized in the Midway Extra gas field area, in northern Putnam County.

3.1.2 Problem areas and suggested improvements

There have been no problems in selecting and planning ground water studies to date. Our only problem is a time delay of one month in initiating field work on the Midway Extra study, due to a necessary summer geology course taken by the student investigator involved. That delay is not a significant one with regard to the whole time scale of this project phase.

3.1.3 Work plan for next quarter

We plan to accomplish all field work related to the ground water study in the Midway Extra area. A brief progress report will appear in the annual report of October 1, 1978.

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3.2 Work Package 3200-2-3 SURFACE RESISTIVITY

Subtask - Conduct resistivity surveys over ground water study areas (defined under 3200-1-2).

3.2.1 Current status of work and scheduled deliverables

All resistivity surveying has been completed with regard to photolineaments in the Cottageville study area. Four resistivity surveys have been conducted across three photolineaments. There are no deliverables scheduled for this quarter.

Henry Rauch

3.2.2 Problem areas and suggested improvements

No new problems have developed recently. The Bison resistivity meter has not worked out as well as expected for resistivity surveying.

3.2.3 Work plan for next quarter

Initiate and complete resistivity surveying across selected lineaments in the Midway Extra study area. A brief progress report will appear in the annual report of October 1, 1978.

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3.3 Work Package - 3200-5-1 STRUCTURE/PRODUCTION CORRELATION

Subtask - Correlate all data and attempt to establish a relationship between geologic features, lineaments, fractures, ground water *, and oil and gas production.

* "Ground water" has just been added to this task for the first time this quarter.

3.3.1 Current status of work and scheduled deliverables

Data comparisons and statistical tests have been performed to test for associations between ground-water data and Devonian shale gas production for the Cottageville study area. Tests to date indicate that short photolineaments of certain orientations and ground water quality (but not yield) are related to production rates from nearby gas wells in the Cottageville area. The only deliverable item (which was unscheduled) is an abstract by D. Scott Jones and Henry W. Rauch. This abstract was delivered in June, and it summarizes associations of ground water data and gas production as known at that time.

3.3.2 Problem areas and suggested improvements

None

Henry Rauch

3.3.3 Work plan for next quarter

A paper will be prepared for MERC's EGSP conference, regarding correlations between ground-water data and gas production in the Cottageville study area. This paper will also be a deliverable item (under item #13) for this quarter.

We will also proceed with an initial analysis of ground water and gas production data for the Midway Extra gas field study area. We will report briefly on progress to date.

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3.4 Work Package - 3200-5-3 LINEAMENT/STRUCTURE CORRELATION

Correlate fractures and lineaments derived from photo analysis with results of ground-water tests to determine if any relationship exists between ground-water production and the occurrence of lineaments.

3.4.1 Current status of work and scheduled deliverables

Work for the Cottageville study area is now complete, and a report meeting the requirements of deliverable item #13 - second part is located in an Appendix to this quarterly report. The report is titled "A Hydrologic Study of Water Well Yields and Ground-water Quality Related to Stratigraphic and Structural Settings in Western Jackson County, West Virginia," by D. Scott Jones and Henry W. Rauch.

3.4.2 Problem areas and suggested improvements

None

3.4.3 Work plan for next quarter

Another deliverable item (under #13 - second part) will be delivered during the next quarter concerning the Cottageville study area. This deliverable is the same paper mentioned under 3.3.3 above, regarding the EGSP conference in October, 1978. We will proceed with an initial analysis of ground water and lineaments for the Midway Extra study area. There will be a brief report on progress, but no deliverable items for next quarter.

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Abstract for Second Eastern Gas Shales Symposium, October, 1978

Influence of Photolineaments on Water Well and Gas Well Yields in the Cottageville Gas Field Area of Jackson County, West Virginia

By D. Scott Jones and H. W. Rauch

Photolineaments were mapped from low-altitude black and white photographs and from large-scale topographic maps for the Cottageville gas field, for comparison with water wells and Devonian shale gas wells. Short straight photolineaments less than one mile in length are significantly associated with both water well and gas well yields, respectively measured in gallons per minute and in MCFPD (initial open flow) units. Water wells located within 100 feet and especially within 50 feet of such a lineament have significantly higher yields than more distant wells. Gas wells have significantly greater yields when located within 0.5 miles of a short straight photolineament oriented west-north-west (WNW), or N 60°W - N 90°W. Median yields are 88-353 MCFPD for the WNW lineament wells, and 15-17 MCFPD for wells near lineaments having other orientations. On the other hand, gas wells have significantly lower yields when located within 0.5 miles of a curvalinear photolineament over one mile in length or within 0.25 miles of a straight Landsat lineament defined by aligned stream meanders. Also, Landsat lineaments have no significant influence on the yields of nearby water wells.

In conclusion, short straight photolineaments have certain positive associations with both water well and gas well yields, whereas Landsat lineaments have no associations or negative associations with water and gas well yields, for the Cottageville gas field area.

1.0 EXECUTIVE SUMMARY

QUARTERLY REPORT: ERDA CONTRACT EY-76-C-05-5194

July - September 1978

1.0 EXECUTIVE SUMMARY

The following are significant events which occurred during the fourth quarter of the contract year, 1977-78.

1.0.1 General Introduction

Our staff's major effort this past quarter was toward presenting the preliminary results of our research to other scientists within the program. We presented orally and wrote two papers for the Enhanced Oil and Gas Recovery and Improved Drilling Methods Meeting at Tulsa, Oklahoma. Five papers were written and are to be presented orally at the Second Eastern Gas Shales Symposium in Morgantown in October. In addition, six poster displays and a three-dimensional model of the Eastern Kentucky shale gas field were prepared for presentation at the poster session of the same EGSP meeting. The contract director is in charge of arrangements for the scientific papers at the poster session of the EGSP meeting.

These efforts combined with fourth quarter and annual reporting responsibilities for our contract accounted for much of our work effort; this particularly applies to the efforts of the project director.

Because we have completed one year of research effort at full staff level, we are now beginning to see more tangible results of our efforts toward obtaining the objectives of the contract. Certain tasks appear to have promise toward the ultimate goal of "developing a method for selecting areas for drilling shale gas wells that have a potential for gas production." At present, the most promising of our tasks in this respect, that is selecting well sites, include: Regional Structure, thru detailed shallow structure map preparation; Ground water, by lineament-water quantity and water quality mapping; and Geophysics, thru detailed shallow seismic and resistivity surveying techniques. While the first results from these three programs are encouraging, they are preliminary, and they must be viewed with a certain degree of caution concerning wide application of results. This is true because the primary study site of our program thus far is limited to one area, the Cottageville Field area (Figure 1). We are still studying that area, and the universal techniques developed at this site may not have application to all other areas. For instance, early study of production within the large eastern Kentucky gas field already shows that the controls on production are somewhat different from those in the Cottageville field. While we are enthusiastic and encouraged, we also

realize that broad application of these developing techniques would be hazardous. However, once they are fully evaluated at Cottageville and at Midway Extra (Figure 1), they should be tested by the drill in similar geologic situations elsewhere.

Our other research continues to be both fruitful and promising; from the shale characterization viewpoint, from the viewpoint of understanding shale production, and from the viewpoint of developing additional exploration techniques or rationales. These task efforts are presently not as promising as those listed above for well site selection, but I want to emphasize that work on these tasks is generally not as far along in the planned research program. They are, of course, still a fundamental part of the overall program, and therefore they are no less important to attaining our ultimate goals.

1.0.2 Regional Structure

We have completed the preliminary map compilation (see Table 1), and we have shifted the emphasis of our effort from compilation to detailed analysis of structures along the periphery of the Devonian shale producing area; specifically between the Cottageville and Midway Extra fields. We are now moving toward the exploratory use of delineated regional structural trends. As a result of our initial production studies at the Cottageville (deWys and Shumaker, 1978, Nuckols manuscript in preparation) and at the Midway Extra (Schaefer, manuscript in preparation) fields, we noted an interrelationship between shale gas production and subdued basin structure. This discovery is being investigated further because each field appears to be a slightly different variation of the same theme. We are compiling well data to construct detailed shallow structure maps for the non-producing area between these two fields (Figure 1). This effort should ultimately lead to selection of shale gas prospects.

1.0.3 Production Studies

During this past quarter we submitted a preliminary draft manuscript of a production study on the Cottageville - Mount Alto field (Figure 1) by E. B. Nuckols III to the U. S. Department of Energy - METC. After review, revision, and if approved, it will be resubmitted in final form to METC.

Steady progress continues on our investigation of the large Eastern Kentucky gas field. Initial open flow data is now in computer format and several programs have been applied to these data. Preliminary computer and hand contoured maps have been produced for comparative analysis. We have started on lithologic and geochemical analysis of well cuttings during this past quarter. The geochemical program is an independent University study.

In another University sponsored research study, William Schaefer has demonstrated an interrelationship between shale gas production and geologic structure within the Midway Extra gas field of West Virginia. Plans call for submission of a master's thesis final manuscript to the Department of Geology by the end of the fall semester 1978.

A positive statistical association among ground water production lineaments, and shale gas production within the Cottageville field was presented in our last quarterly report. Work is progressing on a similar comparative study of the Midway Extra gas field area. This work is in the data gathering stage.

1.0.4 Geophysical Studies

Test site two (Figure 1) was shot by shallow seismic and resistivity methods this past quarter with the following encouraging results: Both methods recorded an anomaly associated with an interpreted fracture zone. This fracture zone was first selected as a surface lineament in an independent photo study. We are encouraged that the system will define shallow fracture zones, and that these zones reflect fracture porosity. We hope that this relationship will also reflect fracture porosity in the deeper Devonian shales. To test this hypothesis, we have moved to Cottageville and are now collecting geophysical data there. We are also attempting to further define the depth capability of the system at that site.

We have temporarily abandoned the use of an acetylene popper in favor of a dynamite energy source for the shooting program. We will continue to work on improving the design of a less hazardous popper during this coming quarter, and we will further investigate the feasibility of using other surface sources for our program. Work is also progressing on a computer plotting system for the digitally recorded seismic data. We expect that an in-house capability will be available by the end of next quarter. This capability will not only reduce plotting time, but it will increase our capability for analysis of the basic data. (See also Dr. Russell Wheeler, West Virginia University, contract no. EY-77-C-21-8087.)

1.0.5 Structural Studies

Steady progress was made this past quarter on surface structural study of the effects of the Parson's lineament on Devonian silts and shales within the Middle Mountain Syncline of West Virginia.

Study of methods for determinating surface joint (fracture) intensity in covered terrain is also progressing on schedule. Results of last summer's field work is being tabulated for computer analysis of the data. This study is in a data analysis phase.

2.0 CONTRACT OBJECTIVES

2.0 CONTRACT OBJECTIVES

Collect, compile and analyze geological data and prepare geological structure maps for eastern Kentucky and western West Virginia.

Determine if structural types and styles and surface lineations for productive areas of the Black Shales differ from those in non-productive areas.

Identify and define along with other contractors those geologic parameters that control gas production from the shales.

Determine the feasibility of using shallow penetration resistivity and seismic surveys to detect near surface faults and fractures and demonstrate their relationship to lineations observed on airborne imagery.

Determine if a relationship exists between ground water movement and shale gas productivity.

In conjunction with other contractors develop a method for selecting areas for drilling shale wells that have a potential for gas production.

3.0 TECHNICAL PROGRESS

3.1 Work Package 2100-1-1 CROSS SECTIONS — J. Negus de Wys

3.1.1 Current status of work and deliverables

Current status of work: 30% completed

Scheduled deliverables: None

- Log correlation: 60 logs
- Data posting from correlated logs completed.
- Thirteen preliminary cross sections completed. Three of the traverses are represented in three modes. All are shown in stratigraphic-structural cross sections using the Top of the Berea as the datum level. All sections have been reviewed by Ernie Jenkins of Kentucky-West Virginia Gas and by Wally DeWitt and Laurie Wallace of the U.S.G.S. in Reston, Virginia. See Figure 1 for locations of cross sections.
- Drafting of preliminary cross sections has been completed.
- Samples prepared for lithologic-geochemical studies are being studied. Microscope/camera request is being processed.
- Protosalvinia samples from Martin County and Perry County cores are being studied. Photographs have been made. Sections and macerals are being prepared.
- Meetings attended per monthly reports.
- International Devonian Symposium in Bristol, U. K., attended on University support.

3.1.2 Problem areas and suggested improvements

None. API counts postponed.

3.1.3 Work plan for next quarter

- Progress in lithology studies.
- Attend log interpretation school which has been arranged for October 26, 1978, with Schlumberger.
- Correlate additional logs.
- API counts to be initiated with additional log correlation and carried on simultaneously.

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3.2 Work Package 2100-1-2 ISOPACH MAPS — J. Negus de Wys

3.2.1 Current status of work and deliverables

Current status of work: ~ 30%

Scheduled deliverables: None

- Log correlation and data tabulation on 20 additional logs completed. (Total: 60) of 300 total to be done.

3.2.2. Problem areas and suggested improvements

None

3.2.3 Work plan for next quarter

- Continue log correlation.
- Plot data on maps.

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3.3 Work Package 2100-2-1 STRUCTURE CONTOUR MAPS — J. Negus de Wys

3.3.1 Current status of work and deliverables

Current status of work: 30% completed

Scheduled deliverables: None

- Three dimensional stratigraphic-structural model completed with 7 cross sections showing relationship of structure to an initial open flow 3-D histogram on the base.
- Data being plotted on base maps as logs are correlated.

3.3.2 Problem areas and suggested improvements

- Release of basement seismic map negotiated with four companies. The fifth will discuss this with us at the Lakeview meetings.
- Kentucky-West Virginia Gas has given permission for a structure study to be carried out on two horizons using data from about 4750 driller's logs. A student will work with Kentucky-West Virginia Gas for three months next summer in the Prestonsburg office to accomplish data retrieval.

3.3 Work Package 2100-2-1 STRUCTURE CONTOUR MAPS - continued J. N. de Wys

3.3.3 Work plan for next quarter

- Continue log correlation and data plotting.
- Complete negotiations for basement seismic map release.

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3.4 Work Package 3200-4-1 OIL AND GAS MAPS J. Negus de Wys

3.4.1 Current status of work and deliverables

Current status of work: 30% completed

Scheduled deliverables: None

- Initial open flow map of 4 level breakdown completed and drafted (one of pattern as a result of levels; one of overall pattern as a function of highest 3 levels).
- SYMAP completed: computer drawn map of initial open flow data on 4,750 points.
- ADMINMAP completed: computer drawn map of initial open flow data of 4,750 points.
- Trend analysis map of entire field run. Section study in progress.
- Hand contouring of 4,700 points with initial open flow in progress (70% complete).
- Gas occurrence from well logs (60) posted on cross sections and 3-D Model. About 30 logs must be examined to complete this correlation with cross sections.
- See Figures in Annual Report of initial open flow patterns and maps.

3.4.2 Problem areas and suggested improvements

None

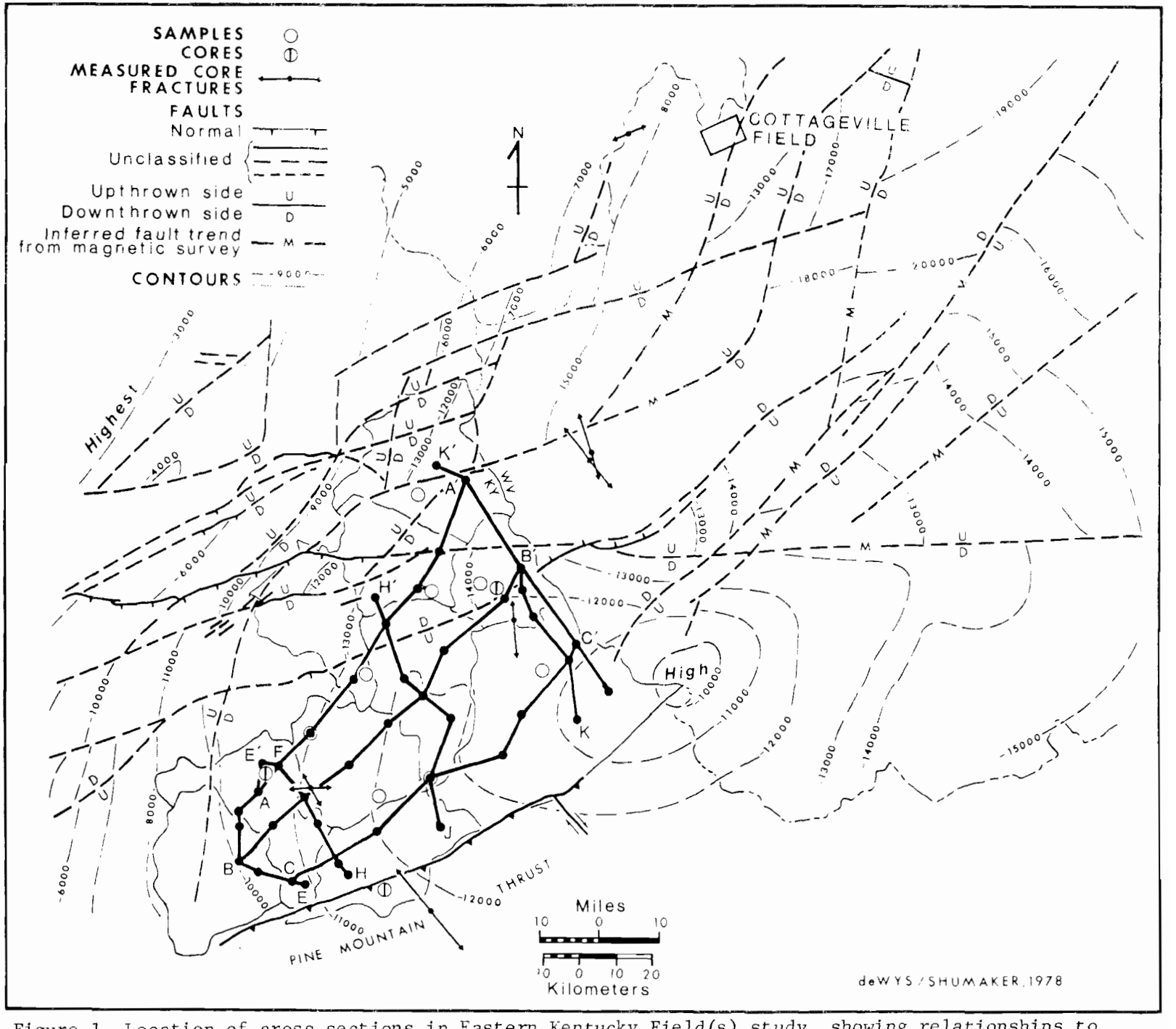

Figure 1 Location of cross sections in Eastern Kentucky Field(s) study, showing relationships to present structural interpretation.

3.4 Work Package 3200-4-1 OIL AND GAS MAPS - continued J. N. de Wys

3.4.3 Work for next quarter

- Complete trend analysis.
- Initiate cross sections of SYMAP and ADMINMAP computer drawn maps of initial open flow to relate to stratigraphic structural cross sections.
- Complete hand contouring of initial open flow data.
- Attend Schlumberger log interpretation school October 26, 1978.

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ABSTRACTS AND REPORTS THIS QUARTER

- Report on Cottageville Pilot study of gas production given at Department of Energy meetings in Tulsa in August.
- Slides and reports for Lakeview October meetings:

  1. Cottageville Pilot study of gas production (conclusions); and
  2. Status report of Eastern Kentucky Gas Field(s) study (stratigraphic-structural cross sections, initial open flow patterns, and planned studies in this ongoing three-year study)

Next Quarter

- Deliver report on Eastern Kentucky study at Lakeview meetings, October.
- Poster session at Lakeview meetings in October on comparison of portions of SYMAP, ADMINMAP, and hand contour mapping of initial open flow data.
- Three-D Model of stratigraphic-structural cross sections of Eastern Kentucky gas field(s) and initial open flow histogram to be presented at Lakeview meetings in October.
- Deliver Cottageville Pilot Study Report at Lakeview meetings in October.

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3.1 Work Package 1000-2 STRUCTURE STUDIES — Jeanette M. Dixon

3.1.1 Current status of work and scheduled deliverables

Field work for the development and application of measuring systematic-joint intensity has been completed. The Parsons lineament in western Tucker County is being investigated. Statistical analysis of the data is under way. Joint roses and preliminary joint intensity maps have been made.

3.1.2 Problem areas and suggested improvements

None

3.1.3 Work plan for next quarter

Final joint rose maps and joint intensity maps will be completed for the next quarter. The writing of the final report will be initiated.

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3.1 Work Package 2100-2-2 STRUCTURE STUDIES — Thomas H. Wilson

3.1.1 Current status and deliverables

Fracture orientation, spacing, length, and depth were measured for fractures found at several outcrops in the Middle Devonian shales exposed in the Middle Mountain syncline. Fracture examination was confined to those areas of the syncline intersected by the Parsons structural lineament.

Further data collection is required before this study can be completed. Field work in the spring and possibly early summer of next year should provide the data needed to complete this investigation. No additional work in this area is planned for the coming quarter.

Several illustrations elucidating the internal structures of the Middle Mountain syncline have been prepared for the poster session of the EGSP symposium at Lakeview.

Several contour maps have been prepared which examine the patterns found in the strike and dip contours of the Middle Mountain syncline. A report on this study is currently underway, but as yet incomplete.

3.1.2 Problem areas and suggested improvements

None

3.1.3 Work plan for next quarter

A gravity survey is currently underway and scheduled for completion early this coming quarter. This survey is being conducted primarily in Pendleton County, West Virginia, for the purpose of supplying more detailed gravity information on the structures associated with the Parsons structural lineament. The data collected in this survey will be tied into data collected by Kulander and Dean (1978). Latitude, free air, Bouguer, and terrain corrections of the data will be completed by mid November at which time modeling of the sedimentary cover along the length of the Parsons lineament can begin. It is hoped that these models can be generated by the end of this quarter or early the following quarter.

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3.1 Work Package 2200-1-2 FRACTURE STUDIES — Kevin D. Lee

3.1.1 Current status of work and scheduled deliverables

Field work was undertaken during the last quarter to obtain joint and macro-structure data along the Pine Mountain thrust in Eastern Kentucky. The data collected is currently being processed, with hopes of having preliminary results by the end of this quarter.

3.1.2 Problem areas and suggested improvements

None

3.1.3 Work plan for next quarter

Process field data in the following ways:

1. Construct stratigraphic columns where data was collected to show macro-structures and joint inclinations in their respective stratigraphic positions.

2. Construct a cumulative plot of all joint data.

3. Construct cumulative plots of joint data for different stratigraphic intervals in the shales.

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3.1 Work Package: 2200-1-2 FRACTURE STUDIES — Brian R. Long

3.1.1 Current status and deliverables

Collection of field data on Devonian shale joints in eastern Kentucky has been completed. Measured Devonian sections by Potter, Kepferele, and Provo were examined in detail to determine fracture data within known stratigraphic sequences. Devonian shale outcrops along the east side of the Cincinnati Arch from Vanceburg, Kentucky, to the Lake Cumberland area were taken to document joint styles over a large area. In addition to normal data collection, the Devonian outcrops were measured by scintillometer to determine their radioactivity.

Previously collected data indicated the possibility of a change in coal cleat strike and face-butt cleat relationships in the Prestonsburg, Pikeville, and Hazard, Kentucky, areas. Field collection of coal data was completed in the above areas to increase the density of data points and better determine the strike and relationships of coal cleats. Additional data on sandstone and shale units associated with coal were collected routinely.

3.1.2 Problem areas and suggested amprovements

None

3.1.3 Work plan for next quarter

All field data will be placed in computer data sets for use with map plotting programs and statistical programs.

Corrected maps showing joint strike directions as rose diagrams will be plotted on a 1:250,000 map scale. Maps for individual sandstone, limestone, coal, shale, and Devonial shale will be produced.

The measured Devonian shale sections previously discussed will be separated into upper, middle, and lower sections and rose diagrams will be plotted individually and on maps to show their relationships with the other Devonian shale data.

Coal face cleat strikes will be separated out of the data and plotted on maps to illustrate changes in their orientations over the eastern Kentucky area. Possibly the face cleat directions of one major coal bed will be plotted to eliminate differences in orientation related to stratigraphic position.

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3.1 Work Package: 2200-1-2 FRACTURE DENSITY AND ORIENTATION Mark A. Evans

3.1.1 Current status and deliverables

The fracture report on the Reel Energy #3 D/K core has been completed and the fracture report on the MERC #1 core is 75% complete. Data collection on fractures in the Lincoln County #20403 core is 75% complete. Photographs have been taken of many of the natural fractures and some of the core induced fractures in this core.

3.1.2 Problem areas and suggested improvements

A problem exists in that the Lincoln County #20402 and #20403 cores, as well as the Jackson County #11905 and #12041 cores are in very poor condition. Data collection on fracture frequency and orientation is difficult and in some instances impossible. Progress has been slow.

3.1.3 Work plan for next quarter

During the next quarter, data collection on the fractures in the two Lincoln County cores and the two Jackson County cores should be completed. Many of the fractures in these cores will also be photographed. If time permits, visual and statistical analysis of this data will begin. The fracture report of the MERC #1 core should be completed soon into the quarter.

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3.1 Work Package 2100-1-1 SEISMIC — James E. Ruotsala

3.1.1 Current status of work and scheduled deliverables

Various computer data analysis procedures are now in development. These include:

Seismic data plot routines

Computation and plotting of synthetic seismograms

Currently alternative energy sources for reflection seismic data acquisition are under investigation. These include various surface sources and a gas (propane or acetylene) popper. The object is to find an energy source that will yield good data with a minimum of effort in drilling holes, obtaining permits, etc.

3.1.2 Problem areas and suggested improvements

Virtually a total lack of sonic logs of wells in the areas of interest will make it very difficult, if not impossible, to positively tie our seismic data to subsurface geology.

3.1.3 Work plan for next quarter

Additional data analysis procedures will be developed, including data processing routines.

Continuation of the effort in finding alternative energy sources.

In addition, the winter will be used in interpreting and analyzing data currently being collected.

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3.1 Work Package 2100-1-1 SEISMIC — Keith Kirk

3.1.1 Current status and deliverables

The fourth quarter was spent completing the collection of and analyzing the data at the first test site along with laying out the seismic lines to be run at the other two test sites. Excellent results were obtained at the first test site. A report detailing this work will be included with the yearly report. Frequencies up to 600 Hz were recorded at the first test site, and in some cases beds as thin as 6 inches were resolved.

3.1.2 Problem areas and suggested improvements

Explosives have continued to be used as an energy source because no remedy has been found to the problem of the water logging of the acetylene cannon that was detailed in the last quarterly report. However, explosives have proved to be more than adequate for the purposes of this research.

3.1.3 Work plan for next quarter

Data will be collected and analyzed from the additional two test sites in conjunction with Task 3200-2-3.

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3.1 Work Package 3200-2-3 SURFACE RESISTIVITY — Keith Kirk

3.1.1 Current status and scheduled deliverables

Work is on schedule. A long line was run over the test site at the Cottageville field that suggests the presence of a fault along the major structural trend of the system. There a are no scheduled deliverables for this quarter.

3.1.2 Problem areas and suggested improvements

None

3.1.3 Work plan for next quarter

The next quarter will be spent collecting data at the Cottageville and Kermit test sites.

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3.1 Work Package 3200-1-2 SUBSURFACE GEOLOGY — Henry W. Rauch

Subtask -- Identify 3 areas in which to conduct ground water studies.

3.1.1 Current status of work and scheduled deliverables

A ground water study has been initiated in the Midway Extra gas field area in northern Putnam County. To date, physical well data have been collected from the owners of about 80 wells in the study area, and some of these wells have been sampled for water quality. There are no deliverables for this quarter.

3.1.2 Problem areas and suggested improvements

There were some delays encountered during the summer in collecting field data in the Midway Extra area; a delayed paycheck and a delay in the purchase of a car for field work by Mr. Beebe were temporary factors which have been corrected. Mr. Beebe is currently assisting Keith Kirk on a part-time basis with completion of field geophysical surveying work left over from the summer. He is currently about one month behind our original work plan for the past quarter, but he should be caught up with all research work within the next few months.

3.1.3 Work plan for next quarter

We plan to accomplish all field work related to the ground water study in the Midway Extra area. A report on progress to date, with appropriate data, will appear in the 1978 annual report. A second progress report with more data will appear in the quarterly report for January.

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3.2 Work Package 3200-2-3 SURFACE RESISTIVITY — H. W. Rauch

Subtask - Conduct resistivity surveys over ground water study areas (defined under 3200-1-2).

3.2.1 Current status of work and scheduled deliverables

Resistivity surveying across selected photolineaments has been completed for the Cottageville study area, but such work has been delayed in the Midway Extra study area. There are no scheduled deliverables for this quarter.

3.2 Work Package 3200-2-3 SURFACE RESISTIVITY - continued H. W. Rauch

3.2.2 Problem areas and suggested improvements

Our only problem has been a delay in doing resistivity field surveying in the Midway Extra area, for reasons mentioned under 3.1.2 above. We do not anticipate any long-range problems, however.

3.2.3 Work plan for next quarter

Continue work on the resistivity surveying as the weather permits. We plan to complete this surveying within the next 3 to 6 months.

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3.3 Work Package 3200-5-1 STRUCTURE/PRODUCTION CORRELATION H. W. Rauch

Subtask - Correlate all data and attempt to establish a relationship between geologic features, lineaments, fractures, ground water, and oil and gas production.

3.3.1 Current status of work and scheduled deliverables

A paper has been prepared for METC's EGSP conference, regarding correlations between ground water data and gas production data for the Cottageville study area; this paper also appears as a deliverable for the month of August and for this quarter.

A comparison of ground water and gas production data for the Midway Extra has not yet been done.

3.3.2 Problem areas and suggested improvements

None

3.3.3 Work plan for next quarter

We will continue to test the tentative associations of ground water quality with gas production data for the Cottageville area, by the analysis of additional well data from October, 1978. The latest evidence will be reported at the second EGSP conference and in the next quarterly report.

3.3 Work Package 3200-5-1 STRUCTURE/PRODUCTION CORRELATION - continued

We will also proceed with an initial analysis of ground water and gas production data for the Midway Extra gas field study area, and will report briefly on progress to date in next quarter's report.

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3.4 Work Package 3200-5-3 LINEAMENT/STRUCTURE CORRELATION H. W. Rauch

Correlate fractures and lineaments derived from photo analysis with results of ground water tests to determine if any relationship exists between ground water production and the occurrence of lineaments.

3.4.1 Current status of work and scheduled deliverables

See the enclosed deliverable item for task 3.3 above, for a summary of associations between water well yield and lineament proximity.

To date we have not yet compared water well yield to lineament proximity in the Midway Extra study area.

3.4.2 Problem areas and suggested improvements

None

3.4.3 Work plan for next quarter

We will proceed with an analysis of ground water and lineaments for the Midway Extra study area. There will be a report on progress, but no deliverable items for next quarter.

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LINEAMENTS AND GROUND-WATER QUALITY AS EXPLORATION TOOLS FOR GROUND WATER AND GAS IN THE COTTAGEVILLE AREA OF WESTERN WEST VIRGINIA

by

D. Scott Jones
and
Dr. Henry W. Rauch

(Rauch)

ABOUT THE AUTHORS

Mr. Jones received his BA degree in Geology from Susquehanna University in 1976. He has been attending West Virginia University since 1976 and is working toward an MS degree in Geology. He is presently employed by the Pennsylvania Department of Environmental Resources - Division of Strip Mine Reclamation.

Dr. Rauch received his BA degree in Chemistry-Geology from Alfred University in 1965. He also received his Ph.D. degree in Geochemistry from The Pennsylvania State University in 1972. Since 1970 he has been employed by West Virginia University, Department of Geology and Geography, and is an Associate Professor of Geology. He is also a co-investigator on an Eastern Gas Shale Project contract at West Virginia University, which is funded by the U. S. Department of Energy. His primary research interests are in hydrogeology and geochemistry.

ABSTRACT

As part of a hydrogeologic study of west-central Jackson County, lineaments were mapped and water wells were characterized for physical and chemical parameters, especially in the Cottageville area. Short straight photolineaments are significantly associated with water well yields in gallons per minute, with wells closer than 100 feet having higher yields. Such lineaments act as anomalous zones about 200 feet in width with respect to water wells. Short photolineaments are not in general associated with gas well yield, but gas wells located within 0.5 miles of a short photolineament bearing N 60°W-N90°W (WNW) yield at significantly greater rates (as natural initial open flow) than wells near other photolineaments. The density of WNW photolineaments is also significantly and directly associated with gas well yield. Water well yield has no relationship to Landsat or curvilinear lineaments. However, gas wells located within 0.25 miles of one Landsat lineament or within 0.5 miles of a curvilinear lineament over one mile long yield at significantly lower rates. High concentrations of nitrate and sulfate, and especially of bicarbonate and total hardness in shallow ground water are significantly associated with high expected (interpolated) gas well yield. Tentative conclusions from sparce data indicate that gas well yield will be significantly higher when gas wells are located in areas having ground-water concentrations exceeding 500 mg/l, 250 mg/l, 13 mg/l, and 34 mg/l for bicarbonate, total hardness, nitrate, and sulfate respectively. In summary, short photolineaments make a good exploration tool for locating water wells; both WNW photolineament density and ground water quality may serve new exploration techniques for Devonian shale gas in the Cottageville, but Landsat and curvilinear lineaments should be avoided.

INTRODUCTION

A hydrogeologic investigation in the Cottageville area of Jackson County, West Virginia, was undertaken in part to explore the possibility of relating hydrogeology and aqueous geochemistry to the occurrence of Devonian shale gas. Any relationships established between near-surface hydrogeologic or geochemical parameters and gas yield would be useful in developing additional exploration techniques for Devonian shale gas.

Figure 1 depicts the study areas. The first phase of this study involved the investigation of 86 water wells and one spring in the hydrogeology study area.[1] Physical well parameters such as well depth, depth to water, well yield, and casing depth were obtained from well owners or drillers. The topographic setting and most probable aquifer unit were determined with the aid of topographic maps, a structural contour map of the Pittsburgh Coal, and a general stratigraphic column for the study area.

Short photolineaments were also mapped for the hydrogeologic study area from low altitude black and white photography having scales of 1:20,000 and 1:38,000. The photolineaments represent nearly straight stream channel or valley segments over 0.25 miles in length (but usually less than one mile long). These were identified and plotted on 7 1/2 minute topographic maps for the study area.[1] Also identified and plotted were a few Landsat lineaments defined by straight stream or valley sections or aligned stream meander bends. A third type of lineament is the curvilinear type. These lineaments are generally at least one mile in length and are defined by continuously curved valleys or streams which lack inflection points in their general curvature. They were determined from and plotted on the 7 1/2 minute topographic maps.

Water quality tests were also performed for 86 wells and one spring.[1] Temperature and specific conductance were measured in the field, and two water samples were taken from each well. One sample was treated with acid and later analyzed in the laboratory for iron, calcium, and magnesium concentrations. The second sample was treated with a biocidal agent which also retarded algae growth, and was kept cool until chemical analyses for pH, bicarbonate, nitrate, sulfate, chloride, and sodium could be performed in the laboratory.

PHOTOLINEAMENT ASSOCIATIONS

Mapped lineaments for the gas field study area are shown in Figure 2. Several short photolineaments five curvilinear lineaments, and one Landsat lineament are evident in this area. Water well yield (in gallons per minute) was tested as a function of well proximity to each of the three types of mapped lineaments for the entire hydrogeology study area (see Figure 1).

Water wells located within 100 feet of a short photolineament yield water at significantly greater rates than more distant wells. This difference is significant with a 0.06 probability of error (probability that there is no significant difference between two groups of tested data), by the

Mann Whitney U (1-tailed) statistical test.[2] Of those wells within 100 feet of a short photolineament, wells within 50 feet yield water at significantly greater rates (about 50 percent greater) than wells 50-100 feet from such a lineament, This difference is significant with a 0.05 error probabilityby the Mann Whitney U test. These trends in well yield were expected and have been well documented by Lattman and Parizek as well as other researchers.[3] Apparently, short photolineaments often represent underlying fracture zones which are associated with significantly increased aquifer permeability. Hence water wells located on photolineaments usually have higher-than-average yields. The probable fracture zones under photolineaments of the study area are roughly 200 feet in width.

Landsat and curvilinear lineaments seem to have no definite relationships with water well yield. No significant associations were found between water well yield and well proximity to either Landsat or curvilinear lineaments, based on the Mann Whitney U test. Landsat lineaments (and other lineaments from high altitude imagery) mapped by Werner were tested in addition to those few Landsat lineaments mapped by the authors.[4] Water wells near the curvilinear lineaments produced at about the same rate as wells in other valleys. Whatever the reason for these non-associations, Landsat and curvilinear lineaments are both distinctly different from short photolineaments in both appearance and effects.

Gas well yield was next tested for possible associations with mapped lineaments in the gas field study area (see Figures 1 and 2). Figure 2 shows the locations of Devonian shale gas wells both within and surrounding the Cottageville gas field. Only depicted are those wells for which natural initial open flows are known (E. B. Nuckols III, personal communication, 1978). Natural initial open flow was judged to be the most reliable gas production variable representing relative gas reservoir and gas well potential. Therefore, only this variable was used in statistical tests of lineament associations. Significant research on gas well production trends and associations is reported by several researchers.[4,5,6,7,8,9]

Considering short photolineaments of Figure 2 first, there is no apparent relationship between natural open flow and the proximity of gas wells to short photolineaments. No significant flow difference exists (by the Mann Whitney U test) between gas wells within 0.5 miles and gas wells greater than 0.5 miles from a short photolineament. Natural open flow likewise does not change significantly for wells between 0.0 and 0.5 miles of a photolineament.

However, when short photolineament orientation is taken into account, it is evident from Figure 3 that natural open flow varies with the orientation of nearby photolineaments. Gas wells within 0.5 miles of short photolinraments bearing N 60°W to N 90°W, or WNW, have a greater proportion of high-yielding gas wells (over 100 MCF/day) than do gas wells within 0.5 miles of other short photolineaments. This difference is significant by the 2X2 Fisher contigency test, with an error probability of 0.03. Furthermore, Figure 3 indicated that gas wells within 0.5 miles of short photolineaments oriented N 75°E to N 90°E are relatively high producers, on average. Combining this class of gas wells with the WNW class produces a combined class within 0.5 miles of photolineaments bearing N 60°W to N 105°W, which has the maximum potential for high-yielding gas wells. A 2X2 chi-square contingency test comparison of this enlarged well class with other wells shows a significant difference at the 0.05 alpha probability.

Although WNW-bearing photolineaments have a significantly great proportion of high-yielding gas wells in their vicinity, a more direct test of such photolineaments was necessary to determine their usefulness as an exploration tool. The density of WNW photolineaments is compared to contoured trends for natural initial open flow in Figure 4. The 100 and 500 MCF/day contours for natural open flow were plotted assuming that the changes in gas flow rate would be linear between adjacent gas wells. These contours are partly a function of the density of gas wells; contours in areas with low gas well densities, such as the northwestern extension of the 100 MCF/day contour, are probably overly optimistic in their prediction of shale gas reserves. These contours therefore represent a liberally depicted version of the Cottageville gas field.

The density of plotted WNW photolineaments was calculated from Figure 2 by use of a moving average technique and an orthogonal grid of lines defining square sections. the grid was oriented parallel to the north-south and east-west directions, and had sections that were 0.5 miles long on each side. The WNW photolineament density was calculated for 1.0 square mile sections by the moving average technique, and was plotted at the center of each square mile section. This density was then contoured. Figure 4 illustrates WNW photolineament density contours of 1.0 mile length per square mile area, and of 50 percent by total length per square mile area. The highest WNW photolineament densities occur inside the depicted contours and within the Cottageville gas field.

Chi-square contingency (2X2) tests were then performed on the moving average data for WNW photolineaments. Eighty one sample points were classified in two 2X2 tests for each density variable. One test compared greater-than-100 MCF/day with less-than-100 MCF/day points, and the second test compared greater-than-500 MCF/day with less-than-500 MCF/day points. The statistical test results indicate that WNW photolineament density (both as miles length per square mile area and as percentage of lineament lenght per square mile) is significantly associated with both the greater-than-100 MCF/day and greater-than-500 MCF/day contoured areas of Figure 4, at alpha probability values ranging from 0.02 to 0.001. However, these tests are biased because the 81 tested points are not mutually independent samples, since they were generated by the moving average technique.

Therefore, a second set of contingency tests were performed on the four sets of independent 1.0 mile square sections that define the 81 points tested above. First, the number of tested points was increased from 20 to 80 by multiplying each box of the 2X2 contingency tables by 4. This step had the effect of increasing the sample frequencies to a hypothetical number of independent sample points which were about equal to the 81 non-independent points tested initially. This action was taken to overcome the biasing effect of 2X2 contingency tests against statistical significance for a low number of samples. The net result of these test sets was that at least 3 out of 4 tests of independent sample points were significant at a 0.05 or lower alpha probability, for associations between WNW photolineament density and gas well yield areas from Figure 4. Therefore, the association of high WNW photolineament density and high gas production areas (either greater-than-100 MCF/day or greater-than-500 MCF/day) is considered significant by the authors.

The WNW photolineament density could serve as the basis of a new exploration tool for Devonian shale gas in the Cottageville area. Figure 4 shows that if gas wells are located within areas having densities greater than 1.0 mile per square mile, about 75 percent of these wells would have natural open flows exceeding 100 MCF/day, and about 50 percent of these wells would have flows exceeding 500 MCF/day. When gas wells are located in areas with more than 50 percent of photolineaments bearing WNW per square mile, about 62 percent of the wells would have natural open flows exceeding 100 MCF/day and about 38 percent would exceed 500 MCF/day.

Statistical tests were also performed on gas well yield as a function of WNW photolineament densities of less-than-0.50 versus greater-than-0.50 miles length per square mile. The associations are again significant at the 0.05 alpha probability, but using the area within the 0.50 density contour (not shown in Figure 4) would not prove as successful as the area within the 1.0 density contour for gas exploration. Testing of gas wells within 0.5 miles of short photolineaments bearing N 60°W-N 105°W yielded similar results to those already described for the WNW photolineaments. However, the density of photolineaments in the enlarged orientation class do not associate quite as well with gas production rate as the WNW photolineaments previously described.

An explanation of the associations between WNW photolineaments and gas yield must involve the subsurface geologic structure represented by these photolineaments. It is reported that a major fracture orientation exists in the east-west direction in the Cottageville gas field, based on surface outcrop and core data.[8] Increased gas reservoir permeability, along fractures oriented approximately east-west, is probably a major cause for the high gas yields in the Cottageville field. A more extensive structural analysis of gas trends is given by Nuckols.[8]

Both Landsat and curvilinear lineaments were also tested against gas well yield for the gas field study area. The one Landsat lineament along Mill Creek appears to have a negative effect on gas production, as shown in Figure 4. Natural open flow is lower for gas wells located within 0.25 miles of this lineament than for wells 0.25 to 0.50 miles distant. This relationship is significant at the 0.05 alpha probability level by the Mann Whitney U test, but not by the contingency test. This result supports the conclusion of Werner, that Landsat lineaments appear to be detrimental to gas production in the Cottageville area.[4,5] A test of curvilinear lineaments shows gas yield to be significantly lower for gas wells located within 0.5 miles of such lineaments than for more distant wells. This difference is significant for a 0.01 alpha probability by the Mann Whitney U test. Therefore, Landsat and curvilinear lineaments are to be avoided in exploring for Devonian shale gas, at least in the Cottageville area. Perhaps deeply penetrating fractures have bled off the shale gas under these lineaments, as suggested by Werner.[4,5]

GROUND WATER-GAS YIELD ASSOCIATIONS

Water well yield and well water quality were next compared to the yields of nearby gas wells in the gas field study area, to see if water well data could provide new exploration techniques for Devonian

shale gas. A hypothetical figure for expected gas well yield was generated by linear interpolation between the two gas wells nearest and on opposite sides of a water well or spring, for each of the 20 wells and one spring within the gas field area. Only one water well could not be assigned an expected gas yield value.

Results of plots and tests for water well (and spring) yield indicate that no apparent relationships exist between water yield (in gallons per minute) and expected natural open flow (in MCF/day).

Water quality parameters were next tested for possible associations with expected natural open flow. Figure 5 illustrates plots of concentration versus gas flow rate, for the four most promising parameters of those analyzed. The horizontal dashed lines on these four plots arbitrarily separate the gas yields into high and low classes, for comparison to concentration. Statistical tests, involving 2X2 contingency tables and the Fisher exact probability test, were used to identify any significant gas yield differences between high and low concentrations. Vertical lines were arbitrarily drawn to distinguish high from low concentration values. Although the data are sparce, statistically positive trends are evident from the statistical tests; expected gas yield tends to be higher near wells with high concentrations of bicarbonate, total hardness, nitrate, or sulfate. Test results are significant at the 0.007, 0.031, 0.079, and 0.094 error probabilities respectively, for bicarbonate, total hardness, nitrate, and sulfate. High concentration samples also show significantly higher gas yields than low concentration values, as determined by the Mann Whitney U test at the 0.05 alpha level. Other tested chemical parameters which did not significantly relate to expected gas yield are total iron, temperature, pH, chloride, and sodium.

The chemical parameters of ground water which seem to best relate to expected gas yield are bicarbonate and total hardness concentrations. These parameters show the strongest statistical associations which are least likely to be coincidental. These two ground water parameters may be applied with caution as exploration tools. From the tested data, about 83 percent of the selected well sites with over 500 mg/l bicarbonate have high expected gas open flows (over 100 MCF/day). An even higher percentage of wells with over 250 mg/l hardness would make good gas well sites, as defined above. These data suggest that some relationship exists between gas reservoir production potential and shallow ground water quality. However, the scarcity of data requires that these associations be considered tentative, until more water well information can be collected to further test the observed associations of Figure 5.

No explanations are apparent to the authors for the observed associations of ground water quality and expected natural open flow. Water wells with high concentrations of bicarbonate, total hardness, nitrate, or sulfate have no common factor in their hydrogeologic setting. These wells differ in aquifer type, well elevation, well depth, well bottom elevation, well yield, topographic setting, and lineament proximity.

ACKNOWLEDGEMENTS

The authors would like to thank the Mid-Ohio Valley Regional Council of the Appalachian Regional Commission and the U. S. Department of Energy for partial financial support of this study. Appreciation is also extended to the many individuals who provided useful data or advice for this project.

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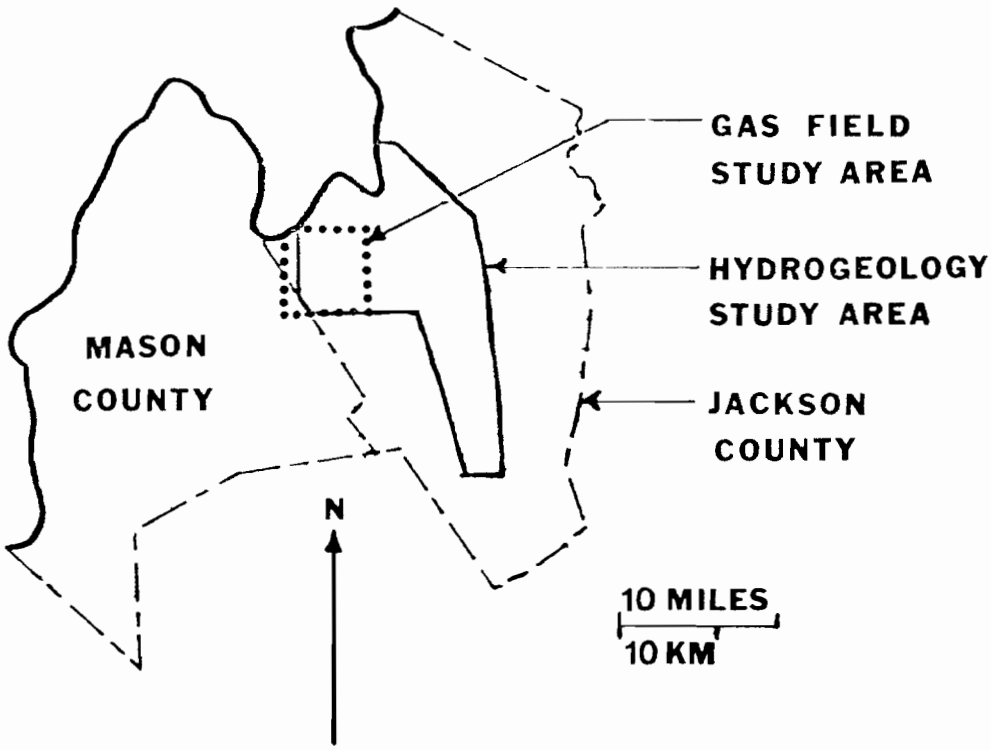


Fig. 1 - Location of study areas in West Virginia.

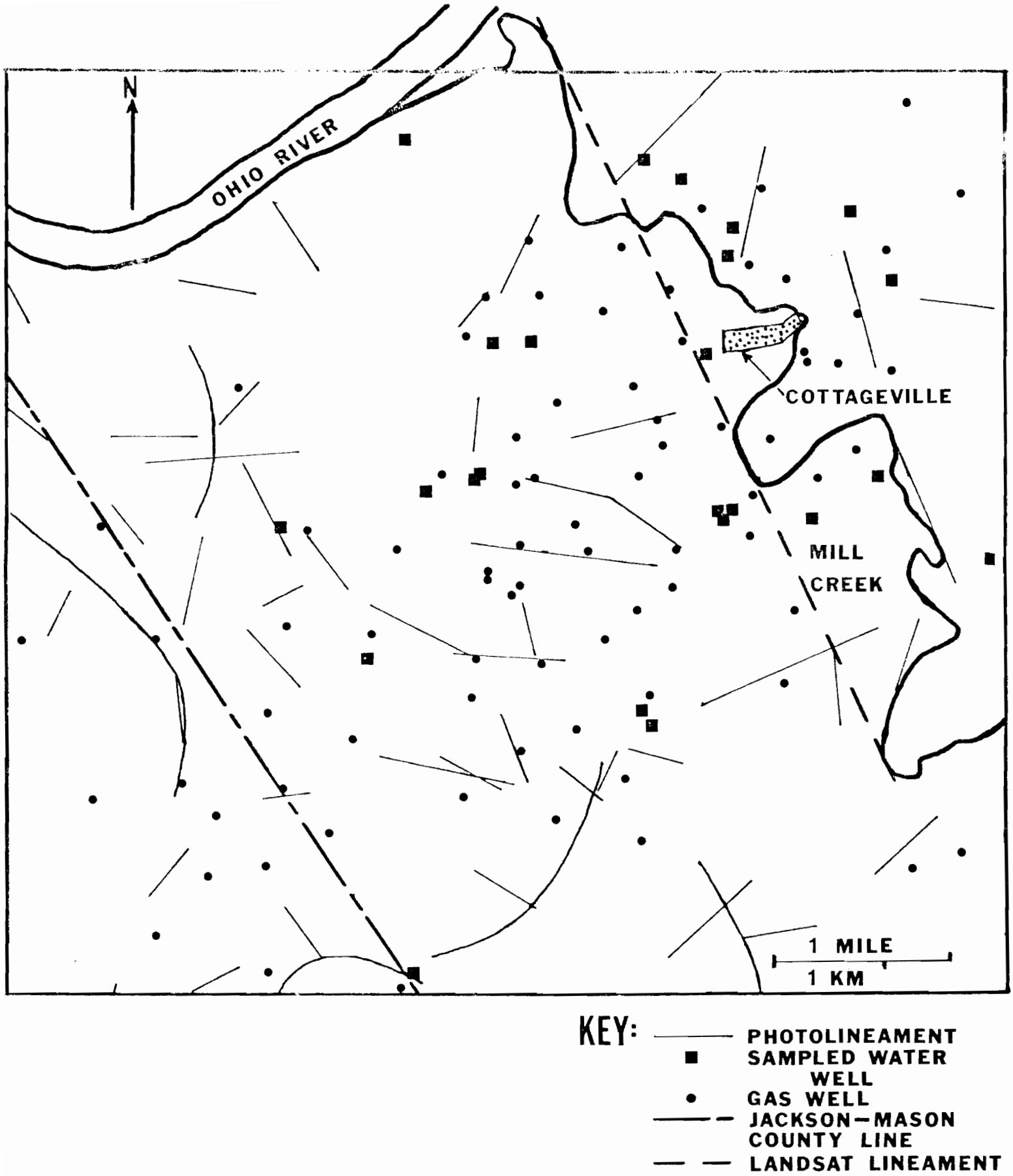


Fig. 2 - Map of gas field study area, near Cottageville.

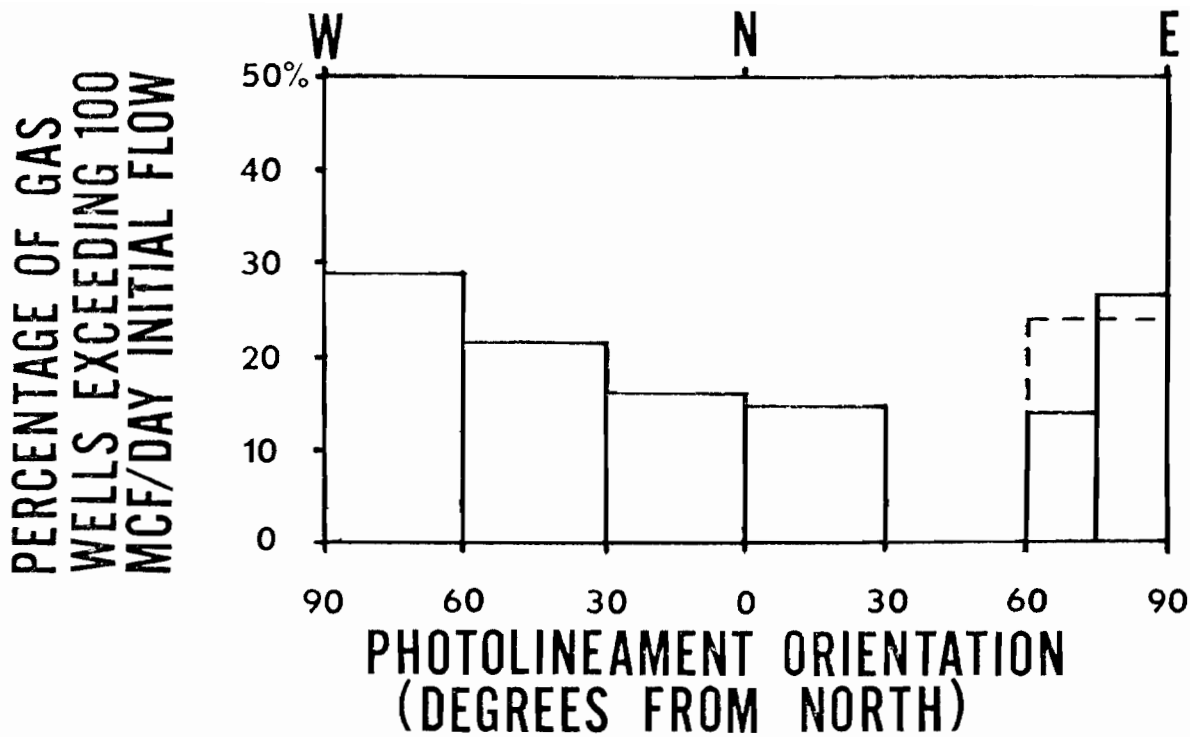
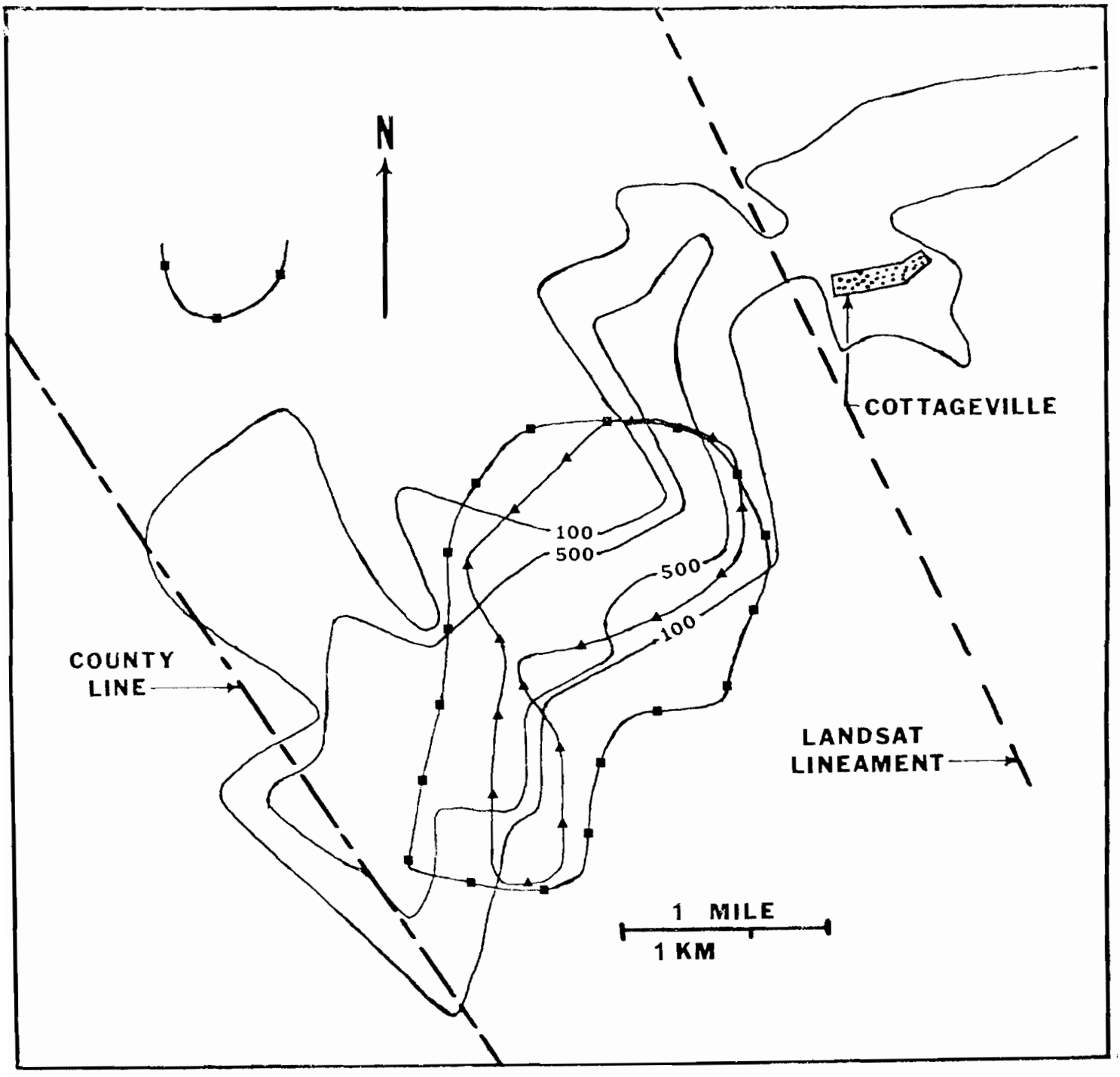


Fig. 3 - Gas well yield versus photolineament orientation.



KEY: —100-100 MCF/DAY CONTOUR FOR INITIAL GAS FLOW
—500-500 MCF/DAY CONTOUR FOR INITIAL GAS FLOW
—▲—1 MI/MI^2 DENSITY CONTOUR FOR SHORT PHOTOLINEAMENTS BEARING N 60° W—N 90° W
—■—50% CONTOUR FOR PERCENTAGE OF SHORT PHOTOLINEAMENTS PER SQUARE MILE BEARING N 60° W—N 90° W

Fig. 4 - Gas well yield related to photolineament density.

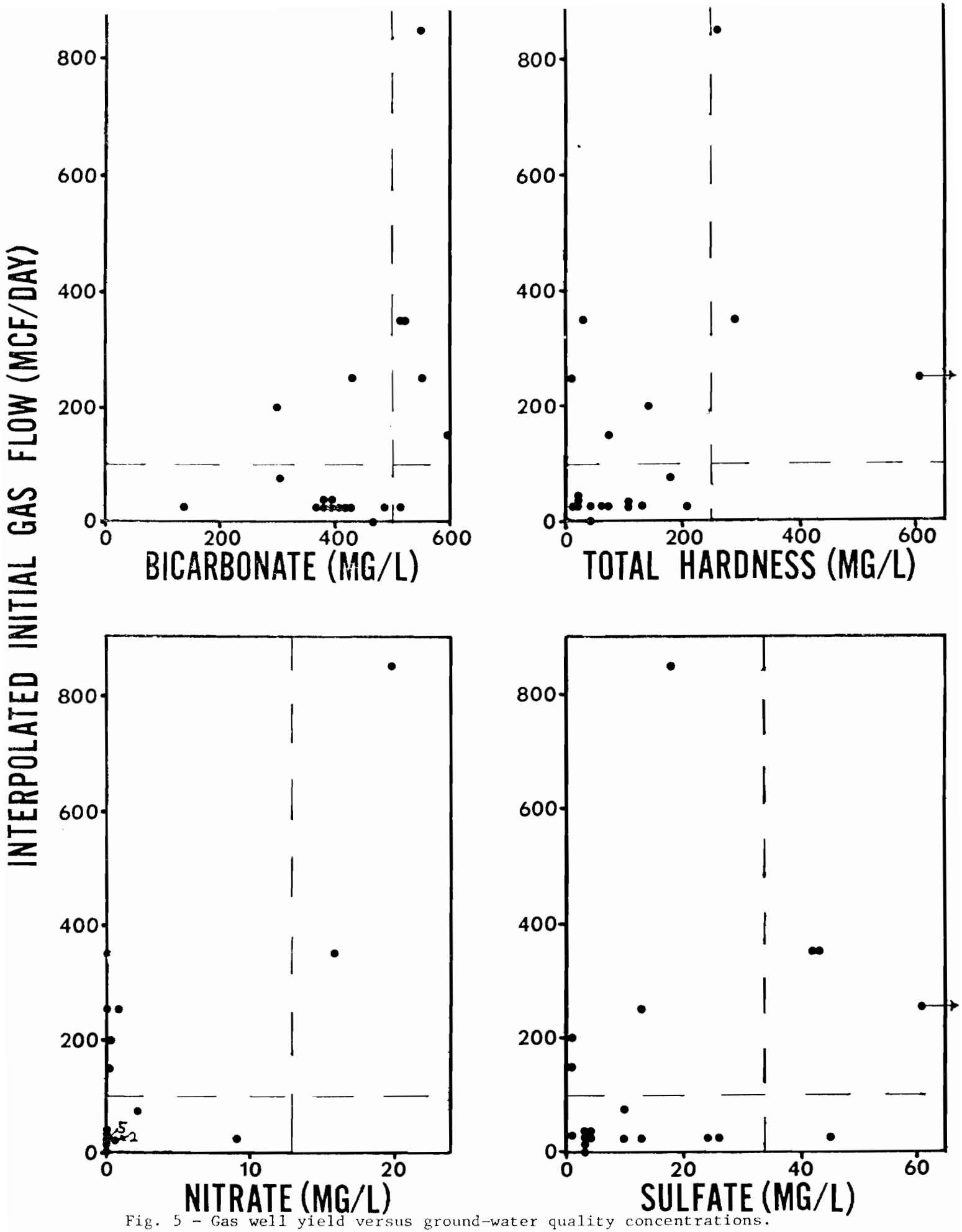


Fig. 5 - Gas well yield versus ground-water quality concentrations.

Oct.-Dec. 1978
WVU Dept. of Geog. & Geogr,

QUARTERLY PROGRESS REPORT

U. S. Department of Energy Contract No. EY-76-C-05-5194

October - December 1978

submitted by:

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Principal Investigators

1.0 EXECUTIVE SUMMARY

QUARTERLY REPORT: ERDA CONTRACT EY-76-C-05-5194

October - December 1978

1.0 EXECUTIVE SUMMARY

The following are significant events which occurred during the first quarter of the contract year, 1978-1979.

1.0.1 General Introduction

Our staff's major effort at the beginning of the quarter was toward presenting the results of our research to other scientists attending the Second Eastern Gas Shales Symposium in Morgantown. At that meeting we presented six separate poster displays, a three-dimensional model of the Eastern Kentucky Gas Field, and five formal papers (see papers listed below).

In November and December our efforts centered on compilation and analyses of data gathered during the 1978 summer field season. These efforts are summarized below under the specific task headings.

Three reports were delivered during this quarter fulfilling requirements under our pending contract (see details below).

It should be noted that the 1978-79 contract has not yet been received. Our efforts are continuing on the project with the promise of a forthcoming contract. Lack of 1978-79 contract funds has caused some delay in ordering supplies and equipment as specified under the pending contract. Thus far, the delay has been one of inconvenience rather than any set back to the attainment of deliverables under the pending contract.

1.0.2 Regional Structure Studies

As a result of our research a relationship between geologic structure and shale gas production has been noted at the periphery of the shale gas producing area. Specifically, increased production was found on the high side of a slight monoclinal flexure at Cottageville (Figure 1), and on the low side of a flexure at the Midway - Extra field (Schaefer, manuscript in progress). We have now channeled the main thrust of efforts under this task toward a more detailed study of these interrelationships and toward prediction of potentially productive trends in the area between these two fields (see Figure 1). We are in the data compilation stage of this exploratory effort.

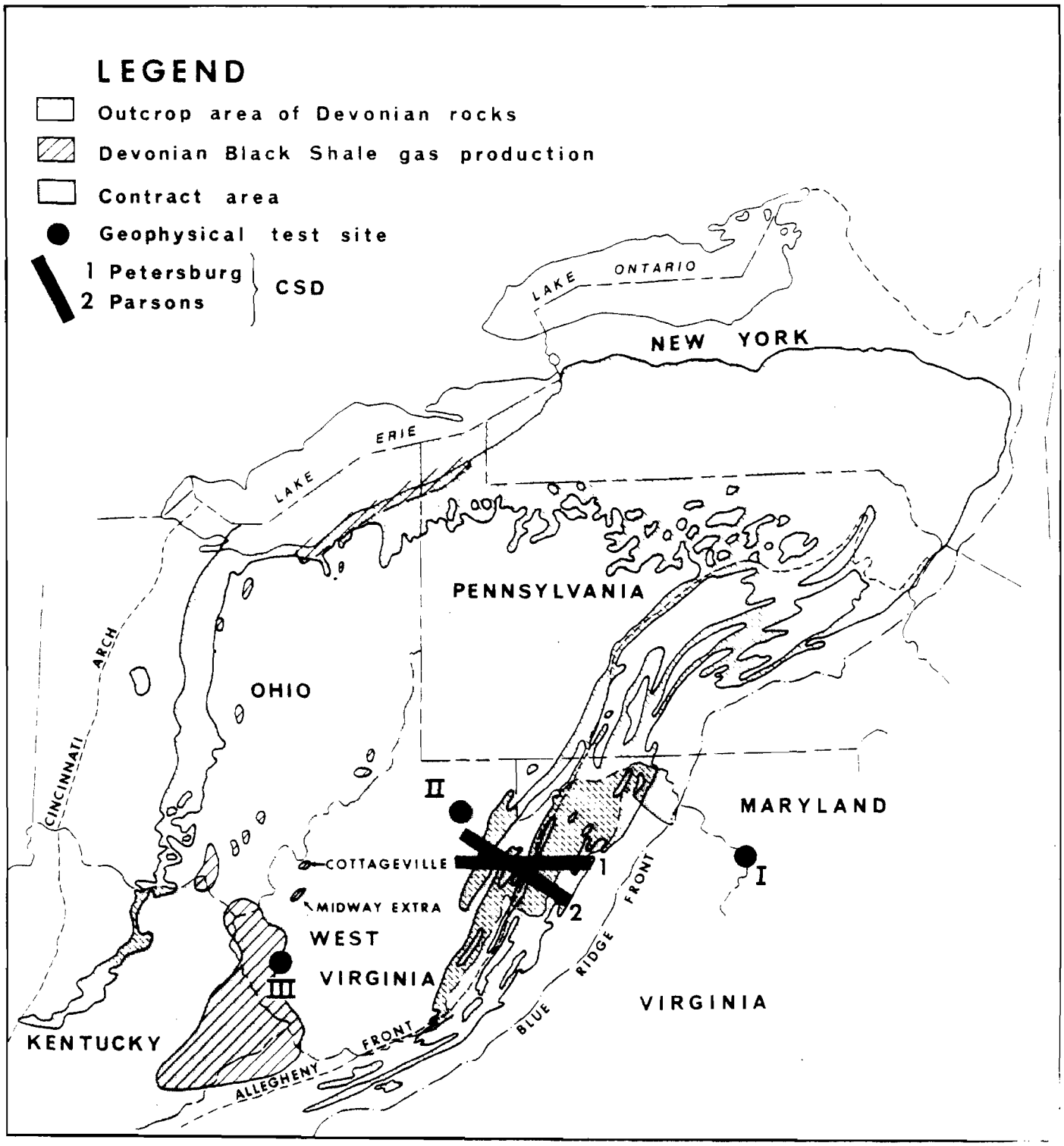
LEGEND
Outcrop area of Devonian rocks
Devonian Black Shale gas production
Contract area
Geophysical test site
1 Petersburg
2 Parsons
CSD
LAKE ONTARIO
NEW YORK
LAKE ERIE
PENNSYLVANIA
OHIO
CINCINNATI ARCH
MARYLAND
COTTAGEVILLE
MIDWAY EXTRA
WEST VIRGINIA
VIRGINIA
KENTUCKY
ALLEGHENY FRONT
BLUE RIDGE FRONT
I
II
III
1
2

Figure 1

1.0.3 Production Studies

During this past quarter we edited and reviewed a preliminary draft manuscript submitted by E. B. Nuckols III (formerly employed under our contract) for the author's revising. The final revised manuscript is due from the author the first day of the next quarter.

Near the end of the quarter we initiated a separate study of the Cottageville field data thru Dr. Gerald R. Hobbs, Jr., of the Department of Statistics and Computer Science at West Virginia University. This project is not presently funded by the U. S. Department of Energy, but the results of this research will be important to the project, and they will be integrated into our work. Basically, this study will not only statistically analyze the data, but it should expand and test certain of our ideas concerning the interrelationship of production and geologic structure.

The major emphasis of our research efforts concerning Devonian shale production continues to be on the giant eastern Kentucky gas field. Significant events of the past quarter include the construction and display of a three-dimensional model of that field at the Second EGSP Meeting. This model showed the interrelationships of production, stratigraphy, and structure across the field. The model also graphically demonstrated that the patterns of initial open flow production are complex, and that a detailed geologic analysis will be necessary to understand those patterns. In order to accomplish this detailed analysis the open flow data from the nearly 5000 wells was utilized to construct computer generated (SYMAP and ADMINMAP) maps of the field.

Our analysis of these maps suggests that the computer programs do not adequately display the abrupt fluctuations in the open flow data noted from one well to the next. Because of averaging characteristics of these programs they do not show the details of possible production trends that must be visible in order to utilize and extrapolate trends for exploration. Furthermore, it is necessary to define these trends if we are to locate areas to collect detailed data for our analysis of parameters that affect production. We decided that the only suitable approach to define production trends is to hand contour the nearly 5000 wells. We started the arduous task during this past quarter, and we expect to complete the map during the upcoming quarter. The completed map will form the basis for comparative analysis of open flow data with other geological and geochemical data. We expect also to select a graduate student during the upcoming quarter who will spend this coming summer in Prestonsburg, Kentucky, gathering structural tops from the Kentucky-West Virginia Company data files for construction of structural maps in detail comparable to that of the initial open flow map.

1.0.4 Geophysical Studies

The field testing and demonstration of seismic and resistivity equipment moved into the Cottageville shale gas field area (Figure 1) this past quarter. A line of section was located across the field, and a resistivity survey profile along this line was completed. This survey showed an anomaly where it intersected the slight monoclinal flexure which seemingly defines the line of most productive wells. Seismic shot and geophone holes were drilled on 80 foot centers along the same section line, but once the seismic recording started we experienced an equipment failure that required returning the equipment to the manufacturer. Again the holes were redrilled (nearly one mile on 80 foot centers), and again another equipment failure was experienced. We are attempting to locate the nature of the problem in the equipment in order to start the field program again when the weather permits.

During this past quarter we accumulated geophysical logs for the Cottageville area, and we made arrangements to digitize radioactive logs preparatory to constructing pseudo-sonic logs. The computer generated pseudo-sonic logs will be utilized to construct synthetic seismograms of the shale sediments in the Cottageville field. These seismograms will be compared with the seismograms collected within the field area as an aid to our interpretation.

Seismic data recorded on tape in the Cottageville field area should be displayed rapidly by a computer plotting program now being developed within our group. This program should come on line during the upcoming quarter.

1.0.5 Fracture Studies

We completed input of data and generated computer maps of joint data collected in eastern Kentucky during last summer's field season. Inasmuch as all joints are vertical to nearly vertical in dip, we plotted only strike trends. Joints segregated and plotted by lithology show that coal face cleats (equivalent to systematic joints) present the simplest areal pattern. However, the trends of face cleats in Kentucky appear more complex than those in adjacent West Virginia. Several trend domaine boundaries have been delineated, but their relationship to shale gas production awaits definition of production trends (see summary of Production above).

Our study of fractures within the Pine Mountain Thrust block show increasing complexity of fracture trend downward thru the stratigraphic section to the base of the shale, which is the thrust zone.

1.0.5 Fracture Studies - continued

The first of several reports to be written on fractures within oriented shale cores was completed and submitted to DOE-METC this quarter. This report on the Reel Energy #3 D/K well showed a correspondence of partially mineralized northeast trending natural fractures with the major show of shale gas in the hole.

1.0.6 Structural Studies

Maps showing the joint station locations, joint intensities, and average joint spacings of each set in Parsons lineament area (Figure 1) were completed and submitted to DOE-METC this past quarter. A draft manuscript describing methods of measuring joint intensities was started for final submittal early in the next quarter.

During the quarter gravity data was collected and reduced to model subsurface geology along the Parsons lineament (Figure 1). Several short seismic lines in the Parsons area were obtained from the Shell Oil Company. This older data, which is of marginal quality, will be datumned and inspected next quarter to ascertain if it sheds light on the nature of the lineament.

A report by Philip S. Berger entitled, "Extension Structures in the Central Appalachians," was submitted to DOE-METC this past quarter in fulfillment of a May 1979 deliverable listed in our pending contract. The report not only discusses the nature and origin of late stage open fractures of Appalachian folds, but it also suggests the structural position on several specific structures that might be drilled for shale gas.

1.0.7 Hydrology Studies

We completed the collection of water quality and water well yield data in the Midway - Extra shale gas field area.

Our efforts now will be toward compilation of shale gas well yields and comparison of these data with photo lineament positions, water quality data, and water well yield data.

PAPERS DELIVERED AT SECOND ANNUAL GAS SHALES SYMPOSIUM, OCTOBER 1978

1. de Wys, J. Negus, and R. C. Shumaker, "Eastern Kentucky Gas Field: Structural-Stratigraphic Cross Sections and Potential Production Patterns"

2. de Wys, J. Negus, and R. C. Shumaker, "Trend Analysis of Gas Production in the Cottageville Field"

3. Jones, D. Scott and Dr. Henry W. Rauch, "Lineaments and Ground-water Quality as Exploration Tools for Ground Water and Gas in the Cottageville Area of Western West Virginia"

4. Nuckols, III, E. B., "Exploration Parameters Derived from Historical Devonian Shale Production in Western West Virginia"

5. Shumaker, R. C., "Structural Parameters that Influence Devonian Shale Gas Production in West Virginia and Eastern Kentucky: A Summary of Progress for 1977-1978"

DELIVERABLES

Deliverable Item No.	
18	"Extension Structures in the Central Appalachians" by Philip S. Berger (under the direction of Dr. Russell Wheeler, West Virginia University)
12 (in part)	"Fracture Density and Orientation Study of the Reel Energy #3 D/K Core from Mason County, West Virginia" by Mark A. Evans
	"The Cottageville Gas Field, Jackson County, West Virginia: A Case Study of Devonian Shale Gas Production" by E. B. Nuckols III (preliminary manuscript submitted and revised)

2.0 CONTRACT OBJECTIVES

2.0 CONTRACT OBJECTIVES

Collect, compile and analyze geological data and prepare geological structure maps for eastern Kentucky and western West Virginia.

Determine if structural types and styles and surface lineations for productive areas of the Black Shales differ from those in non-productive areas.

Identify and define along with other contractors those geologic parameters that control gas production from the shales.

Determine the feasibility of using shallow penetration resistivity and seismic surveys to detect near surface faults and fractures and demonstrate their relationship to lineations observed on airborne imagery.

Determine if a relationship exists between ground water movement and shale gas productivity.

In conjunction with other contractors develop a method for selecting areas for drilling shale wells that have a potential for gas production.

3.0 TECHNICAL PROGRESS

3.1 Work Package 2100-2-1 STRUCTURE CONTOUR MAPS Robert C. Shumaker

3.1.1 Current status of work and deliverables

Work started toward a detailed structural analysis of the area between and including the Cottageville shale gas field and the Midway - Extra shale gas field. There are over 1200 well location reports that are being inspected for data concerning well location formation tops and shale gas production. We are perhaps 60% complete on the data collection. There are no deliverables.

3.1.2 Problem areas and suggested improvements.

No problems.

3.1.3 Work plan for next quarter

The work plan for the upcoming quarter is to complete abstracting structural data preparatory to spotting wells with Berea tops.

* * * * * *

3.1 Work Package 2100-1-1 CROSS SECTIONS — J. Negus de Wys

3.1.1 Current status of work and deliverables

Current status of work: 50% completed.

Scheduled deliverables: none.

- Log correlation: 90 logs (total)
- Data posting from correlated logs completed.
- Log interpretation school October 26, 1978, with Schlumberger.
- Microscope and camera ordered for lithology studies.
- API counts initiated.
- Paper on Cottageville Pilot Study presented at Lakeview Meetings.
- Paper on Eastern Kentucky Study presented at Lakeview Meetings.
- 3-D Model of Eastern Kentucky Gas Field presented at poster sessions at Lakeview Meetings.
- 13 Preliminary Cross Sections (stratigraphic and structural) completed, drafted.

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for next quarter

- Progress in lithology studies.
- Correlate additional logs.
- Continue API counts.
- Prepare paper accepted for AAPG Meetings, April, 1979, Houston, on The Eastern Kentucky Gas Field(s).

* * * * * *

3.2 Work Package 2100-1-2 ISOPACH MAPS — J. Negus de Wys

3.2.1 Current status of work and deliverables

Current status of work: ~40%

Scheduled deliverables: None

- Log correlation of 30 additional logs completed. (Total: 90) of 300 total to be done.

3.2.2 Problem areas and suggested improvements

None.

3.2.3 Work plan for next quarter

- Continue log correlation.
- Plot data on maps
- Punch computer cards.

* * * * * *

3.3 Work Package 2100-2-1 STRUCTURE CONTOUR MAPS J. Negus de Wys

3.3.1 Current status of work and deliverables

Current status of work: 40% completed

Scheduled deliverables: None

- Continued progress on log correlation and data plotting.
- On-going negotiations for release of basement seismic map.
- Assignment of student to structure data retrieval (Kentucky-West Virginia Gas) to be accomplished next summer.

3.3.2 Problem areas and suggested improvements

None.

3.3.3 Work plan for next quarter

- Continue log correlation and data plotting.
- Hopefully complete negotiations for basement seismic map release from Weaver and Hill.

* * * * * *

3.4 Work Package 3200-4-1 OIL AND GAS MAPS J. Negus de Wys

3.4.1 Current status of work and deliverables

Current status of work: 50% completed.

Scheduled deliverables: None.

- Papers (2) and 3-D Model presented at Lakeview Meetings (See 3.1).
- Schlumberger school (See 3.1).
- Paper accepted for AAPG (see 3.1).
- SYMAP and ADMINMAP computer drawn maps prepared for reduction prior to drafting.
- Hand contoured map of initial open flow in Eastern Kentucky Gas Field(s) using 4750 data points COMPLETED and delivered to drafting.

3.4.2 Problem areas and suggested improvements

None.

3.4.3 Work plan for next quarter

- Prepare discussions of Trend Analysis, SYMAP, and ADMINMAP computer drawn maps.
- Drafting of reduced copies of ADMINMAPS and SYMAP computer drawn maps.
- Drafting and delivery of hand contoured (4750 data points) Initial Open Flow Map of Eastern Kentucky Gas Field(s).
- Continue work on cross sections of initial open flow maps for comparison with stratigraphic/structural cross sections.

* * * * * *

3.1 Work Package 2100-1-1 SEISMIC — James E. Ruotsala

3.1.1 Current status of work and scheduled deliverables

1. Little progress has been made on the job of seismic data plotting due to the unavailability of the digital recorder. The component needed to interface the digital recorder to the PDP-11 mini-computer has been delivered.

2. A computer procedure for the computation of synthetic seismograms has been developed. It will be used initially for seismic modeling in the Cottageville field.

3. Work on the problem of constructing synthetic seismograms for wells that have no sonic logs has begun. The approach is guided by study of the gamma ray, resistivity, and density logs of wells that have sonic logs to formulate a reasonable way of constructing a crude pseudo-sonic log for a well that has no sonic log. The Cottageville area only is being examined now.

3.1.2 Problem areas and suggested improvements

Nothing insurmountable.

3.1.3 Work plan for next quarter

1. Seismic data plotting capability will be achieved.

2. Seismic modeling of the Cottageville field will be done.

3. Plans for next summer's field work will be made.

* * * * * *

3.1 Work Package 2100-1-1 SEISMIC — Keith G. Kirk

3.1.1 Current status and deliverables

The layout of the second survey line was completed. Shot holes and geophone holes were drilled along the two mile survey route. Data collection is underway at the Cottageville test site.

3.1.2 Problem areas and suggested improvements

Because the Cottageville test site is much wetter than the Wetzel County test site problems developed with geophone cables and connectors. During this quarter the connectors were replaced with hermaphroditic water-tight connectors. The digital recorder malfunctioned and time was lost during its repair. The conditions at the test site have required the shot holes and geophone holes to be redrilled several times. Now the holes are redrilled on an as needed basis. Many of the problems encountered in this work would not have occurred if initially more sophisticated equipment would have been used. The monies initially saved by inexpensive equipment have been overshadowed by expensive and time-consuming repairs. It is recommended that future work of this nature include sufficient funding for adequate tool up at the start of the project.

3.1.3 Work plan for next quarter

Data will continue to be collected at the remaining two test sites and analyses will begin.

* * * * * *

3.1 Work Package 2100-2-2 STRUCTURE STUDIES — Thomas H. Wilson

3.1.1 Current status and deliverables

A.) Gravity Survey: completed. At some point, however, additional stations may become necessary.

B.) Data Reduction: incomplete.

C.) Gravity Modeling: incomplete.

Work on data reduction and gravity modeling delayed because of literature survey and work on deformational scale models of layered clay. This diversion was considered necessary and preparatory to the modeling of balanced cross sections.

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for next quarter

A.) Work will begin on reduction of gravity data.

B.) Additional models will be constructed to observe the effects of basement relief, variations in thickness of low viscosity layers, isostatic adjustments in the basement, surface slope, vertical and horizontal gradients in the strain rate tensor, energy balance, etc., on the character of the detached structures beyond the allocthonous Blue Ridge. A month will be spent at Alfred University, Alfred, New York, working with Byron Kulander on these models.

C.) A talk will be prepared and given at the GSA northeastern section meeting in Hershey, Pennsylvania, March 2, 1979. The title of the talk is "Bedding Orientation Contours of Middle Devonian Shales in the Middle Mountain Syncline, Valley and Ridge Province, West Virginia."

D.) A manuscript on bedding orientation data will be completed this quarter.

* * * * * *

3.1 Work Package 2100-2-2 STRUCTURE STUDIES Jeanette M. Dixon

3.1.1 Current status of work and scheduled deliverables

The poster session for the Eastern Gas Shales Meeting in October was presented, illustrating ongoing work of the Parsons lineament joint intensity study.

Maps showing station locations, joint intensities of all sets, and average spacings of each individual set were completed and drafted. Joint roses were also finalized. The preliminary maps were submitted December 1, 1978, and finalized maps will be submitted in January, 1979, along with the final report.

3.1.2 Problem areas and suggested improvements

Course work required a great deal of time. One more semester of courses and comprehensive exams will complete the required class work; then more time can be devoted to research.

3.1.3 Work plan for next quarter

An attempt will be made to make a statistical model for measuring joint intensities in order to determine how much variation in intensities is due to actual differences in jointing and how much variation is due to geographical locations.

* * * * * *

3.1 Work Package: 2200-1-2 FRACTURE STUDIES — Brian R. Long

3.1.1 Current status and deliverables

Field data has been placed in computer data sets. Individual maps showing joint strike directions for sandstone, limestone, coal, shale, and Devonian shale have been plotted at 1:250,000 scale. Coal face cleat strikes have been plotted separately at 1:250,000 scale to show differences in orientation over eastern Kentucky. Separate maps for black, gray, and brown shales have been plotted.

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for next quarter

Correlation of coal face cleat strikes with regional trends including structural basement contours, coal form line features, topography, and gas production areas. The writing of the final report will begin.

* * * * * *

3.1 Work Package: 2200-1-2 FRACTURE DENSITY AND ORIENTATION Mark A. Evans

3.1.1 Current status and deliverables

The fracture report on the MERC #1 core is 80% complete. Data collection on all cores has stopped. Data analysis has begun on the available data from the Wise County, VA, core and the Martin County, KY, core. Also, photolineament and fracture trace studies have begun for areas surrounding the core wells being studied.

3.1.2 Problem areas and suggested improvements

Due to the transfer of the cores from Morgantown to Granville data collection on the cores has stopped.

3.1.3 Work plan for next quarter

Until the cores are again available for study. Work will continue on the data taken on the Wise County, VA, and Martin County, KY, cores. Photolineament and fracture trace studies will also continue. When the cores become available, data collection will resume on the fracture density and orientation of natural and induced fractures in the cores.

* * * * * *

3.1 Work Package 2200-1-2 FRACTURE STUDIES Kevin D. Lee

3.1.1 Current status of work and scheduled deliverables

a.) Four stratigraphic columns showing joint data and macro structures were constructed.

b.) A comprehensive report on the structure of the Cumberland thrust block was prepared in conjunction with a class assignment.

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for next quarter

a.) Continue to analyze joint data.

b.) Run computer studies of joint data where impractical to do it by hand.

c.) Plan field work for the coming summer based on the results of last summer's work.

* * * * * *

3.1 Work Package 3200-1-2 SUBSURFACE GEOLOGY — Henry W. Rauch

Subtask - Identify 3 areas in which to conduct ground water studies.

3.1.1 Current status of work and scheduled deliverables

Work continues in the Midway-Extra study area, by Mr. Robert Beebe under supervision of Henry Rauch. No new studies have been initiated in other areas during this quarter. See other task reports below for progress status on the Midway-Extra study.

3.1.2 Problem areas and suggested improvements

Some additional delays related primarily to automobile mechanical problems have prevented Mr. Beebe from catching up on planned research work. This particular study remains about one month behind our original planned schedule. This delay is not serious, however, and all work including final reports should be concluded for this study within six months.

3.1.3 Work plan for next quarter

No new studies will be initiated during next quarter. See other task reports for specific plans for the Midway-Extra study.

* * * * * *

3.2 Work Package 3200-2-3 SURFACE RESISTIVITY Henry W. Rauch

Subtask - Conduct resistivity surveys over ground water study areas (defined under 3200-1-2).

3.2.1 Current status of work and scheduled deliverables

No resistivity surveying was accomplished during the last quarter in the Midway-Extra study area. The scope and importance of this task have been recently downgraded; instead, more work emphasis is being placed on an analysis of possible associations between ground water quality and gas well yield for this area, following our tentative conclusions from the Cottageville study. There are no scheduled deliverables for next quarter.

3.2.2 Problem areas and suggested improvements

These are discussed above in sections 3.2.1 and 3.1.2 above.

3.2.3 Work plan for next quarter

Work on resistivity surveys as weather and time permit in the Midway-Extra study area. Such surveys will be completed in the third quarter.

* * * * * *

3.3 Work Package 3200-5-1 STRUCTURE/PRODUCTION CORRELATION Henry W. Rauch

Subtask - Correlate all data and attempt to establish a relationship between geologic features, lineaments, fractures, ground water, and oil and gas production.

3.3.1 Current status of work and scheduled deliverables

Attempts to obtain more water well information from within the high-producing gas well area were unsuccessful. Three extra water wells were surveyed near low-producing gas shale wells just north of the Cottageville. Two of these wells support earlier conclusions concerning ground-water quality and gas production, while one well contradicts these conclusions.

3.3.2 Problem areas and suggested improvements

None, other than those mentioned under section 3.1.2 above.

3.3.3 Work plan for next quarter

Complete all remaining sampling, data measurements, and photo-lineament mapping for the Midway-Extra study. Also complete an analysis of statistical associations of photolineaments and water-well data with gas well yields. A summary of data and conclusions will be delivered next quarter, but a final study report will not be delivered until the following quarter (April - June 1979).

* * * * * *

3.4 Work Package 3200-5-3 LINEAMENT/STRUCTURE CORRELATION Henry W. Rauch

Correlate fractures and lineaments derived from photo analysis with results of ground water tests to determine if any relationship exists between ground water production and the occurrence of lineaments.

3.4.1 Current status of work and scheduled deliverables

To date we have not yet compared water well yield to lineament proximity in the Midway-Extra study area. This cannot be done until task 3.3 (described above) is completed.

3.4.2 Problem areas and suggested improvements

None, other than those described under section 3.1.2 above.

3.4.3 Work plan for next quarter

We will complete an analysis of ground water and lineaments for the Midway-Extra study area and will report our conclusions in next quarter's report. A final report on this task for the Midway-Extra study will be forthcoming in the April - June Quarterly Report.

* * * * * *

3.1 Work Package 3200-2-3 SURFACE RESISTIVITY Keith G. Kirk

3.1.1 Current status and scheduled deliverables

Work is on schedule. There are no scheduled deliverables for this quarter.

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for next quarter

Additional data will be collected at test sites.

* * * * * *

UGR File #C048/7903
April-June 1979
WVU Dept. of Geology and Geography

QUARTERLY PROGRESS REPORT

U. S. Department of Energy

Contract no. DE-AC21-76MC05194
(formerly EY-76-C-05-5194)

April - June 1979

submitted by

Department of Geology and Geography
West Virginia University

Robert C. Shumaker, Project Director

co-authored by

J. Negus-de Wys, Jeanette M. Dixon, Mark A. Evans,
Kevin D. Lee, Brian R. Long, Henry W. Rauch,
James E. Ruotsala, Richard T. Williams, Thomas H. Wilson

Principal Investigators

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open File 048/7993

1.0 EXECUTIVE SUMMARY

QUARTERLY REPORT

U. S. DEPARTMENT OF ENERGY CONTRACT NO. DE-AC21-76MC05194
(formerly EY-76-C-05-5194)

APRIL - JUNE 1979

1.0 EXECUTIVE SUMMARY

1.0.1 General Introduction

The major accomplishments this past quarter have been the completion of manuscripts concerning: shale production at the Midway-Extra field of West Virginia (Figure 1) and surface fracture study in the Big Sandy field of eastern Kentucky (Figure 1). In our other areas of research we entered the summer field season where scientists working on the project are busy collecting data.

In last quarter's report delay was noted in the geophysical and subsurface fracture studies. We resolved the problems in both areas this quarter so that we are making good progress in both areas. The specifics of progress under each task are summarized below.

1.0.2 Regional Structure Studies

We have completed the tabulation of subsurface tops for several formations as noted on drillers' logs for the Midway-Extra - Cottageville area (Figure 1). We hope that detailed maps of this area will permit us to map basement fault trends that will be prospective for shale gas drilling to recover gas flows above the norm for that region.

We have expanded our structure study area to include part of Kanawha and Putnam Counties along the fracture domaine boundary as shown by Kulander (1978 - manuscript in press).

By the end of next quarter the subsea elevations should be spotted preparatory to constructing a detailed structural map on a shallow formation.

1.0.3 Production Studies

As noted above, a major accomplishment this past quarter was the completion of a study on the Midway-Extra field of West Virginia by Mr. William W. Schaefer (Figures 1 and 2).

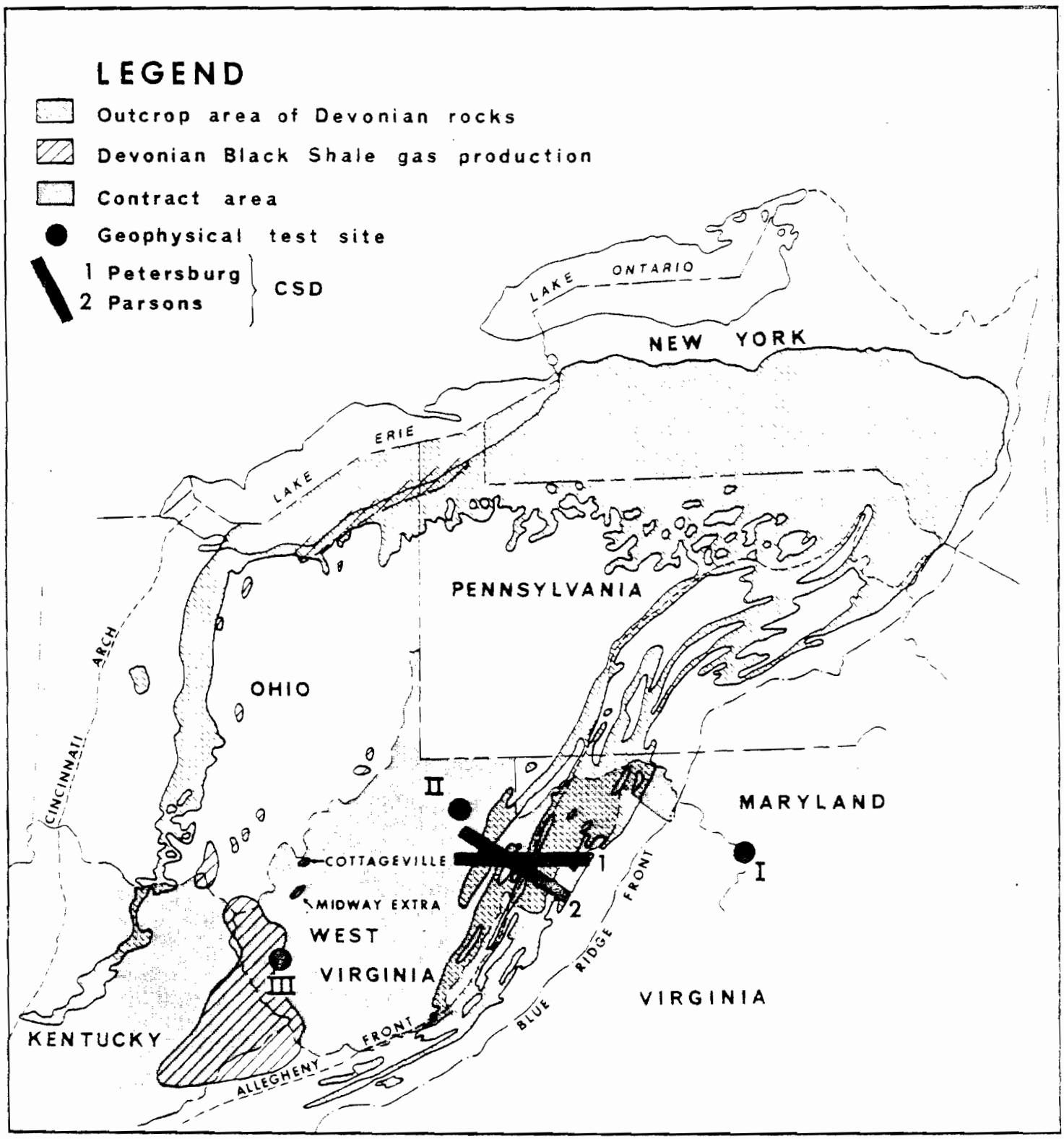
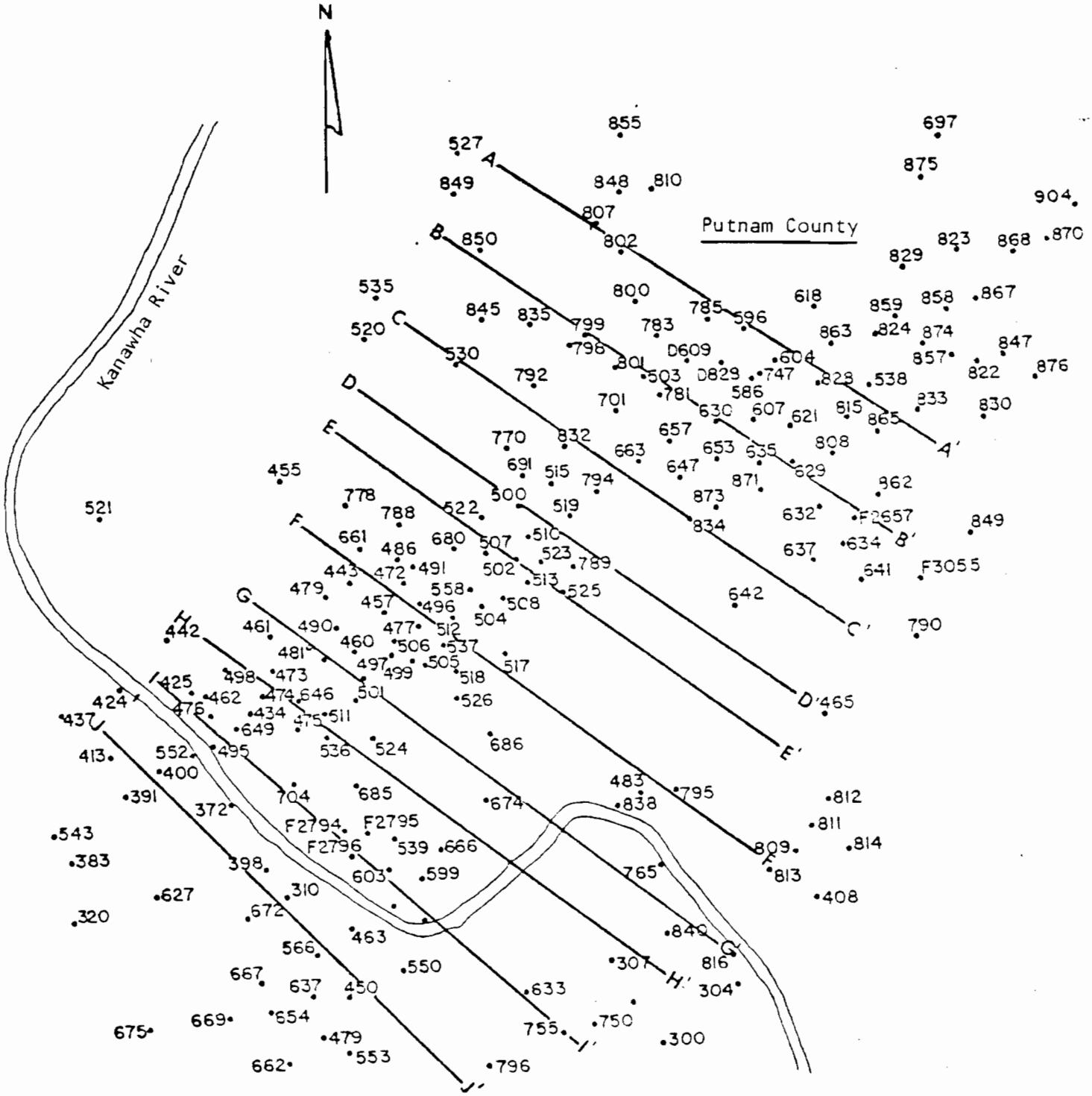

LEGEND
Outcrop area of Devonian rocks
Devonian Black Shale gas production
Contract area
Geophysical test site
1 Petersburg
2 Parsons
CSD
LAKE ONTARIO
NEW YORK
LAKE ERIE
PENNSYLVANIA
OHIO
CINCINNATI ARCH
MARYLAND
COTTAGEVILLE
MIDWAY EXTRA
WEST VIRGINIA
VIRGINIA
KENTUCKY
ALLEGHENY FRONT
BLUE RIDGE FRONT
I
II
III
1
2

Figure 1



MIDWAY-EXTRA FIELD

INDEX OF CROSS SECTIONS
(see Figure 1 for location)

W. Schaefer, 1979

FIGURE 2

1.0 EXECUTIVE SUMMARY - continued R. C. Shumaker

1.0.3 Production Studies - continued

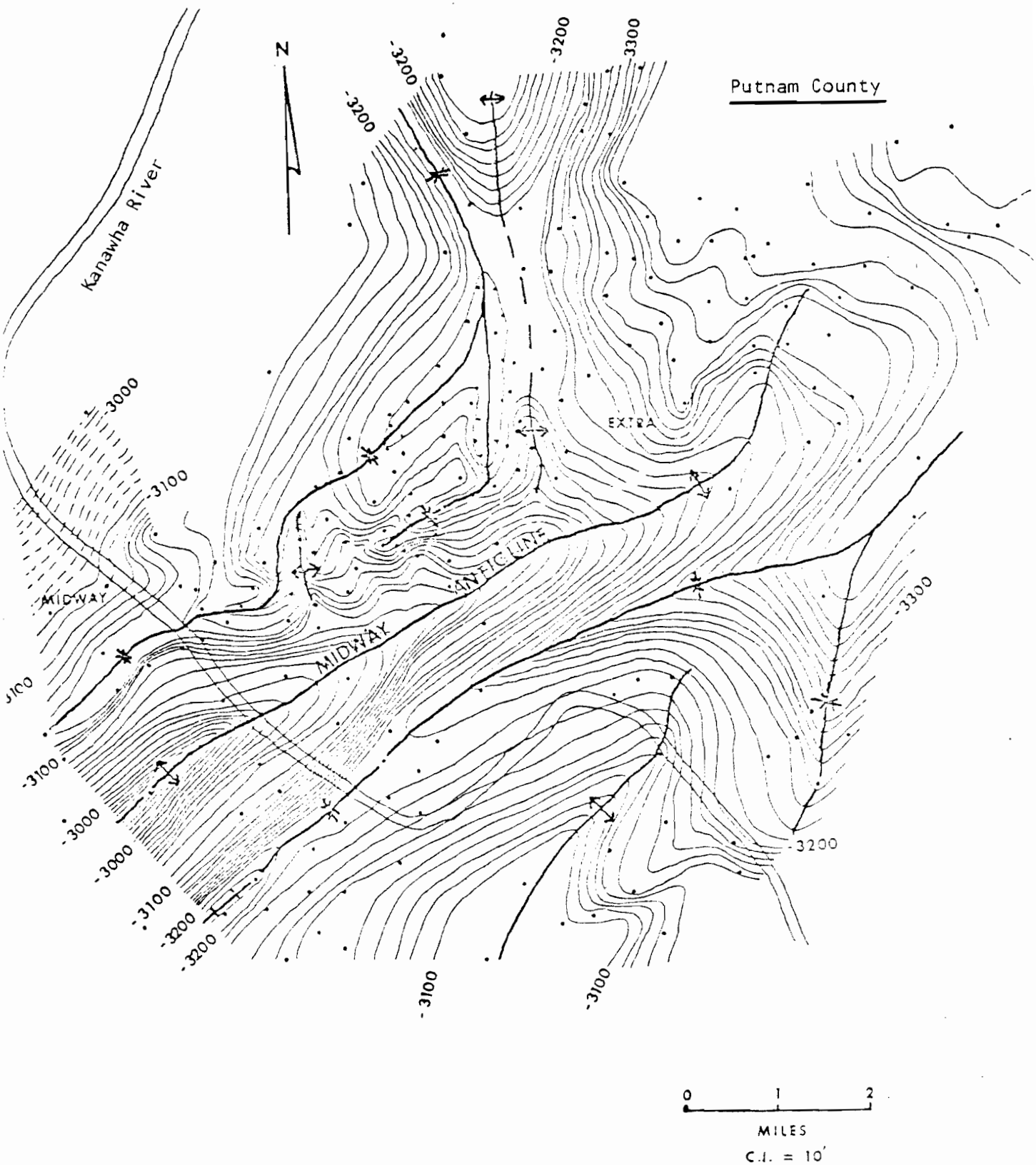
He found a direct relationship between the subsurface structural trend in the area and productivity from the Lower Huron member of the Devonian shale (compare structure map Figure 3 and isopotential maps (Figures 4 and 6). Furthermore, he concluded that the structure was growing during the Devonian, and that this growth affected sedimentation of the reservoir (compare Figure 3 and Figure 5).

The relationships found at Midway-Extra are very similar to those found at Cottageville in that the production parallels subsurface structural trends. At Cottageville far more complete production data are available (de Wys and Shumaker, 1978) to establish this relationship, whereas, at Midway-Extra the production data available are only initial open flows. In both areas we have interpreted the shale structure to relate to basement faulting, and at Cottageville this interpretation was recently confirmed by seismic investigations (Sundheimer, 1978). The focal point of these observations is to explore for shale production off-structure above basement highs. Further, it suggests that the fracture porosity in this type field is not blanket-like, but is related either to compaction or a basement-linked stress field. We favor a basement-linked stress field based on the identical position of a mapped basement fault and highly productive wells at Cottageville.

1.0.4 Geophysical Studies

Last quarter we were experiencing electronic problems with the seismic equipment that caused serious delays to our geophysical program. These problems have been largely corrected, and we have successfully collected data on digital tape at Cottageville. We are presently in the process of arranging to process that data. The electronic problems were present in the equipment when we shot test site II; so we will reshoot the Wetzel County line A (Figure 1, site II) to verify the hand plotted results.

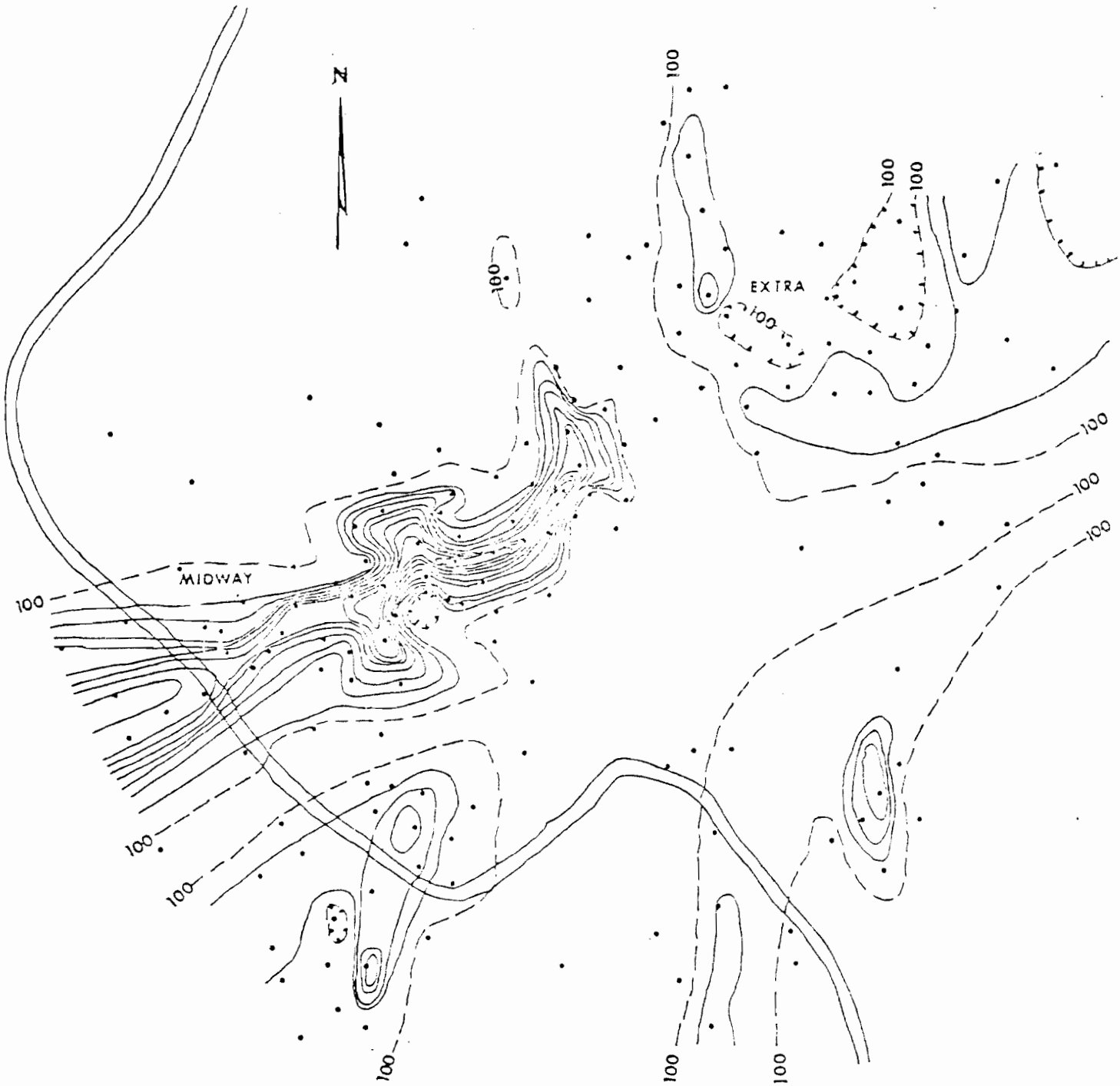
We have not received permission to shoot the Warfield fault site (Figure 1, site III) from the Norfolk and Western Railway; so we will delete that test site and return to Cottageville to shoot more reflection seismic and initiate refraction shooting thru that field.



STRUCTURE BASE OF BROWN SHALE (L. HURON)

W. Schaefer, 1979

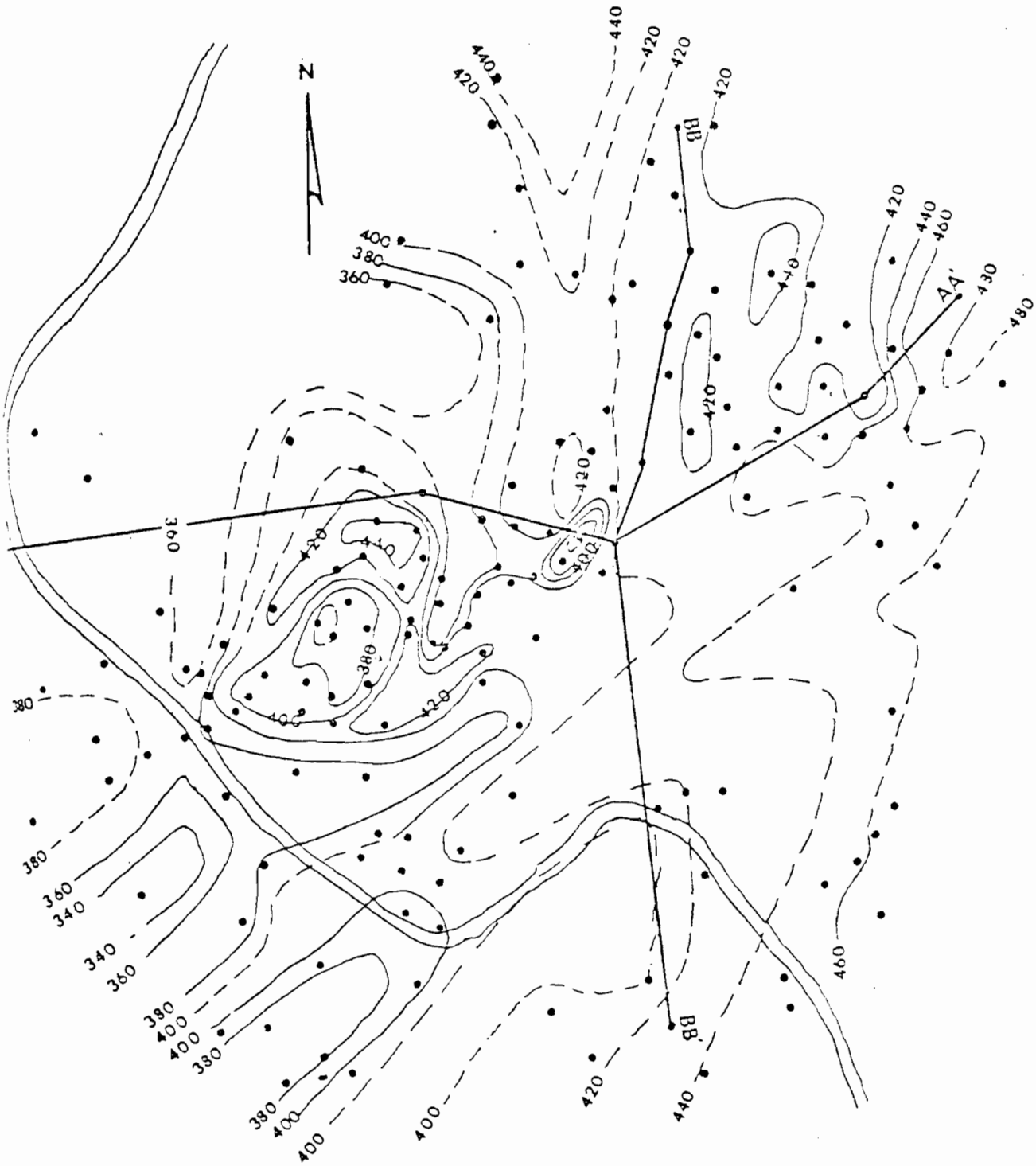
Figure 3



BROWN SHALE ISOPOTENTIAL
OPEN FLOW AFTER STIMULATION

Figure 4

0 1 2
MILES
C.I. = 100
MCF/D
W. Schaefer, 1979



LOWER HURON ISOPACH MAP

Figure 5

0 1 2
MILES

W. Schaefer, 1979

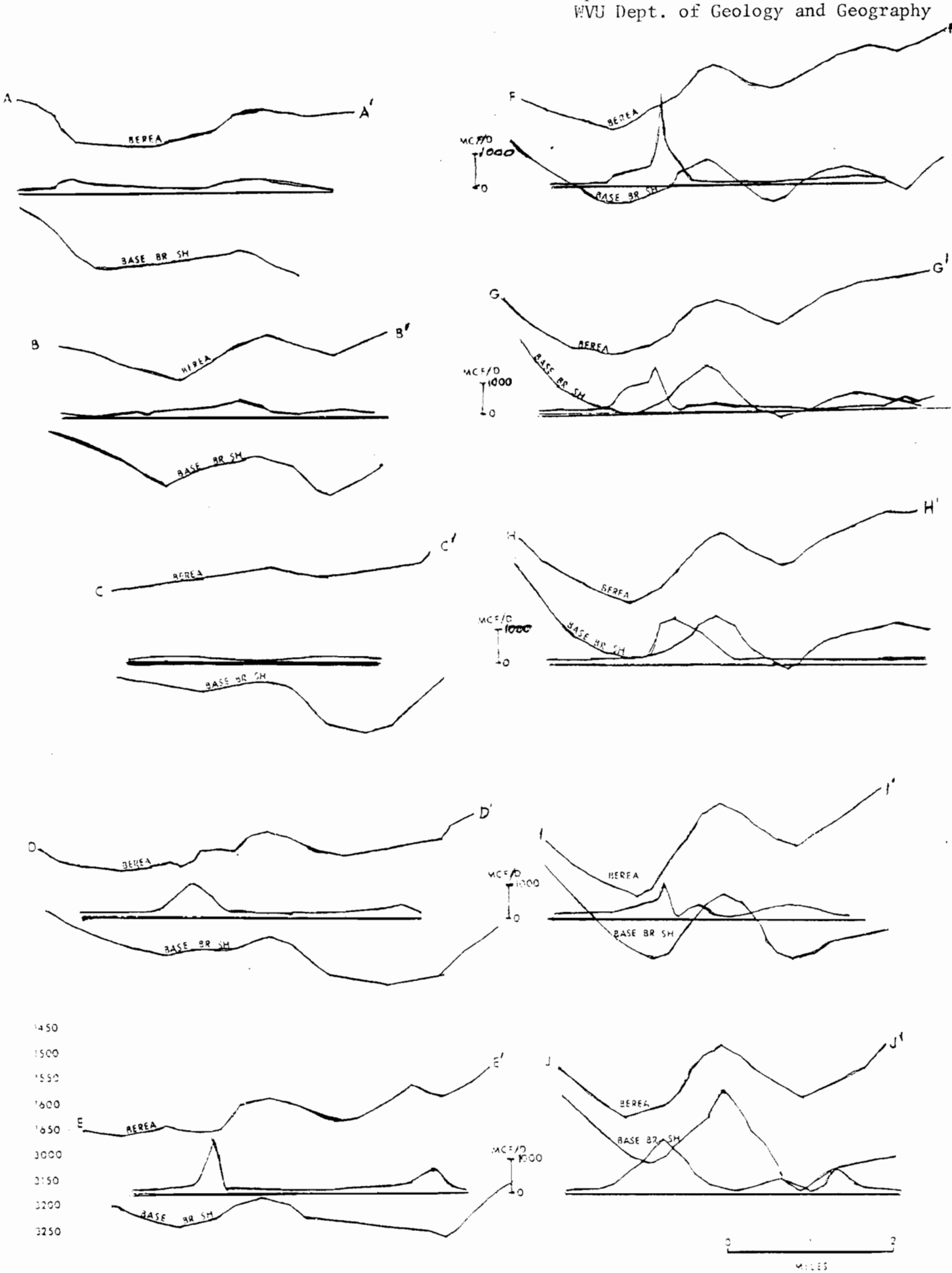


Figure 6 STRUCTURE AND ISOPOTENTIAL CROSS SECTIONS W. Schaefer, 1979

1.0 EXECUTIVE SUMMARY - continued - R. C. Shumaker

1.0.5 Fracture Studies

A report on the surface fractures of eastern Kentucky was completed this past quarter. We found that fracture trends in each lithology were unique, and that none of the surface joint patterns in the Big Sandy gas field match the Devonian shale joint patterns exposed along the Cincinnati Arch (Figure 1). The ubiquity of pattern trends makes the use of surface joint data suspect for predicting subsurface fracture trends. The noted complexity in eastern Kentucky may be unique, and joint trends elsewhere throughout the basin and continental interior appear to be more regular. This noted complexity may account in part for the occurrence of widespread, highly productive shale gas wells found in eastern Kentucky.

Progress continues on fracture studies of oriented Devonian shale wells. We have completed study of 10 wells within the Appalachian basin, and we should complete all 13 wells of the study during the next quarter.

1.0.6 Structural Studies

Our effort here centered on completion of a manuscript concerning deformation of Devonian shales in a synclinal fold typical of the Appalachian Valley and Ridge Province. This report will be complete next quarter. Secondarily, we are attempting to test the validity of extending the Parsons and Petersburg lineaments (Figure 1 cross-strike structural discontinuities) westward in the Appalachian Plateau by fracture intensity studies. Preliminary analysis suggests that the Parsons lineament affects joint intensity in the Plateau. Therefore, we have extended this CSD toward the shale portion of the basin. We are presently field sampling joint intensity in the Plateau portion of the Petersburg lineament.

We completed a "drilling depth to the base of the shale" map so that one can rapidly estimate the depth and cost to drill at any location within the northern West Virginia plateau area.

1.0.7 Hydrologic Studies

Preliminary analyses of data suggest a positive relationship among certain low-altitude photo linears, ground-water geochemistry, ground-water productivity, and shale gas well productivity in the Midway-Extra field area (Figure 1). The ground-water relationships are similar to those found at

1.0 EXECUTIVE SUMMARY - continued - R. C. Shumaker

1.0.7 Hydrologic Studies - continued

Cottageville (Jones and Rauch, 1978), but the correlation is established with the north-northwest trending photo "fracture" trace trend in Midway-Extra field rather than the west-northwest trend as found at Cottageville. The cause for this difference is under investigation. Regardless of the underlying cause for this difference, the relationship among shallow ground-water geochemistry, photo fracture traces, and shale gas well productivity is sufficiently strong to permit empirical use for exploration in a limited area.

* * * * * *

Abstracts submitted to Joint DOE/EGSP-ES/AAPG Symposium, to be held Oct. 1-4, 1979.

Paleozoic Disruptive Deformation in North American Continent and its Relationship to the Formation and Development of Interior Basins and Deformation Within the Orogenic Core by Robert C. Shumaker

Parameters of Geologic Structure Which Affect Devonian Gas Shale Production in West Virginia and Eastern Kentucky - A Progress Report 1978-1979 by R. C. Shumaker, J. Negus de Wys, J. M. Dixon, M. A. Evans, K. G. Kirk, K. D. Lee, B. R. Long, H. W. Rauch, J. E. Ruotsala, T. H. Wilson, W. W. Schaefer, R. T. Williams

Cross-strike Structural Discontinuities: Exploration Rationale for Eastern Plateau Province by Russell L. Wheeler

Tectonic Thinning by Extension Faulting and Shale Flowage, and Implications for Fractured Gas Reservoirs by Philip S. Berger and Russell L. Wheeler

Possible Plate Tectonic Effects on the Appalachian Upper Devonian Basin and the Eastern Kentucky Gas Field by Jane Negus-deWys

Lithology Studies of Upper Devonian Well Cuttings in the Eastern Kentucky Gas Field by Jane Negus-de Wys

Inorganic Geochemical Studies of Eastern Kentucky Gas Field(s) and Comparison with Gas Production by Jane Negus-de Wys and John J. Renton

Regional Survey of Surface Joints in Eastern Kentucky by Brian R. Long

Lineaments and Water Wells as Exploration Tools in the Midway-Extra Gas Field by Robert R. Beebe and Henry W. Rauch

The Parsons Cross Strike Structural Discontinuity as an Exploration Area for Fractured Gas Reservoirs by Thomas H. Wilson and Jeanette M. Dixon

APRIL THRU JUNE, 1979

PAPERS GIVEN

Jane Negus-de Wys: "Relations of Gas Occurrence to Geologic Parameters in Eastern Kentucky Gas Fields," Negus-de Wys, Jane and R. C. Shumaker, AAPG Annual Convention, Houston, Texas, April, 1979.

Mrs. Negus-de Wys chaired a session on Natural Gas Habitats at this AAPG Annual Meeting.

Jeanette M. Dixon: "A Method to Identify Zones of Intense Jointing with Application to the Parsons Lineament, West Virginia," Southeastern Section of Geological Society of America, Blacksburg, Virginia, April 25-28, 1979.

MEETINGS ATTENDED

Thomas H. Wilson: NATO Advanced Study Institute's Conference on Plate Tectonics and Continental Drift, School of Physics, University of Newcastle-upon Tyne, England, March 27 thru April 8, 1979.

Mr. Wilson attended the Thrust and Nappe Tectonics Symposium, April 9 thru April 11, 1979, Imperial College, London, England.

Jane Negus-de Wys: Met with Claude Dean, George Fingleton, R. C. Shumaker concerning geochemical studies, which are related to the lithology studies.

Henry W. Rauch: Met with Claude Dean and George Fingleton on May 7 to review the status of hydrogeology work in the Midway-Extra study area.

Jane Negus-de Wys and Robert C. Shumaker: Met with John M. Pezzetta, Grury Associates to review the Big Sandy gas field.

APRIL THRU JUNE, 1979

DELIVERABLES AND MILESTONES DELIVERED

Deliverable 3.3.15 Milestone 3.4.30	"A Method to Identify Zones of Intense Jointing with Application to the Parsons Lineament, West Virginia," - Jeanette M. Dixon (delivered April 9, 1979).
Deliverable 3.3.13 Milestone 3.4.23	"Fractures from Devonian Shale Outcrops Along the Pine Mountain Thrust," - Kevin D. Lee (delivered May 21, 1979).
Deliverable 3.3.11 Deliverable 3.3.17 (in part)	"Regional Survey of Surface Fractures in Eastern Kentucky," - Brian R. Long (delivered June 22, 1979).
Deliverable 12 (in part)	"Fracture Density and Orientation Study of the MERC #1 Core from Monongalia County, West Virginia," - Mark A. Evans (delivered June 22, 1979).

2.0 CONTRACT OBJECTIVES

2.0 CONTRACT OBJECTIVES

Collect, compile and analyze geological data and prepare geological structure maps for eastern Kentucky and western West Virginia.

Determine if structural types and styles and surface lineations for productive areas of the Black Shales differ from those in non-productive areas.

Identify and define along with other contractors those geologic parameters that control gas production from the shales.

Determine the feasibility of using shallow penetration resistivity and seismic surveys to detect near surface faults and fractures and demonstrate their relationship to lineations observed on airborne imagery.

Determine if a relationship exists between ground water movement and shale gas productivity.

In conjunction with other contractors develop a method for selecting areas for drilling shale wells that have a potential for gas production.

3.0 TECHNICAL PROGRESS

3.1 Work Package 2100-2-1 STRUCTURE CONTOUR MAPS

Robert C. Shumaker
Project Director

3.1.1 Current status of work and scheduled deliverables

We have completed abstracting structural data from drillers' logs preparatory to spotting Berea well tops in the Midway-Extra - Cottageville area.

3.1.2 Problem areas and suggested improvements

No problems.

3.1.3 Work plan for next quarter

Calculate subsea elevations of tops selected in 3.1.1 above and start plotting these data on maps of Cottageville - Midway-Extra area.

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3.1 Work Package 2100-1-1 CROSS SECTIONS — J. Negus-de Wys

3.1.1 Current status of work and scheduled deliverables

Current status of work: 70% completed.

Scheduled deliverables: none.

- Paper presented at AAPG Meeting in Houston on Eastern Kentucky Gas Field.
- Chaired session on Natural Gas Habitat.
- Paper on Plate Tectonics Effects on the Devonian Basin accepted for the AAPG October Meeting.
- Paper on Geochemical Studies of Eastern Kentucky Gas Field accepted for EGSP October Meeting. Co-authored by J. J. Renton.
- Paper on Lithology and Log Studies of Eastern Kentucky Gas Field accepted for EGSP October Meeting.
- Paper on Geology of the Largest Gas Field in the Appalachian Basin submitted for the International Geological Congress, 1980, Paris.
- Paper on Geochemistry and Shale Gas Production in the Appalachian Basin submitted for the International Geological Congress, 1980, Paris.
- Microscope-camera callibration completed for transmitted light.
- Lithology studies in progress.
- Log correlation in progress.
- Meetings per monthly reports.

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for next quarter

- Complete lithology studies.
- Prepare submitted and accepted abstracts and papers.
- Continue log correlation.

* * * * * *

3.2 Work Package 2100-1-2 ISOPACH MAPS — J. Negus-de Wys

3.2.1 Current status of work and scheduled deliverables

Current status of work: 55% completed.

Scheduled deliverables: none.

3.2.2 Problem areas and suggested improvements

Schedule change: complete lithology studies and then return to isopach maps.

3.2.3 Work plan for next quarter

- Continue log correlation, plotting, computer input.
- See under 3.1.1

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3.3 Work Package 2100-2-1 STRUCTURE CONTOUR MAPS — J. Negus-de Wys

3.3.1 Current status of work and deliverables

Current status of work: 55% completed.

Scheduled deliverables: none.

3.3.2 Problem areas and suggested improvements

None.

3.3.3 Work plan for next quarter

Continue log correlation and plotting.

* * * * * *

3.4 Work Package 3200-4-1 OIL AND GAS MAPS — J. Negus-de Wys

3.4.1 Current status of work and scheduled deliverables

Current status of work: 70% completed.

Scheduled deliverables: none.

3.4.2 Problem areas and suggested improvements

None.

3.4.3 Work plan for next quarter

- Work on papers accepted and submitted to meetings (5). See 3.1.1
- Continue production comparisons.

* * * * * *

3.1 Work Package 2100-1-1 SEISMIC — James E. Ruotsala

3.1.1 Current status of work and scheduled deliverables

1. We are now able to record seismic data on magnetic tape cassettes. Work on getting the data onto 9-track tape so it can be plotted is progressing along several fronts. To do the job through WVNET will require hardware now being purchased. Alternative plans of action involve other computer installations.

2. The line at Pricetown II has not yet been re-shot due to equipment problems.

3. Refraction seismic at Cottageville has not been shot.

4. No more seismic modeling in the Cottageville field has been done.

3.1.2 Problem areas and suggested improvements

Nothing new.

3.1.3 Work plan for next quarter

1. The Pricetown II line will be re-shot during the first part of July and should take one week.

2. The seismic reflection line begun by Keith Kirk will be completed immediately following Pricetown.

3. The seismic refraction line will be shot after the reflection work is completed.

   Barring equipment problems, the above field work will be done by August 15.

4. We have given up on using the digital recorder bought from Bison Instruments, Inc. It will either be returned for a refund or salvaged for parts. The system for storage of field data on magnetic tape cassettes uses a microprocessor system on loan from VPI to Dr. Richard Williams. Dr. Williams has programmed the processor to read data from the Bison seismograph and write it on a magnetic tape cassette. We could store the data on a WVNET disk via a telephone line if something better than WYLBUR were available to do it. WYLBUR is both unreliable

3.1 Work Package 2100-1-1 SEISMIC - continued J. E. Ruotsala

3.1.3 Work plan for next quarter - continued

4. - continued - and slow and would probably take one week to reformat and transfer the small amount of data we now have. An alternative course being pursued by Rick is to write the data onto a floppy disk compatible with the IBM system 37 at Stewart Hall here on campus. This will require the purchase of hardware and will take one to two months. A telephone link to the computer at Gulf Research and Development is being looked into. The most promising short term solution is the system 34 compatible floppy disk.

5. As the field work is completed and the data is on tape or disk at WVNET, the plotting and processing will begin.

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3.1 Work Package 2100-2-2 STRUCTURE STUDIES — Thomas H. Wilson

3.1.1 Current status of work and scheduled deliverables

A. Attended the NATO Advanced Study Institute's Conference on Plate Tectonics and Continental Drift, and the Thrust and Nappe Tectonics Symposium. Although Ralph Horne was not in Ireland when I was there, we had a discussion by phone. I was able to discuss the project with many of the participants in both conferences and also talked with other Ireland Geological Survey personnel during the visit.

B. Collection of fracture data is complete except for some remaining checks on fracture intensity in areas of interest. An additional week will be required to check contacts in the Middle Mountain and Elkhorn Mountain structures.

C. The report on bedding orientation contours is being typed and will be complete within a week.

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for next quarter

A. Geologic map of Middle Mountain syncline will be completed.

B. Analysis of fracture data will be completed.

C. Manuscript on the geology of the Middle Mountain syncline will be completed.

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3.1 Work Package 2100-2-2 STRUCTURE STUDIES — Jeanette M. Dixon

3.1.1 Current status of work and scheduled deliverables

I gave a talk at the Southeast Section of the Geological Society of America meeting on method and application of measuring joint intensity.

Field work on the Petersburg and Parsons Lineaments has been initiated.

Field work on operator variability has been completed and analysis has begun.

Comprehensive exams have been successfully completed.

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for next quarter

Finish all field work and complete statistical analysis of field data gathered in the Parsons and Petersburg Lineaments.

* * * * * *

3.1 Work Package: 2200-1-2 FRACTURE DENSITY AND ORIENTATION Mark A. Evans

3.1.1 Current status of work and scheduled deliverables

Fracture data collection is complete on all cores being studied. Data analysis has begun on this data and is proceeding very well. The fracture report on the MERC #1 core has been completed.

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for next quarter

Complete data analysis of fracture orientation data and photo-lineament data. Put together regional fracture maps and begin writing final report.

* * * * * *

3.1 Work Package 2200-1-2 FRACTURE STUDIES — Kevin D. Lee

3.1.1 Current status of work and scheduled deliverables

A. A report entitled "Fractures from Devonian Shale Outcrops Along the Pine Mountain Thrust" was completed and sent out.

B. Work has begun in Prestonsburg, Kentucky, collecting depths of stratigraphic horizons in the Big Sandy gas field. Approximately 1,200 wells out of ~5,000 have been completed.

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for next quarter

A. Continue to collect data during July and August.

B. Do all mathematics necessary on my data to construct maps, and begin the maps in September.

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3.1 Work Package: 2200-1-2 FRACTURE STUDIES — Brian R. Long

3.1.1 Current status of work and scheduled deliverables

All deliverables are completed. The final report has been submitted to DOE.

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for next quarter

Project has been completed.

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3.3 Work Package 3200-5-1 STRUCTURE/PRODUCTION CORRELATION Henry W. Rauch

Subtask - Correlate all data and attempt to establish a relationship between geologic features, lineaments, fractures, ground water, and oil and gas production.

3.3.1 Current status of work and scheduled deliverables

All basic data have been collected or measured, and all statistical analyses have been completed for the Midway-Extra study. All final figures have been prepared and progress is well underway on the preparation of a final report for this study. Significant associations were found between lineaments and gas well yield (both initial and final open flows), and especially between certain ground-water quality parameters and gas well yield (final open flow). There were no scheduled deliverables due for this quarter.

3.3.2 Problem areas and suggested improvements

No problems for this task.

3.3.3 Work plan for next quarter

The final report will be completed and delivered to M.E.T.C. and S.A.I. on the Midway-Extra study, as deliverable 3.3.18. We will also be preparing a paper for presentation and publication in Preprints for the Third Eastern Gas Shales Conference in October, 1979. Our DOE-sponsored project ends officially on October 1, 1979; we are currently seeking private support for continuing this research, so that it has a good chance of being brought to a successful conclusion as new applications for shale gas exploration.

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3.4 Work Package 3200-5-3 LINEAMENT/STRUCTURE CORRELATION Henry W. Rauch

Correlate fractures and lineaments derived from photo analysis with results of ground water tests to determine if any relationship exists between ground water production and the occurrence of lineaments.

3.4.1 Current status of work and scheduled deliverables

All data have been measured, statistical tests have been made, and figures have been prepared for this part of the Midway-Extra study. Landsat lineaments are associated with low-producing shale gas areas for the Midway-Extra area, and should be avoided during gas exploration. A final report is now in preparation. There are no deliverables scheduled for this quarter.

3.4.2 Problem areas and suggested improvements

No problems for this task.

3.4.3 Work plan for next quarter

See task 3200-5-1 above.

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UGR File #C048/79Q4

July-Sept. 1979
W.Va.Univ. Dept. of Geology & Geography

QUARTERLY PROGRESS REPORT

U. S. Department of Energy

Contract no. DE-AC21-76MC05194
(formerly EY-76-C-05-5194)

July - September 1979

submitted by

Department of Geology and Geography
West Virginia University

Robert C. Shumaker, Project Director

co-authored by

J. Negus-de Wys, Jeanette M. Dixon, Mark A. Evans,
Kevin D. Lee, Henry W. Rauch, James E. Ruotsala,
Richard T. Williams, and Thomas H. Wilson

Principal Investigators

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1.0 EXECUTIVE SUMMARY

UGR File #C048/79Q4
July-Sept. 1979
W.Va.Univ. Dept. of Geology & Geography

QUARTERLY REPORT

JULY - SEPTEMBER 1979

U. S. Department of Energy
Contract no. DE-AC21-76MC05194
(formerly EY-76-C-05-5194)

1.0 EXECUTIVE SUMMARY

1.0.1 Major accomplishments this past quarter include the writing and submission of 8 reports summarizing our progress over the last year to be published in the Preprints volume of the third annual EGSP program. In addition, we have prepared four oral papers and five poster session papers to be presented at that meeting. Several exploration rationales concerning Devonian shale gas exploration are included in those manuscripts.

Progress in each task covering our work within the contract area (Figure 1) over the last quarter is summarized below.

1.0.2 Regional Structure Studies

We have completed a detailed structure map of the Jackson, Mason, and Putnam Counties area that shows a subdued flexture at the Berea level (Figure 2) which connects the Midway-Extra and Cottageville shale gas fields. Inasmuch as these two fields can be related by structure (Shumaker, et al., ref. 1) it is presumed that this untested trend has exploration potential. It is recommended here that additional structure and seismic work be accomplished on this trend by the exploration group of DOE-EGSP.

Sub-sea elevations on all available wells penetrating the Berea sandstone are spotted along the eastern flank of the Warfield anticline along the fracture domain boundary as outlined by Kulander (1978, manuscript in press). Structural contours on top of the Berea sandstone should be completed for the east flank of this structure during the next quarter.

1.0.3 Production Studies

A brief report was written by R. C. Shumaker (ref. 1) summarizing and comparing the structural controls on production at the Midway-Extra (ref. 2) and the Cottageville fields (ref. 3). Exploration rationales

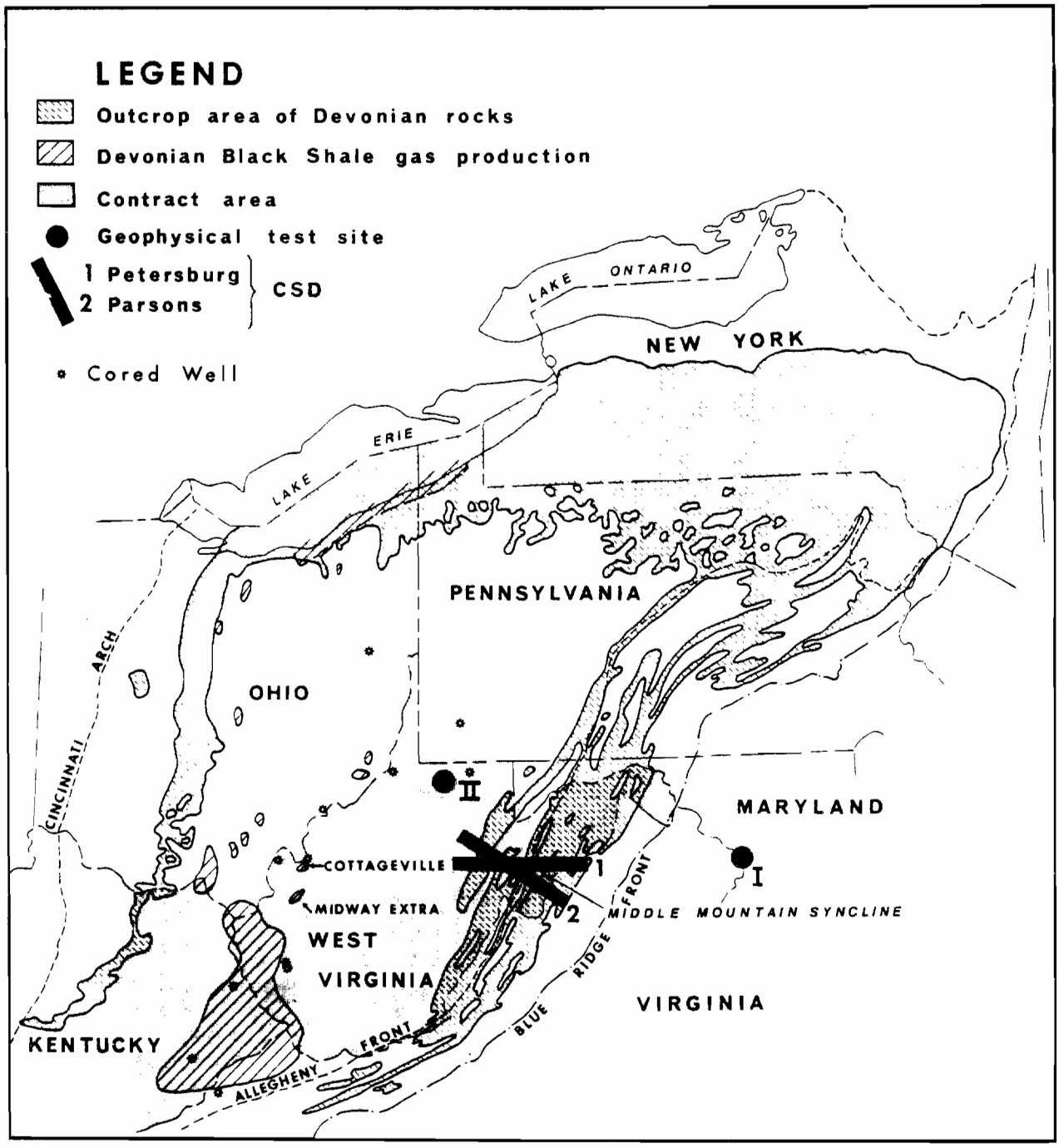

Figure 1. Contract area.

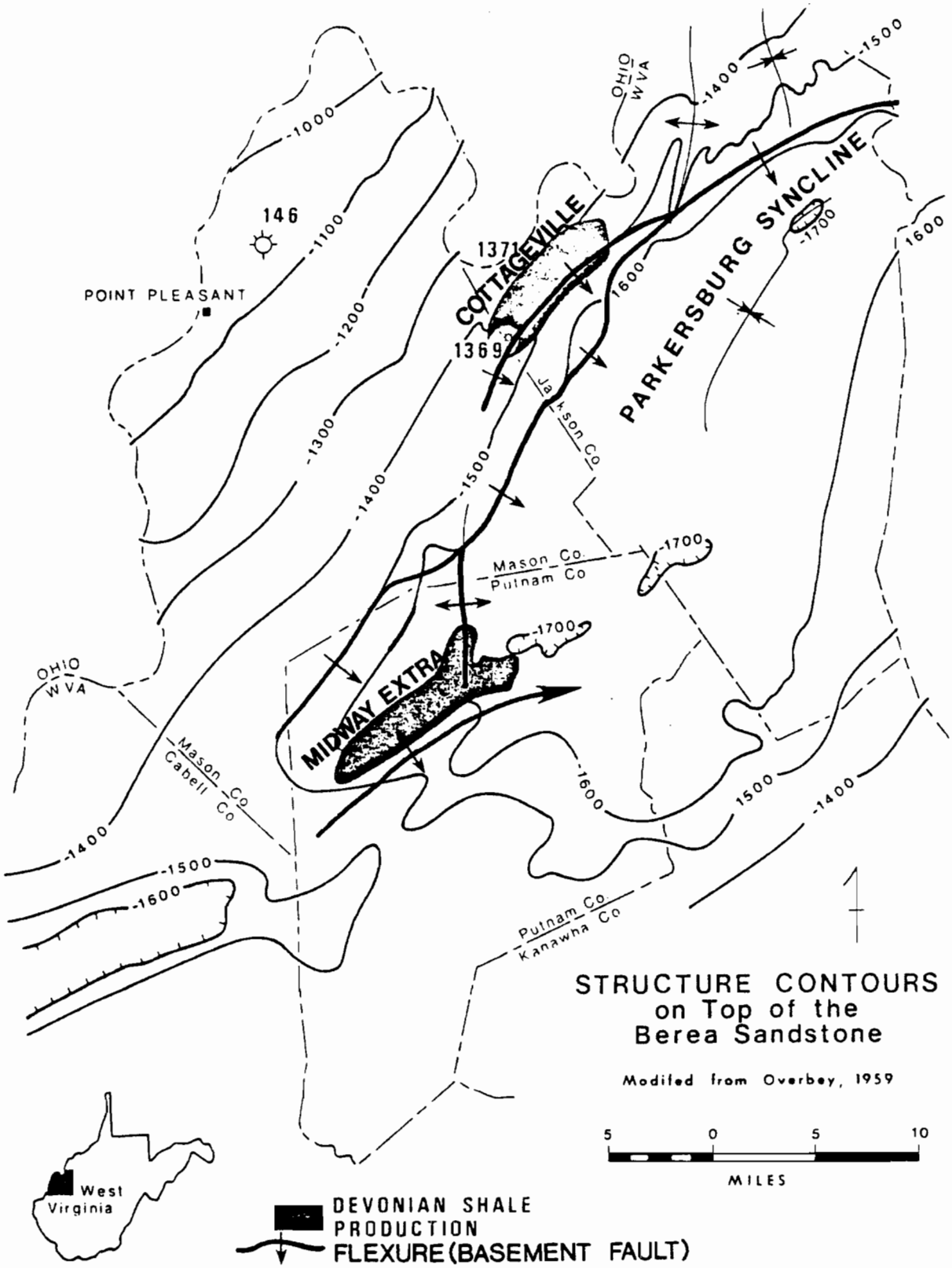

Figure 2. Structure of the Parkersburg Syncline Area, West Virginia.

1.0 EXECUTIVE SUMMARY - continued R. C. Shumaker

1.0.3 Production Studies - continued

were presented that develop as an outgrowth of this comparison. These rationales are the first supported by hard production data in this area. Future exploratory trends can be selected based on the map discussed in 1.0.2 above. Shumaker (ref. 4) predicted that clues to the permeability type could be inferred by the production pattern from the shale. Clearly the linear, off structure, production within the two fields discussed support a fault related fracture permeability, and that the shale does not support a blanket porosity related either to the shale matrix or systematic joint patterns. Furthermore, Rauch's work (ref. 5) also suggests that lineaments picked from remote sensing (ERTS) in the Cottageville and Midway-Extra fields study areas do not correspond to high producing (faulted) zones.

Work on the Eastern Kentucky Shale Gas Field continues to progress as production, lithologic, geochemical, and regional structural studies are completed. Next quarter will include the integration and analysis of these studies.

1.0.4 Geophysics

We returned to test site II in order to reshoot the seismic line completed last year. Analysis of the latter suggests that the fracture anomaly shown on that data may relate to equipment malfunction. Additional recording problems surfaced during the reshoot of test site II, but they should be resolved by early next quarter.

We obtained our first computer generated plot of the seismic line shot at Cottageville (Figure 1). The plot showed very high frequency reception that is encouraging in respect to defining precise bed boundaries. However, the data also showed a malfunctioning start mechanism. This malfunction made datuming individual shot spreads impossible. A new start mechanism has been designed and tested satisfactorily. Unfortunately, the Cottageville data is uninterpretable, and therefore the line must be reshot.

1.0.5 Fracture studies

We have completed the study of 13 oriented cores of Devonian shale wells. A final report covering the results of these analyses is underway, and a rough draft manuscript should be complete by the end of next quarter.

1.0 EXECUTIVE SUMMARY - continued R. C. Shumaker

1.0.6 Structural Studies

Field work to collect joint data concerning fracture intensities across the westward extension of the Parsons and Petersburg CSDs has been completed. Both lineaments are reflected by increased joint intensity within the Plateau sediments. A rough manuscript covering the results of this analysis is in preparation and should be complete by the end of next quarter.

1.0.7 Hydrologic Studies

A manuscript covering hydrologic analysis of the Midway-Extra field has been completed and is submitted with this report. This report is the final manuscript of this program as the financial support has terminated as of this quarter. Results of the analysis of the Midway-Extra field show a positive correlation among shale gas production, short low-altitude photo linears, photo linear density, and mineral content of the ground water. A negative correlation was found between ERTS satellite imagery lineaments and shale gas production.

References

1. Shumaker, R. C., J. Negus-de Wys, J. M. Dixon, M. A. Evans, K. G. Kirk, K. D. Lee, B. R. Long, H. W. Rauch, J. E. Ruotsala, T. H. Wilson, W. W. Schaefer, R. T. Williams, 1979, "Parameters of Geologic Structure Which Affect Devonian Gas Shale Production in West Virginia and Eastern Kentucky - A Progress Report 1978-1979: Preprints 3rd Annual Joint EGSP-ES/AAPG Symposium, Lakeview Country Club, Morgantown, W. Va., October.

2. Schaefer, William W., 1979, "Geology and Producing Characteristics of Certain Brown Shales in the Midway-Extra Field, Putnam County, W. Va.": Masters thesis, Department of Geology and Geography, West Virginia University, Morgantown, W. Va., 67 p.

3. de Wys, J. Negus, and Shumaker, R. C., 1978, "Pilot Study of Gas Production Analysis Methods Applied to Cottageville Field": Devonian Shale Program, Department of Geology and Geography, West Virginia University under Contract EY-76-C-05-5194, Department of Energy, Morgantown Energy Research Center, Morgantown, W. Va.

4. Shumaker, R. C., 1978, "Porous Fracture Facies in the Devonian Shales of Eastern Kentucky and West Virginia": Preprints 2nd Annual Eastern Gas Shales Symposium, U.S.D.O.E., METC/SP 78/6, vol. 1, pp. 360-365.

5. Beebe, R. R., and H. W. Rauch, 1979, "Lineaments and Water Wells as Exploration Tools in the Midway-Extra Gas Field": Preprints 3rd Annual Joint EGSP-ES/AAPG Symposium, Lakeview Country Club, Morgantown, W. Va., October.

JULY THRU SEPTEMBER 1979

PAPERS GIVEN

Shumaker, Robert C., "Form-line Structure and Basement Structure Maps of the Appalachian Basin - a Comparison," Caledonides in U.S.A. Symposium, Caledonide Orogen Project, Virginia Polytechnic Institute and State University, Blacksburg, Va., Sept. 5-9, 1979.

MEETINGS ATTENDED

Robert C. Shumaker - as above.

J. Negus-de Wys - Caledonides in U.S.A. Symposium, Caledonide Orogen Project, Virginia Polytechnic Institute and State University, Blacksburg, Va., Sept. 5-9, 1979.

FIELD TRIPS

J. Negus-de Wys - Participated in the Southern Appalachian Field Trip associated with the Caledonide Orogen Project (as above) held September 9-16, 1979.

J. Negus-de Wys - One week field trip to eastern Kentucky outcrops following the studies of Swager for his Masters thesis at University of Kentucky. Outcrops in Pine Mountain area included and sampled. Accompanied by Dr. Jessie Donahue of Gulf Research Lab, and Dr. Jack Donahue of University of Pittsburgh.

UNSPONSORED RESEARCH

"Predicting Natural Gas Well Production from the Cottageville Gas Field, West Virginia, Using Interactive Computing," by Patrick F. Mbendera, Geology Graduate Student, West Virginia University, Morgantown, W. Va.: placed on Open File at Morgantown Energy Technology Center.

JULY THRU SEPTEMBER 1979

DELIVERABLES AND MILESTONES DELIVERED

Deliverable	3.3.18	"A Study of Hydrogeologic Trends in Exploration for
"	3.3.22	Devonian Shale Gas in the Midway-Extra Gas Field of Putnam County, West Virginia" - Robert R. Beebe
Milestone	3.4.11	(delivered October 1979)
Milestone	3.4.31	"Field Techniques for Measuring Joint Intensity" - Jeanette M. Dixon (delivered October 1979)
Milestone	3.4.29	"Bedding Orientation Contours of Middle Devonian Shales Exposed in the Middle Mountain Syncline, Valley and Ridge Province, West Virginia" - Thomas H. Wilson (delivered July 1979)

2.0 CONTRACT OBJECTIVES

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Collect, compile and analyze geological data and prepare geological structure maps for eastern Kentucky and western West Virginia.

Determine if structural types and styles and surface lineations for productive areas of the Black Shales differ from those in non-productive areas.

Identify and define along with other contractors those geologic parameters that control gas production from the shales.

Determine the feasibility of using shallow penetration resistivity and seismic surveys to detect near surface faults and fractures and demonstrate their relationship to lineations observed on airborne imagery.

Determine if a relationship exists between ground water movement and shale gas productivity.

In conjunction with other contractors develop a method for selecting areas for drilling shale wells that have a potential for gas production.

3.0 TECHNICAL PROGRESS

3.1 Work Package 2100-2-1 STRUCTURE CONTOUR MAPS Robert C. Shumaker

3.1.1 Current status of work and scheduled deliverables

We have completed calculating and spotting Berea sandstone well tops for a structure map of the Midway-Extra to Cottageville area. The contouring is nearly complete and based on this work we have isolated a basement flexture that extends from Cottageville to Midway-Extra. No deliverables required this quarter.

3.1.2 Problem areas and suggested improvements

No problems.

3.1.3 Work plan for next quarter

Construct a detailed structure map on the Berea sandstone for the eastern flank of the Warfield Anticline.

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3.1 Work Package 2100-1-1 CROSS SECTIONS

J. Negus-de Wys

3.1.1 Current status of work and scheduled deliverables

Current status of work: 80% completed.

- Lithology studies completed on well cuttings from 14 wells in the Eastern Kentucky Gas Field.
- Paper on Lithology studies prepared, submitted, and accepted for October meetings at Lakeview.
- Preliminary geochemistry studies on elemental and mineralic analyses of ~700 well cuttings initiated.
- Paper on geochemistry studies prepared, submitted, and accepted for October meetings at Lakeview.
- Paper on structural setting and possible plate tectonics effects on the Eastern Kentucky Gas Field, prepared, submitted, and accepted for Lakeview meetings.
- Abstracts for two papers on the eastern Kentucky studies submitted to the International Geological Congress.
- Meetings per monthly reports including: Blacksburg, Virginia - Caledonide Symposium and field trip in southern Appalachians.

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for next quarter

Prepare final report.

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3.2 Work Package 2100-1-2 ISOPACH MAPS J. Negus-de Wys

3.2.1 Current status of work and scheduled deliverables

Current status: emphasis on lithology studies and geochemistry substituted for redoing Provo isopachs.

3.2.2 Problem areas and suggested improvements

None.

3.2.3 Work plan for next quarter

Prepare final report.

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3.3 Work Package 2100-2-1 STRUCTURE CONTOUR MAPS J. Negus-de Wys

3.3.1 Current status of work and scheduled deliverables

Final report in preparation based on existing structure maps.

3.3.2 Problem areas and suggested improvements

None.

3.3.3 Work plan for next quarter

Prepare final report

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3.4 Work Package 3200-4-1 OIL AND GAS MAPS — J. Negus-de Wys

3.4.1 Current status of work and scheduled deliverables

Preparing final report.

3.4.2 Problem areas and suggested improvements

None.

3.4.3 Work plan for next quarter

Prepare final report (see 3.1.1), and compare gas occurrence and open flow with geological parameters.

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3.1 Work Package 2100-1-1 SEISMIC

James E. Ruotsala

3.1.1 Current status of work and scheduled deliverables

Equipment problems have prevented the completion of data acquisition at the Pricetown II site (Wetzel County) and the start of work in the Cottageville Gas Field. When an electronics technician was hired in August, the problem of establishing time zero at the time of the shot was solved. The reader is referred to the 1978-1979 Annual Report of the Devonian Shale Project (October 1979) for a more complete discussion of this subject.

The data collected at Pricetown last spring was transcribed to nine-track tape and plotted. In spite of its problems (aliasing and uncertain zero-time), it demonstrates a potential for high resolution. The reader is referred to the Devonian Shale Project Annual Report (October 1979) for a more complete discussion.

3.1.2 Problem areas and suggested improvements

The reader is referred to the Annual Report.

3.1.3 Work plan for next quarter

The next few months will be spent in modifications, repairs, and field tests to get the Bison seismograph working up to its full potential. Judgment on what can be done with the current equipment to map subsurface fracture zones will be made after field testing at the Pricetown II site. Work at Cottageville will begin after field testing is successfully completed.

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3.1 Work Package 2100-2-2 STRUCTURE STUDIES

Thomas H. Wilson

3.1.1 Current status of work and scheduled deliverables

A. Mapping of the Middle Mountain syncline has been completed. In addition, the adjacent Elkhorn Mountain and Long Ridge anticlines were mapped to the southeast and the map area was extended an additional five miles to the south of its previous extent.

B. Analysis of fracture data has been taken as far as it can go. Some additional data will have to be collected when time permits.

C. The geology manuscript is about 60% complete. Considerable work remains in the drafting of illustrations and writing.

Additional analysis was initiated on the gravity and magnetic data available for the region along the Parsons structural lineament.

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for next quarter

A. Residual Bouquer anomalies will be calculated for the Nittany anticlinorium cross sections of Roy Sites and Bill Perry.

B. Cross sections through the Appalachian basin from the structural front will be constructed, if possible, by the end of this quarter.

C. Planned calculation of second vertical derivatives for the magnetic data will be continued and hopefully completed. This is primarily a programming problem.

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3.1 Work Package 2100-2-2 STRUCTURE STUDIES

Jeanette M. Dixon

3.1.1 Current status of work and scheduled deliverables

All field work on joint intensities has been completed.

Analyses of all studies are in the final stages and the final descriptions are being written.

Two papers were submitted for the Preprints in the October EGSP meeting: Wilson, Dixon, Shumaker, Wheeler; and Dixon and Wilson.

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for next quarter

Complete the final report.

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3.1 Work Package: 2200-1-2 FRACTURE DENSITY AND ORIENTATION Mark A. Evans

3.1.1 Current status of work and scheduled deliverables

Core fracture analysis is complete; writing of final report entitled "Fractures in Oriented Devonian Shale Cores from the Appalachian Plateau" is in progress. Drafting of illustrations for that report is proceeding.

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for next quarter

Complete final report and illustrations.

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3.1 Work Package 2200-1-2 FRACTURE STUDIES

Kevin D. Lee

3.1.1 Current status of work and scheduled deliverables

A. Work was completed in Prestonsburg, Ky., at Kentucky-West Virginia Gas Company, collecting depths of stratigraphic horizons in the Big Sandy gas field. Approximately 4,500 wells were collected over a ten county area.

B. The mathematics on the data has been completed, and work has started on a structure contour map on the top of the drillers' Corniferous.

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for next quarter

A. Complete the Corniferous map and construct structure contour maps on the top and bottom of the Devonian brown shale.

B. Construct sufficient cross sections as needed.

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3.3 Work Package 3200-5-1 STRUCTURE/PRODUCTION CORRELATION Henry W. Rauch

Subtask - Correlate all data and attempt to establish a relationship between geologic features, lineaments, fractures, ground water, and oil and gas production.

3.3.1 Current status of work and scheduled deliverables

All work has been completed for the Midway-Extra study and a final project paper and M.S. thesis have been prepared; this paper and thesis appear in the annual report for fiscal year 1979.

3.3.2 Problem areas and suggested improvements

No problems.

3.3.3 Work plan for next quarter

METC/DOE has terminated funding for this project; so no more work will be done under U.S. government sponsorship, Instead, I have arranged private funding for continuing the research in other study areas.

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3.4 Work Package 3200-5-3 LINEAMENT/STRUCTURE CORRELATION H. W. Rauch

3.4.1 Current status of work and scheduled deliverables

Correlate fractures and lineaments derived from photo analysis with results of ground water tests to determine if any relationship exists between ground water production and the occurrence of lineaments.

3.4.1 Current status of work and scheduled deliverables

See 3.3.1 of task 3200-5-1 above.

3.4.2 Problem areas and suggested improvements

None.

3.4.3 Work plan for next quarter

See task 3200-5-1 above.

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UGR File #C048/80Q1
October-December 1979

QUARTERLY PROGRESS REPORT

U. S. Department of Energy

Contract no. DE-AC21-76MC05194
(formerly EY-76-C-05-5194)

October - December 1979

submitted by

Department of Geology and Geography
West Virginia University

Robert C. Shumaker, Project Director

co-authored by

J. Negus-de Wys, Jeanette M. Dixon, Mark A. Evans,
Kevin D. Lee, James E. Ruotsala, Thomas H. Wilson,
and Richard T. Williams

Principal Investigators

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1.0 EXECUTIVE SUMMARY

QUARTERLY REPORT

OCTOBER - DECEMBER 1979

U. S. Department of Energy
Contract no. DE-AC21-76MC05194
(formerly EY-76-C-05-5194)

1.0 EXECUTIVE SUMMARY

1.0.1 The first quarter of the 1979-80 contract year started with the presentation of the results of our work accomplished during the 1978-79 contract year at the 3rd annual EGSP meeting in Morgantown. Some 17 papers were written or presented orally at that meeting. Our efforts during the remainder of the quarter was primarily dedicated to analysis of data and writing final reports on (1) core fractures, (2) methodology of measuring joint intensities, and (3) geologic parameters that affect gas production in eastern Kentucky.

Structural maps were completed on top of the Berea sandstone and the Onesquethaw group along the east flank of the Warfield anticline. These maps are in the area of the surface joint domain boundary noted by Kulander (manuscript in press). The domain boundary area is considered to be a likely region for increased shale gas production.

Geophysical investigations centered on the repair, testing, and tuning of the Bison seismic system equipment.

1.0.2 Regional Structure Studies

Subsurface structural maps on top of the Berea sandstone and the Onesquethaw group were completed along the eastern flank of the Warfield anticline in the area of the fracture domain boundary as outlined by Kulander (manuscript in press). Subsurface structure maps on the top and base of the Devonian brown shale, based on drillers' logs, in the eastern Kentucky shale gas field were started this quarter. The $\pm$4500 data points are the same as those used in production studies of that area by J. Negus-de Wys (see 1.0.3 Production Studies). These preliminary structure maps should be completed and revised during the next quarter, and a report analyzing the

1.0.2 Regional Structure Studies - continued

structural style of that region should be written during the third quarter of the contract year. These detailed maps will then be utilized in conjunction with the production maps of the same 4500 wells to estimate the importance of structure to shale gas productivity.

1.0.3 Production Studies

A final report entitled "The Eastern Kentucky Gas Field: a geological study of the relationships of Ohio Shale gas occurrences to structure, stratigraphy, lithology, and inorganic geochemical parameters" by Jane Negus-de Wys was completed during this past quarter describing geologic influences on shale gas production in the eastern Kentucky area. Because of the encouraging results of the geochemical phase of this study, emphasis will be placed on analysis of cuttings from additional wells in eastern Kentucky during the upcoming quarter.

1.0.4 Geophysical Studies

This past quarter was spent repairing, testing, and tuning the Bison seismic system. Most of the problems have been resolved, but cross talk and noise within the filter portion of the system remain to be remedied during the upcoming quarter. Considerable progress has been made altering the equipment, and reliable reflections were recorded digitally as tested at site II for the first time this past quarter.

1.0.5 Fracture Studies

A study of 13 oriented cores was completed this past quarter. The manuscript entitled "Fractures in Oriented Devonian Shale Cores from the Appalachian Basin" is in the final stages of preparation. This report will be submitted during the upcoming quarter. A separate report on remote sensing studies of the surface around each core well site is also being prepared for submission either late in the upcoming quarter or in the third quarter of this contract year.

1.0.6 Structural Studies

A final manuscript covering the results of fracture intensity studies across the Parsons and Petersburg lineaments was completed this past quarter, and a manuscript entitled "Techniques and Tests for Measuring Joint Intensity" was submitted. Part of the manpower effort from this group is now directed to the structural analysis of the Big Sandy field.

1.0.6 Structural Studies - continued

In addition, two structural cross sections were completed across the study area to investigate the effect of the Parsons lineament on the amount of structural shortening in the foreland.

* * * * * *

MEETINGS ATTENDED

Energy for the Eighties, Joint DOE/EGSP-ES/AAPG Symposium, Oct. 1-3, 1979, Lakeview Inn, Morgantown, West Virginia. The following staff members of the West Virginia University Devonian Shale Program attended: R. C. Shumaker, J. Negus-de Wys, Jeanette M. Dixon, James E. Ruotsala, Thomas H. Wilson, Mark A. Evans, and Richard T. Williams.

PAPERS GIVEN

The following papers were contributed to the above DOE meeting and appear in the Preprints of that meeting:

R. C. Shumaker, "Parameters of Geologic Structure Which Affect Devonian Gas Shale Production in West Virginia and Eastern Kentucky - a Progress Report 1978-1979"

J. Negus-de Wys, "Lithology Studies of Upper Devonian Well Cuttings in the Eastern Kentucky Gas Field"

J. Negus-de Wys, "Inorganic Geochemical Studies of Eastern Kentucky Gas Field(s) and Comparison with Gas Production" (with J. J. Renton)

Brian R. Long, "Regional Survey of Surface Joints in Eastern Kentucky" (formerly on the Devonian Shale staff)

Robert R. Beebe, "Lineaments and Water Wells as Exploration Tools in the Midway-Extra Gas Field" (with Henry W. Rauch)

J. M. Dixon and T. H. Wilson, "The Parsons Cross Strike Structural Discontinuity as an Exploration Area for Fractured Gas Reservoirs"

OCTOBER THRU DECEMBER 1979

DELIVERABLES AND MILESTONES DELIVERED

Task specification 3.2.15) Deliverable 3.3.9) Milestone 3.4.16)	Detailed structure maps on Berea sandstone and Onondaga limestone for the eastern flank of the Warfield anticline
Task specifications 3.2.1,) 3.2.3, 3.2.4, and 3.2.33)	E. B. Nuckols III "The Cottageville (Mount Alto) Gas Field, Jackson County, West Virginia: a Case Study of Devonian Shale Gas Production"
Task specification 3.2.5) Milestone 3.4.14)	Jeanette M. Dixon "Techniques and Tests for Measuring Joint Intensity"
Task specifications 3.2.2,) 3.2.3, 3.2.4, 3.2.13 (all) in part) and 3.2.14) Deliverable 3.3.2 (in part)) and 3.3.3 Milestone 3.4.7, 3.4.9 (in) part) and 3.4.15)	Jane Negus-de Wys "The Eastern Kentucky Gas Field: a geological study of the relationships of Ohio Shale gas occurrences to structure, stratigraphy, lithology, and inorganic geochemical parameters"

2.0 CONTRACT OBJECTIVES

2.0 CONTRACT OBJECTIVES

Collect, compile and analyze geological data and prepare geological structure maps for eastern Kentucky and western West Virginia.

Determine if structural types and styles and surface lineations for productive areas of the Black Shales differ from those in non-productive areas.

Identify and define along with other contractors those geologic parameters that control gas production from the shales.

Determine the feasibility of using shallow penetration resistivity and seismic surveys to detect near surface faults and fractures and demonstrate their relationship to lineations observed on airborne imagery.

Determine if a relationship exists between ground water movement and shale gas productivity.

In conjunction with other contractors develop a method for selecting areas for drilling shale wells that have a potential for gas production.

3.0 TECHNICAL PROGRESS

3.1 Work Package 2100-2-1 STRUCTURE CONTOUR MAPS Robert C. Shumaker

3.1.1 Current status of work and scheduled deliverables

A detailed structural contour map on top of the Berea sandstone was completed for the eastern flank of the Warfield anticline. A regional structure contour map on the basement for western West Virginia and eastern Kentucky was completed at a scale of 1:500,000. Both maps were submitted to the Open File this past quarter.

3.1.2 Problem areas and suggested improvements

No problems.

3.1.3 Work plan for next quarter

The project director will be on sabbatical leave during the quarter, and Alan Donaldson, Chairman of the Department of Geology and Geography, West Virginia University, is assuming the responsibilities of temporary director. During the upcoming quarter a base map at a scale of 1:500,000 of the Appalachian basin will be constructed. This base will serve as a standard for overlays showing the structure on several horizons to be constructed over the upcoming year. A near surface form-line structure map will be started during the upcoming quarter to be completed in May of this year. If necessary, the basement structure map just delivered will be redrafted to fit the new base. The new base will show the county and state outlines, prominent towns and the surface drainage.

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3.1 Work Package 2100-1-1 CROSS SECTIONS J. Negus-de Wys

3.2 Work Package 2100-1-2 ISOPACH MAPS

3.3 Work Package 2100-2-1 STRUCTURE CONTOUR MAPS

3.4 Work Package 3200-4-1 OIL AND GAS MAPS

3.1.1 Current status of work and scheduled deliverables

Current status: 100% complete - final report submitted.

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for next quarter

Geochemistry Addendum:

- Pick adjusted stratigraphic tops from lithology studies
- Preparation of elemental maps in eastern Kentucky
- Preliminary cross section of organic geochemistry of black, brown, gray, and green shale facies
- Hand contouring of elemental geochemistry
- Advertise and select doctoral candidates for geochemical research

Papers given:

1. Lithology Studies in Eastern Kentucky Gas Field: DOE/EGSP-ES/AAPG Symposium
2. Geochemical Studies in Eastern Kentucky Gas Field: DOE/EGSP-ES/AAPG Symposium
3. Possible Plate Tectonics Effects on the Eastern Kentucky Gas Field: DOE/EGSP - ES/AAPG Symposium

Paper accepted:

The Anatomy of a Large Devonian Black Shale Gas Field: International Geological Congress, Paris, France, July, 1980.

Abstracts submitted:

1. Geochemistry relationships in upper Devonian shale to structure, lithology, and gas production in eastern Kentucky (SPE/DOE May meeting, Pittsburgh, Pennsylvania)

2. Preliminary depositional model for highly organic black shale facies of the upper Devonian shales (SPE/DOE May meeting, Pittsburgh)

3. Preliminary thin section study of black shales in eastern Kentucky (Junior Jenkins, student) (SPE/DOE May meeting, Pittsburgh)

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3.1 Work Package 2100-1-1 SEISMIC

James E. Ruotsala

3.1.1 Current status of work and scheduled deliverables

Field testing of the Bison seismograph at the Pricetown site was completed. No events interpretable as reflections were observed among the acoustic events recorded. Some cross-talk, originating in the geophone filters, were observed.

3.1.2 Problem areas and suggested improvements

Nothing new.

3.1.3 Work plan for next quarter

The geophone filters will be worked on and our technician will attempt to eliminate the cross-talk. Further field testing will await the completion of that work.

A new system for recording seismic data onto floppy disk will be put together as the borrowed equipment we are currently using is no longer available.

* * * * * *

3.1 Work Package 2100-2-2 STRUCTURE STUDIES — Thomas H. Wilson

3.1.1 Current status of work and scheduled deliverables

The construction of the cross-sections through the Appalachian basin monopolized the work effort this quarter. This is justified as follows:

1) an analysis of possible subsurface structural interpretations of surface structural characteristics in both the Valley and Ridge and Plateau Provinces is of fundamental importance to the question of what is a CSD;

2) surface control on the earth's residual gravitational field is limited and minimizes the usefulness of modelling as the priority effort;

3) barometric corrections were not made on the USGS's aeromagnetic data. Since the anomalies or second vertical derivatives along the lineament will be quite small if they exist (from inspection of total magnetic intensity map), inferred basement structure would be questionable. An analysis of this data has the potential to be quite fruitful, but again, its usefulness to this specific project is considered as secondary to the structural interpretations.

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for next quarter

A. Work on the cross sections will be completed.

B. Some additional figures will be drafted to illustrate fracture data.

C. Writing will begin on a first draft of the final report.

D. Some gravity modelling may be done along specific parts of the cross sections, but this is a lower priority effort.

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3.1 Work Package 2100-2-2 STRUCTURE STUDIES — Jeanette M. Dixon

3.1.1 Current status of work and scheduled deliverables

Final report on CSD's and joint intensity studies has been completed.

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for next quarter

This portion of Work Package 2100-2-2 is complete.

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3.1 Work Package: 2200-1-2 FRACTURE DENSITY AND ORIENTATION Mark A. Evans

3.1.1 Current status of work and scheduled deliverables

The final report, "Fractures in Oriented Devonian Shale Cores from the Appalachian Basin," is nearly complete. Approximately ten illustrations need yet to be drafted.

3.1.2 Problem areas and suggested improvements

- None.

3.1.3 Work plan for next quarter

Complete drafting of illustrations and complete final report.

* * * * * *

3.1 Work Package 2200-1-2 FRACTURE STUDIES — Kevin D. Lee

3.1.1 Current status of work and scheduled deliverables

A) Locations of 4,500 wells with sub-sea elevations on the top and bottom of the Ohio shale were plotted.

B) Structure contour maps were drawn and revised for the top and bottom of the Ohio shale.

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for next quarter

A) Construct cross sections across the Big Sandy Gas Field.

B) Compare the structure contour maps of the top and bottom of the Ohio shale, and an isopach map of the Ohio shale to be drawn by Jeanette M. Dixon.

C) Complete a first draft of my thesis by the end of this quarter. This will involve further revision of the structure contour maps, correlation of the isopach map (where possible) with structure, correlation of Mark Evans' slickenline findings (where possible) with structure, etc.

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WVU Dept. of Geology & Geography
Jan.-Mar. 1980

QUARTERLY PROGRESS REPORT

U.S. Department of Energy
Contract number DE-AC21-76MC05194
(formerly EY-76-C-05-5194)

January - March 1980

submitted by

Department of Geology and Geography
West Virginia University

Alan C. Donaldson, Chairman
Department of Geology and Geography
(for Robert C. Shumaker, Project Director
Devonian Shale Program)

co-authored by

J. Negus-de Wys, Kevin D. Lee, James E. Ruotsala,
Thomas H. Wilson and Richard T. Williams

Research Associates

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1.0 EXECUTIVE SUMMARY

QUARTERLY REPORT

JANUARY - MARCH 1980

U.S. Department of Energy
Contract no. DE-AC21-76MC05194
(formerly EY-76-C-05-5194)

1.0 EXECUTIVE SUMMARY

1.0.1 The second quarter of the 1979-1980 contract year resulted in the delivery of a report by Mark Evans on "Fractures in Oriented Devonian Shale Cores from the Appalachian basin," 3 maps by Mark Evans indicating the linear features near Devonian shale core wells, and one map by Robert Shumaker showing structure on the basement for eastern Kentucky and West Virginia.

In addition, work completed (with the exception of drafting) includes geochemical data from the Eastern Kentucky Gas Field that is plotted stratigraphically on a cross section using 3 wells and on maps of the Lower Huron shale using the geographical distribution of elements and minerals based on 14 wells for this same gas field by Jane Negus-de Wys.

Structural evaluation of rocks associated with the cross-strike lineaments (Petersburg and Parsons) are in various stages of completion. The field study of the fractured, folded and faulted rocks spanning the Petersburg lineament is completed and cross sections have been constructed but not yet drafted. The geophysical analysis is near completion but already with sufficient knowledge to indicate the nature of structural shortening in this area.

The detailed structure contour map of the Eastern Kentucky Gas Field is now in the writing and drafting phase with analysis limited to reworking problem areas.

The geophysical seismic study is ready for the field-work phase finally. The Bison system is working in the lab and now will be tested at Pricetown within the next two weeks.

1.0.2 Regional Structure Studies

This work was completed last quarter before Robert Shumaker left on sabbatical leave for England. The regional map showing structure on the basement for eastern Kentucky and West Virginia has been drafted and delivered during this quarter.

1.0.3 Production Studies

The correlation between geochemical parameters and gas production in the Eastern Kentucky Gas Field seemed promising in the completed report by Jane Negus-de Wys, and she expanded on this study during this second quarter. Essentially, she has plotted elemental and mineralogical data on maps of the Lower Huron shale, and these maps suggest initial relationships with production based on data from 14 wells. A second set of data currently is being selected in order to confirm and refine the relationship between the geochemistry and gas production.

In an additional request, Jane Negus-de Wys delivered a set of 15 maps showing the criteria for the selection of test wells to be drilled in the future. A final map, at a scale of 1:250,000, indicated the priorities for drilling and the justification for these priorities. This analysis represents a major contribution to the Devonian Gas Shale Project as it provides a rationale and strategy for siting future exploratory wells.

1.0.4 Geophysical Studies

This second quarter again mainly was used to repair, test, and tune the Bison seismic system as well as recommend the need for specific equipment in order to insure the success of the seismic investigation. Finally, the seismic system checked out favorably in the lab and now is ready for field testing at the Pricetown U.G.S. site.

Delays in delivery of hardware required for writing the seismic onto a floppy dish frustrated work on this phase of the program. On the other hand, work on developing a ray-tracing seismic modeling capability is progressing satisfactorily.

1.0.5 Fracture Studies

Detailed mapping of the Berea sandstone in the subsurface of the Eastern Kentucky Gas Field essentially is complete. Kevin Lee has constructed a structure contour map that displays minor structures previously undetected on maps of greater contour intervals and fewer control points. A first draft of a report is nearing completion. Examples of interpretations now possible from this analysis are: 1) the Warfield fault in Martin County, Kentucky, suggests no growth during Devonian and Mississippian time, and it appears to be a detachment structure related to previously formed deeper structures; and 2) the recognition of a strike-slip fault in eastern Pike County, Kentucky, affecting the D'Invelliers anticline and with an orientation parallel to the Russell Fork fault. The fracture implications of such structures presently are being assessed.

1.0.6. Structural Studies

Reconstruction of structural cross sections across the Parsons lineament is based on field mapping and geophysical data recalculated in order to determine the kind and amount of structural shortening in the foreland. These studies by Tom Wilson indicate the following three evaluations that will be significant in siting gas wells in the Middle Devonian gas shales:

1) The northwest limbs of folds are more intensely fractured than the southeast limbs.

2) The change from lower to higher order folds in discontinuities observed in the Plateau for the Parsons' discontinuity (Mullennex, 1975; Trumbo, 1975) is also associated with an increase in the abundance of faults in the discontinuity. The faulted lithologies are more intensely fractured in the vicinity of the faults (Wilson, et al., 1978; Wilson, 1979).

3) Field mapping of the Middle Mountain syncline which exposes Middle Devonian shales reveals that a) splay thrusts cutting Silurian and Lower Devonian lithologies wrap over into the Middle Devonian shales thickening these formations, and b) Middle Devonian shales are most intensely deformed in the discontinuity.

These observations are significant for a rationale for gas reservoir exploration in the Plateau. More intensely fractured and thickened organic-rich shales will be found on the northwest limbs of the Plateau folds and particularly within cross-strike structural discontinuities.

Work currently underway will recommend drilling of specific areas. Recommendations will be made on the basis of field mapping, fracture studies, local and regional structural cross sections, and geophysical studies.

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JANUARY THRU MARCH 1980

DELIVERABLES AND MILESTONES DELIVERED

Task specification 3.2.8 Deliverable 3.3.1 Milestones 3.4.1 & 3.4.2	"Fractures in Oriented Devonian Shale Cores from the Appalachian Basin, Mark A. Evans, final report. Delivered 2-7-80.

MAPS

Task specification 3.2.10 Milestone 3.4.3	3 maps by Mark A. Evans. Delivered 2-13-80. Linear features near Devonian shale core wells (2 sheets); lineament orientation, weighted with lineament length; and lineament orientations unweighted.
Milestone 3.4.11	1 map by R. C. Shumaker. Delivered 2/80. Regional map showing structure on the basement for eastern Kentucky and West Virginia.

UNSPONSORED RESEARCH

"A Statistical Analysis of Geochemical Data for the Eastern Kentucky Gas Field," Jean Cheng, Graduate Student, Statistics and Computer Science, West Virginia University: placed on Open File at Morgantown Energy Technology Center.

* * * * * *

2.0 CONTRACT OBJECTIVES

2.0 CONTRACT OBJECTIVES

Collect, compile and analyze geological data and prepare geological structure maps for eastern Kentucky and western West Virginia.

Determine if structural types and styles and surface lineations for productive areas of the Black Shales differ from those in non-productive areas.

Identify and define along with other contractors those geologic parameters that control gas production from the shales.

Determine the feasibility of using shallow penetration resistivity and seismic surveys to detect near surface faults and fractures and demonstrate their relationship to lineations observed on airborne imagery.

Determine if a relationship exists between ground water movement and shale gas productivity.

In conjunction with other contractors develop a method for selecting areas for drilling shale wells that have a potential for gas production.

3.0 TECHNICAL PROGRESS

3.1 Work Package 2100-1-1 CROSS SECTIONS J. Negus-de Wys

3.2 Work Package 2100-1-2 ISOPACH MAPS

3.3 Work Package 2100-2-1 STRUCTURE CONTOUR MAPS

3.4 Work Package 3200-4-1 OIL AND GAS MAPS

3.1.1 Current status of work and scheduled deliverables

Work plan for this quarter included:

- Picking adjusted stratigraphic tops;
- Preparation of elemental maps in eastern Kentucky initiated;
- Hand-contouring of maps initiated;
- Preliminary cross section of organic geochemistry of black, brown, gray, and green shale facies; and
- Initiation of advertisement and selection of Ph.D. candidate(s) for geochemical research.

All above maps have been completed or are in progress for the first data set of 14 wells. A table of data ranges for Lower Huron black shale is shown in Table 1. Hand-contoured elemental data maps using data set 1 are shown in Figures 1 through 11. Sample computer drawn map is shown in Figure 15.

Current status on 2 year program: 10% completed

A preliminary procedure for locating a well in high gas producing areas was prepared and submitted to Dr. Claude Dean, per his request. This procedure included eight priority areas, using 15 maps to develop the final map. A transparent map at a scale of 1:500,000 with the priority areas was included. Joint probabilities using assumptions on which the areas were developed, ranged from 75 to 96% for the areas suggested.

3.1.2 Problem areas and suggested improvements

Delay in implementation of procurement package on contract. Problem addressed by METC. Anticipated date of on-track recovery: April 15th.

3.1.3 Work plan for next quarter

Continuation of map preparation and data reduction for data set 1.

Initiation of data interpretation and analysis on data set 1.

Preparation and presentation of paper for the SPE/DOE meeting in Pittsburgh, May, 1980.

Meetings attended: See monthly reports

Papers accepted

1. Negus-de Wys, Jane, "The anatomy of a large Devonian black shale gas field," 26th International Geological Congress, Paris, 1980.

2. Negus-de Wys, J. and J.J. Renton, "Inorganic geochemistry as an exploration tool," 26th International Geological Congress, Paris, 1980.

3. Negus-de Wys, J. and J.J. Renton, "Preliminary depositional model for upper Devonian organic black shale in the eastern Kentucky gas field," SPE/DOE Meeting, Pittsburgh, May, 1980.

Papers in preparation

1. Negus-de Wys, Jane, "Relationships of gas occurrence to geologic parameters in eastern Kentucky gas field," requested by AAPG for submission for journal publication.

2. Erickson, S.S., J. Negus-de Wys, and W.V. Dashek, "Comparison of plant responses to atmospheric sulfur dioxide with reported effects on human health," for quarterly Review of Biology.

3. J. Jenkins, J. Negus-de Wys, and H.D. Bennett, "Color changes in megaspores observed at visual and fluorescence wavelengths for Upper Devonian black shale in the eastern Kentucky gas field."

Other activities

Technical chairman for The Appalachian Basin Symposium March 31 - April 2, Lakeview Country Club, Morgantown, West Virginia.

WVU Dept. of Geology & Geography
Jan.-Mar. 1980

SPE/DOE SYMPOSIUM ON UNCONVENTIONAL GAS RECOVERY
Pittsburgh, Pennsylvania
May 18-21, 1980

Paper Title: Preliminary Depositional Model for Upper Devonian Organic Black Shale in the Eastern Kentucky Gas Field

Principal Author: J. Negus-de Wys Telephone No. (304) 293-5603
(With whom SPE will correspond)
Company West Virginia University
Mailing Address: Department of Geology, WVU, Morgantown, WV 26506
Co-authors: J. J. Renton
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Company and Mailing Address: Department of Geology, West Virginia University, Morgantown, WV 26506

ABSTRACT: The abstract, containing not less than 200 words, should be provided in the space below, and on the reverse side of this page.

The constraints on a depositional model are discussed for the Upper Devonian organic black shale facies in the high gas production area of the Big Sandy Gas Field in eastern Kentucky. Commencing with the onlapping lower Huron black shale, which is deposited over a recognizeable basal unconformity, the lithology, geochemistry, structural-stratigraphic relationships and production are discussed.

The lower Huron is recognized as the zone of high gas recovery in the Ohio Shale sequence in eastern Kentucky. Since gas recovery is dependent upon natural fracture permeability, this zone may also be the most highly fractured. From gamma-ray logs this basal black shale shows a characteristically higher natural radioactivity than all other Ohio shale units except the Cleveland shale, which is very similar to the lower Huron shale.

The elemental geochemistry of the black, gray, green, and brown shale lithofacies are compared. Preliminary organic geochemistry for these lithofacies are compared by cross section with other parameters such as lithology and structural-stratigraphic cross-sections.

Thin sections from highly organic black shale in the center of the area of high production in Floyd County are compared with thin sections of subbituminous coal. The abundance of spores, cuticles, and carbonaceous plant fragments is apparent, and very similar to a subbituminous coal.

Evidence at outcrops of lower Huron black shale to the west of the field area suggest residual soil horizon at the base of the Huron and channels in the lower Huron black shale.

The highly organic black shale at the base of the Ohio shale sequence is concluded to be the result of transgression of shallow Upper Devonian seas, destruction and deposition of abundant plant growth developing both in shallow water and on low-lying cratonic margins in incipient coal-swamp environments.

Drowning of such growth as evidenced by occurrence of a high density of spores, vitrinitic or woody fragments, and reported occurrence of logs of the largest Upper Devonian plant, the tree-fern Archeopteris, is suggested.

SOCIETY OF PETROLEUM ENGINEERS AIME

ABSTRACT DEADLINE: January 9, 1980
RETURN TO: John L. Moore, 952 Four Gateway Center, Pittsburgh, PA 15222

UGR File #C048/80Q2
WVU Dept. of Geology & Geography Jan.-Mar. 1980

SPE/DOE SYMPOSIUM ON UNCONVENTIONAL GAS RECOVERY
Pittsburgh, Pennsylvania
May 18-21, 1980

12,

Paper Title: PETROGRAPHIC STUDY OF DEVONIAN BLACK SHALE IN THE AREA OF HIGH PRODUCTION IN THE BIG SANDY GAS FIELD OF EASTERN KENTUCKY

Principal Author: Junior L. Jenkins Telephone No. 293 5603 (304)
(With whom SPE will correspond)
Company Department of Geology and Geography, West Virginia University, Morgantown, W.Va.
Mailing Address: above 26505
Co-authors: Jane Negus-de Wys, Milton T. Heald
(If more than one, list on separate page)
Company and Mailing Address: same as above

ABSTRACT: The abstract, containing not less than 200 words, should be provided in the space below, and on the reverse side of this page.

Working under a grant from Gulf Research Center in Pittsburgh, several hundred thin sections of Upper Devonian black shale were obtained from the Kentucky-West Virginia Gas Company for petrographic study. Coleman D. Hunter studied over 700 of these thin sections from 86 wells during the early 1930's, but only a general average of the results were reported. No other record of previous work on these thin sections has been found.

Locations of the sample wells are plotted on a base map of eastern Kentucky. All sample wells are located in the Big Sandy gas field. The majority of the wells are located in the center of high gas production in Floyd County with other wells located in Pike, Martin, and Knott Counties. In general, thin sections have been made from cable tool-drilled well samples taken about every 10 feet from the top to the bottom of the Upper Devonian black shale sequence which is the main producing horizon in the largest gas field in the Appalachian basin.

Petrographic descriptions and photography of the thin sections is currently in progress. Study of the thin sections is based on the two parameters, rock fabric and rock constituents. The general rock fabric study is based on silt content, clay content and laminae features. Recently more detailed fabric studies and lithotype classification systems of the Devonian black shales have been done. However, using only small thin section specimens these more elaborate classification systems are not practical. A general list of shale constituents in a decreasing order of abundance consists of clays, quartz, organic matter, pyrite, mica, and a variety of other minor constituents. Clays are the most abundant constituents usually constituting well over half of the total rock volume. The predominate clay type is illite with chlorite occurring in some sections. Kaolinite is present, but is only rarely easily identified. Quartz, occurring as subangular to subrounded grains, is abundant, ranging from clay size to coarse silt size particles. The organic matter consists mainly of spores, carbonaceous plant fragments, cuticles, and woody material. The unusually high concentration of spore material undoubtedly contributes as a hydrocarbon source. Pyrite is commonly seen as disseminated grains and framboidal forms extensively replacin organic material. Mica, especially muscovite, commonly occurs throughout the specimens as elongated flakes up to 0.25 mm in length. Preliminary point count results are also presented.

Evidence of fractures within the thin sections are apparent. The fractures are seen on a micro scale and are only a few mm in length. Sparry material seems to occur inside of these microstructures. Larger fractures are not expected to be found since

ABSTRACT DEADLINE: January 9, 1980
RETURN TO: John L. Moore, 952 Four Gateway Center, Pittsburgh, PA 15222

the samples are chips from a cable tool drilled well.

Three general lithotypes are apparent at this time. The lithotypes include a siltstone type, a laminated organic-rich shale type, and a non-laminated clay-rich type.

MINERAL DATA RANGES FOR HURON SHALE *

Minerals	Lower Huron	Middle Huron	Upper Huron
Illite	31.9 - 79.7%	44.3 - 63.1%	41.3 - 61.9%
Quartz	13.6 - 39.2	24.5 - 43.2	27.8 - 44.4
Pyrite	2.2 - 8.2	2.8 - 8.7	0.8 - 8.8
Siderite	1.2 - 5.3	0.9 - 3.3	11 0 - 4.2
Bassanite	1.4 - 2.5	1.3 - 2.3	1.4 - 2.3
Dolomite	0.1 - 3.8	0.0 - 1.3	0.0 - 3.7
Plagioclase	0.0 - 1.1	0.6 - 1.2	0.7 - 1.5
Chlorite	0.3 - 1.3	0.3 - 1.2	0.3 - 1.1
Orthoclase	0.0 - 0.4	0.0 - 0.7	0.0 - 0.6
Anhydrite	0.0 - 0.3	0.0 - 0.2	0.0 - 0.4
Calcite	0.0 - 24.8	0.0 - 1.0	0.0 - 1.3
Kaolinite	0.0 - 1.0	0.0 - 0.5	0.0 - 1.9
Szmolnokite	0.0 - 0.1	0.0 - 0.2	0.0 - 0.4
RATIOS			
(1)	0.0 - 0.2	0.0 - 0.0	0.0 - 0.0
(2)	0.3 - 0.5	0.3 - 0.5	0.3 - 0.5
(3)	0.0 - 0.9	0.4 - 1.0	0.4 - 1.0
(4)	0.0 - 0.9	0.0 - 0.6	0.0 - 1.0
(5)	0.8 - 1.0	0.8 - 1.0	0.4 - 1.0

* % represents % of total integrated intensity. The use of one decimal place is not meant to indicate level of precision, which is probably ±10%.

TABLE 1

ELEMENT DATA RANGES FOR HURON SHALE

Element	Lower Huron	Middle Huron	Upper Huron
Si	51.70 - 58.50%	51.27 - 55.50%	52.71 - 57.20%
Ca	0.52 - 19.18	0.36 - 1.41	0.46 - 1.93
Al	8.37 - 16.60	13.54 - 15.97	12.37 - 15.65
Fe	5.53 - 10.13	7.52 - 10.23	6.77 - 10.09
K	2.21 - 4.21	3.18 - 4.26	2.82 - 3.74
S	1.89 - 3.4	1.59 - 4.65	0.68 - 3.62
Mg	1.29 - 2.93	1.21 - 1.89	1.07 - 1.47
Ti	0.34 - 0.92	0.81 - 1.01	0.75 - 1.06
Na	0.41 - 0.70	0.59 - 0.70	0.59 - 0.71
P	0.116 - 0.626	0.11 - 0.14	0.11 - 0.16
Mn	0.03 - 0.07	0.03 - 0.07	0.02 - 0.11
Zn	0.008 - 0.02	0.009 - 0.034	0.007 - 0.017
Sr	0.002 - 0.016	0.003 - 0.011	0.0 - 0.007

All are percentage values.
All oxides except sulfur.

TABLE 2

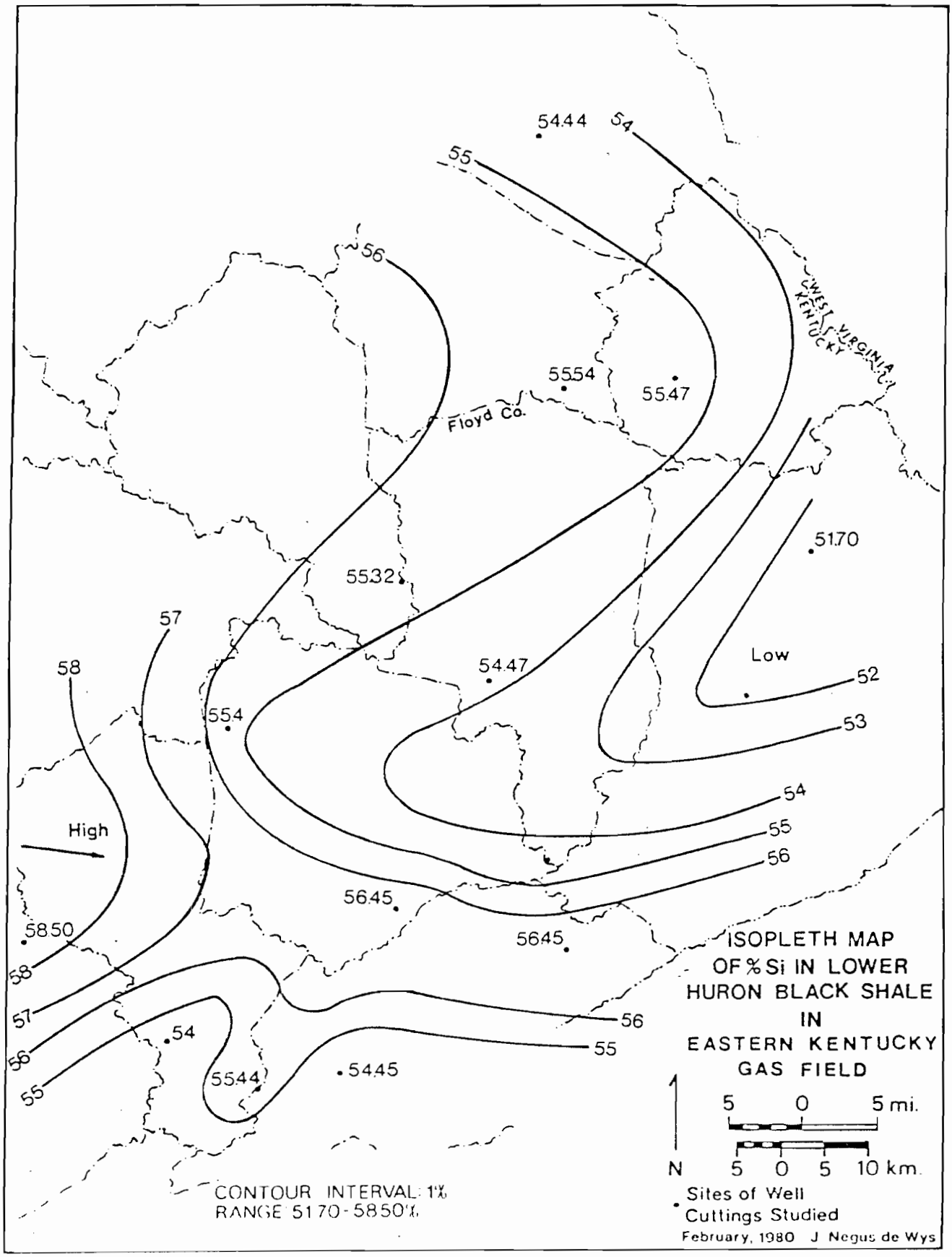

FIGURE 1: Isopleth map of % Si in Lower Huron black shale in eastern Kentucky gas field.

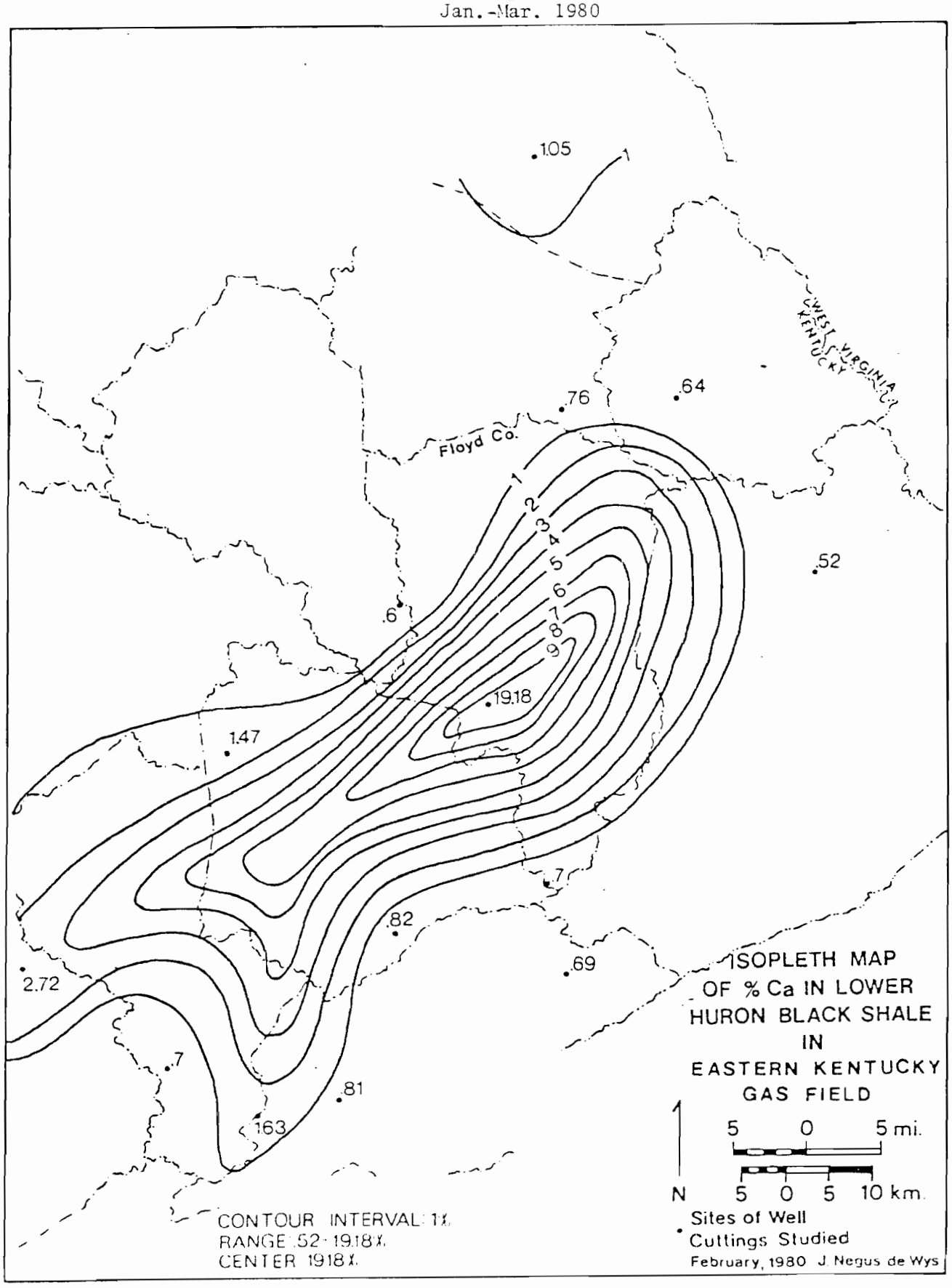

FIGURE 2: Isopleth map of % Ca in Lower Huron black shale in eastern Kentucky gas field.

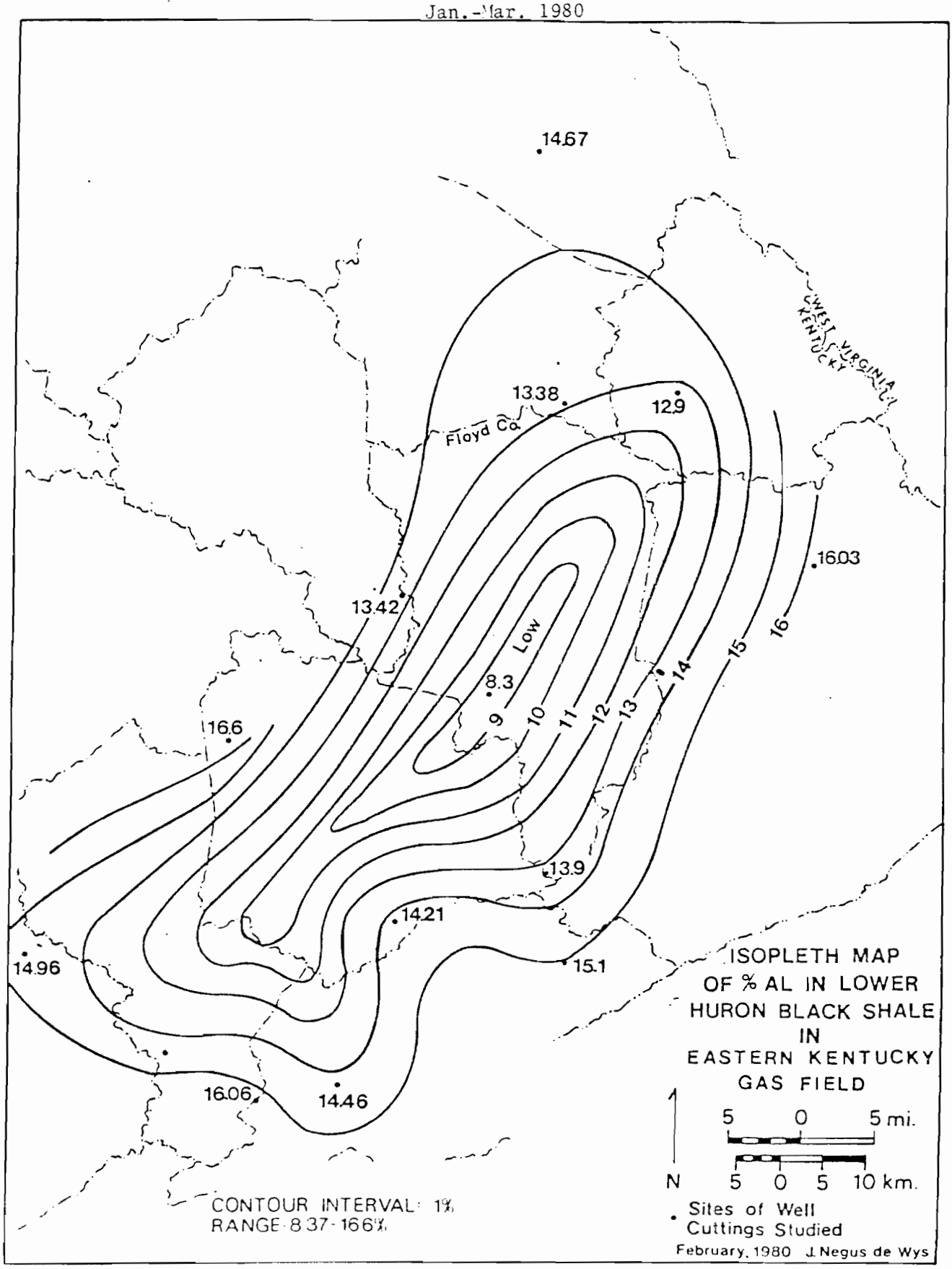

FIGURE 3: Isopleth map of % AL in Lower Huron black shale in eastern Kentucky gas field.

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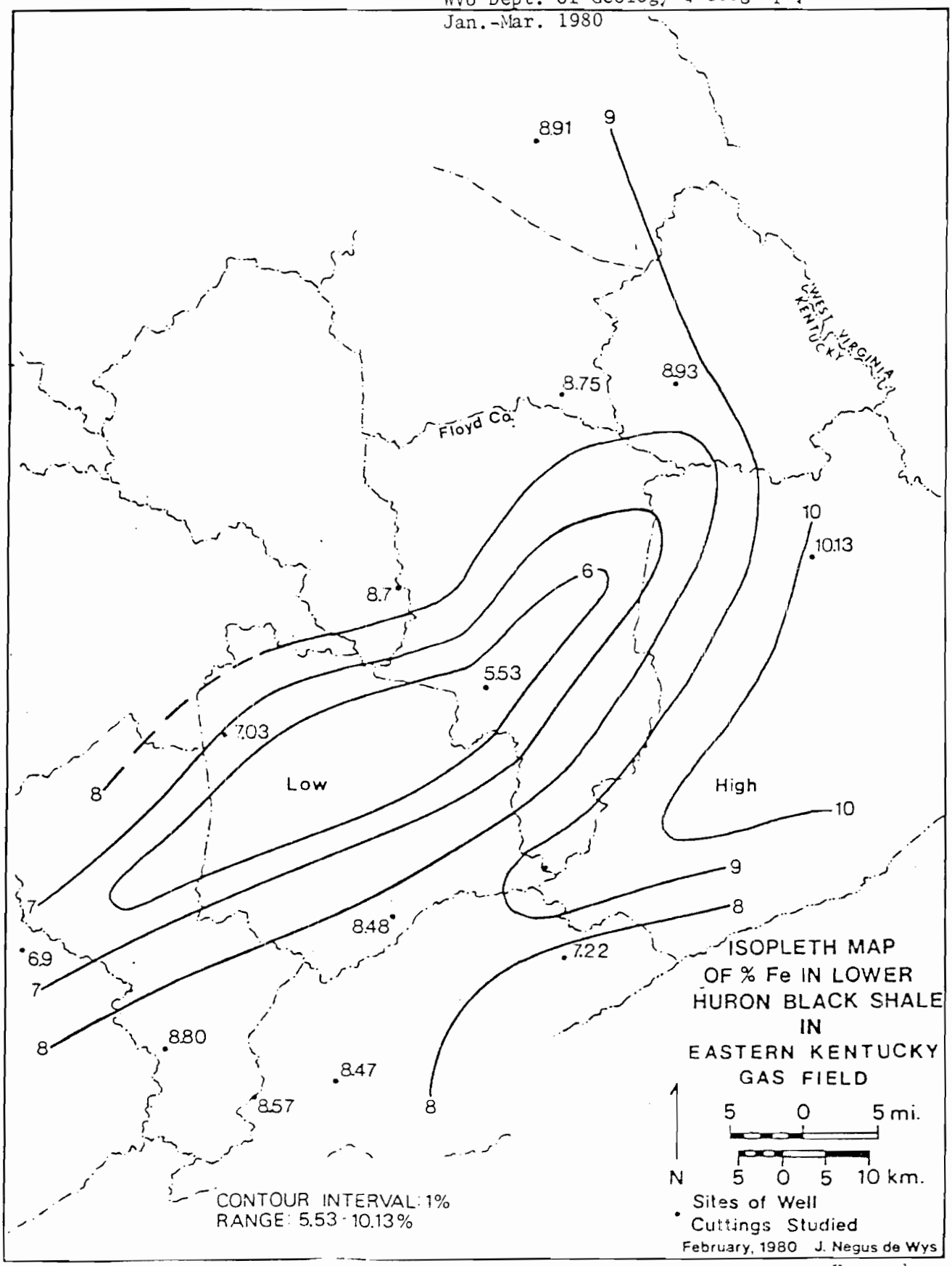

FIGURE 4: Isopleth map of % Fe in Lower Huron black shale in eastern Kentucky gas field.

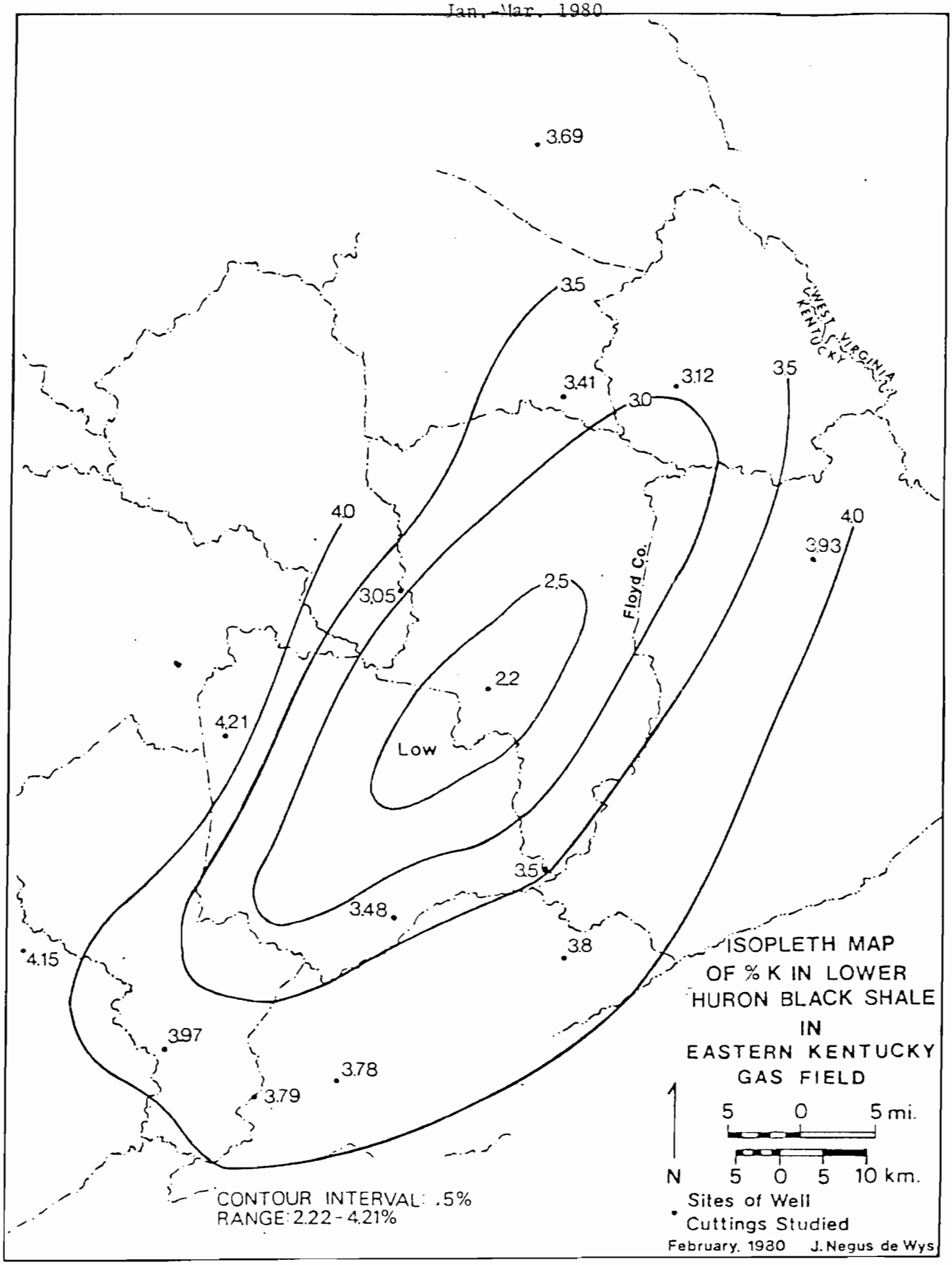

FIGURE 5: Isopleth map of % K in Lower Huron black shale in eastern Kentucky gas field.

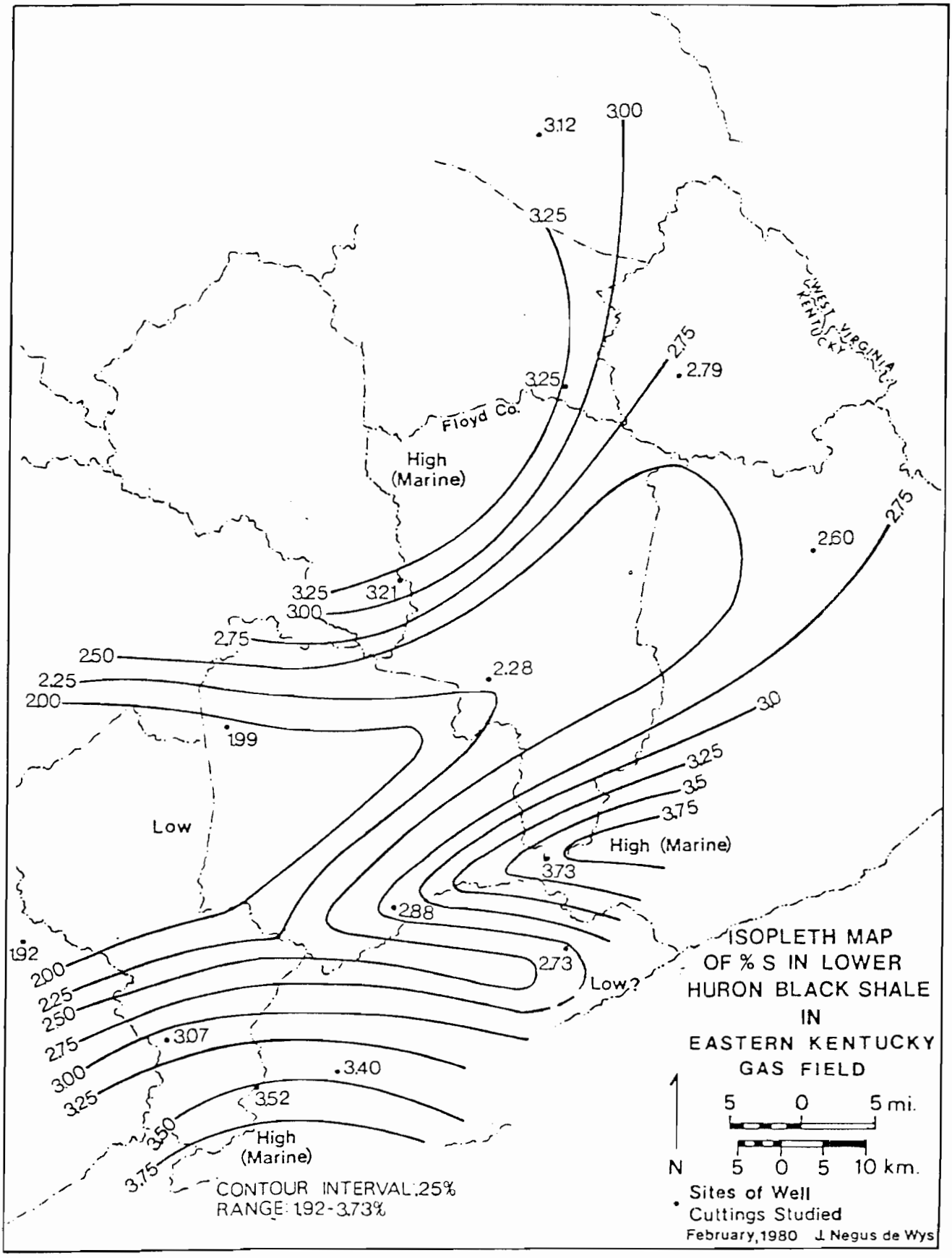

FIGURE 6: Isopleth map of % S in Lower Huron black shale in eastern Kentucky gas field.

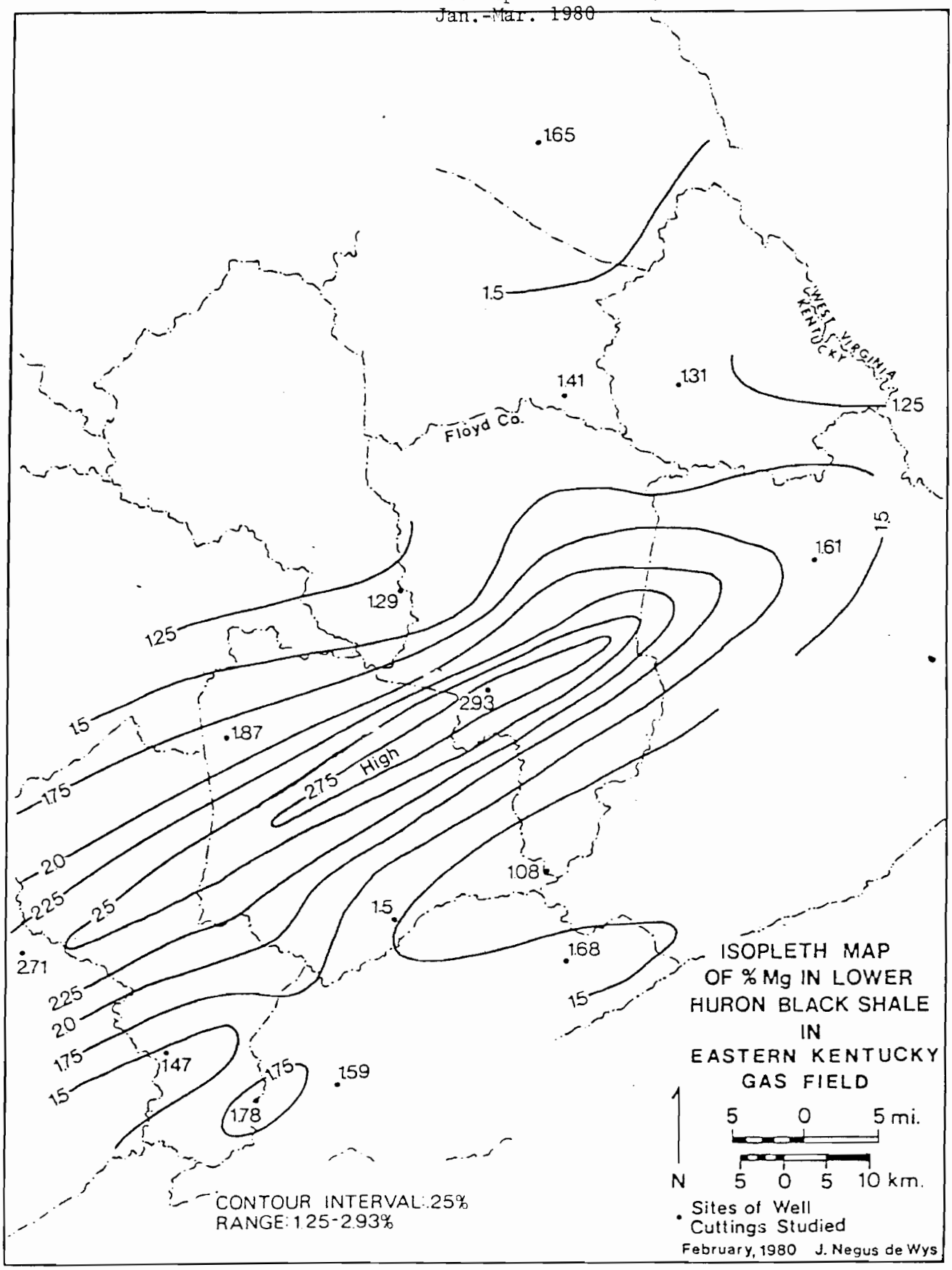

FIGURE 7: Isopleth map of % Mg in Lower Huron black shale in eastern Kentucky gas field.

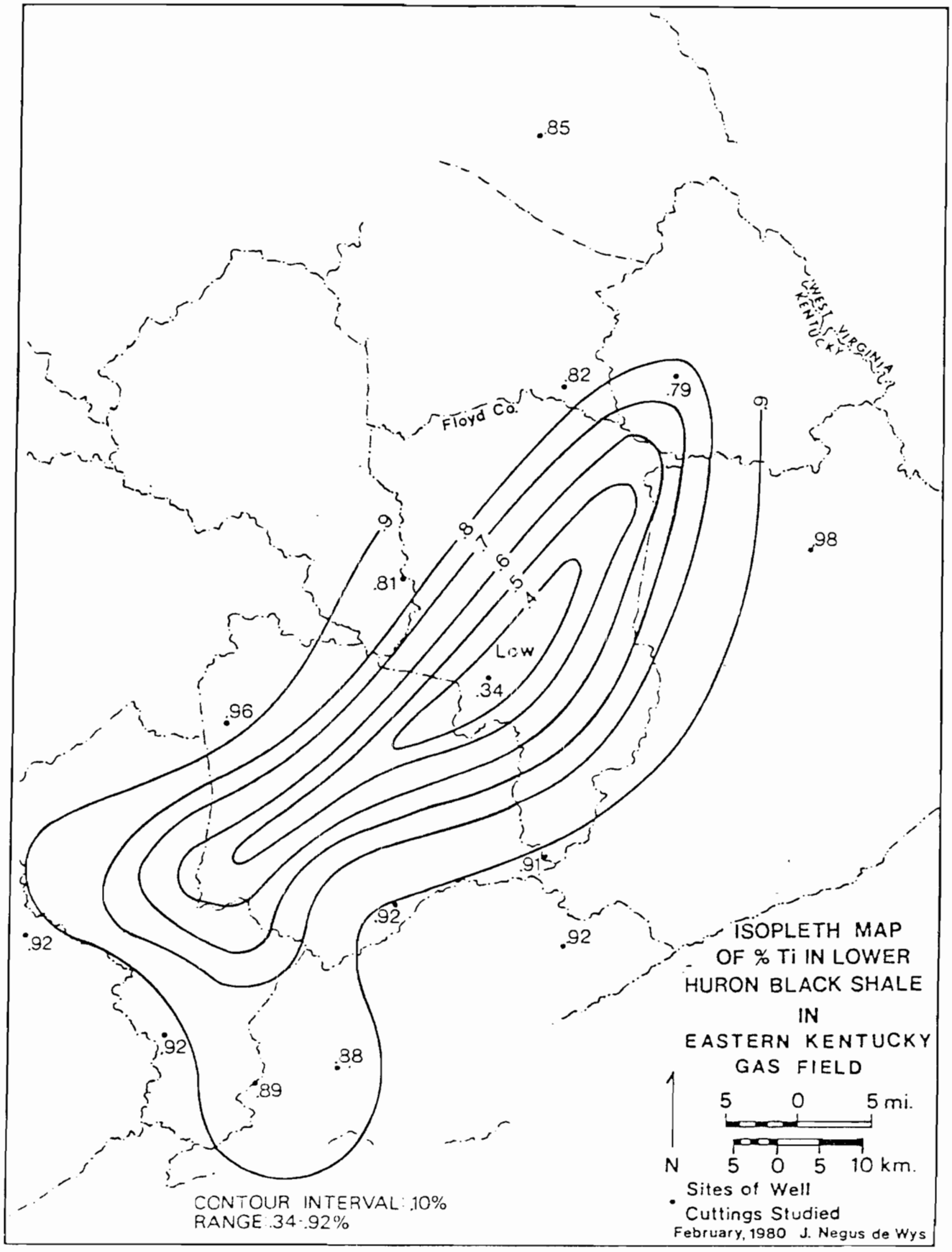

FIGURE 8: Isopleth map of % Ti in Lower Huron black shale in eastern Kentucky gas field.

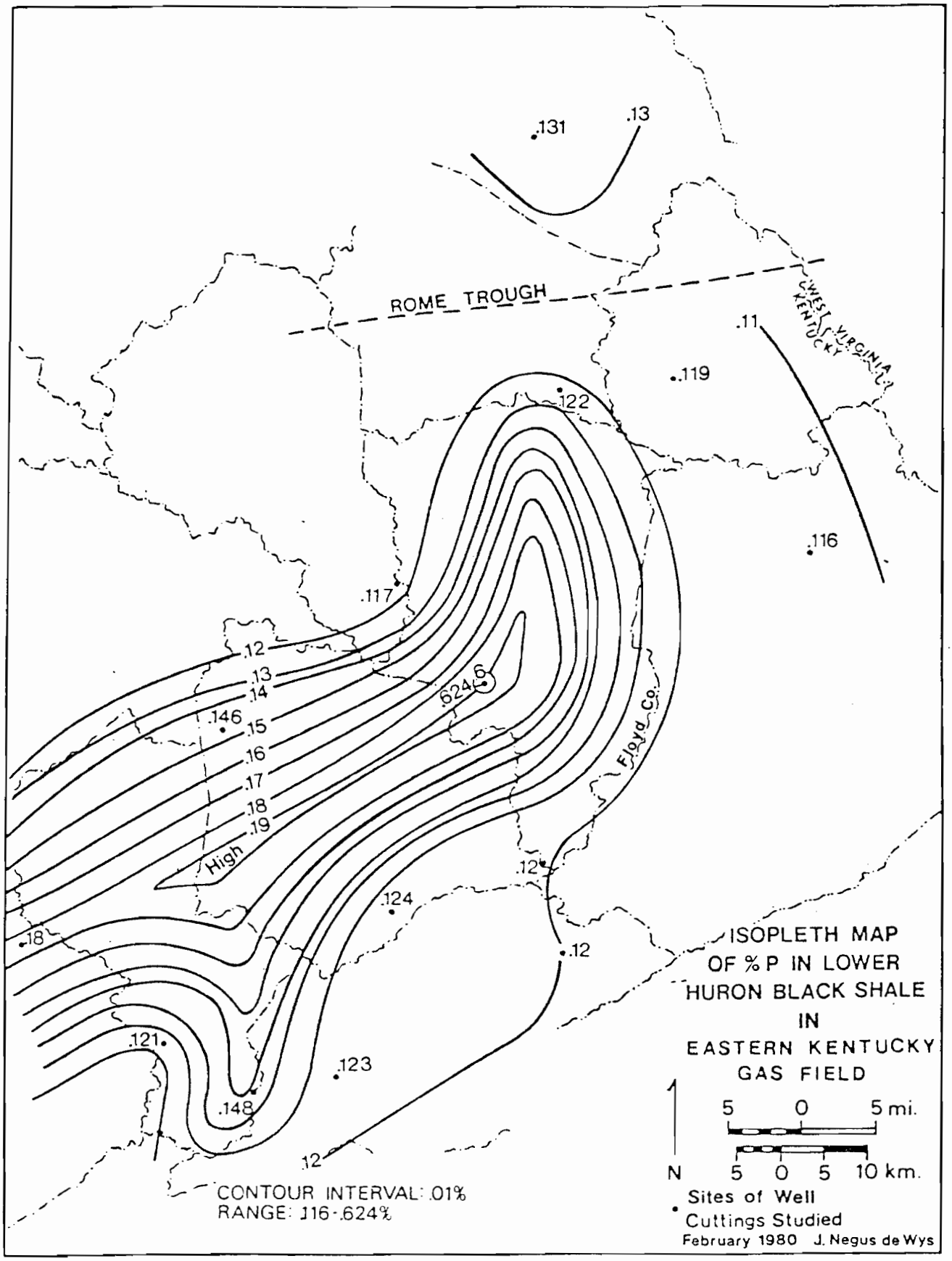

FIGURE 9: Isopleth map of % P in Lower Huron black shale in eastern Kentucky gas field.

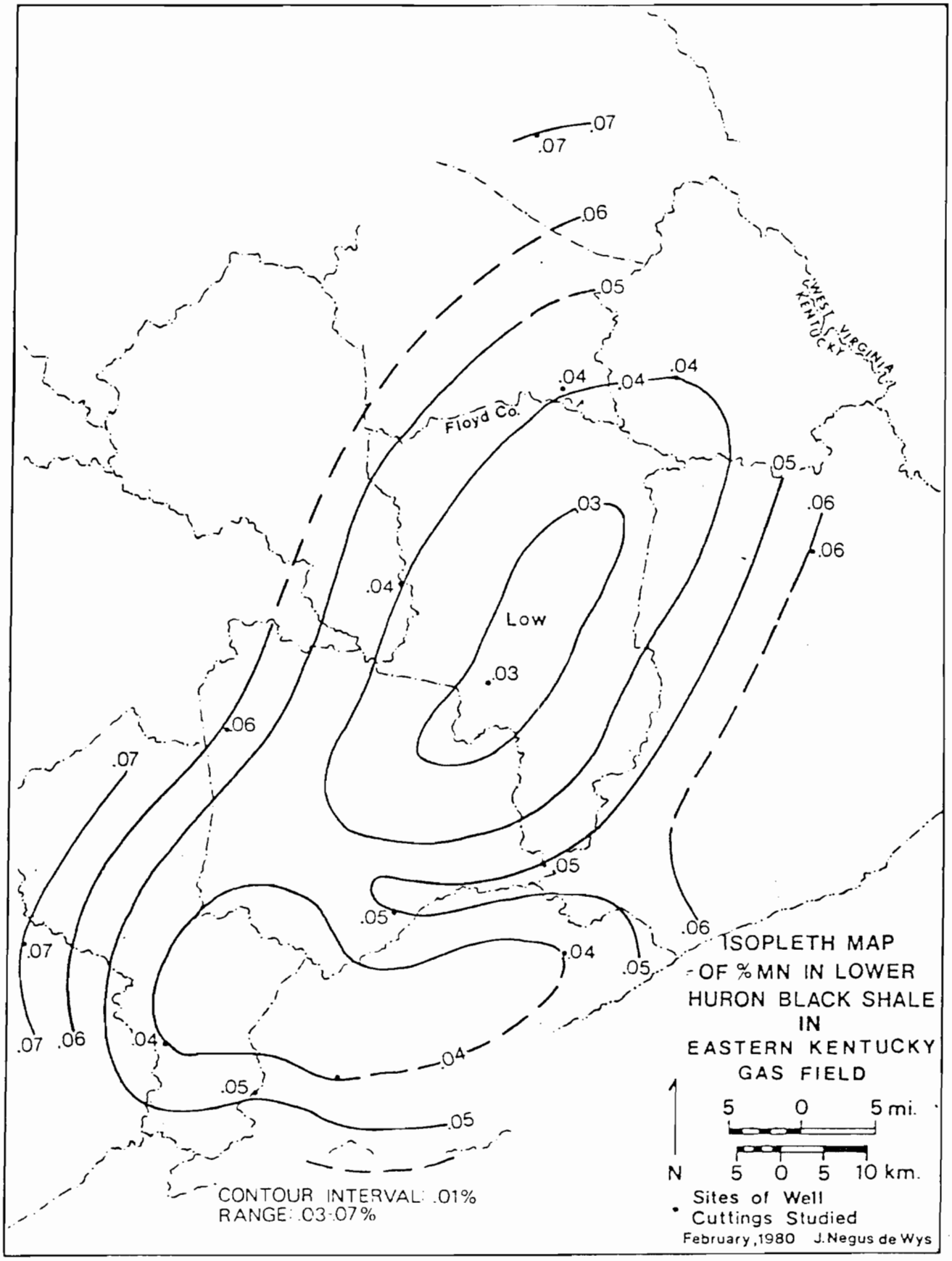

FIGURE 10: Isopleth map of % MN in Lower Huron black shale in eastern Kentucky gas field.

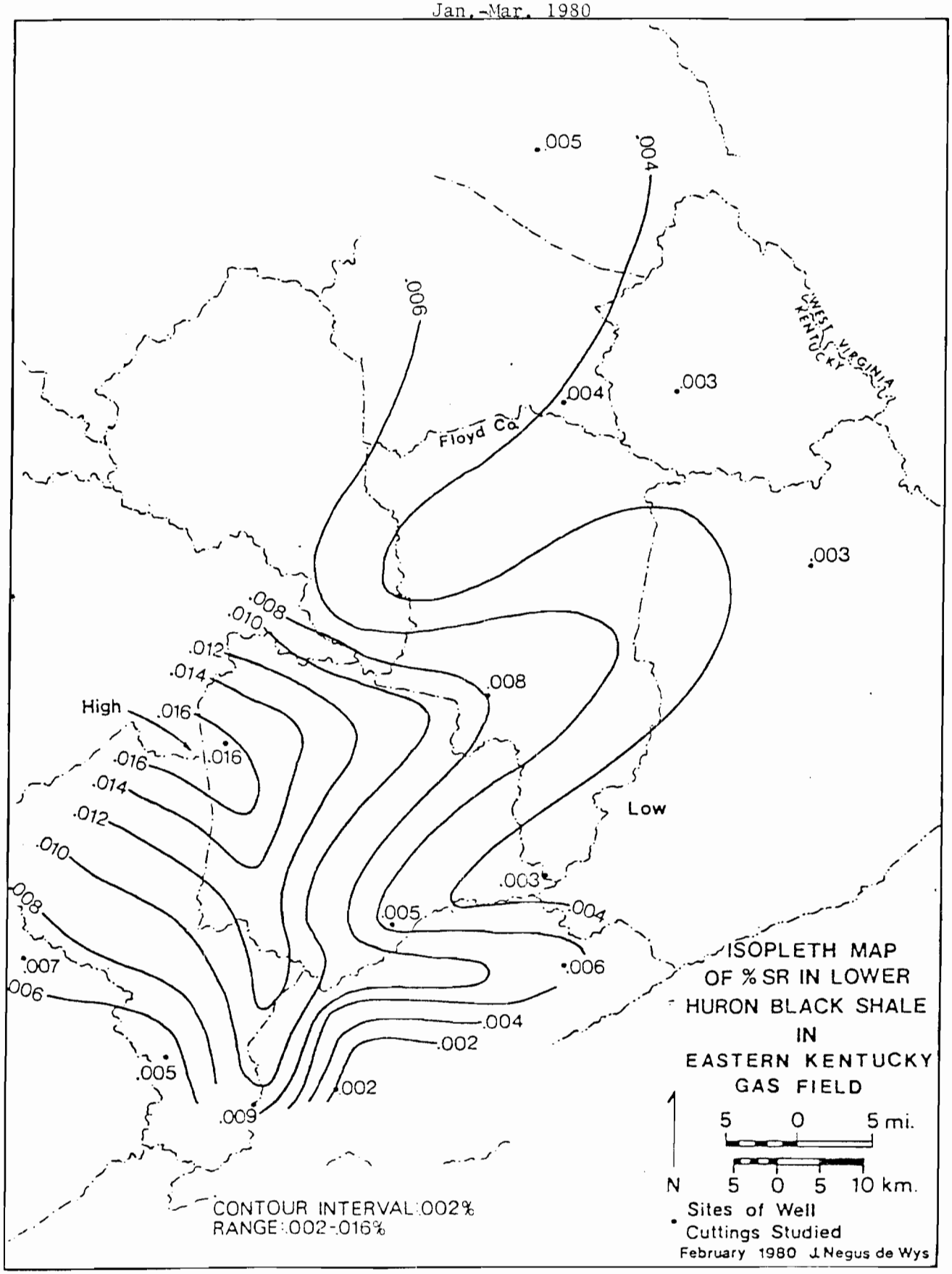

FIGURE 11: Isopleth map of % SR in Lower Huron black shale in eastern Kentucky gas field.

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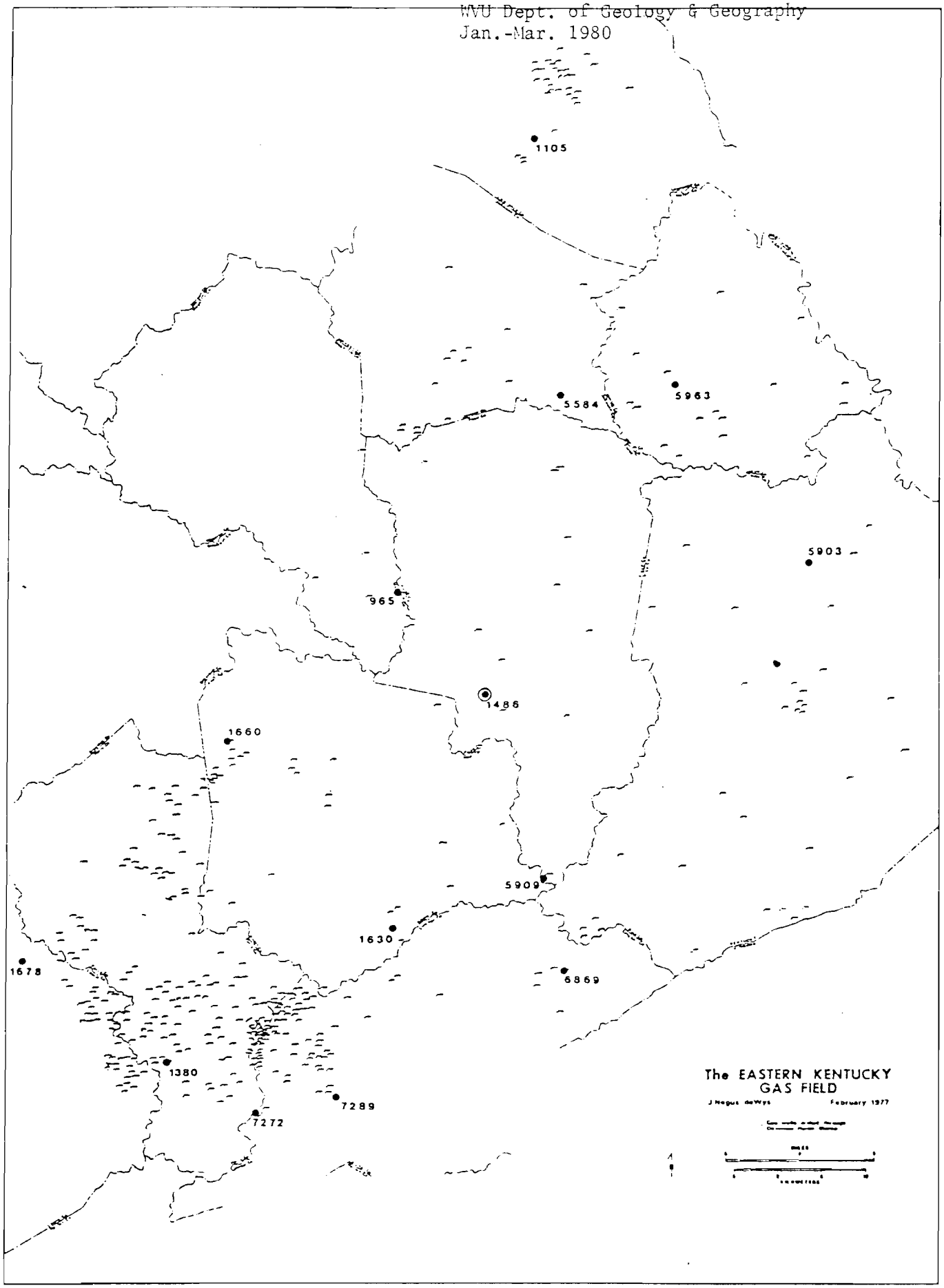

FIGURE 12: Location of well in Floyd County for which data is shown in Figure 13.

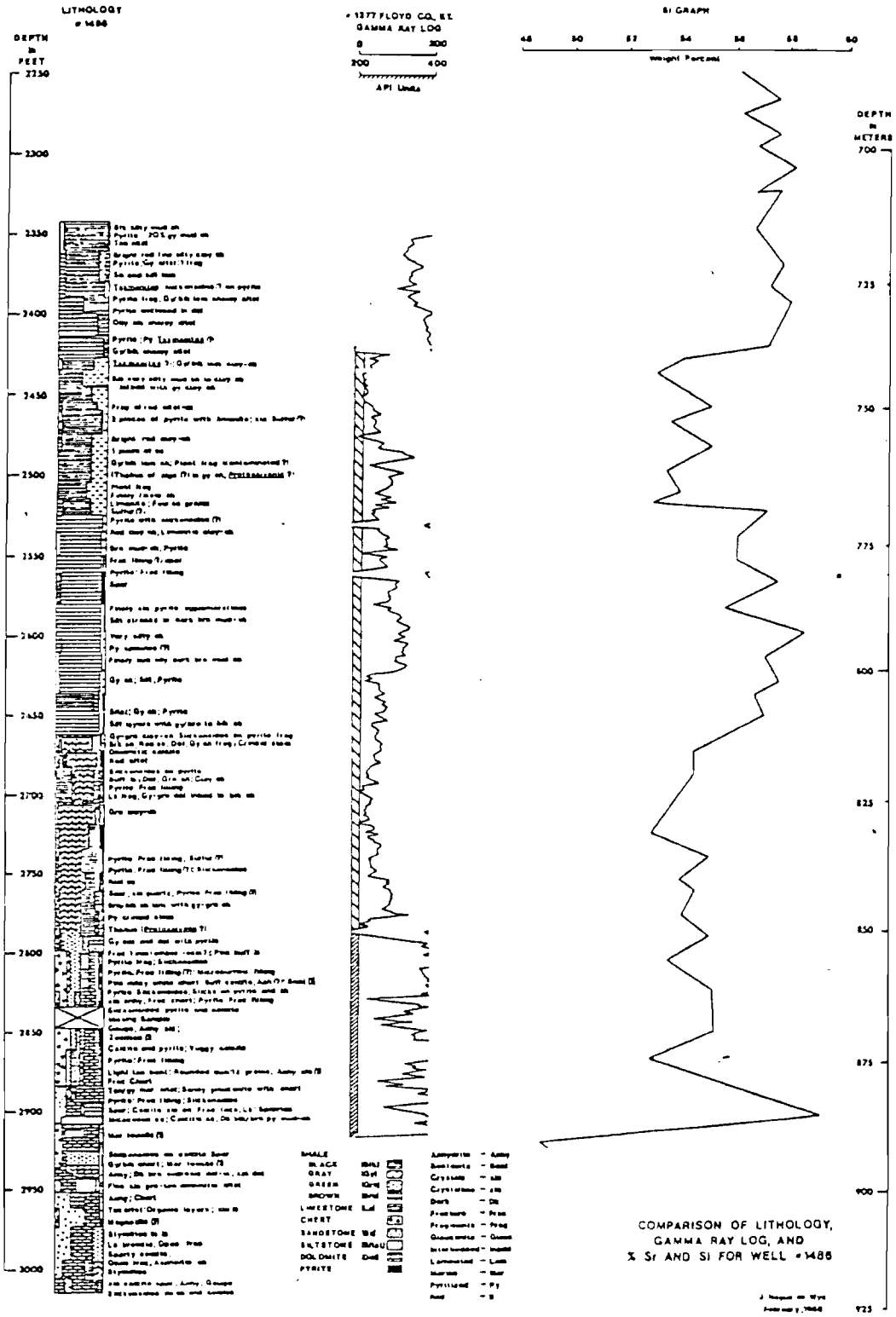

FIGURE 13: Lithology of well #1486 in Floyd County compared with nearby gamma ray log and Si graph from X-ray fluorescence.

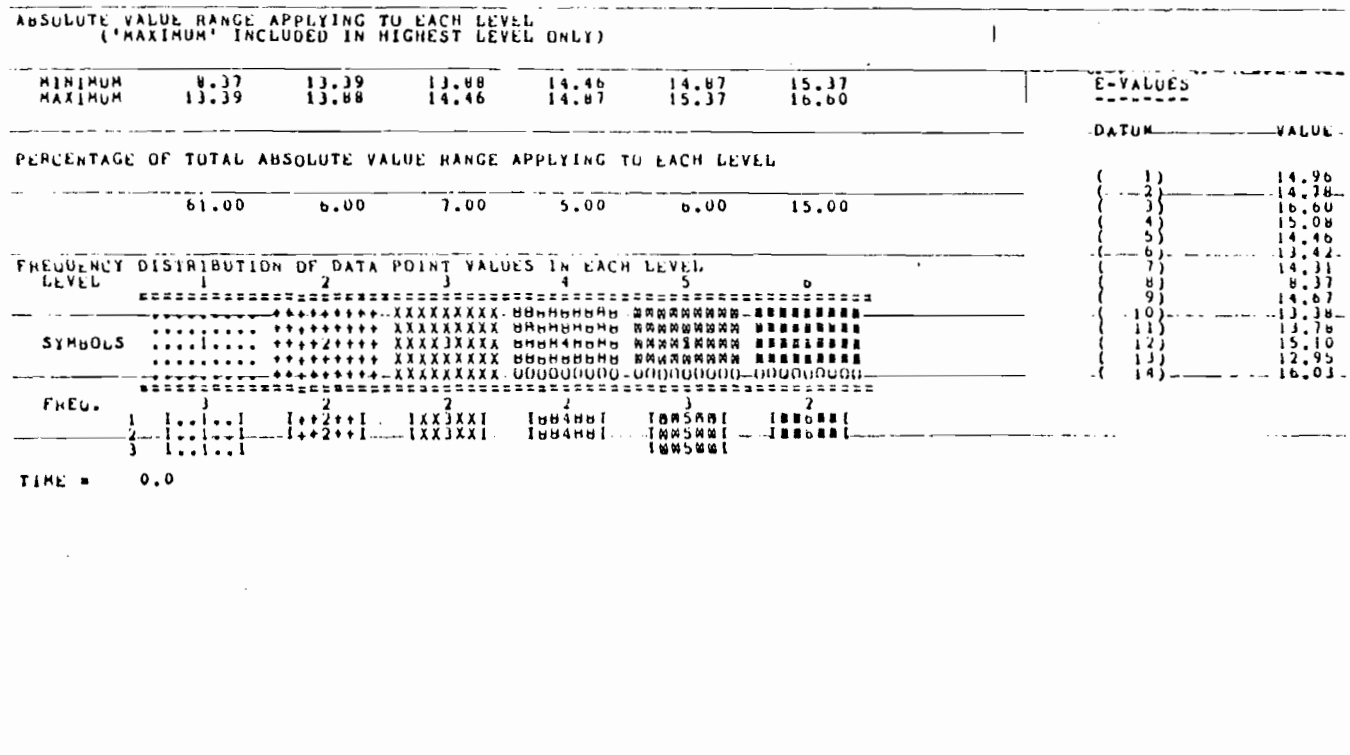

FIGURE 14: Computer data for legend for Figure 15.

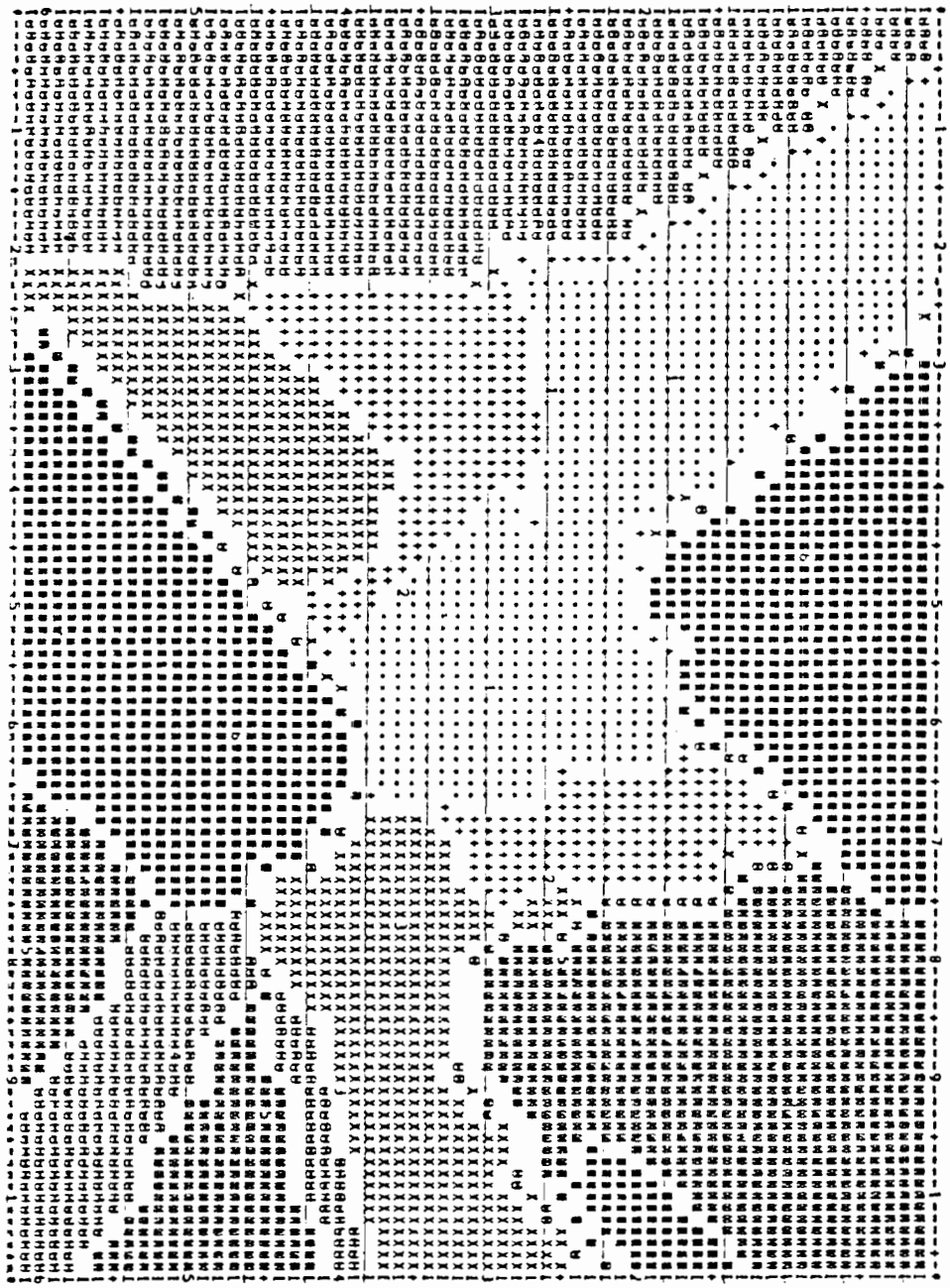

FIGURE 15: Average values of AL in 14 wells for Lower Huron Shale. Data value extremes are 8.4 and 16.6%.

3.1 Work Package 2100-1-1 SEISMIC

James E. Ruotsala

3.1.1 Current status of work and scheduled deliverables

Our technician has completed repairs and modifications to the geophone filters. The Bison seismograph system is functioning properly in the lab.

The hardware required for writing the seismic onto a floppy disk has not yet been delivered. Delivery is expected within a few weeks.

Work on developing a ray tracing seismic modeling capability is progressing satisfactorily.

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for next quarter

The Bison seismograph system will be field tested at the Pricetown site as soon as weather permits. Judgement of the system's capability for recording reflection seismic data will be made after a successful field test.

The new system for writing seismic data onto a floppy disk will be put together when the hardware is delivered.

Work on developing ray tracing seismic modeling capability will be completed.

* * * * * *

3.1 Work Package 2100-2-2 STRUCTURE STUDIES — Thomas H. Wilson

3.1.1 Current status of work and scheduled deliverables

The processing and analysis of various structural and geophysical data collected for this project is near completion. Remaining work will be completed early in the next quarter at which time efforts will be concentrated on the preparation of the final report (already a third complete).

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for next quarter

It is hoped that a first draft of the final report can be prepared and delivered to the chairman of my dissertation committee, Dr. Russell Wheeler, by July 1.

* * * * * *

3.1 Work Package 2200-1-2 FRACTURE STUDIES Kevin D. Lee

3.1.1 Current status of work and scheduled deliverables

The first draft of my thesis was not entirely completed, but good progress was made. Each section of my study requires a literature search and numerous maps and cross sections to be drawn. The first draft will be completed very early in the next work quarter.

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for next quarter

1. Finish first draft of thesis.
2. Revise first draft of thesis.
3. Have many of the maps included in my study drafted.

* * * * * *

UGR File No. C048/80Q3
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QUARTERLY PROGRESS REPORT

U.S. Department of Energy
Contract number DE-AC21-76ET12138
(formerly DE-AC21-76MC05194)

April - June 1980

submitted by

Department of Geology and Geography
West Virginia University

Alan C. Donaldson, Chairman
Department of Geology and Geography
(for Robert C. Shumaker, Project Director
Devonian Shale Program)

co-authored by

J. Negus-de Wys, Kevin D. Lee, James E. Ruotsala,
Thomas H. Wilson and Richard T. Williams

Research Associates

1.0 EXECUTIVE SUMMARY

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QUARTERLY PROGRESS REPORT

April - June 1980

U.S. Department of Energy
Contract no. DE-AC21-76ET12138
(formerly DE-AC21-76MC05194)

1.0 EXECUTIVE SUMMARY

1.0.1 The third quarter of the 1979-1980 contract year resulted in the delivery by the draftsman of the regional map (1:500,000) prepared by Robert Shumaker of form lines indicating important surface tectonic elements for eastern Kentucky and West Virginia. This map should be compared with the previously submitted regional map of basement structures of this same area. The unfinished regional map using the Devonian shales as the datum will enable one to determine which structures extend from the basement to the surface, which structures are unique to the Devonian shale unit, and which structures exhibit "thin skin tectonic" characteristics.

Jane Negus-de Wys negotiated with Kentucky-West Virginia Gas Company for a well to be drilled, cored, and logged in an area of high gas production in the Big Sandy Gas Field. The selection of the well site is based on criteria developed by Jane from her research, and it indicates an exploration rationale which is the purpose of the entire project. The opportunity to examine a gas pay zone which is highly productive should yield clues for developing new fields as well as improving production in known gas fields. Jane Negus-de Wys also prepared 180 maps of geochemical parameters for comparison with gas production information. She estimates that twenty-five percent of the two-year project now is completed.

The geophysical seismic subproject successfully tested the Bison system at the Pricetown #2 coal gasification site. This test represents the first time reliable data were recorded and obviously the researchers are encouraged to proceed to the next phase.

Tom Wilson completed a 28-page report on Central Appalachian gravity models which is appended to this quarterly report.

Kevin Lee has completed two drafts of the final report and currently is preparing the third draft for Robert Shumaker's return on August 1. Kevin Lee apparently has discovered a potential gas field in Kentucky that could be similar to the Cottageville Gas Field. The detailed subsurface mapping apparently has resulted in encouraging support for finding new gas in the Devonian shales.

The presentation of papers at the International Geological Congress at Paris, France by personnel of the project indicates the significant results of this research project. The competition for selected papers is great and only high quality efforts are chosen for this congress.

1.0.2 Regional Structure Studies

This work was completed last quarter before Robert Shumaker left on sabbatical leave for England. The regional map on surface structure for eastern Kentucky and West Virginia has been drafted and delivered during this quarter.

1.0.3 Production Studies

Jane Negus-de Wys completed 180 geochemistry maps and these now are being drafted. In addition, 360 graphs have been computer-run. These data are testing the validity of geochemical parameters for recognizing potential gas production. The correlation in the Eastern Kentucky Field is positive and documentation of this exploration tool by additional data is occurring.

1.0.4 Geophysical Studies

The third quarter demonstrated that the Bison seismic system is capable of obtaining reliable data from the Pricetown site. Now that this first phase has been completed, the next step will be to use a new pressure sensitive geophone in order to provide better coupling to the ground at high frequencies. Once this is completed (hopefully early in July) the geophysical study of the Cottageville Gas Field can commence.

1.0.5 Fracture Studies

Detailed structural geology of the Eastern Kentucky Gas Field is near completion by Kevin Lee. The discovery of promising gas-producing trends is developing from this research, and this fact certainly justifies the time and money invested in the project.

1.0.6 Structural Studies

Tom Wilson expects to complete the final draft of his final report by August 1. Some concepts developed in this project are discussed in a paper written by Tom and appended to this report.

The need for the continuation of this project into the fifth and final year is critical. The various parts of the puzzle completed in the first four years need to be analyzed as a whole during the anticipated concluding year. Project continuation information was submitted for this funding. The results of the project so far are outstanding and on target according to the grand design of the project. The final assessment and geological integration of the various parts is scheduled for 1980-81 and hopefully D.O.E. recognizes the importance of funding this phase which determines whether or not an exploration strategy is feasible from the structural parameters investigated.

All results so far indicate that the structural parameters are the key to the solution for finding new gas production and/or improving production in older fields. The step-by-step building of a data base for good decision making is approaching the final year of study and evaluation. The probability of a good outcome from this study is excellent in my estimation.

* * * * * *

APRIL THRU JUNE 1980

DELIVERABLES AND MILESTONES DELIVERED

Map submitted 5-31-80 by Robert C. Shumaker fulfills:

Task Specification 3.2.3 To prepare regional structure map in final form for eastern Kentucky and the plateau portion of West Virginia for the following horizon: Surface Structure Form Line Map

Milestone 3.4.12 Regional map showing the near surface form-line structure for eastern Kentucky and western West Virginia

2.0 CONTRACT OBJECTIVES

2.0 CONTRACT OBJECTIVES

Collect, compile and analyze geological data and prepare geological structure maps for eastern Kentucky and western West Virginia.

Determine if structural types and styles and surface lineations for productive areas of the Black shales differ from those in non-productive areas.

Identify and define along with other contractors those geologic parameters that control gas production from the shales.

Determine the feasibility of using shallow penetration resistivity and seismic surveys to detect near surface faults and fractures and demonstrate their relationship to lineations observed on air-borne imagery.

Determine if a relationship exists between ground water movement and shale gas productivity.

In conjunction with other contractors develop a method for selecting areas for drilling shale wells that have a potential for gas production.

3.0 TECHNICAL PROGRESS

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3.1 Work Package 2100-1-1 CROSS SECTIONS — Jane Negus-de Wys

3.2 Work Package 2100-1-2 ISOPACH MAPS

3.3 Work Package 2100-2-1 STRUCTURE CONTOUR MAPS

3.4 Work Package 3200-4-1 OIL AND GAS MAPS

3.1.1 Current status of work and scheduled deliverables

Work plan for this quarter included:

- Computer mapping of elemental data (14 elements) trends from 12 wells in eastern Kentucky for 6 stratigraphic units (lower Huron through Berea/Bedford).
- Computer mapping of mineralic data (16 minerals) trends from 12 wells in eastern Kentucky for 6 stratigraphic units (lower Huron through Berea/Bedford).
- Hand-contouring of mineralic data (16 minerals) trends from 12 wells in eastern Kentucky for 6 stratigraphic units (lower Huron through Berea/Bedford).
- Run computer-plotted graphs of geochemical data for all 12 wells.
- Pick additional study wells in Floyd County.

All 180 maps have been computer-run. All 180 maps have been hand-contoured, and are in final drafting for deliverables.

All 360 graphs have been computer-run. Points must be connected by hand. Selection of additional wells in Floyd County is in progress.

Current status on two (2) year program: 25% completed

Negotiations with Kentucky-West Virginia Gas Company, for a well to be drilled, cored, and logged in an area of high gas production in the Big Sandy Gas Field, were initiated on the basis of the procedure developed by Dr. J. Negus-de Wys from a three-year study of the gas field. Negotiations for this well are being interfaced with Dr. Claude Dean and Karl Frohne at METC and Ernie Jenkins at Kentucky-West Virginia Gas Company. This would be the first such cored well in an area of high gas production, and is thus of considerable scientific and engineering interest to the Devonian Shale Program.

3.1.2 Problem areas and suggested improvements

Funding delay was eventually solved, but is a very undesirable accounting situation. The last three months on the first year of this contract commence October 1, 1980. To avoid further bookkeeping and other associated problems, it is hoped that the funding for this period will be transferred by the start time of that period.

The delay in the drafting of deliverables (maps) was incurred at the University because of loss of a draftsperson and loss of time due to accrued vacation. This time loss will be made up in the next quarter.

3.1.3 Work plan for next quarter

Completion of deliverables due June 1 and September 1, 1980 (180 geochemical trend maps for eastern Kentucky).

Continuing work on completing the geochemical graphs for each of 12 wells.

Procurement of additional well set in Floyd County.

Final agreement and arrangements for drilling, coring, and logging of well in Floyd County.

Commencement of comparison analysis of geochemistry data with open flow data, fracture occurrence, stratigraphy, and structure.

Presentation of two papers at the International Geological Congress in Paris, France.

Preparation of paper for AAPG and GSA journals.

Meetings attended

Technical Director for 11th Annual Appalachian Basin Petroleum Seminar, March 31 - April 2, Lakeview Country Club, Morgantown, WV.

Energy Policy Symposium, May 1-2, Lakeview Country Club, Morgantown, WV.

SPE/DOE Unconventional Gas Recovery Symposium, May 18-20, Pittsburgh, PA.

International Geological Congress and field trips, June 20 - July 20, Paris, France.

April-June, 1980, Quarterly Progress Report J. Negus-de Wys

Paper delivered

Negus-de Wys, J., and J. J. Renton, Preliminary depositional model for upper Devonian Huron-age organic black shale in the eastern Kentucky gas field, SPE/DOE meeting, Pittsburgh, PA, May 18-20, 1980.

Papers accepted

Negus-de Wys, J., and J. J. Renton, Inorganic geochemistry as an exploration tool, 26th International Geological Congress, Paris, France, 1980.

Negus-de Wys, J., The anatomy of a large Devonian black shale gas field, 26th International Geological Congress, Paris, France, 1980.

Papers in preparation

Negus-de Wys, Jane, Relationships of gas occurrence to geological parameters in the eastern Kentucky gas field, requested by AAPG for submission for journal publication.

Jenkins, J., J. Negus-de Wys, and H. D. Bennett, Color changes in megaspores observed at visual and fluorescence wavelengths for upper Devonian black shale in the eastern Kentucky gas field.

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QUARTERLY PROGRESS REPORT

April - June 1980

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3.1 Work Package 2100-1-1 SEISMIC

James E. Ruotsala
and Richard T. Williams

3.1.1 Current status of work and scheduled deliverables

On Monday, May 19, a full-scale field test of the Bison-band reflection seismograph was conducted at the Pricetown #2 coal gasification site. Although this exercise was purely an equipment test, the survey covered roughly the same area as an earlier study reported by Keith G. Kirk. Common-depth-point data was obtained with 300% coverage in places. The results of this field test are summarized here.

Performance of the instruments. No serious malfunctions of the seismograph or support electronics were observed during this test. In the past this system has failed to provide usable data because of technical problems with the instruments themselves. These problems have been eliminated either by repair or more often redesign of the malfunctioning subsystem.

Seismic results. Acoustic events were recorded from a total of seven shots. Some of these were redundant, for the purpose of examining the effect of changing the size of the explosive charge or the filter settings on the recording instruments. The events which were observed were precisely those which would be theoretically expected based on a sonic log of the nearby #2 Dallison well.

On each trace, the first event is the direct wave from the shot, travelling at about 11,000 ft/sec. Prior to this arrival the trace is quiescent, but afterwards the trace is clipped, in both the positive and negative directions for a period of 50-100 ms due to saturation of the seismograph analog-to-digital converter. During this interval the surface wave presumably arrives. Both the direct and surface waves have amplitudes which are large relative to a reflection, and may be expected to cause the seismograph to clip when it is set up to record the reflections. Within the clipped interval (between positively and negatively clipped portions), and after clipping has ceased, event arrivals can be identified which correlate reasonably well with those expected based on a synthetic reflection trace generated from the #2 Dallison sonic log. These are presumably reflections from the various subsurface coal seams at that location, but sufficient data were not taken for a detailed interpretation. The deepest event, tentatively identified as the Pittsburgh coal seam, was continuous across the entire seismic line. This event occurs at about 175 ms two-way time, corresponding to a depth of about 950 ft.

April thru June, 1980, Quarterly Progress Report

J. E. Ruotsala
and R. T. Williams

3.1.1 Current status of work and scheduled deliverables - continued

We have delivery of the hardware necessary to write seismic data (recorded by the Bison based system) onto floppy disks.

Most of the software necessary for ray tracing modeling has been written.

3.1.2 Problem areas and suggested improvements

None

3.1.3 Work plan for next quarter

The seismograph will be tested the first week of July with a new pressure sensitive geophone (hydrophone). This should provide better coupling to the ground at high frequencies. Following a successful test, a complete set (12) of these phones will be purchased and all future data will be recorded with these.

Following a successful field test with the new geophones, seismic data will be recorded in the Cottageville gas field.

Work will continue with the ray trace modeling, in anticipation of a successful field effort at Cottageville.

* * * * * *

QUARTERLY PROGRESS REPORT

April - June 1980

3.1 Work Package 2200-1-2 FRACTURE STUDIES — Kevin D. Lee

3.1.1 Current status of work and scheduled deliverables

The first and second drafts of my thesis were completed and reviewed by Dr. Shumaker. In general, my structural interpretations have been accepted.

Some figures have been given to the draftsman, but maps will not be drafted until Dr. Shumaker has given them personal approval.

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for next quarter

1. Finish a third draft of my thesis.
2. Orally defend my thesis.
3. Write a fourth draft of my thesis, and hopefully have that draft accepted as final.

* * * * * *

QUARTERLY PROGRESS REPORT

April - June 1980

3.1 Work Package 2100-2-2 STRUCTURE STUDIES — Thomas H. Wilson

3.1.1 Current status of work and scheduled deliverables

Unforeseen additional work at the end of last quarter has set the time table for the completion of the first draft back a bit.

The preparation of illustrations has required a considerably greater effort than originally planned for.

Additional analysis of the data has also resulted in delays.

However, progress on the final draft is proceeding quite well and should be completed by August 1.

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for next quarter

Final report on the project will be completed.

NOTE: Attached report discusses some of the results of the modelling effort.

* * * * * *

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WVU Dept. Geology and Geography

CENTRAL APPALACHIAN GRAVITY MODELS

by

Thomas H. Wilson

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UGR File No. C048/80Q3
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CENTRAL APPALACHIAN GRAVITY MODELS

by

Thomas H. Wilson
Research Associate

A. Introduction

Previous use of observed gravity as a means to unravel details of central Appalachian structure is limited. Kulander and Dean (1978) occupied several stations in central and eastern West Virginia, western Maryland, and Virginia. Their study is primarily regional in nature with detailed coverage limited to a profile across the Warm Springs anticline in Bath County, Virginia. Byerly (1973) surveyed a detailed profile across the Massanutten Synclinorium in northern Berkely County, West Virginia.

Calculated gravity for several balanced cross sections of the Appalachian Valley and Ridge and Plateau structures are discussed here and compared to contours of terrain corrected residual Bouquer anomalies from Kulander and Dean (1978). A detailed gravity profile surveyed across the Middle Mountain syncline is presented along with a subsurface model based on the terrain corrected Bouquer gravity. Two interpretations of Jacobsen and Kanes (1974) section line through Mineral and Hampshire Counties, West Virginia, are also presented along with calculated gravity for both profiles.

Gravity profiles were calculated using a program developed by Smith, Higgins, and Robertson (1970) of the Princeton University Department of Civil and Geological Engineering. The method of calculation was derived by Hubbert (1948) and evaluated by Talwani and others (1959) and involves the numerical integration of a line integral which evaluates the vertical component of the gravitational field associated with unit thickness n-sided polygonal laminae.

B. Observed Gravity

Calculated gravity for the balanced structural interpretations may differ from observed gravity because of error in the observed gravity, error in the model, or both. Terrain corrected Bouquer gravity values are considered to have cumulative errors of no greater than 0.1 milligal (Byerly, 1973; Kulander and Dean, 1978). However, dispersion in projected values of residual gravity onto the residual gravity profile along the Warm Springs section line (Kulander and Dean, 1978, Figure 6) is calculated to be 1 milligal, and 1.3 milligals when compared to the calculated gravity for their model. Similarly, dispersion in value about a curve fit to the Middle Mountain data is 0.65 milligals, and dispersion about the calculated gravity is 1 milligal (see Figure 7). Some error is introduced in projecting values along strike onto the profile line where the assumption of structural invariance perpendicular to the profile is incorrect. Near surface density distributions are much more complex than represented by the generalized regional gravity models presented here. Such error may be related to near surface lateral density contrasts produced by unrecognized structure, or ground water solutioning of near surface limestones (Byerly, 1973). Byerly (1973) also related 1.5 to 1.8 milligal variations above the regional background to a subsurface zone of high density dolomite.

During the gravity survey across the Middle Mountain syncline a bench mark occupied the previous year was reoccupied. The measured value of gravity was 0.6 milligals off the earlier measured value. It is possible that extension in the quartz spring during the interval of time between measurements may have produced significant changes in the spring constant.

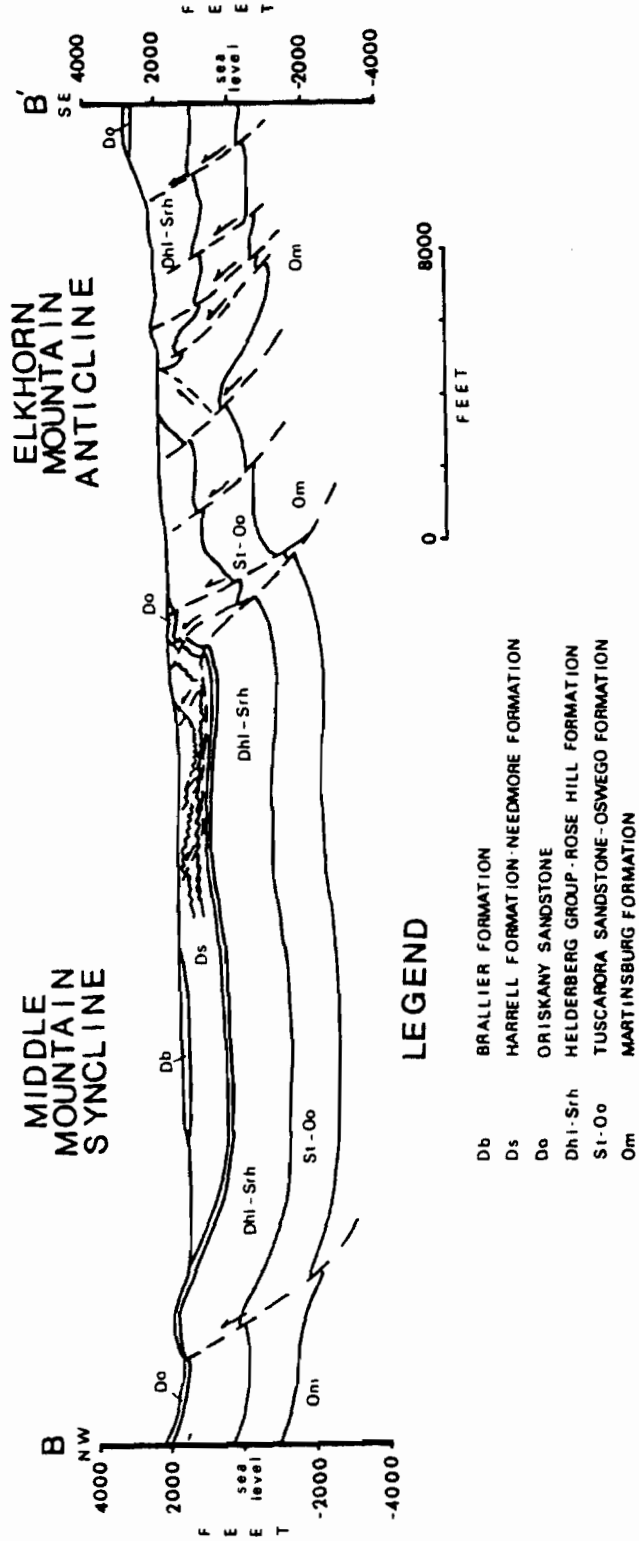

B
NW
B'
SE
4000
2000
sea level
-2000
-4000
FEET
MIDDLE MOUNTAIN SYNCLINE
ELKHORN MOUNTAIN ANTICLINE
Do
Db
Ds
Dhl-Srh
St-Oo
Om
0
8000
FEET
LEGEND
Db BRALLIER FORMATION
Ds HARRELL FORMATION-NEEDMORE FORMATION
Do ORISKANY SANDSTONE
Dhl-Srh HELDERBERG GROUP-ROSE HILL FORMATION
St-Oo TUSCARORA SANDSTONE-OSWEGO FORMATION
Om MARTINSBURG FORMATION

Figure 6

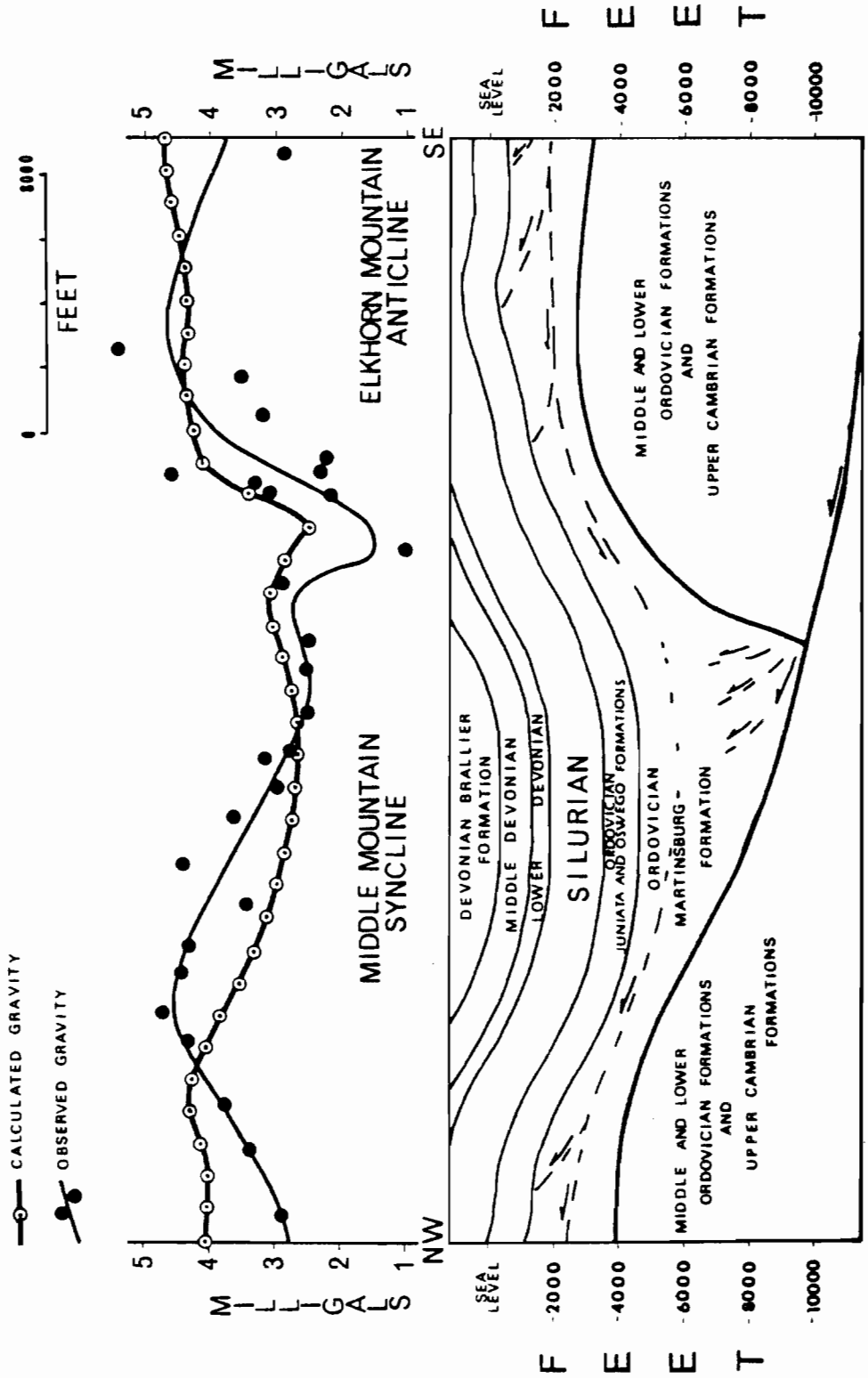

CALCULATED GRAVITY
OBSERVED GRAVITY
0
1000
FEET
MILLIGALS
5
4
3
2
1
MIDDLE MOUNTAIN SYNCLINE
ELKHORN MOUNTAIN ANTICLINE
NW
SE
SEA LEVEL
-2000
-4000
-6000
-8000
-10000
FEET
DEVONIAN BRALLIER FORMATION
MIDDLE DEVONIAN
LOWER DEVONIAN
SILURIAN
JUNIATA AND OSWEGO FORMATIONS
ORDOVICIAN
MARTINSBURG-FORMATION
MIDDLE AND LOWER ORDOVICIAN FORMATIONS AND UPPER CAMBRIAN FORMATIONS

Figure 7

Not much can be said on the basis of one sample. However, it is a source of error that may appear in surveys conducted over long periods of time.

C. Regional Gravity Profiles

Regional structural interpretations have been constructed of the Valley and Ridge and Plateau provinces of the central Appalachians of West Virginia and Virginia. Portions of these cross sections covered by gravity observations are located on the residual Bouquer anomaly map (Figure 1) taken from Kulander and Dean (1978). Calculated gravity for the regional sections south and north of the Parsons structural discontinuity is compared to contours of residual Bouquer anomalies along these profiles (Figures 3 and 4).

Closest correlation between calculated and observed gravity occurs for the structural interpretation south of the discontinuity. A two milligal amplitude anomaly in observed gravity rises to a peak northwest of the Elkins Valley anticline. The calculated effect of the thrust faulted and folded high density Cambrian and Ordovician dolomites and carbonates is roughly a three milligal anomaly rising to a peak just southeast of the crest of Elkins Valley anticline. There is rough correlation between the positions of the six milligal high in observed gravity on the southeast limb of the Wills Mountain anticline and the calculated plus ten milligal peak just southeast of the crest of Wills Mountain anticline. No plausible structural interpretations can be made to explain variations in observed residual Bouquer anomaly between the Wills Mountain and Elkins Valley anticlines.

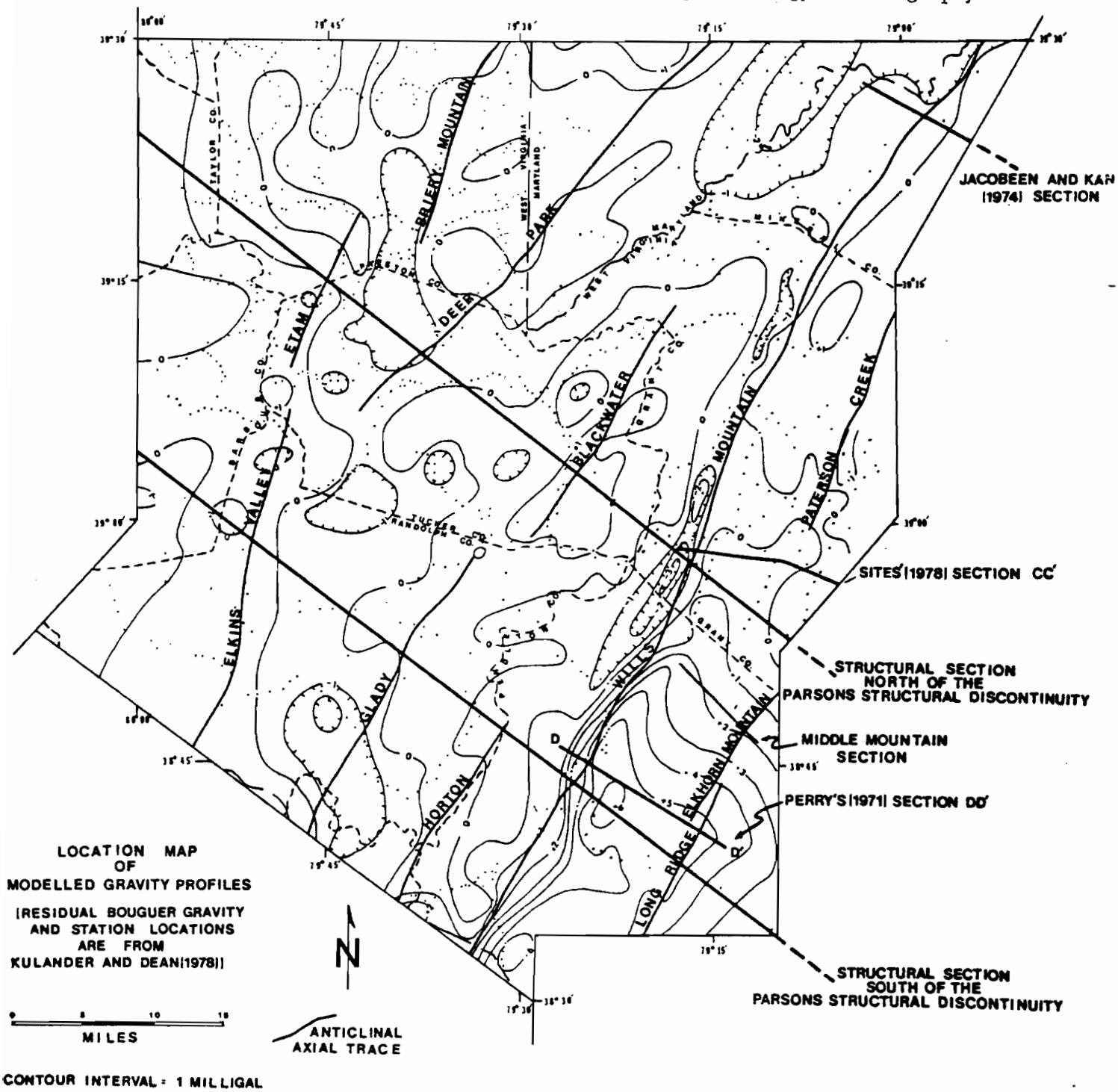
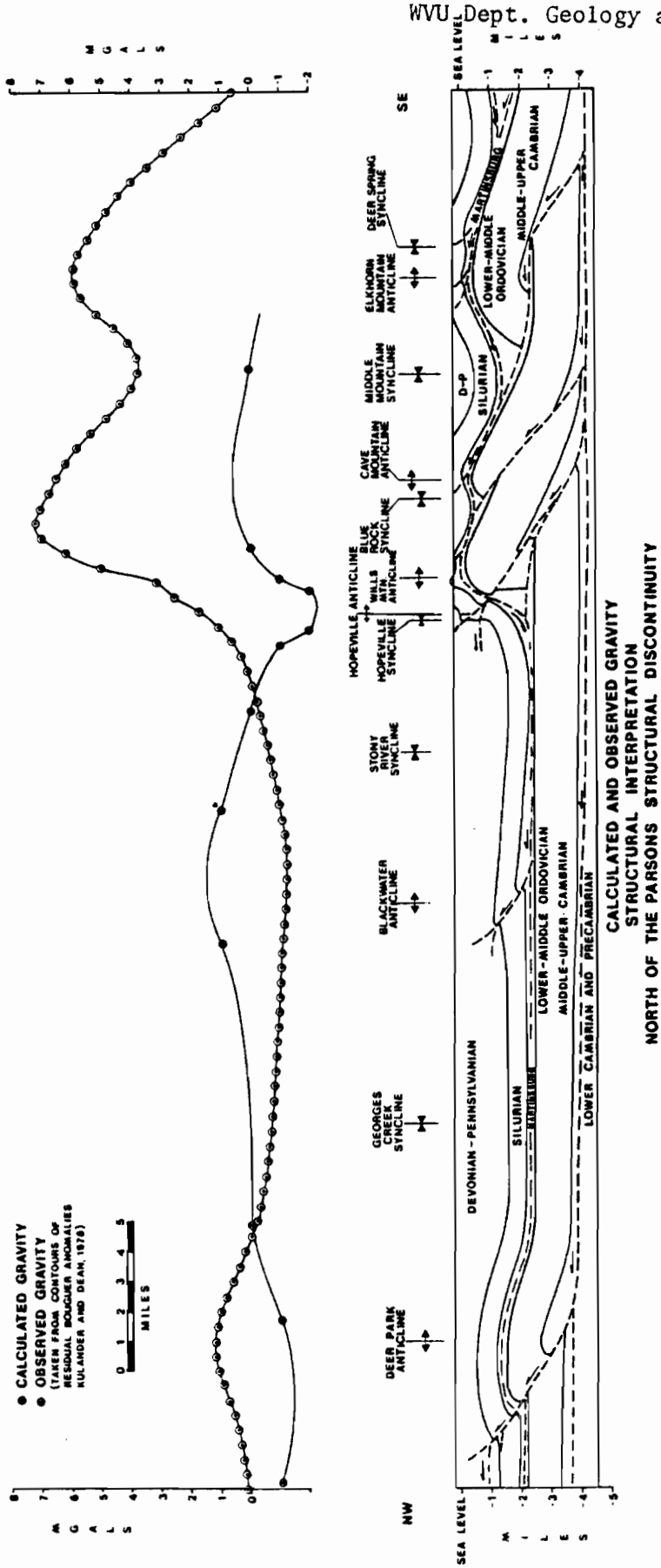
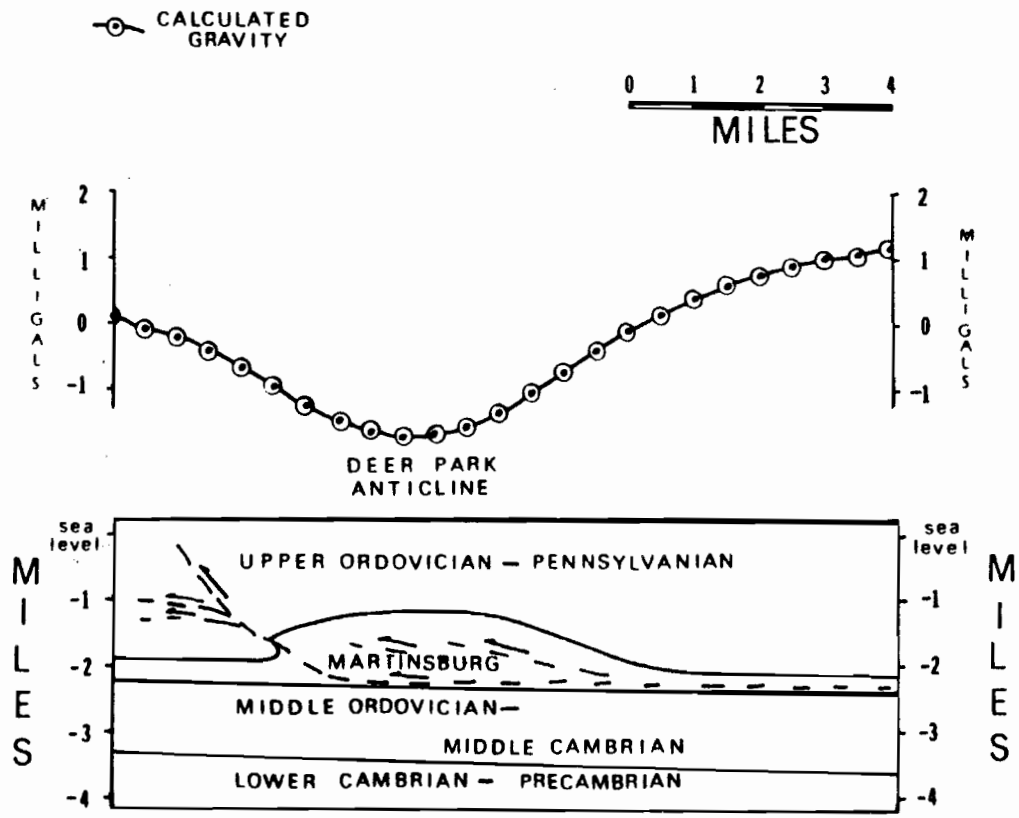

JACOBEEN AND KAN (1974) SECTION
SITES (1978) SECTION CC'
STRUCTURAL SECTION NORTH OF THE PARSONS STRUCTURAL DISCONTINUITY
MIDDLE MOUNTAIN SECTION
PERRY'S (1971) SECTION DD'
STRUCTURAL SECTION SOUTH OF THE PARSONS STRUCTURAL DISCONTINUITY
LOCATION MAP OF MODELLED GRAVITY PROFILES
(RESIDUAL BOUGUER GRAVITY AND STATION LOCATIONS ARE FROM KULANDER AND DEAN (1978))
MILES
ANTICLINAL AXIAL TRACE
CONTOUR INTERVAL = 1 MILLIGAL
N
BRIERY MOUNTAIN
PARK
DEER
ETAM
VALLEY
BLACKWATER
MOUNTAIN
PATERSON
CREEK
ELKINS
GLADY
HORTON
WILLS
ELKHORN MOUNTAIN
LONG RIDGE
TAYLOR CO.
TUCKER CO.
RANDOLPH CO.
WEST VIRGINIA
MARYLAND
D
D'

Figure 1



CALCULATED AND OBSERVED GRAVITY
STRUCTURAL INTERPRETATION
NORTH OF THE PARSONS STRUCTURAL DISCONTINUITY

Figure 3



CALCULATED GRAVITY
FOR THE
DEER PARK ANTICLINE
(MARTINSBURG CORE)

Figure 4

Disagreement between observed and calculated gravity along the profile north of the Parsons structural discontinuity is almost complete (Figure 3). The low in observed gravity over the Deer Park anticline might imply that the Cambrian and Ordovician sequence is not thrust into the core of the anticline as shown in the cross section. Calculated gravity for a Deer Park anticline with a Martinsburg shale core (Figure 4) agrees with the observed gravity profile. However, the wavelength of the Deer Park fold is anomalously large for folds developed above a Martinsburg detachment. Martinsburg detachment produces folds of wavelengths similar to that for the Hopeville anticline (Figure 3) and Colic Mountain anticline (Figure 2). The numerous intermediate scale folds observed at the surface in the Chemung Formation (Wheeler, 1974) are probably developed above a Martinsburg and/or higher level detachments. It seems likely therefore that considerably more shale is present than indicated in Figure 3, but that the Cambrian and Ordovician dolomites and limestones are faulted in the Deer Park core.

The 1.5 milligal high over the Blackwater anticline may imply that the Cambrian and Ordovician sequence is thrust faulted. An uplift of 4000 feet was required to produce the 1.5 milligal high over the Deer Park anticline. However, beneath the Blackwater anticline there is so little space available that even if the Cambrian and Ordovician is thrust faulted, it is certainly not responsible for the observed anomaly.

The ends of the models have been extended 50 miles to the southeast and northwest of the calculated profile to reduce edge effects. Some of the disagreement between the observed and calculated gravity may be due in part to the generalized nature of the models. Assigned densities are shown in Table 1. Average densities for a stratigraphic interval were

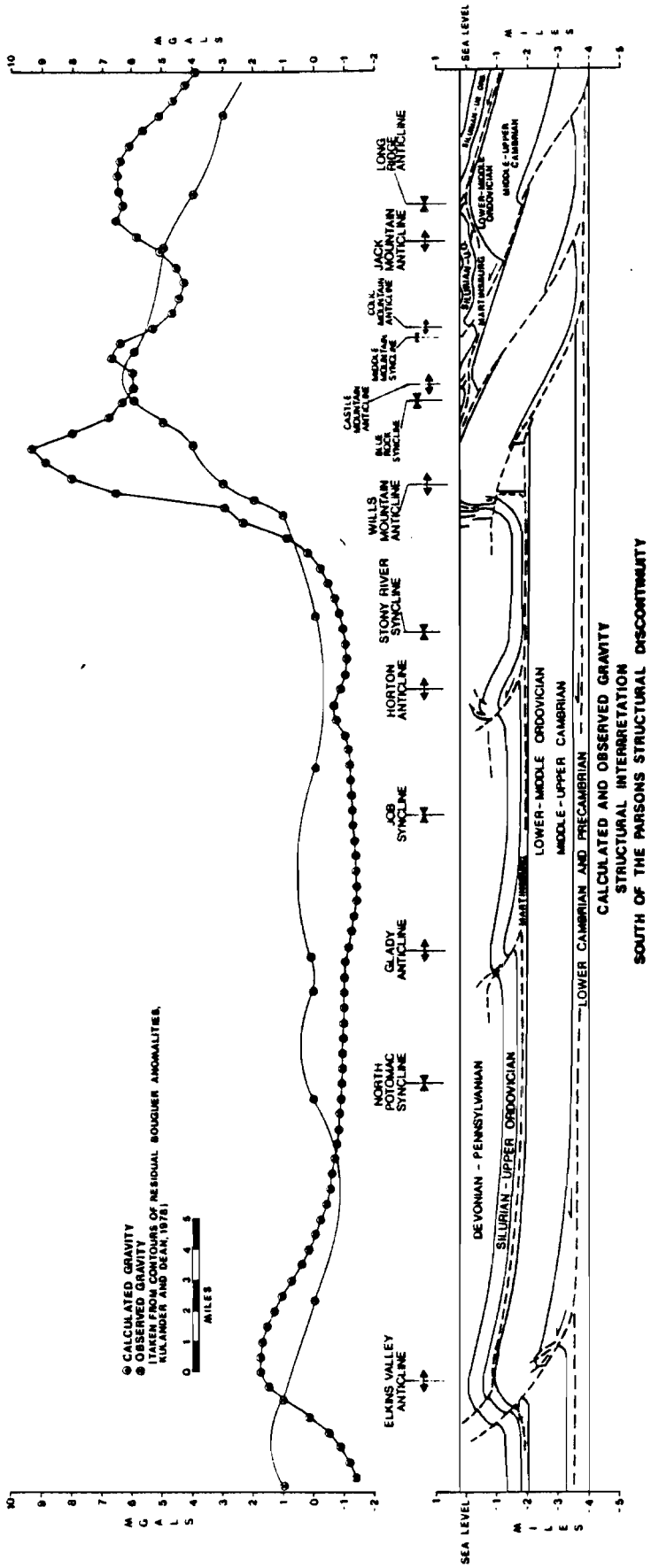

CALCULATED GRAVITY
OBSERVED GRAVITY
(TAKEN FROM CONTOURS OF RESIDUAL BOUGUER ANOMALIES, KULANDER AND DEAN, 1978)
MILES
MGALS
SEA LEVEL
ELKINS VALLEY ANTICLINE
NORTH POTOMAC SYNCLINE
GLADY ANTICLINE
JOB SYNCLINE
HORTON ANTICLINE
STONY RIVER SYNCLINE
WILLS MOUNTAIN ANTICLINE
BLUE ROCK SYNCLINE
CASTLE MOUNTAIN ANTICLINE
MIDDLE MOUNTAIN SYNCLINE
COLE MOUNTAIN ANTICLINE
JACK MOUNTAIN ANTICLINE
LONG RIDGE ANTICLINE
DEVONIAN - PENNSYLVANIAN
SILURIAN - UPPER ORDOVICIAN
LOWER - MIDDLE ORDOVICIAN
LOWER - MIDDLE ORDOVICIAN
MIDDLE - UPPER CAMBRIAN
LOWER CAMBRIAN AND PRECAMBRIAN
CALCULATED AND OBSERVED GRAVITY
STRUCTURAL INTERPRETATION
SOUTH OF THE PARSONS STRUCTURAL DISCONTINUITY

Figure 2

AVERAGE DENSITIES ASSIGNED TO STRATIGRAPHIC INTERVALS

FOR CALCULATING GRAVITY PROFILES FOR THE STRUCTURAL INTERPRETATIONS

NORTH AND SOUTH OF THE PARSONS STRUCTURAL DISCONTINUITY

STRATIGRAPHIC INTERVAL	DENSITY	
	SOUTH	NORTH
Pennsylvania through Devonian Oriskany ss	2.61 gm cm^{-3}	2.62 gm cm^{-3}
Devonian Oriskany ss through Ordovician Oswego ss	2.64 gm cm^{-3}	
Ordovician Martinsburg shale	2.55 gm cm^{-3}	2.55 gm cm^{-3}
Ordovician Trenton fm through Cambrian Elbrook fm	2.71 gm cm^{-3}	2.71 gm cm^{-3}
Cambrian Waynesboro into Precambrian	2.69 gm cm^{-3}	2.69 gm cm^{-3}

Table 1

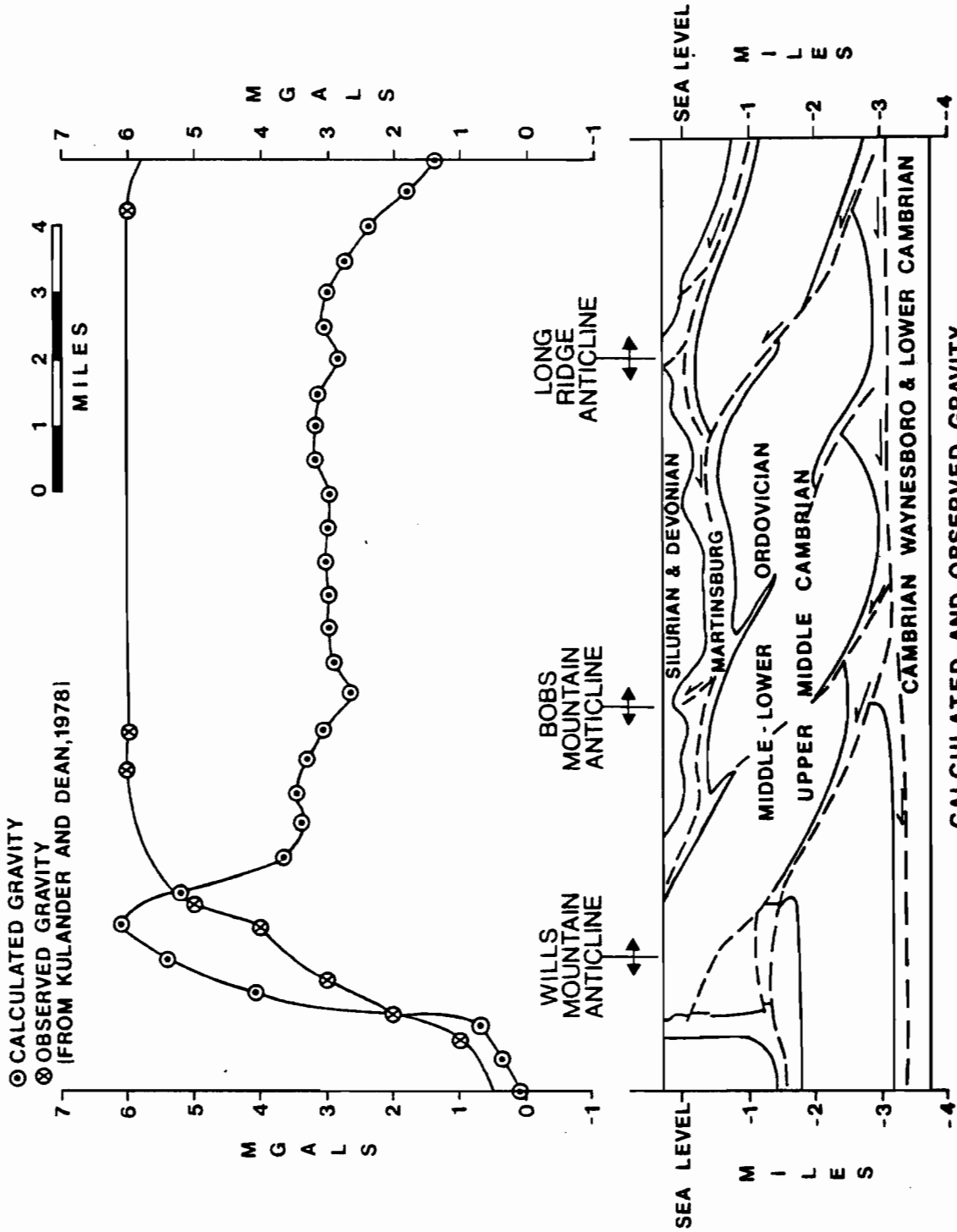
calculated using individual formation densities weighted by thickness. Formation densities were taken from Kulander and Dean (1978, Figure 5a).

E. Valley and Ridge Models

(i) Perry's (1971) Section D-D'

Perry's (1971) section D-D' lies a couple of miles north of the regional structural interpretation south of the Parsons discontinuity (Figure 5). The model was extended several miles beyond the ends of the calculated profile to reduce edge effects. An average density assignment of 2.64 gm cm^{-3} (Table 2) to Silurian and Devonian rocks when carried beyond the northwestern edge of the profile has reduced the gravity high by 4 milligals from its value in the southern section (Figure 5 and Figure 2).

Perry's (1971) section D-D' (Figure 5) is different from the Valley and Ridge structure of the southern section (Figure 2) in two respects: 1) there are four thrust slices in Perry's (1971) section but only three in the southern section; and 2) the Martinsburg shale in Perry's (1971) section has not been thickened in front of the advancing thrust sheets as is the case for the southern section. This ductile behavior of a shale at the leading edge of a brittle thrust sheet was documented for the Middle Devonian shales on the faulted southeast limb of the Middle Mountain syncline (Figure 6) and on the faulted northwest limb of the Wills Mountain anticline near Keyser, West Virginia (Bagnall, Beardsley, and Drabish, 1979). This thickened wedge of shale would produce a 2-3 milligal saddle in the observed gravity if present (Figures 2 and 3). Kulander and Dean (1978) occupied very few stations in this area (Figure 1) so its existence cannot be ruled out from the residual Bouquer anomalies profiled in Figures 2 and 3.



CALCULATED AND OBSERVED GRAVITY FOR PERRY'S SECTION DD'(1971)

Figure 5

AVERAGE DENSITIES ASSIGNED TO STRATIGRAPHIC INTERVALS

FOR CALCULATING GRAVITY PROFILES

FOR PERRY'S SECTION D-D' (1971), SITES' SECTION C-C' (1978)

AND THE CORRESPONDING VALLEY AND RIDGE SEGMENT

FROM THE STRUCTURAL INTERPRETATION

SOUTH OF THE PARSONS STRUCTURAL DISCONTINUITY

STRATIGRAPHIC INTERVAL	DENSITY
Devonian Oriskany ss through Ordovician Oswega ss	2.64 gm cm^{-3}
Ordovician Martinsburg shale	2.55 gm cm^{-3}
Ordovician Trenton fm through Cambrian Elbrook fm	2.71 gm cm^{-3}
Cambrian Waynesboro sh into Precambrian	2.69 gm cm^{-3}

Table 2

AVERAGE DENSITIES ASSIGNED TO STRATIGRAPHIC INTERVALS

IN CALCULATING THE GRAVITY PROFILE

ACROSS THE MIDDLE MOUNTAIN SYNCLINE

STRATIGRAPHIC INTERVAL	DENSITY
Devonian Brallier fm	2.60 gm cm^{-3}
Middle Devonian shales	2.63 gm cm^{-3}
Oriskany ss and Helderberg ls	2.69 gm cm^{-3}
Silurian	2.65 gm cm^{-3}
Juniata fm and Oswego ss	2.63 gm cm^{-3}
Martinsburg sh	2.55 gm cm^{-3}
Ordovician Trenton fm and beneath	2.71 gm cm^{-3}

Table 3

(ii) The Middle Mountain Syncline

A gravity profile was surveyed across the Middle Mountain syncline to place constraints on the deep Ordovician and Cambrian structure. Twenty-eight stations were occupied or approximately four to five stations per mile. Where bench marks were not available, elevations were established with a field altimeter. Differences in elevation produced by fluctuations in barometric pressure were corrected for by using a continuous record of pressure changes recorded on a baragraph located in the field area. Errors in elevation were checked by periodically reoccupying a bench mark of known elevation. The error is from one to three feet or 0.1 to 0.3 milligals. As mentioned above (Section B) dispersion in value about a curve fit to the data is 0.65 milligals and dispersion about the calculated gravity for the proposed model is 1 milligal (Figure 7).

The structural model proposed for subsurface structure in Ordovician and Cambrian Formations beneath the Middle Mountain syncline is shown in Figure 7. The observed gravity supports the existence of a thickened wedge of the Ordovician Martinsburg shale to the northwest of a thrust slice of Cambrian and Ordovician dolomites and carbonates. In fact the observed gravity suggests that the area of thickened shale may be more extensive than represented in the model.

Observed gravity values higher than those calculated for the model along the northwest flank of the syncline may imply that the Martinsburg shale is abnormally thinned by flexural flow.

Extension of the model layers horizontally to considerable distances from either end of the calculated profile has produced values of calculated gravity that are greater than the observed gravity near the edges

of the profile. Thus this disagreement does not represent a serious discrepency in the model. The low observed values at the edges of the profile result from decolement related thickening in the cores of the Cave Mountain anticline to the northwest and Elkhorn Mountain anticline to the southeast. The Cave Mountain anticline and higher order folds in the Elkhorn Mountain complex developed above a Martinsburg detachment which predated the development of the deeper Cambrian and Ordovician structure (Sites, 1978).

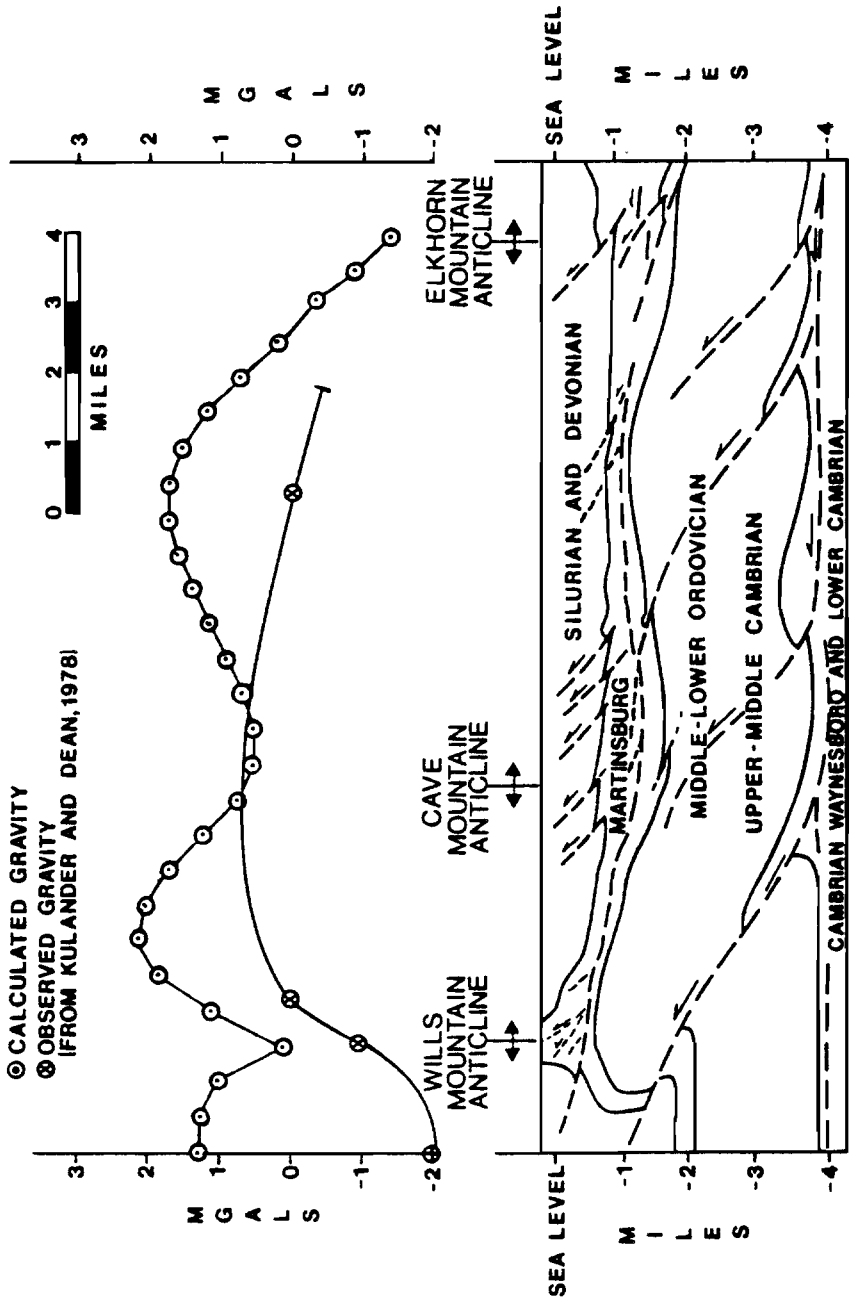
Densities assigned to stratigraphic intervals used in the Middle Mountain Model are listed in Table 3.

(iii) Sites (1978) Section C-C'

The gravity low over the Wills Mountain anticline (Figure 8) is produced by the thickened Martinsburg shale. Similar lows occur in the calculated gravity over the Cave Mountain and Elkhorn Mountain anticlines. The Cave Mountain and Elkhorn Mountain anticlines in particular are shown to result entirely from Martinsburg detachment. Whether the Cambrian and Ordovician involvement in these structures observed in the Middle Mountain gravity profile (Figure 7) dies out southwest of Sites' (1978) section is an interesting question that will require more detailed observation.

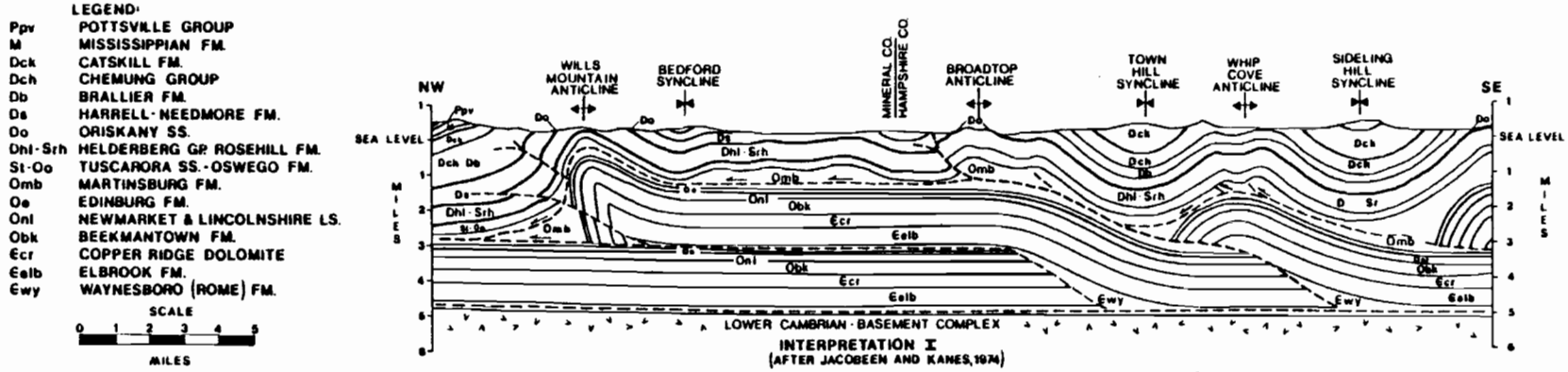
(iv) Jacobeen and Kanes (1974) Section

The Jacobeen and Kanes (1974) section located in Mineral and Hampshire Counties, West Virginia, (Figures 1 and 9) shows a complete duplication of the Ordovician Edinburg through Cambrian Elbrook formations. Net slip of the upper sheet of carbonates and dolomites to the northwest over the lower sheet is approximately 12 miles. Figure 9 is in error in that the lower sheet is faulted on the northwest limb of the Wills Mountain anticline.



CALCULATED AND OBSERVED GRAVITY FOR SITES' SOUTHERN SECTION (1978)

Figure 8



INTERPRETATION I
(AFTER JACOBEEN AND KANES, 1974)

STRUCTURAL INTERPRETATION OF VALLEY AND RIDGE STRUCTURES
NORTH OF THE PETERSBURG AND PARSONS STRUCTURAL DISCONTINUITIES

Figure 9

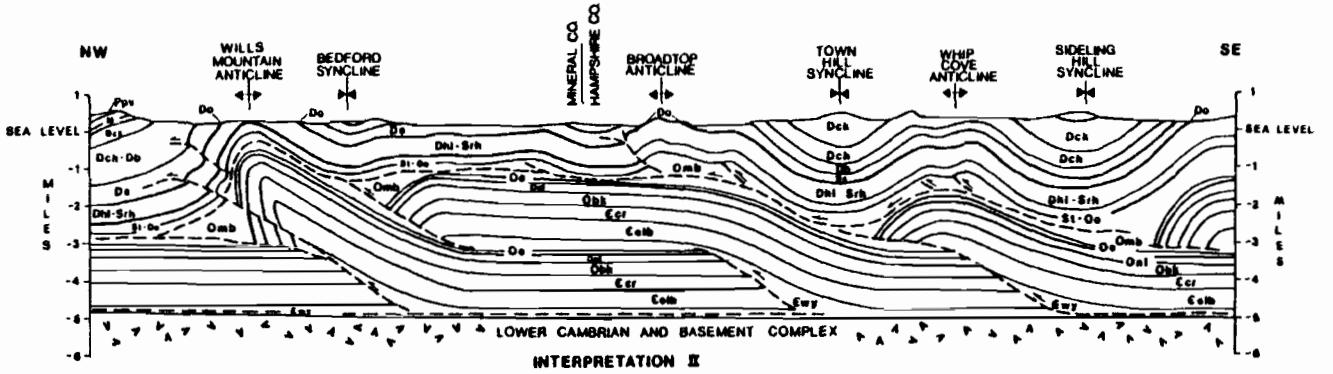
A double thickness interpretation is supported by seismic profiles across the Broadtop anticline (Jacobeen and Kanes, 1974, 1975; Zurgani, 1975) and across the Wills Mountain anticline (Bagnall, Beardsley, and Drabish, 1979). Some question remains concerning the intervening Cambrian and Ordovician structure.

As mentioned previously (Sections E(i) and E(ii)) thickening of ductile Middle Devonian shales is observed in the field and in the subsurface in front of splay thrusted more brittle Lower Devonian and Silurian rocks. The gravity profile across the Middle Mountain syncline discussed in Section E(ii) supports the existence of a thickened wedge of Martinsburg shale in front of splay thrusted Cambrian and Ordovician formations. If there are intervening thrust slices between the Broadtop and Wills Mountain anticlines the shale wedges in front of these faults could be detected by observed gravity as done for the Middle Mountain syncline.

The deep Bedford syncline presents the greatest difficulty to drawing a complete duplication of the Cambrian and Ordovician formations (Figure 9). It is possible that the Bedford syncline is developed between two thrust slices (Figure 10). Gravity profiles are calculated for both interpretations (Figures 11 and 12). Preliminary results of a gravity profile surveyed across the Wills Mountain anticline and Bedford syncline along the Jacobeen and Kanes (1974) section line indicate that no thickened wedge of shale is present beneath the Bedford syncline (Perkey, 1980, oral comm.) Thus if Cambrian and Ordovician formations are faulted beneath the Broadtop syncline only minor amounts of displacement occur along them and there must be a complete duplication of these formations from the Broadtop anticline to the Wills Mountain anticline.

Ppv POTTSVILLE GROUP
M MISSISSIPPIAN FORMATIONS
Dck CATSKILL FM.
Dch CHEMUNG GROUP
Db BRALLIER FM.
Ds HARRELL-NEEDMORE FMS.
Do ORISKANY Ss.
Dhl-Srh HELDERBERG GR-ROSEHILL FM.
St-Oo TUSCARORA Ss.-OSWEGO FM.
Omb MARTINSBURG FM.
Oe EDINBURG FM.
Onl NEWMARKET and LINCOLNSHIRE Ls.
Obk BEEKMANTOWN FM.
Ꞓcr COPPER RIDGE DOLOMITE
Ꞓelb ELBROOK FM.
Ꞓwy WAYNESBURG (ROME) FM.

SCALE
0 1 2 3 4 5
MILES



INTERPRETATION II

STRUCTURAL INTERPRETATION OF VALLEY AND RIDGE STRUCTURES
NORTH OF THE PETERSBURG AND PARSONS STRUCTURAL DISCONTINUITIES

Figure 10

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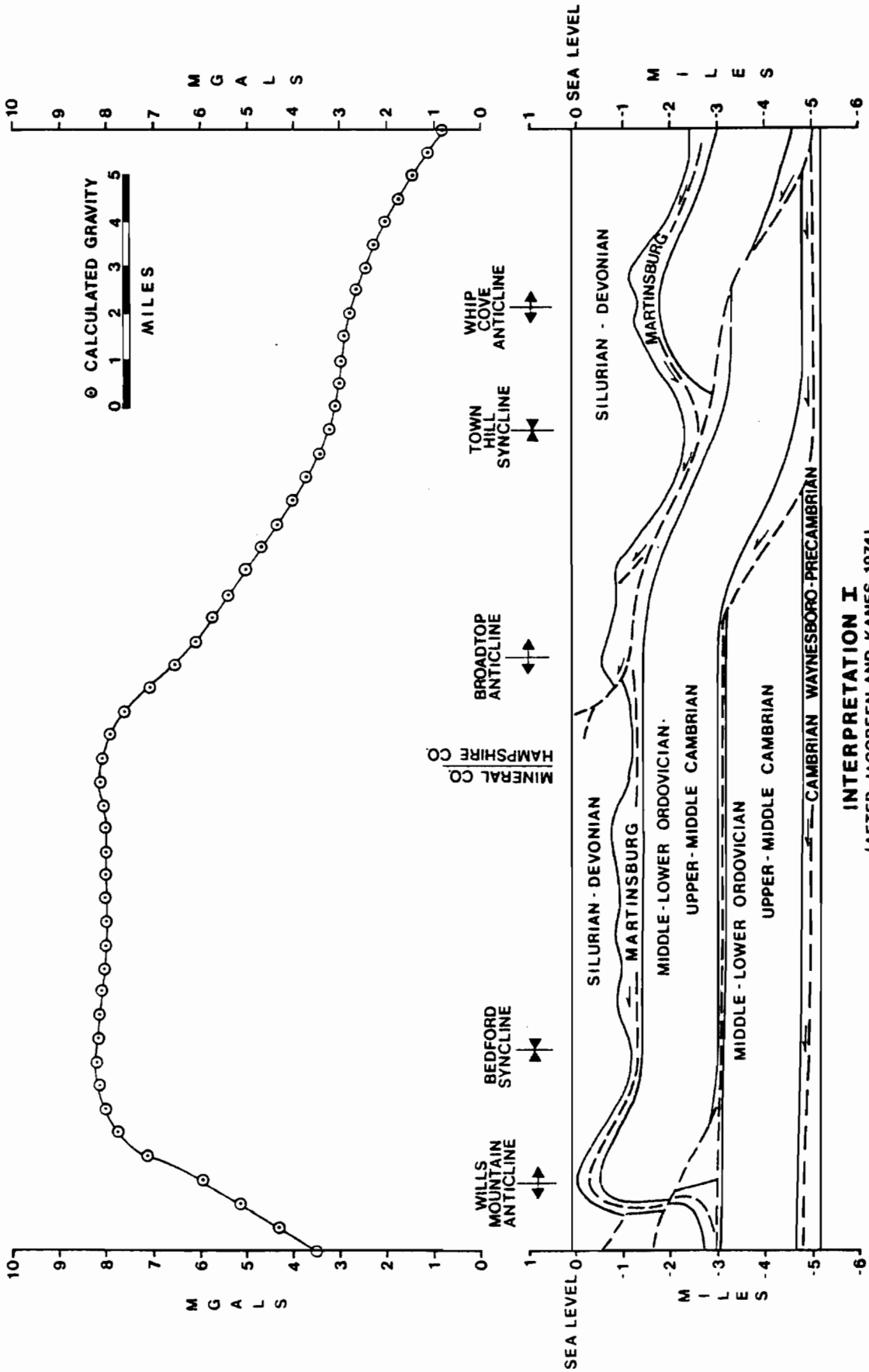
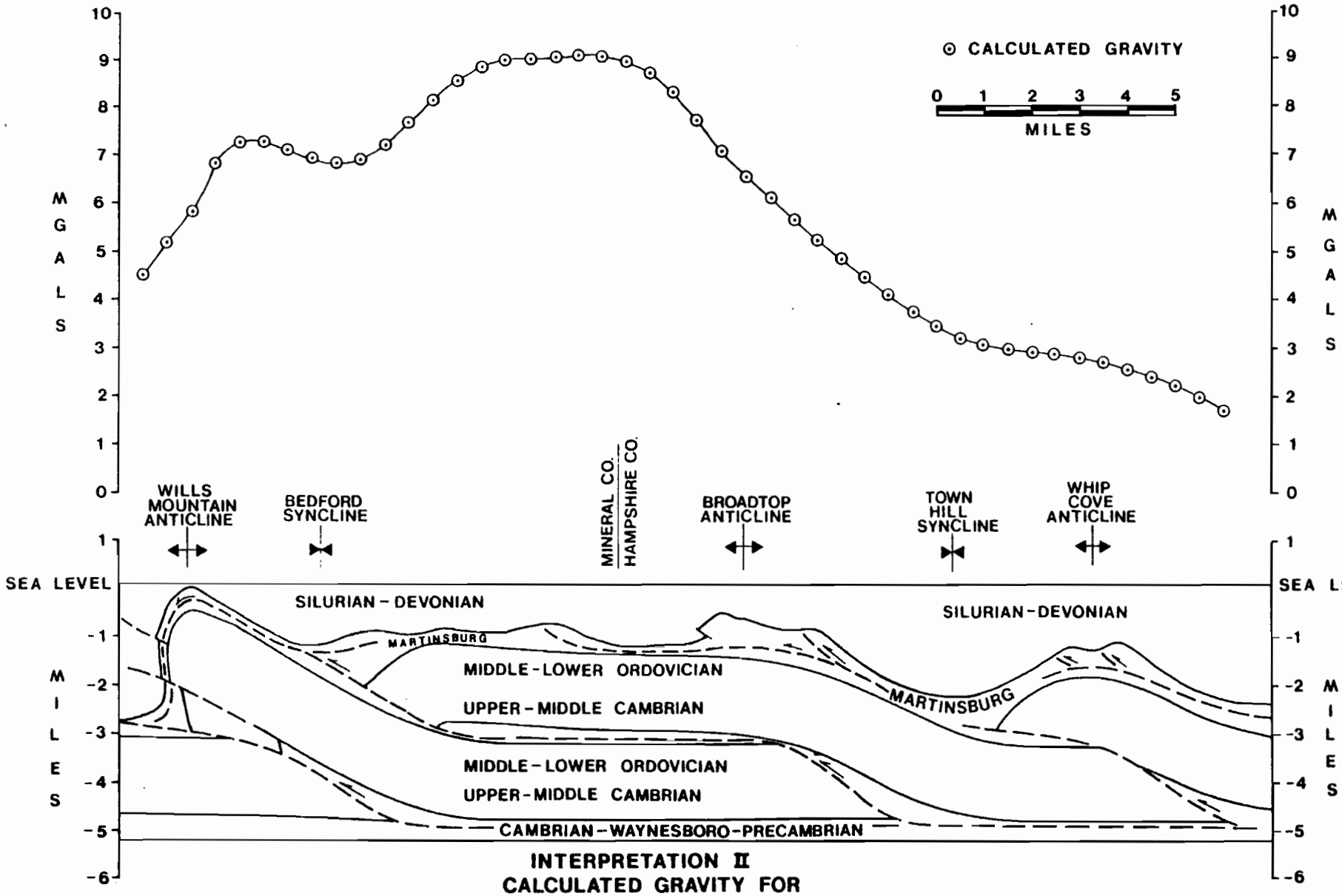


STRUCTURAL INTERPRETATION OF VALLEY AND RIDGE STRUCTURES
NORTH OF THE PETERSBURG AND PARSONS STRUCTURAL DISCONTINUITIES
CALCULATED GRAVITY FOR

Figure 11



INTERPRETATION II
CALCULATED GRAVITY FOR
STRUCTURAL INTERPRETATION OF VALLEY AND RIDGE STRUCTURES
NORTH OF THE PETERSBURG AND PARSONS STRUCTURAL DISCONTINUITIES

Figure 12

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The faulted Cambrian and Ordovician beneath the Middle Mountain syncline does not rule out complete duplication of these formations from the Long Ridge anticline across the Wills Mountain anticline. A complete duplication is shown for the Valley and Ridge segment of the southern regional section (Figure 13) along with the calculated gravity for that interpretation. The thickened wedge of Martinsburg shale can be detected, but aside from that there are no substantial differences between the calculated gravity for Perry's (1971) series of imbricate slices and the complete duplication presented above.

Density values used for these models are listed in Table 4.

F. Discussion

The poor agreement between the calculated gravity for the subsurface structural models and the observed residual Bouquer gravity of Kulander and Dean (1978) is due largely to the regional nature of that survey (see station locations, Figure 1). Surveys having closely spaced stations across the structure(s) to be modelled produce structurally consistent Bouquer gravity that can be modelled to provide more detailed information on subsurface structure (Byerly, 1973; Kulander and Dean, 1978; see also the Middle Mountain model presented in this report).

Where differences between observation and theory cannot be explained as errors of observation or measurement in the survey, and cannot be reconciled by adjustments of the model consistent with the assumed style of deformation, then the assumed structural style must be incorrect. It is possible that much of the disagreement between Kulander and Dean's (1978) residual Bouquer gravity and the calculated gravity lies in higher order regional features (Wheeler, oral communication). Higher order regional

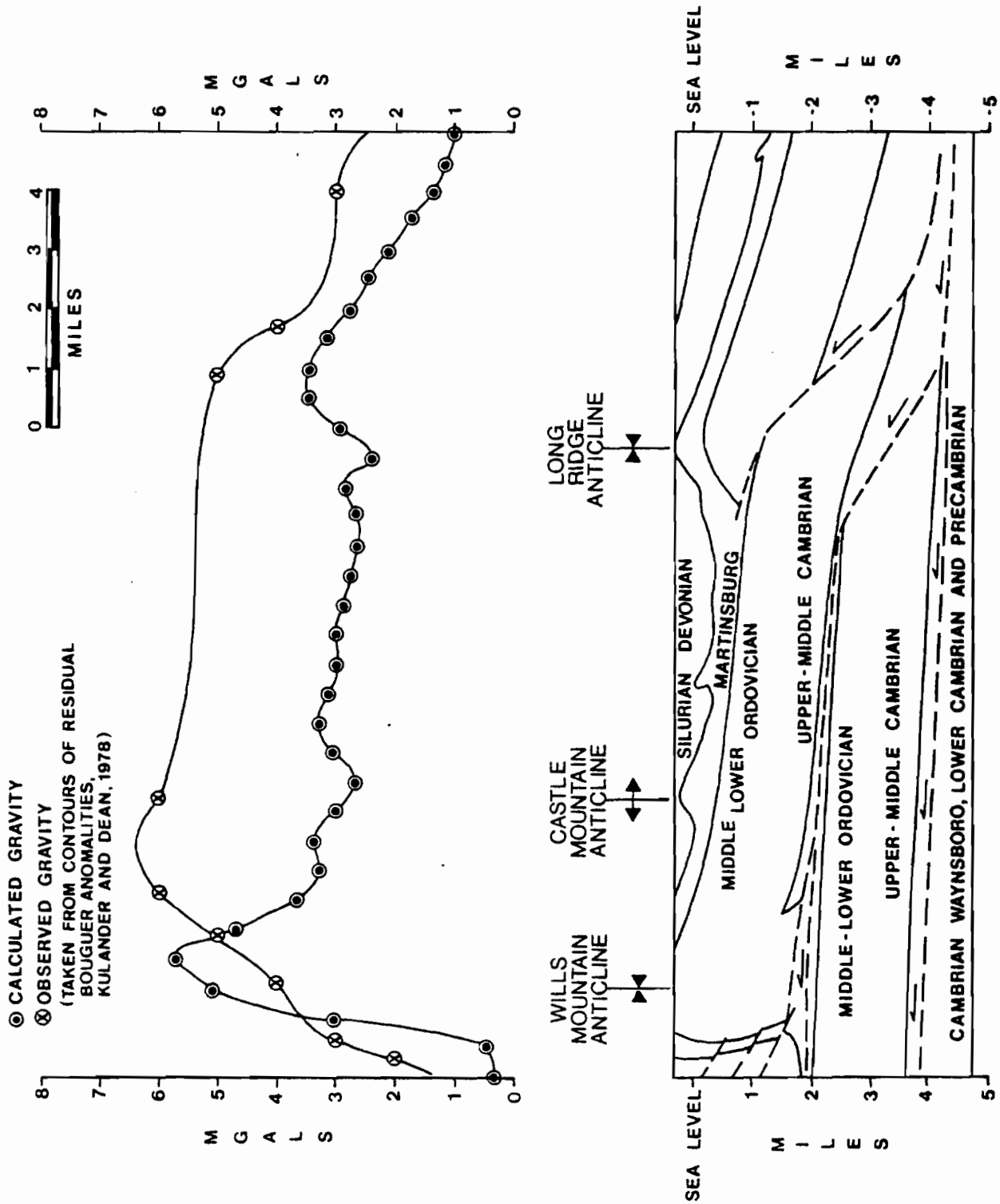
CALCULATED GRAVITY
OBSERVED GRAVITY
(TAKEN FROM CONTOURS OF RESIDUAL BOUGUER ANOMALITIES, KULANDER AND DEAN, 1978)
MILES
MGALS
LONG RIDGE ANTICLINE
CASTLE MOUNTAIN ANTICLINE
WILLS MOUNTAIN ANTICLINE
SEA LEVEL
SILURIAN DEVONIAN
MARTINSBURG
MIDDLE LOWER ORDOVICIAN
UPPER-MIDDLE CAMBRIAN
MIDDLE-LOWER ORDOVICIAN
UPPER-MIDDLE CAMBRIAN
CAMBRIAN WAYNSBORO, LOWER CAMBRIAN AND PRECAMBRIAN

Figure 13

AVERAGE DENSITIES ASSIGNED TO STRATIGRAPHIC INTERVALS

IN THE CALCULATIONS OF GRAVITY PROFILES

ALONG THE JACOBEEN AND KANES (1974) SECTION LINE

NORTH OF THE PARSONS AND PETERSBURG STRUCTURAL DISCONTINUITIES

STRATIGRAPHIC INTERVAL	DENSITY
Devonian Catskill fm through Ordovician Oswego ss	2.62 gm cm^{-3}
Ordovician Martinsburg shale	2.55 gm cm^{-3}
Ordovician Trenton fm through Cambrian Elbrook fm	2.71 gm cm^{-3}
Cambrian Waynesboro sh into Precambrian	2.69 gm cm^{-3}

Table 4

features in the earth's gravitational field could be produced by lateral density contrasts in the basement Grenvillian structural complex.

The disagreement between calculated and observed gravity over the Blackwater anticline cannot be compensated for by Cambrian-Ordovician structure. Interpretations of the Ray Sponaugle well in Pendleton County, West Virginia, (Perry, 1964), of the Ray Sponaugle and Greenland Lodge (Grant County, West Virginia) wells (Sites, 1978), and a published seismic interpretation across the Wills Mountain anticline near Keyser, West Virginia (Bagnall, Beardsley, and Drabish, 1979) support the complete duplication of the Cambrian-Ordovician dolomite and carbonate sequence along the length of the Wills Mountain anticline. The detailed gravity profile across the Middle Mountain syncline (see Section E (ii)) is consistent with folding and faulting of the Cambrian-Ordovician sequence beneath the Cave Mountain and Elkhorn Mountain anticlines. Thus, the disagreement between observed gravity and calculated gravity across the Valley and Ridge structural model in the northern section cannot be compensated for by a reasonable alternative structural model of the Paleozoic sedimentary cover.

The regional gravity map (Kulander and Dean, 1978, Figure 1) was constructed graphically from a series of orthogonal profiles of the terrain-corrected Bouquer gravity. Regional gradients were visually chosen for each profile. The regional gravity map was then compiled from the profile data. It would be impossible to anticipate the presence of smaller scale features in the regional gravity without other sources of information on basement composition or structure. With gravity calculated for reasonable structural models of the Plateau, and Valley and Ridge

paleozoic sedimentary cover, it is possible to construct hypotheses about compositional variations in the basement that could be responsible for the disagreement between the observed and calculated gravity.

A regional gravity low trending northeast-southwest generally lying along the Allegheny structural front (Kulander and Dean, 1978) is related to a still cooling, felsic pluton intruded into Grenville rocks (Dennison and Johnson, 1971). Recent reports of seismic events occurring in the Grenville basement and having a N37E trend (Ballanger, 1980, oral communication) may be related to cooling of the pluton. Larger volumes of this low density material beneath the Valley and Ridge segment of the northern section (Figure 3) would lower the regional gravity bringing the residual Bouquer gravity into better agreement with the calculated gravity. Similarly, if a smaller concentration were present beneath the Blackwater anticline the regional gravity would be increased and the residual gravity, decreased.

QUARTERLY PROGRESS REPORT

U.S. Department of Energy
Contract number DE-AC21-76ET12138
(formerly DE-AC21-76MC05194)

July - September 1980

submitted by

Department of Geology and Geography
West Virginia University

Robert C. Shumaker, Project Director
Devonian Shale Program

co-authored by

J. Negus-de Wys, Kevin D. Lee, James E. Ruotsala,
Thomas H. Wilson and Richard T. Williams

Research Associates

July-Sept. 1980
WVU
Dept. of Geog. & Geogr.

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1.0 EXECUTIVE SUMMARY

QUARTERLY PROGRESS REPORT

July - September 1980

U.S. Department of Energy
Contract no. DE-AC21-76ET12138
(formerly DE-AC21-76MC05194)

1.0 EXECUTIVE SUMMARY

1.0.1 During the fourth quarter of the 1979-80 contract year we have been working on completion of manuscripts covering our studies on the subsurface structure of the Devonian shales in the Big Sandy (eastern Kentucky) gas field and surface structure including fracturing of a folded portion of the Valley and Ridge province.

Results of the subsurface investigation in eastern Kentucky have defined several low relief structures and fault zones not previously recognized for that area. The significance of these structures to production from the shale will be accessed during the upcoming contract year.

Results of surface structure mapping have added significantly to understanding cross strike structural discontinuities which have higher fracture density and thus production potential from the shale.

In geochemistry, the major trends reported previously based on composite samples for the eastern Kentucky wells have been substantiated on a formation by formation basis.

In geophysics, the Bison seismograph has been modified to increase its dynamic range. Efforts continue toward defining computer programs that will permit detailed analysis of Geophysical Services, Inc. tapes of the Cottageville area.

Task efforts as defined under this contract will continue during the upcoming federal year, 1980-81, under three separate contracts.

* * * * * *

2.0 CONTRACT OBJECTIVES

2.0 CONTRACT OBJECTIVES

Collect, compile and analyze geological data and prepare geological structure maps for eastern Kentucky and western West Virginia.

Determine if structural types and styles and surface lineations for productive areas of the Black shales differ from those in non-productive areas.

Identify and define along with other contractors those geologic parameters that control gas production from the shales.

Determine the feasibility of using shallow penetration resistivity and seismic surveys to detect near surface faults and fractures and demonstrate their relationship to lineations observed on air-borne imagery.

Determine if a relationship exists between ground water movement and shale gas productivity.

In conjunction with other contractors develop a method for selecting areas for drilling shale wells that have a potential for gas production.

3.0 TECHNICAL PROGRESS

QUARTERLY PROGRESS REPORT

July - September 1980

Jane Negus-de Wys

3.1 Work Package 2100-1-1 CROSS SECTIONS

3.2 Work Package 2100-1-2 ISOPACH MAPS

3.3 Work Package 2100-2-1 STRUCTURE CONTOUR MAPS

3.4 Work Package 3200-4-1 OIL AND GAS MAPS

3.1.1 Current status of work and scheduled deliverables

Work plan for this quarter included:

- Completion of deliverables due June 1 and September 1, 1980 (180 geochemical trend maps for eastern Kentucky.)
- Continuing work on completing the geochemical graphs for each of 12 wells.
- Procurement of additional well set in Floyd County.
- Final agreement and arrangements for drilling, coring, and logging of well in Floyd County.
- Commencement of comparison analyses of geochemistry data with open flow gas data, fracture occurrence, stratigraphy, and structure.
- Attend 26th International Geological Congress and two field trips.
- Presentation of two papers at the International Geological Congress in Paris, France.
- Preparation of papers for AAPG and GSA journals.

All 180 geochemical data trend maps have been completed and drafting is 60% complete. Delay has been caused by lack of draftsman.

Graphs of geochemical data are nearing completion in preparation for drafting.

Well data in Floyd County has been received and an additional data set can be added if the second year of funding is received from GRI.

The upper management of Kentucky-West Virginia Gas has not given Ernie Jenkins permission to proceed with drilling a well in Floyd County for coring and logging. Thus, if this project is to be pursued, it must be with another company or arrangement.

Quarterly Progress Report
July - September 1980

Jane Negus-de Wys

3.1.1 Current status of work and scheduled deliverables - continued

Comparison and analysis of geochemistry data trend maps has been initiated. Junior L. Jenkins has been added to the staff in the geochemistry grad student position. He is a master's candidate under Dr. Milton Heald and will be working on the computer comparison of maps, including the geochemistry, gas production, structure, and stratigraphy.

Dr. J. Negus-de Wys attended the 26th International Geological Congress in Paris, the pre-meeting field trip on structure of the Austrian Alps, and the post-meeting field trip on structure and metamorphism in the Hebrides.

Dr. J. Negus-de Wys had two papers accepted for the 26th International Geological Congress, one given orally in the Fossil Fuels Section, the other accepted for the Geochemical Section. The first is reprinted in its entirety in the pre-meeting publication. The second is being published in a French geochemical journal. Abstracts of both papers were included in the program.

The papers for the AAPG and GSA journals are in preparation.

3.1.2 Problem areas and suggested improvements

The delay due to drafting is being solved 1) by temporary workers, and 2) continuing to advertise the position. It is difficult to fill because the funds have not yet been transferred to the University for the three month period, and, second, it is at present only a three month job. We will continue to use temporary or student help to fulfill the contract until the position is filled or the contract is met.

Concern is present over the second year funding of the geochemistry study. A proposal for the second year's work has been submitted to GRI at Chuck Komar's suggestion.

3.1.3 Work plan for next quarter

This quarter will complete the first year on the geochemical aspect of this project.

Completion of deliverables (180 geochemical trend maps and report).

Preparation of invited abstract for KGS meeting in Natural Bridge, Kentucky, April, 1981.

Quarterly Progress Report
July - September 1980

Jane Negus-de Wys

3.1.3 Work plan for next quarter - continued

Preparation of abstract for SPE/DOE meeting in Denver, May, 1981.

Preparation of abstract for AAPG meeting, San Francisco, 1981.

Continue preparation of papers for AAPG and GSA journals.

Meetings attended

26th International Geological Congress and two field trips, June 26 - July 29, 1980.

Meeting with Kentucky-West Virginia Gas in Ashland, Kentucky: Ernie Jenkins, Bob Hager, Dr. R. C. Shumaker, Kevin Lee, Dr. Jane Negus-de Wys.

Meeting with Dr. Shya Chitaley, Cleveland Natural History Museum, Cleveland, Ohio: Dr. Chitaley, Dr. Jane Negus-de Wys.

Meeting with Dr. Jessie Donahue, Delta Drilling, Morgantown, West Virginia: Dr. Donahue, Dr. R. C. Shumaker, Dr. Jane Negus-de Wys.

Meeting with NSF, Washington, D. C.: NSF personnel, Dr. Jane Negus-de Wys.

Meeting with Howard Ritzma, Assistant Director, Utah Geological and Mineral Survey, at Morgantown, West Virginia.

Meeting with Claude Dean, METC, at West Virginia University, Morgantown, West Virginia.

Papers delivered/published

Negus-de Wys, Jane, The anatomy of a large Devonian black shale gas field, 26th International Geological Congress, Paris, France, 1980 (Fossil Fuels Section). Oral presentation, published abstract and paper in program and pre-convention publication Fossil Fuels Section.

Negus-de Wys, Jane, and J. J. Renton, Inorganic geochemistry as an exploration tool, 26th International Geological Congress, Paris, France, 1980 (Geochemistry Section). Discussion Session, abstract in program, in press in French geochemical journal.

Paper solicited/in preparation

Negus-de Wys, Jane, Studies on relationships of gas occurrence to geological parameters in eastern Kentucky, requested by Paul Potter for presentation to the Kentucky Geological Survey Symposium at Natural Bridge State Park, Kentucky, April, 1981.

Quarterly Progress Report
July - September 1980

Jane Negus-de Wys

Papers in preparation for publication

Negus-de Wys, Jane, Relationships of gas occurrence to geological parameters in the eastern Kentucky gas field, requested by AAPG for submission for journal publication.

Jenkins, J. and J. Negus-de Wys, Color changes in megaspores observed at visual and fluorescence wavelengths for upper Devonian black shale in the eastern Kentucky gas field.

* * * * * *

QUARTERLY PROGRESS REPORT

July - September 1980

3.1 Work Package 2100-1-1 SEISMIC

James E. Ruotsala
and Richard T. Williams

3.1.1 Current status of work and scheduled deliverables

A new geophone (hydrophone) which is sensitive to both ground velocity and pressure was acquired and tested in July. It was found that this new hydrophone gave improved performance, relative to the Mark L100 geophone, in areas where it was not possible to plant the L100 solidly. It was also found that the field procedure was speeded up considerably by using the hydrophone. Using the L100 geophone planted in a shallow borehole, it was frequently difficult to retrieve the geophone from the borehole, and the geophones were sometimes damaged when retrieved. No such problems are encountered with the hydrophone, since it is not planted, just suspended in the borehole. As an unanticipated bonus, the hydrophone is approximately two times as sensitive as the Mark L100 geophone used previously. This is significant since it allows a proportionally smaller explosive shot to be used.

A new analog signal compression circuit has been designed and successfully tested in the lab on the Bison 1580 seismograph. This circuit effectively extends the dynamic range of the recording system from 48 dB to 96 dB. If it works under field conditions as it does in the lab it will alleviate the recording problems which were previously encountered using the Bison system.

Preparations are under way to record a shallow reflection profile across the region of high production in the Cottageville gas field. These include acquisition of a new set of hydrophones to replace the Mark L100 geophones, modification of the recording system for increased dynamic range, and repair of the drilling truck.

In anticipation of a successful field effort at the Cottageville gas field, acquiring reflection seismic data with the Bison-based seismograph, preparation for the processing, analysis, and interpretation of that data has begun. These analyses include:

1. Computer assisted modeling, by raytracing, of the deviation of event alignment on a seismogram from the hyperbolic, caused by a vertical low-velocity zone (Fracture zone). The software for this procedure has been written and is being tested.

Quarterly Progress Report
July - September 1980

James E. Ruotsala
and Richard T. Williams

3.1.1 Current status of work and scheduled deliverables - continued

2. Spectral estimation of time slices using the maximum entropy technique. The software for this procedure has been acquired (from the current literature) and tested.

3. Stratigraphic modeling of the reflection seismic data in terms of acoustic impedance and bed geometry. Software to compute a one-dimensional synthetic seismogram has been written to aid in this effort.

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for next quarter

A field program in the Cottageville gas field is scheduled to begin in the third week of October.

* * * * * *

QUARTERLY PROGRESS REPORT

July - September 1980

3.1 Work Package 2200-1-2 FRACTURE STUDIES — Kevin D. Lee

3.1.1 Current status of work and scheduled deliverables

The oral defense of my thesis is scheduled for October 10.

Thirteen of fourteen figures and three of four plates have been drafted. The remaining figure and plate will be drafted by October 10.

A third draft of my thesis was completed and revised after one committee member found major objections. The fourth draft is now being typed.

3.1.2 Problem areas and suggested improvements

None

3.1.3 Work plan for next quarter

Defend my thesis October 10.

Write a fifth draft of my thesis and hopefully have that draft accepted as final.

* * * * * *

QUARTERLY PROGRESS REPORT

July - September 1980

3.1 Work Package 2100-2-2 STRUCTURE STUDIES Name Thomas H. Wilson

3.1.1 Current status of work and scheduled deliverables

A draft of my dissertation has been approved by Dr. Russell L. Wheeler and is currently being reviewed by Dr. Robert Shumaker.

3.1.2 Problem areas and suggested improvements

None

3.1.3 Work plan for next quarter

Revisions in the report suggested by Dr. Wheeler and Dr. Shumaker will be completed and submitted to METC.

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UGR File #Co48/81Q1
Oct.-Dec. 1980
WVU Dept. of Geology & Geography

QUARTERLY PROGRESS REPORT

U.S. Department of Energy
Contract Number DE-AC21-76ET12138
(formerly DE-AC21-76MC05194)

October - December 1980

submitted by

Department of Geology and Geography
West Virginia University

J. Negus-de Wys, Project Director
Devonian Shale Program

co-authored by

R.C. Shumaker and Junior L. Jenkins

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1.0 EXECUTIVE SUMMARY

QUARTERLY PROGRESS REPORT

October - December 1980

U.S. Department of Energy
Contract No. DE-AC21-76ET12138
(formerly DE-AC21-76MC05194)

1.0 EXECUTIVE SUMMARY

1.0.1 During the first quarter of the 1980-81 contract year, we have been working on 1) the completion of strataspecific geochemical trend maps in eastern Kentucky, based on data from XRF and XRD of well cuttings, 2) the completion of the annual report, and 3) detailed structure maps on the top and bottom of the Ohio Shale.

The geochemical trend maps were first computer-drawn for 13 minerals and 14 elements, for eight stratigraphic intervals (216 maps). These were later hand-contoured and some of those with limited data were eliminated, resulting in 177 hand-contoured trend maps. These will be delivered to METC early in January.

Comparisons, anlaysis, and changes in geochemistry with a given stratigraphic interval are now in progress.

Grids were designed to extract data for comparison on the strataspecific geochemical trend maps and on maps from previous studies in eastern Kentucky including these on structure and gas recovery. Results from these comparisons are computer-correlated to obtain Spearman, Pearson, and Kendall coefficients of correlation, in addition to X-Y plots. It is too early in the analysis to draw specific conclusions, other than the earlier obvious correlations of striking similarity of some elemental and mineralic trend maps to maps of density of high gas producing wells. We anticipate that quantitative values can be put on these comparisons at the conclusion of analyses.

A more regional look has been taken with five elemental maps, incorporating work from the Kentucky Geological Survey and the West Virginia Geological and Economic Survey. The data from the three areas could be easily integrated to show regional trends.

Comparison of structures on different stratigraphic horizons has commenced and will be reported under a separate contract in the next quarter.

Milestones 3.4.14 and Task 3.2.5 completed under structure studies.

Work Package 2200-1-2 Fracture Studies completed.

* * * * * *

2.0 CONTRACT OBJECTIVES

2.0 CONTRACT OBJECTIVES

Collect, compile, and analyze geological data and prepare geological structure maps for eastern Kentucky and western West Virginia.

Determine if structural types and styles and surface lineations for productive areas of the black shales differ from those in non-productive areas.

Identify and define along with other contractors those geologic parameters that control gas production from the shales.

Determine the feasibility of using shallow penetration resistivity and seismic surveys to detect near surface faults and fractures and demonstrate their relationship to lineations observed on air-borne imagery.

Determine if a relationship exists between ground water movement and shale gas productivity.

In conjunction with other contractors develop a method for selecting areas for drilling shale wells that have a potential for gas production.

3.0 TECHNICAL PROGRESS

QUARTERLY PROGRESS REPORT

October - December 1980

Jane Negus-de Wys

3.1 Work Package 2100-1-1 CROSS SECTIONS

3.2 Work Package 2100-1-2 ISOPACH MAPS

3.3 Work Package 2100-2-1 STRUCTURE CONTOUR MAPS

3.4 Work Package 3200-4-1 OIL AND GAS MAPS

3.1.1 Current status of work and scheduled deliverables

Work plan for this quarter included:

- Completion of geochemical trend maps and report (deliverables).
- Preparation of invited abstract for Kentucky Geological Survey conference at Natural Bridge, Kentucky, April, 1981.
- Preparation of abstracts for 1981 meetings.
- Preparation of journal articles for AAPG and GSA.

Drafting of 177 strataspecific geochemical maps for eastern Kentucky has been completed. These will be delivered to METC early in January (Table 1).

Analysis and map comparison are underway. The first set of correlation coefficients have been run and comparisons are now in progress on strataspecific geochemical trend maps and gas data.

Work on final report for this phase has commenced.

An abstract was prepared for the Kentucky meetings.

Abstracts were submitted to the Denver DOE meeting and San Francisco AAPG.

Abstracts were submitted to the 4th International Conference on Basement Tectonics and the Uppsala Caledonide Symposium.

Journal articles are in progress.

Table 1. Geochemical Trend Maps

Stratigraphic Interval	Minerals Included	Elements and Elemental Oxides Included
	Anhydrite, Bassinite, Calcite, Chlorite, Dolomite, Illite, Kaolinite, Orthoclase, Plagioclase, Pyrite, Quartz, Siderite, and Szmolnokite	Oxides of Al, Ca, Cu, Fe, K, Mg, Mn, Na, P, Si, Sr, Ti, and Zn, and the element Sulphur.
Berea/Bedford	X	✓
Cleveland	✓	✓
Three Lick	✓	✓
Upper Huron	✓	✓
Middle Huron	✓	✓
Lower Huron	✓	✓
Total Huron	X	✓
Total Ohio Shale	X	✓

Quarterly Progress Report
October - December 1980

Jane Negus-de Wys

3.1.2 Problem areas and suggested improvements

Funding is needed for the second year (regional) phase of the geochemical exploration studies. The tremendous amount of work represented thus far should be extended to a regional application for hydrocarbon exploration.

3.1.3 Work plan for next quarter

Deliver 177 strataspecific geochemical maps.

Work on final report.

Work on journal papers.

Complete map comparisons and analysis of relationships of strataspecific geochemistry with other geological parameters and gas occurrence in eastern Kentucky.

Structural maps and analysis will be reported separately next quarter.

Meetings attended (See monthly reports)

AAPG NE Section, Evansville, Indiana and western Kentucky field trip.

Appalachian Geological Society, Charleston, West Virginia.

Papers delivered

Negus-de Wys, J., Overview of Studies on the Devonian Shale Gas Program in Eastern Kentucky. Invited lecture, U.C. Los Alamos Scientific Laboratories, Los Alamos, New Mexico.

Abstracts submitted/accepted

Negus-de Wys, J., Overview of Upper Devonian Gas Occurrence and Relationships to Geological Parameters in Eastern Kentucky, invited paper for Kentucky Geological Survey Conference at Natural Bridge State Park, Kentucky, April, 1981.

Negus-de Wys, J., The Caledonian Evolution and Gas Recovery in the Largest Gas Field in the Appalachian Basin, North America. Submitted to the Uppsala Caledonide Symposium, 1981.

Quarterly Progress Report
October - December 1980

Jane Negus-de Wys

Abstracts submitted/accepted - continued

Negus-de Wys, J., Basement Structure, Structural History, Lineaments, and Fractures Related to Gas Production in the Largest Gas Field in the Appalachian Basin. Submitted to the 4th International Conference on Basement Tectonics.

* * * * * *

QUARTERLY PROGRESS REPORT

October - December 1980

Junior L. Jenkins

3.1 Work Package 2100-1-1

3.2 Work Package 2100-1-2 ISOPACH MAPS

3.3 Work Package 2100-2-1 STRUCTURE CONTOUR MAPS

3.4 Work Package 3200-4-1 OIL AND GAS MAPS

3.1.1 Current status of work and scheduled deliverables

Work on this project on computer map comparisons was initiated in October, 1980. The objective of this project is to provide a quantitative dimension to the project through the use of computer plots and simple statistics to correlate map information obtained from this geochemical study and related studies.

Grids were developed to overlay on the various maps so the data could be recorded on gas open flow maps, structure maps, spore color isoline map, and a grain size distribution map. Initial computer plots and simple statistics have been completed on these map comparisons. Grids are presently being completed on the remaining geochemical maps.

Initial correlation coefficients on the first set of maps are presently being interpreted and analized.

3.1.2 Problem areas and suggested improvements

None

3.1.3 Work plan for next quarter

Grids will be completed and additional computer comparisons will be made as well as be analized.

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QUARTERLY PROGRESS REPORT

October - December 1980

3.1 Work Package 2100-2-2 STRUCTURE STUDIES Name Thomas H. Wilson

3.1.1 Current status of work and scheduled deliverables

Completed report with maps and cross sections describing the effects of cross strike structural discontinuities on fracture characteristics and other structures in the Devonian shale clastic sequence. Milestone 3.4.14 and Task 3.2.5.

3.1.2 Problem areas and suggested improvements

None

3.1.3 Work plan for next quarter

Task complete; report to be submitted in January, 1981, which will be reported in the next quarterly report given under contract DE-AC-21-81MC16360.

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QUARTERLY PROGRESS REPORT

October - December 1980

3.1 Work Package 2200-1-2 FRACTURE STUDIES

Kevin D. Lee

3.1.1 Current status of work and scheduled deliverables

Task Completed.

* * * * * *

UGR File #C048/A79, v.1
WVU Dept. of Geology and Geography
Oct. 1979

AN ANALYSIS OF THE STRUCTURAL PARAMETERS THAT INFLUENCE GAS PRODUCTION FROM THE DEVONIAN SHALE

1978 - 1979

ANNUAL PROGRESS REPORT

CONTRACT DE-AC21-76MC05194
Formerly EY-76-C-05-5194

SUBMITTED BY

DEPARTMENT OF GEOLOGY AND GEOGRAPHY
WEST VIRGINIA UNIVERSITY

ROBERT C. SHUMAKER, PROJECT DIRECTOR

CO-AUTHORED BY:

J. NEGUS-DE WYS, JEANETTE M. DIXON, MARK A. EVANS,
KEVIN D. LEE, HENRY W. RAUCH, JAMES E. RUOTSALA,
THOMAS H. WILSON AND RICHARD T. WILLIAMS

RESEARCH ASSOCIATES

UGR File #C048/A79, v.1
WVU Dept. of Geology and Geography
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PREFACE TO VOLUMES I AND II

This report is written to document progress made during the third year of our study for the Eastern Gas Shales (EGSP) Project, and it is organized to meet the needs of readers who have a variety of interests in the project. The first portion of Volume I includes the Executive Summary which gives a general overview highlighting the progress made over this contract year. The second portion of Volume I includes task reports written by the specific task investigators, and it is written primarily for scientists interested in a technical overview of the third years' work. Volume II of the report consists of appendices of data compiled by the principal investigators. The appendices serve as a data bank for work accomplished during fiscal 1978-1979. These data can be used by other scientists with the permission of the principal investigator responsible for the specific compilation.

UGR File #C048/A79, v.1
WVU Dept. of Geology and Geography
Oct. 1979

PERSONNEL

Robert C. Shumaker, Project Director

REGIONAL STRUCTURE TASK

Robert C. Shumaker, Principal Investigator

SURFACE STRUCTURE TASK

Russell L. Wheeler, Task Director *
Jeanette M. Dixon, Principal Investigator
Thomas H. Wilson, Principal Investigator

SURFACE FRACTURES TASK

Brian R. Long, Principal Investigator *
Mark A. Evans, Principal Investigator
Kevin D. Lee, Principal Investigator

PRODUCTION TASK

Jane Negus de Wys, Principal Investigator

HYDROLOGY TASK

Henry W. Rauch, Task Director
Robert R. Beebe, Principal Investigator *

GEOPHYSICAL TASK

Richard T. Williams, Task Director
Keith G. Kirk, Principal Investigator *
James E. Ruotsala, Principal Investigator

GEOLOGIC DRAFTING SPECIALISTS

Philip E. Haring *
Patricia P. Stockdale
John G. Wright

SECRETARY

Jean A. Toren

Other major contributions to our project were made by:

Jean Cheng	Statistics
David Kutner	Structure
Dr. John Renton	Geochemistry
William Schaefer	Production

* No longer attached to project.

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AN ANALYSIS OF THE STRUCTURAL PARAMETERS THAT INFLUENCE GAS PRODUCTION FROM THE DEVONIAN SHALE

1978 - 1979

ANNUAL PROGRESS REPORT

VOLUME I

EXECUTIVE SUMMARY AND TASK REPORTS

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VOLUME I

PART I

EXECUTIVE SUMMARY - BACKGROUND AND PROGRESS 1978-1979

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INTRODUCTION

This report presents the scientific progress of our efforts toward understanding shale gas production from the Devonian shale within the project area (Figure 1). We consider that two major advances toward understanding the nature of Devonian shale production have occurred during fiscal 1978-1979: one relates shale gas production to structural position along basement flexures, and the other relates gas production to the geochemistry of the shale.

It is not only interesting but important to note that while both advances were directly dependent upon certain equipment and at least one person funded thru the DOE's EGSP program, neither research project was directly funded under our contract. The work was accomplished under West Virginia University funding. We have always had the encouragement of DOE/METC's scientific management to pursue ideas that could not be directly funded, and in this case the results have been significant to our contractual objectives. The senior author feels that it is important to point out the value of this latitude in research within a university. Too often the criticism is made that university research is not goal oriented. It is essential to a research program that it not be too goal oriented demanding contract deliverables, and that latitude and flexibility are not sacrificed to restrictive contractual obligations. The kiss of death to successful research is very often excessive managerial regulation specified by non-scientific personnel. Mutual trust, flexibility, combined with a tolerance of failure in university-governmental research is essential if true scientific progress is anticipated.

PURPOSE OF THE STUDY

The specific objectives of our contract are given in the section entitled Objectives found within the Task Report section of this Volume. In general, the purpose of our research under the EGSP program is to analyze structural parameters of local and regional geology that influence Devonian shale gas production within the contract area (Figure 1). Our project was designed in 1976, initiated in early 1977, and it became fully staffed for significant work in 1978. Our efforts thus far have been channeled toward defining the structural parameters that influence shale gas production, but we are to develop, in conjunction with other contractors, techniques or rationales for shale gas (fracture porosity) exploration. We are just entering the "results" phase of the project which will permit us to characterize the shale and thus assist the exploratory phases of the EGSP program.

A second goal of the EGSP program at West Virginia University is to provide support for geologists and geophysicists who are studying to obtain advanced degrees in the mineral industry sciences.

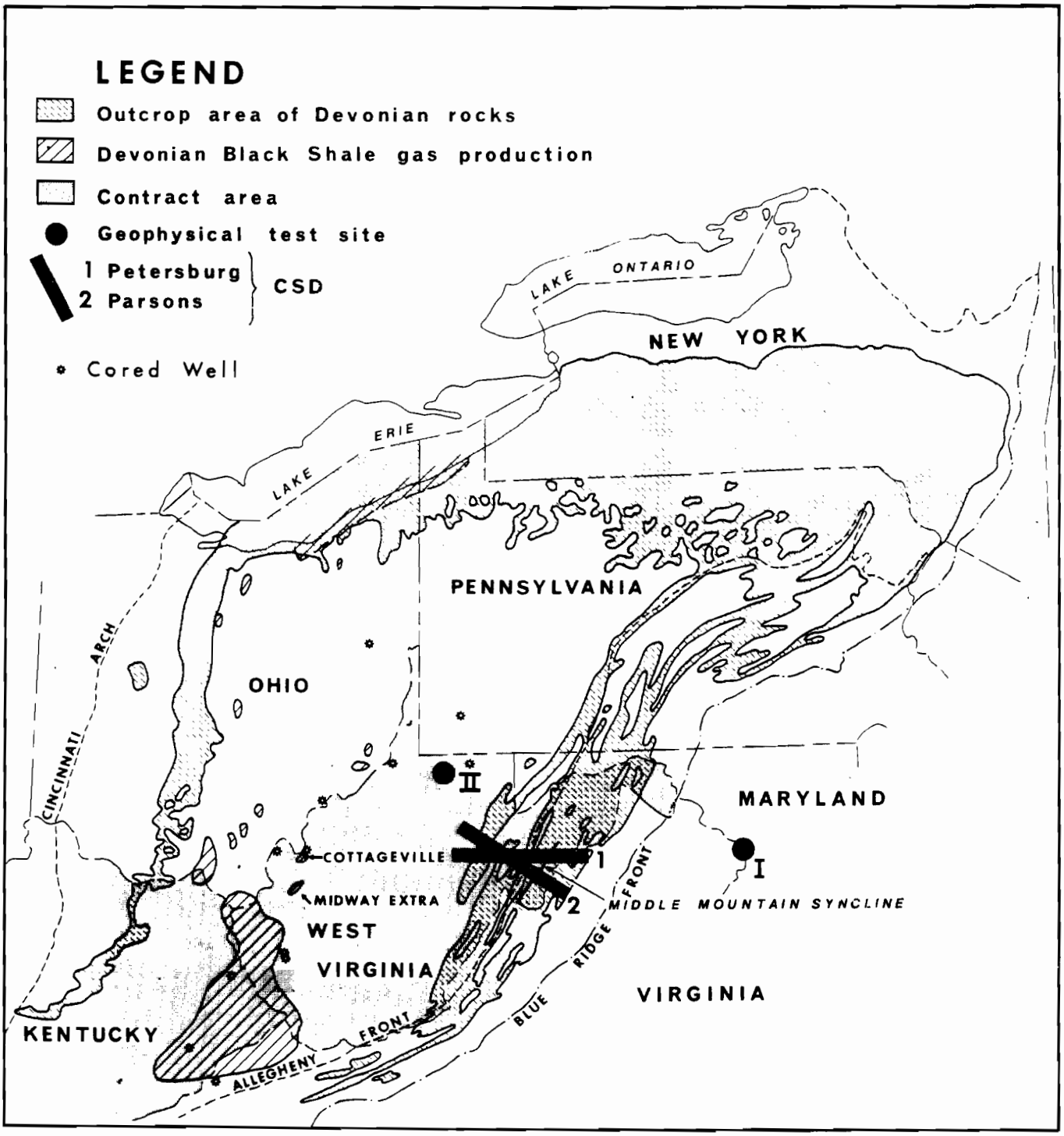

Figure 1. Contract area

METHODS OF APPROACH AND ORGANIZATION

We are attacking the problem of locating fracture zones within the Devonian shale along several avenues: thru our remote sensing studies, subsurface and surface geologic studies, thru geochemical, geophysical, and hydrologic studies. Our attack is broad and yet it is integrated into one work contract. Our method of approach to attain the contractual objectives is thru organization of our efforts into several tasks: one group is compiling the regional structure; a second is studying surface fractures and subsurface fractures found in oriented shale cores. A third group is studying shale gas production in detail where reliable production data is available. A fourth study group is investigating surface structures which would have production potential if found in the subsurface, and a fifth group is studying ground water-lineament-gas production (hydrology) interrelationships. These five study groups, that is: regional structure, fractures, surface structures, production, and hydrologic studies are supported under the EGSP Resource Inventory Tasks.

Another of our study groups, the geophysical task, is carried under the EGSP Shale Characterization Task. Our geophysical task is to develop inexpensive seismic and resistivity techniques which can locate shallow fracture zones.

In essence, the first two tasks, regional structure and fracture studies, are designed to provide a regional or basin structure framework for the entire project. The surface structure studies seek to document, by analytical field work, those details of structure which are either similar to structure producing gas or those structures which we feel are prospective for shale gas production. The production studies will seek out and study those gas fields where detailed well production records are available that permit thorough analysis and documentation of the geologic parameters that influence gas production from the shale. The geophysical studies are charged with the task of developing inexpensive geophysical techniques that can locate shallow fracture zones of high permeability. We have coordinated our studies so that most of the task groups are working in specific shale gas producing areas where we have reliable production data (Cottageville, Midway-Extra, and the Big Sandy fields - Figure 1).

The attention of all study groups focuses on fracture porosity within the shale: its origin, distribution, and methods of locating zones of more intense fracturing. It is important to realize that even though each study group is carried as a Resource Inventory Task or the Characterization Task, each group has the additional and longer ranged goal of defining parameters that would be useful in exploring for potentially productive fracture porosity in the shale. Often overlooked is this latter goal of developing a method or rationale for selecting areas for

drilling shale gas wells that have a higher than normal potential for shale gas production. It is further emphasized that our basic research approach applies to many other DOE projects such as the Tight Sands Project, Methane Drainage Project, mine hazards, underground coal gasification, etc. Indeed, any project which deals with fractured rocks will be interested and derive benefits from our work on fractures and gas production from fractured shale.

MAJOR ACCOMPLISHMENTS 1978-1979

Because we have completed two years of research effort at full staff levels, we are now completing discrete segments of research that lead to obtaining the objectives of the contract.

Specific relationships between shale gas production and both local and regional structures are now apparent, and we can specifically characterize structural aspects of the shale gas production. Based on this characterization we have developed empirical exploration rationales for the West Virginia portion of our contract area. These major accomplishments for this year are briefly reported in the Noteworthy Accomplishments below, but for the details of specific accomplishments the reader is referred to the individual task reports (Part II of this Volume).

Over the long term it is difficult to evaluate what is or will be most significant from this year's effort. Within shale characterization, we now have a far better understanding of the nature of relationship between surface and subsurface fracturing. We know that it is highly speculative to estimate subsurface fracture trends from surface trends (Long, ref. 1). We continue to document a relationship, albeit nebulous, between low-altitude photo linears, ground water production, ground water quality, and shale gas production (Beebe, ref. 2). The results obtained by Beebe (ref. 2) at Midway-Extra (Figure 2) are similar to those found by Jones and Rauch (ref. 3). We know much more about subsurface fracturing of the Devonian shale thru our study of oriented cores (Evans, ref. 4 & 5), and we have determined that cross-strike structural discontinuities are zones of more intense fracturing that extend at depth to the shale (Dixon and Wilson, ref. 6). We have found that the maximum gas production in the two shale gas fields (Figure 2) studied thus far follows the syncline and certain flanks of basement folds (Shumaker, ref. 7). Furthermore, we have found that the highest productive areas of the Big Sandy gas field coincide with shale that can be characterized geochemically (Negus-de Wys, ref. 8).

All of these new understandings have significance in relationship to characterization, but the last three, that is, empirical relationships between: (1) low-altitude photo linears and production, (2) structural position and production, and (3) shale geochemistry and production, should have an immense impact on the EGSP exploration program. The author suggests that individuals interested in these subjects should read the articles referenced for significant details.

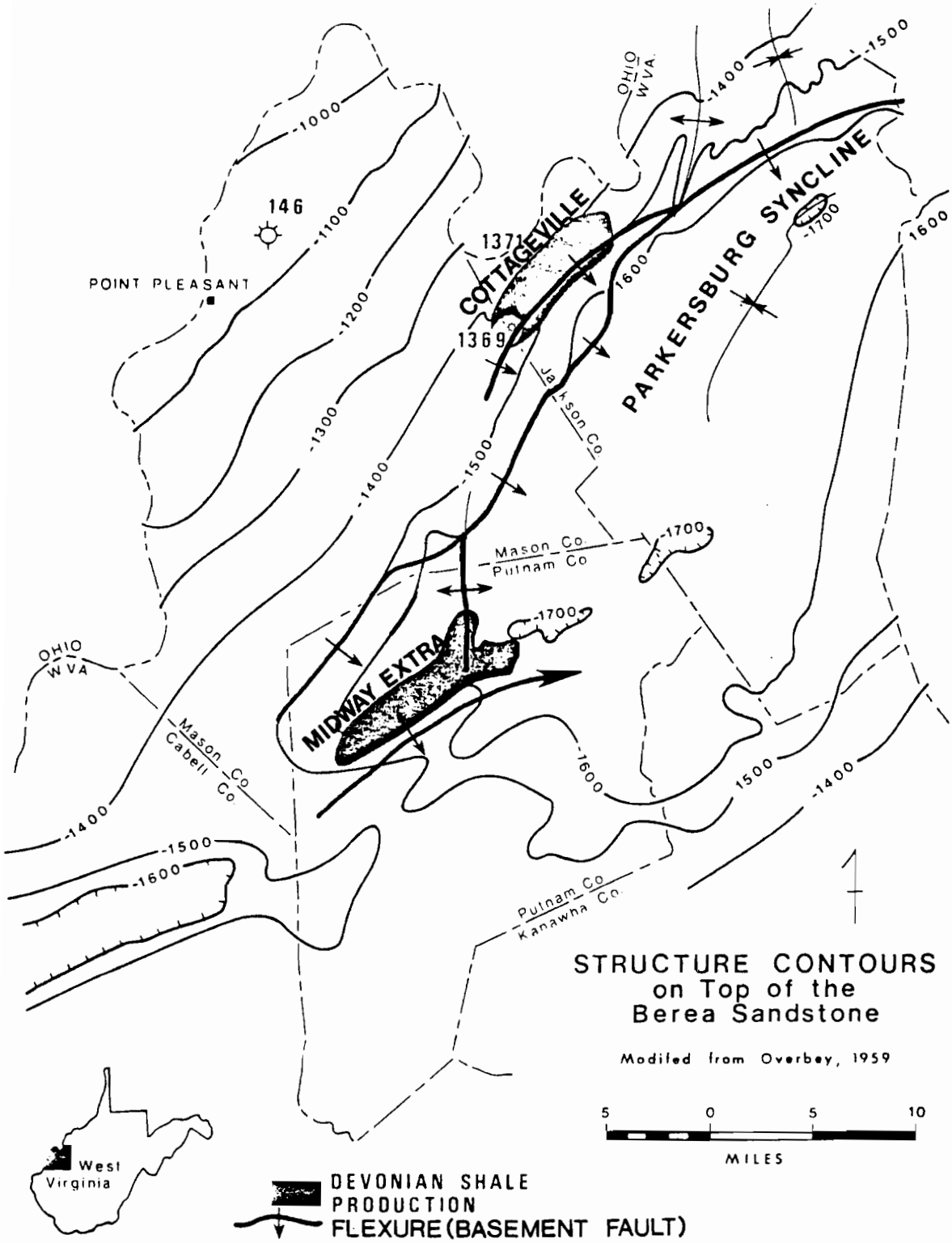

Figure 2. Structure Contours on Top of the Berea Sandstone

Noteworthy accomplishments during 1978-1979 include:

1. Documentation of the geologic parameters that affect shale gas production from the Midway-Extra field (Figure 1). The significant variable that controls production is geologic structure. Producing wells of this field are off-structure, following the synclinal trough and western flank of the Midway anticline (Schaefer, ref. 9).

2. Reinterpretation of the Cottageville field production data (de Wys and Shumaker, ref. 10) supports the Midway-Extra model that production increases off structure, and that the very highest producing wells occur above a mapped basement fault (Shumaker, ref. 7).

3. Detailed structural analysis of Berea sand suggests that a major basement fault connects these two fields (Figure 2).

4. Chemical analysis of well sample cuttings within the Big Sandy field of eastern Kentucky indicates that the Devonian shale can be characterized, and that there is a direct relationship between the distribution of geochemical elements or minerals and production from the shale (Negus-de Wys, ref. 8).

5. A hydrologic study of the area in and around the Midway-Extra field (Figure 1) has been completed. Preliminary analyses suggest a positive association among the density of low-altitude photo lineaments of a particular trend, ground water well productivity, ground water quality, and shale gas productivity.

6. Surface fracture studies in eastern Kentucky in and around the Big Sandy gas field show very complex fracture patterns and that the patterns differ greatly from one lithology to the next. Coal face cleats have the simplest pattern, and within the field they show a swing from a cross-strike Appalachian trend to a trend parallel to the adjacent Pine Mountain thrust. The significance of this change in trend is not known, but the higher gas yield may relate to the diverse fracture pattern of that area. This surface fracture study (Long, ref. 1) will be integrated with our on-going subsurface geologic and production study of the Big Sandy gas field (Negus-de Wys, ref. 8).

7. In areas of limited outcrop it has been difficult to determine joint intensity which will permit geologists to determine if lineaments represent zones of more intense fracturing. A method of determining joint intensity was developed this past year (Dixon, ref. 11), and it was applied with positive results to Petersburg and Parsons lineaments (Figure 1) (Dixon and Wilson, ref. 6).

8. Fractures in 13 oriented shale cores were described and analyzed (Figure 1). Fractures within the shale cores are divisible into two

broad categories as either natural and induced fractures. Results of analyses support a tectonic origin for the fractures and the concept of the fracture facies (Shumaker, ref. 12) associated with commercial production from the shales. This documentation of core fractures is fundamental to characterization of the shale reservoir permeability and production, and it is essential for understanding the extent of a permeable fracture facies.

9. Major accomplishments in the geophysical studies include the isolation and correction of major electronic design flaws within the equipment, the writing of computer programs for plotting seismic data, the preliminary shooting of one line in the Cottageville field, and the reshooting of Test Site II.

REFERENCES

1. Long, Brian R., "Regional Survey of Surface Fractures in Eastern Kentucky," 1979, Masters thesis, West Virginia University, Morgantown, W. Va.

2. Beebe, Robert R., "A Study of Hydrogeologic Trends in Exploration for Devonian Shale Gas in the Midway-Extra Gas Field of Putnam County, West Virginia," 1979, Masters thesis, West Virginia," 1979, Masters thesis, West Virginia University, Morgantown, W. Va.

3. Jones, D. Scott and Henry W. Rauch, "A Hydrologic Study of Water Well Yields and Ground-water Quality Related to Stratigraphic and Structural Settings in Western Jackson County, West Virginia," January 1978, DOE-Morgantown Energy Technology Center UGR File No. 107, Morgantown, W. Va., 24 p.

4. Evans, Mark A., "Fracture Density and Orientation Study of the Reel Energy #3 D/K Core from Mason County, West Virginia," December 1978, DOE-Morgantown Energy Technology Center UGR File No. 052, 48 p.

5. Evans, Mark A., "Fracture Density and Orientation Study of the MERC #1 Core from Monongalia County, West Virginia," June 1979, West Virginia University, Department of Geology and Geography, Devonian Shale Program, Morgantown, W. Va.

6. Dixon, Jeanette M. and Thomas H. Wilson, "The Parsons Cross Strike Structural Discontinuity as an Exploration Area for Fractured Gas Reservoirs," October 1979, Proceedings Third Eastern Gas Shales Symposium, METC/SP-79/6.

7. Shumaker, Robert C., et al., "Parameters of Geologic Structure which Affect Devonian Gas Shale Production in West Virginia and Eastern Kentucky - a Progress Report 1978-1979," October 1979, Proceedings Third Eastern Gas Shales Symposium, METC/SP-79/6.

8. Negus-de Wys, Jane and John J. Renton, "Inorganic Geochemical Studies of Eastern Kentucky Gas Field(s) and Comparison with Gas Production," October 1979, Proceedings Third Eastern Gas Shales Symposium, METC/SP-79/6.

9. Schaefer, William W., "Geology and Producing Characteristics of the Devonian Brown Shale Midway-Extra Field, Putnam County, West Virginia," 1979, Masters thesis, West Virginia University, Department of Geology and Geography, Morgantown, W. Va.

10. de Wys, Jane Negus and Robert C. Shumaker, "Pilot Study of Gas Production Analysis Methods Applied to the Cottageville Field," February 1978, DOE-Morgantown Energy Technology Center UGR File No. 101, 45 p.

11. Dixon, Jeanette M., "A Method to Identify Zones of Intense Jointing with Application to the Parsons Lineaments, West Virginia," April 1979, DOE-Morgantown Energy Technology Center UGR File No. 169, 46 p.

12. Shumaker, Robert C., "Porous Fracture Facies in the Devonian Shales of Eastern Kentucky and West Virginia," June 1978, DOE-Morgantown Energy Technology Center UGR File No. 099, 10 p.

PROBLEMS

Two problem areas have developed in our program over the past year. The first and most significant lies within our geophysical task effort, and the second relates to mounting a multi-spectral camera within the University aircraft.

Our seismic work is behind schedule because of instrumentation problems. When we purchased the Bison reflection seismic system nearly three years ago it was with the expressed purpose of using this portable model as a basic unit for building and developing a low-cost, high-frequency seismic system. We considered that a low-cost and high-frequency system was the only one that would be practical for locating fracture zones in a marginally economic venture such as exploration for Devonian shale gas. We have been successful in this endeavor to the extent of redesigning the system, shooting two test sites (Figure 1) and obtaining chart recordings of the data by the end of the second year. Hand copies of strip-chart plots were satisfactory so long as our interest centered on a few test sites that required short seismic spreads. Last fall we moved to the Cottageville field where longer lines were to be shot and much more data recorded. We started to use the Bison digital recorder to store our data. This digital recorder is an integral part of the purchased system. After a major effort to shoot our first long line at Cottageville we found, to our dismay, that the recorder was not

functioning properly. At that point we were on the edge of winter; so we decided to correct the problem during the winter and to reshoot the line in the spring. We spent most of the winter months shuffling the equipment back and forth to the Bison company. By early spring it was apparent that Bison either would not or could not make the necessary repairs to their own equipment. We redesigned the equipment and by early summer we had redrilled shot and phone holes, and we re-shot the line at Cottageville. We found, again to our dismay, that the firing mechanism for the Bison was malfunctioning, giving us a variable start-time for each shot point. Datuming each shot was impossible with this malfunction. Again after protracted discussions and shuttling of equipment back and forth to the Bison company, we redesigned and built a start system ourselves. At this point, we felt that the fracture anomaly seen on the strip-chart seismic record at Wetzel County (Test site II - Figure 1) was in doubt, and that the anomaly might be related to a delayed start time or malfunction in the equipment. We have returned to Wetzel County to re-shoot that line to verify the chart-plotted data. Seemingly, we have corrected the equipment problems, and we are finally collecting seismic data on digital tape.

While awaiting resolution of the equipment problems we designed, wrote, and tested a program for computer display digitally recorded seismic data. We successfully test-plotted our first undatumed line at Cottageville, but correlation of coherent seismic events is impossible. The quality of that seismic data is good, and we are encouraged by the high frequency (high resolution) recorded by the Bison system when compared with commercially recorded data. However, the recording system cannot sample the data in sufficient detail to characterize the entire record. In addition, there are insurmountable problems in recording near surface data in the reflection mode. We feel that recording a narrow time-slice of high-frequency shallow data is the most feasible approach to isolating a fracture zone with our seismic system.

The second problem area - that of mounting the multi-spectral camera in the University airplane - presents several problems that are not easily resolved. During the past year we searched, without success, for a West Virginia state aircraft that would readily accept the particular equipment we have on loan from NASA. We have purchased a kit for conversion of the University aircraft, but the cost of installation of that kit and the camera has risen astronomically. In addition, we have not been able to locate an installation contractor who is situated nearby. We may have to abandon our plans for mounting the multi-spectral camera in the University aircraft to attain our own imagery over selected sites of geological interest.

EDUCATION

All six principal investigators have made satisfactory progress toward obtaining advanced degrees in Geology at West Virginia University. Three of our former principal investigators are now employed in energy-related industry or governmental work. This fall, all principal investigators

working on the project and employed by DOE under this grant are enrolled half-time in graduate studies leading toward advanced degrees in Geology. In addition, several graduate students have been supported in part on an hourly pay basis for their part-time work on the project.

It is difficult to estimate the long term benefits that other University students will derive from DOE support. Clearly the use of equipment purchased with DOE funds will have a significant effect on future research.

EQUIPMENT

During the third year of the project the following major piece of equipment has been purchased:

Nikon SCB Labophote Microscope with Objective 4X, 10X, 40X, 100X and with Nikon PFM camera and Manual.

FINANCES

The responsibility for financial accounting for this grant lies with the comptroller of West Virginia University. Detailed financial reports are forwarded to DOE by the comptroller's office as separate reports.

PUBLICATIONS

Listed below are the titles of articles published during 1978-1979 which report the results of our research efforts.

We are including a copy of each manuscript written over the past year in the Appendices (see appropriate appendix by task title).

Titles of articles published in fiscal year 1978-1979

Beebe, Robert R., "A Study of Hydrogeologic Trends in Exploration for Devonian Shale Gas in the Midway-Extra Gas Field of Putnam County, West Virginia," 1979, Masters thesis, West Virginia University, Department of Geology and Geography, Morgantown, W. Va.

Berger, Philip S., "Extension Structures in the Central Appalachians," January 1979, Masters thesis, West Virginia University, Department of Geology and Geography, Morgantown, W. Va. (DOE-METC UGR File No. 159)

de Wys (see Negus-de Wys) "Eastern Kentucky Gas Field: Structural-Stratigraphic Cross Sections and Potential Production Patterns."

de Wys (see Negus-de Wys) "Trend Analysis of Gas Production in the Cottageville Field."

Dixon, Jeanette M., "A Method to Identify Zones of Intense Jointing with Application to the Parsons Lineament, West Virginia," Southeastern Section of Geological Society of America, Blacksburg, Virginia, April 25-28, 1979. (DOE-METC UGR File No. 169, 46 p.)

Dixon, Jeanette M., "Field Techniques for Measuring Joint Intensity," September 1979, West Virginia University, Department of Geology and Geography, Devonian Shale Program, Morgantown, W. Va.

Dixon, Jeanette M., R. L. Wheeler, Sally M. Holland, Byron R. Kulander, "Style Elements, Intensity, and Relative Ages of Joints on a Detached Anticline," 14th Annual Northeast Section of the Geological Society of America Meeting, Hershey, Pa., Abs. Vol. 11, No. 1, January 1979.

Evans, Mark A., "Fracture Density and Orientation Study of the MERC #1 Core from Monongalia County, West Virginia," June 1979, West Virginia University, Department of Geology and Geography, Devonian Shale Program, Morgantown, W. Va.

Jones, D. Scott and Dr. Henry W. Rauch, "Lineaments and Ground-water Quality as Exploration Tools for Ground Water and Gas in the Cottageville Area of Western West Virginia," October 1978, DOE-Morgantown Energy Technology Center, Morgantown, W. Va., METC/SP-78/6 Vol. 1.

Lee, Kevin D., "Fractures from Devonian Shale Outcrops Along the Pine Mountain Thrust," May 1979, West Virginia University, Department of Geology and Geography, Devonian Shale Program, Morgantown, W. Va.

Long, Brian R., "Regional Survey of Surface Fractures in Eastern Kentucky," June, 1979, Masters thesis West Virginia University, Department of Geology and Geography, Devonian Shale Program, Morgantown, W. Va.

Negus-de Wys, Jane, and R. C. Shumaker, "Eastern Kentucky Gas Field: Structural-Stratigraphic Cross Sections and Potential Production Patterns," October 1978, DOE-Morgantown Energy Technology Center, Morgantown, W. Va., METC/SP-78/6 Vol. 1.

Negus-de Wys, Jane, and R. C. Shumaker, "Relations of Gas Occurrence to Geologic Parameters in Eastern Kentucky Gas Fields," AAPG Annual Convention, Houston, Texas, April 1979.

Ms. Negus-de Wys chaired a session on Natural Gas Habitats at this AAPG Annual Meeting.

Negus-de Wys, Jane, and R. C. Shumaker, "Trend Analysis of Gas Production in the Cottageville Field," October 1978, DOE-Morgantown Energy Technology Center, Morgantown, W. Va., METC/SP-78/6 Vol. 1.

Nuckols, III, E. B., "Exploration Parameters Derived from Historical Devonian Shale Production in Western West Virginia," October 1978, DOE-Morgantown Energy Technology Center, Morgantown, W. Va., METC/SP-78/6 Vol. 1.

Ruotsala, James E., "Seismic Modeling," 10th Annual Appalachian Petroleum Geology Symposium, March 1979, Lakeview Country Club, Morgantown, W. Va. (Abstract - oral presentation.)

Shumaker, Robert C., et al., "Parameters of Geologic Structure Which Affect Devonian Gas Shale Production in West Virginia and Eastern Kentucky - a Progress Report 1978-1979," Proceedings 3rd Eastern Gas Shales Symposium, October 1979, US/DOE-Morgantown Energy Technology Center, Morgantown, W. Va., METC/SP-79/6.

Wilson, Thomas H., "Bedding Orientation Contours of Middle Devonian Shales Exposed in the Middle Mountain Syncline, Valley and Ridge Province, West Virginia," July 1979, West Virginia University, Department of Geology and Geography, Devonian Shale Program, Morgantown, W. Va.

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PART II

PRINCIPAL INVESTIGATORS' REPORTS

ON

RESOURCE INVENTORY TASKS

AND

SHALE CHARACTERIZATION TASKS

OBJECTIVES

The general objective of our project under contract DE-AC21-76MC05194 (formerly EY-76-C-05-5194) is to study the structural parameters of the Devonian shales that affect gas production in eastern Kentucky and West Virginia.

To that end our program is specifically designed to:

1.) Collect, compile, and analyze geologic data to construct regional structure maps of eastern Kentucky and West Virginia.

2.) Determine if structural types and styles affect production, and determine if minor structures as mapped in outcrop could influence production characteristics.

3.) Determine if shallow seismic surveys can detect near-surface faults and fracture zones, and if such structures can be detected, to further determine how fractures relate to both production from the shale and to lineations observed on remotely sensed data.

4.) Determine if a relationship exists between ground water movement and shale gas productivity.

Through the integration of our work with others it is our ultimate goal to discover if relationships exist between Devonian shale gas production and geologic structure. If such a relationship is established, we will attempt to develop a method or methods for selecting favorable sites to drill shale wells that have a greater potential for gas production than the norm for that region.

DELIVERABLE ITEMS

Certain items listed below are to be delivered in subsequent contract years and where appropriate several items may be delivered in the same report.

ITEM	STATUS
1. Geologic cross sections thru the eastern Kentucky gas field - 3 southwest-northeast 4 southeast-northwest	Complete
2. Isopach maps for the eastern Kentucky gas field area using ~300 wells of the: a. Bedford-Berea b. Cleveland-Undifferentiated Chagrin (?), black and gray intertonguing shales c. Chagrin-Three Lick d. Upper Huron e. Middle Huron f. Lower Huron	Complete
3. Map showing net thickness of Devonian shale sediments that have a Gamma Ray reading greater than 20 API units for the eastern Kentucky gas field area.	in progress
4. Structure contour map on the top of the Devonian Ohio black shale and base of the Huron shale for the eastern Kentucky gas field area using ~ 300 wells.	Complete
5. Preliminary initial open flow map based on 4750 gas wells in the eastern Kentucky gas field.	Complete
6. Structure contour maps of at least one reflection horizon in areas of resistivity and seismic surveys.	in progress
7. Brief report on seismic test site III, the Warfield fault, which should at least include a geologic cross section, complementary seismic section, shot point map, and subsurface structure or seismic time map on an identifiable seismic event. The report should identify seismic characteristics of the fault zone.	in progress
8. Summary report concerning the development of a petite seismic system and its application to exploration for shallow zones of fracture porosity emphasizing the recognition of porosity within the Devonian shale.	in progress

ITEM	STATUS
9. Regional maps showing core well locations: natural fracture orientation, mineralized fracture orientation, induced fracture orientation, in-situ stress direction, and trend of slickenside fractures (including slick direction and plunge) as determined from core analyses.	in progress
10. Individual reports on cored wells discussing relationship of fractures to local structural geology and gas production where data is available.	in progress
11. Report on the nature and origin of surface fractures in eastern Kentucky. Fracture maps showing orientation of surface fractures by lithology: sand, shale, limestone, and coal.	Complete
12. Map showing orientation of fractures above and below the Devonian shale of the Pine Mountain thrust.	Complete - open file
13. Preliminary report comparing the fractures mapped at the surface in the Pine Mountain thrust area and as compared to fractures logged in eastern Kentucky shale cores.	Complete - open file
14. A description of the characterization, interpretation and westward extension of at least one cross-strike structural discontinuity (CSD) in West Virginia.	in progress
15. A description of the development and methodology of intensity measurement for systematic joint systems and a discussion of outcrop joint system correlation with photolineament, CSD and subsurface structure patterns.	in progress
16. A report on the amount of bed-parallel extension faulting and fracturing in surface folds, including an assessment of the significance of these structural features in Devonian shale gas production.	Complete - open file
17. A model of shale fracture origin in specific areas of West Virginia and eastern Kentucky based on outcrop and core analysis. The model will include a statistical analysis of fracture and slickenside orientation data from cores.	research in progress
18. A report on the feasibility of using ground water occurrence and yield data as a tool for gas exploration based on data from the Midway-Extra gas field area. Also included will be a discussion on the correlation of ground-water yield and lineaments.	Complete

ITEM	STATUS
19. Maps of initial open flow characteristics related to various geologic conditions in the eastern Kentucky gas field analyses.	research in progress
20. A map of eastern Kentucky and West Virginia showing areas which have a high probability of Devonian shale gas production.	research in progress
21. A report of the structural characteristics of the surficial geologic units occurring in the eastern Kentucky gas field and in selected areas that do not have hydrocarbon production adjacent to it.	research in progress
22. A report on the correlation of geology, lineaments, fracturing, and oil and gas production.	research in progress

SCHEDULE OF MILESTONES

	MILESTONE	STATUS
1.	Complete deliverable item 1 - cross sections 1-15-79.	Delivered - open file
2.	Complete deliverable item 2 - isopach maps 300 pts. 9-15-79.	Delivered - open file
3.	Maps of API 20 units as described in deliverable item 3 9-30-79.	in progress
4.	Structure maps for Top of the Ohio shale and base of Huron using 300 pts. 7-15-79.	Complete
5.	Complete computer generated SYMAP contour of initial open flows for eastern Kentucky gas field 9-30-79.	Complete
6.	Pattern recognition study of eastern Kentucky initial open flow maps. Initiated 12-15-78 Completed 1-15-79	Complete
7.	Initiate trend analysis of initial open flow data for eastern Kentucky 2-15-79.	Complete
8.	Complete brief report on shallow seismic and resistivity surveys of a selected area of known faulting including geologic cross sections, subsurface structure map on at least one identifiable seismic event - Milestone 7 1-15-79.	Delayed
9.	Complete analysis of seismic and resistivity survey of Cottageville field outlining areas on seismic lines that indicate fracture porosity near the surface, and if possible, within the shale. Include also structure and isopach maps of key units shown on the seismic lines 5-30-79.	in progress
10.	Complete report on the design, development, and use of a high sensitivity shallow seismic tool and the results of this tool's use in a shallow producing area. Milestone 8 9-30-79.	in progress
11.	Complete a report on the use of resistivity equipment and interpret the results of resistivity surveys in selected ground water area 9-30-79.	Complete
12.	Initiate study of seismic shear waves to detect the position and trend of shallow zones of subsurface fracture porosity 10-1-78.	Complete

MILESTONE	STATUS
13. Complete brief report on feasibility of using a seismic refraction survey to detect any velocity anomaly associated with shallow fracture porosity, 1-15-79.	in progress
14. Design field procedure and obtain equipment to implement study described in Milestone 13, 2-1-79.	in progress
15. Initiate field testing of Method designed in Milestone 14 - at suitable test site, 6-1-79.	in progress
16. Brief report on results of velocity anomalies associated with shallow fracture zones described in Milestone 13, 9-30-79.	in progress
17. Maps showing trends of surface fractures for the eastern Kentucky portion of contract area including a differentiation of fracture domains and fracture orientation by lithology, 12-30-78.	Complete
18. Report on the nature and origin of surface fractures in eastern Kentucky, 9-30-79.	Complete
19. Initiate study of remote sensing data around cored wells to determine lineament patterns, 12-1-78.	in progress
20. Complete analysis outline in Milestone 19, 2-1-79.	Complete
21. Initiate remote sensing study of eastern Kentucky to determine lineament patterns, 2-1-79.	in progress
22. Complete analysis as described in Milestone 21, 5-1-79.	in progress
23. Initiate study of fracture data from Pine Mountain thrust area, 10-1-78.	Complete
24. Complete analysis of data described in Milestone 25 with results plotted in map form by both lithology and fracture domain. Also analyze fracture data to rate variation with distance above and below the Pine Mountain thrust, 2-1-79.	Complete
25. Initiate fracture study of Lincoln County cores, 10-1-78.	Complete
26. Complete Milestone 25, 12-1-78.	Complete
27. Develop methods of bedding orientation analysis to 1) serve as a tool in mapping the structures present in the poorly exposed, mechanically incompetent black shales, and 2) provide an objective sampling rationale for the analysis of fracture orientation and spacing data collected in CSD's. Final report - 7-1-79.	Complete

MILESTONE	STATUS
28. Manuscript reporting results of an investigation of the Parsons lineament, to determine whether some Middle and Upper Devonian clastic rocks are more intensely fractured in the lineament than elsewhere, 1-1-79.	Complete
29. Map the Middle Devonian shales exposed in an area of the eastern outcrop belt where these shales are intersected by the Parsons CSD to examine any structural relationships to the CSD. Final report 9-1-79.	Complete
30. Contour maps of measures of joint intensity in an area containing part of the Parsons lineament, 12-1-78.	Complete
31. Report describing the field technique developed to rapidly estimate the surface area of systematic joints per unit volume of rock in a given locality, and evaluation of operator variability. Due 9-30-79.	Complete
32. Collect fracture data in the Middle Devonian black shales exposed in the eastern outcrop belt where these shales are intersected by the Parsons cross-strike structural discontinuity. Examine differences in fracture orientation and spacing. Relate these differences to the various structural elements present (i.e., folding, faulting, the CSD). Determine which differences (if any) can only be explained by the CSD. Final report 11-1-79.	Complete

Science Applications, Inc. (SAI) is providing technical support to DOE/METC by coordinating and reporting of certain EGSP technical work areas; therefore, it is necessary to incorporate the following provision into this contract (DE-AC21-76MC05194 - formerly EY-76-C-05-5194).

> The work to be performed under this contract is subject to monitoring by W. George Fingleton from the Morgantown office of Science Applications, Inc., or such other persons as designated in writing by the Contracting Officer. The designated individual's responsibility will be to assist the DOE/METC Technical Project Officer (TPO) in coordinating with the Contractor for purposes of administering the detailed technical aspects of this contract. The SAI representative does not have the authority to make any commitments or authorize any changes which affect the contract price, terms, or conditions; any such changes shall be referred to the Contracting Officer for action.

All nonconfidential data generated will be submitted for computer storage to DOE/EGSP.

3.1 Work Package 2100-2-1 REGIONAL STRUCTURE STUDIES Robert C. Shumaker

3.1.1 Current status of work and scheduled deliverables

We have compiled data on the structural tops for the Huron and Corniferous formations from drillers' logs for eastern Kentucky. Approximately 4500 wells have been abstracted.

We have constructed a detailed regional structure map on Top of the Berea sandstone for the area between the Cottageville and Midway-Extra fields of West Virginia (Figure 1). We have found a basement fault that is expressed as a low relief monoclinal flexure that connects the two fields, and presumably this trend has shale gas exploration potential. In our detailed analysis of these two fields we have found that the production relationship to structure is very similar. The detailed analysis of these relationships are given in "Parameters of Geologic Structure Which Affect Devonian Gas Shale Production in West Virginia and Eastern Kentucky - a Progress Report 1978-1979," Shumaker, et al. (Proceedings volume Joint EGSP-ES/AAPG Symposium, October 1979) and "Geology and Producing Characteristics of the Devonian Brown Shale Midway-Extra Field, Putnam County, West Virginia," W. W. Schaefer (Masters thesis 1979, West Virginia University).

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for fiscal year 1979-1980

During the upcoming year we will initiate and complete a detailed structural map on two horizons along the east flank of the large Warfield anticline in the area of fracture domaine changes as outlined by Kulander.

We will start to compile final versions of regional structure maps for the project area. These maps will be compiled on a base scale of 1:500,000 so that a complete picture of the basin can be had. This complete picture is required if we are to form a basis for regional comparison with other shale parameters.

* * * * * *

3.1 Work Package 3200-5-1 PRODUCTION STUDIES — J. Negus-de Wys

This report considers work completed under:

3.1 Work Package 2100-1-1 CROSS SECTIONS,
3.2 Work Package 2100-1-2 ISOPACH MAPS,
3.3 Work Package 2100-2-1 STRUCTURE CONTOUR MAPS, and
3.4 Work Package 3200-4-1 OIL AND GAS MAPS

Work completed under these tasks is reported and summarized in the three papers to be given at the Lakeview meetings in October.

Copies of the Lithology Studies paper and Geochemistry Studies paper accompany this report.

A copy of the Introduction, Figures, and Conclusions of the Plate Tectonics paper is included. This paper relates the structural setting and sequence to gas occurrence (open flow data) and possible fracture trends.

Well cuttings from thirteen wells in the Eastern Kentucky Gas Field were studied under a binocular scope. Descriptions and cross sections were constructed. The shale was divided into black, brown, gray, and green. Lithofacies maps were drawn, and are suggestive of different source directions for the different lithologies. Fracture indicators were noted and contoured. The resultant configuration compares strikingly with the density contours of high producing wells. Density of high producing wells related most closely to 1) fracture frequency, 2) brown shale lithology, and 3) the Middle Huron stratigraphic unit. The complex intertonguing of siltier units of shale with less silty but highly organic facies may be a factor in gas production, and contribute to a "fracture facies."

A bentonite is observed to occur at the base of the Cleveland and is referred to as the "Big Sandy" Bentonite. Basinal subsidence appears to have increased following both the Tioga (below the Huron) and the "Big Sandy" bentonites.

Geochemistry was studied from the same well cuttings. Elemental and mineralic analyses are presented for the state of present research. The Si/Al is one of the best indicators or predictors of density of high producing wells. However, other elements also show an excellent match. The mineralic data is useful in paleogeographic and paleoenvironmental reconstructions. Computer-drawn maps are presented as examples of how these analyses may be used.

It has been proposed to continue work on this promising approach to gas field analysis and exploration. With further proposed analysis of the data it is anticipated that structural prediction may be possible, as well as areas of greatest gas accumulation.

3.1 Work Package 3200-5-1 PRODUCTION STUDIES J. Negus-de Wys

continued -

In the third paper, which is to be presented orally, the structural trends and development in the field area are related to present plate tectonics concepts. Open flow trends are then compared with these structural features. A 3-D computer-drawn map of the open flow data in the center of the field shows the striking northeast-southwest trend of high production. It is planned to use this mapping method for later map predictions of the geochemical data, if the necessary funding is provided.

* * * * * *

As this report is being prepared for submission, word has been received of funding approval.

3.1 Work Package 2100-1-1 SEISMIC — James E. Ruotsala

3.1.1 Current status of work and scheduled deliverables

The past year has been a time of continuing development of a seismic reflection system based on the Bison, Inc., model 1580 seismograph and re-evaluation of project goals and past performance with respect to the geophysical tasks.

On the positive side, the University has demonstrated a commitment to continuing geophysical research in the addition of a geophysicist at the assistant professor level to the Department of Geology and Geography in March of this year. In addition, technical support for geophysical research has been greatly increased by a senior-level electronics technician hired through the College of Arts and Sciences Technical Services Staff in August.

One half mile (about 100 traces) of reflection seismic data was recorded by Keith Kirk in the Cottageville gas field in the spring of 1979. These data were transcribed to nine-track tape and plotted. The data were observed to suffer from a severe time correction problem due to the large uncertainty of the starting time (zero-time) for each 6 trace record. A circuit purchased from Bison, Inc., was used to start the seismograph on the arrival of the direct event from the shot to a geophone above the shot (the "uphole phone"). This circuit has never worked properly, and it is not a satisfactory way to determine zero-time even if it does work. The best way to establish zero-time is at the initiation of the explosion, the falling edge of the current pulse through the blasting cap. An Electrical Engineering graduate student was hired to build the necessary hardware late last spring, but it wasn't until we hired our own technician that the unit was built.

Although the Cottageville data are uninterpretable as a seismic section, it is littered with reflections, recognizable geologically on some of the 6 trace records. Figure 3 shows a comparison of commercially available VIBROSEIS* data (recorded by Geophysical Services, Incorporated) and the West Virginia University data, both from the Cottageville gas field. The WVU data is severely aliased at 1 kHz, indicating significant signal energy up to perhaps 3kHz. The resolution of the WVU data is an order of magnitude better than the GSI VIBROSEIS data.

On the negative side, reexamination of the data from the Pricetown underground coal gasification site (Wetzel County) shows that the

* Trade mark of Conoco, Inc.

3.1 Work Package 2100-1-1 SEISMIC - continued J. E. Ruotsala

3.1.1 Current status of work and scheduled deliverables - continued

data and the interpretation are faulty. Those data and the interpretation were published in last year's Annual Report by Keith G. Kirk. A new interpretation of that data is appended to this report. The implication of this discovery is that no seismic reflection profile has yet been acquired, and no deliverables or milestones requiring such data have been completed.

3.1.2 Problem areas and suggested improvements

Performance of the geophysical tasks under this project has been hampered by a lack of support personnel, both professional and technical. Within the past year substantial improvements have been made in this area with the addition of a geophysicist and a technician to the Department. However, other serious problems remain.

The problems presently contemplated can be roughly separated into two groups: those related to data acquisition, and those related to data analysis. Problems related to data acquisition are discussed in this paragraph. It is well known that the amplitude of a seismic pulse will diminish in proportion to the distance it travels, simply because its energy is distributed on a hemispherical surface whose radius is the distance traveled. This is a purely geometrical effect. In fact the amplitude diminishes even more rapidly with absorption by earth materials, and as it is partially reflected at subsurface acoustic impedance changes. Because of this effect a reflection seismograph must be able to record both large and small amplitude signals. This property is measured in terms of the system's dynamic range. The dynamic range of the Bison seismograph is less than 48 decibels (dB), meaning that it can never record two signals whose amplitude ratio exceeds 256:1. But the situation is even worse because some part of the dynamic range must be reserved to record the signal wave form, at least 24 dB, so that reflection events must have amplitude ratios less than 16:1 to be properly recorded. This is a minimal situation: it would not be excessive to reserve the entire 48 dB range for the wave form. The amplitude of a reflection event is directly proportional to the reflection coefficient of the interface from which it originates. Since the range of reflection coefficients is at least 8:1, one needs 18 dB of dynamic range reserved to recover reflection events from reflectors within an adequate range of reflection coefficients. A further reservation must be made to allow for the less-than-optimum operating conditions encountered in practice, leaving less than 6 dB (2:1) for the geometric effect. In applications of the seismic reflection method, the system dynamic

3.1 Work Package 2100-1-1 SEISMIC - continued J. E. Ruotsala

3.1.2 Problem areas and suggested improvements - continued

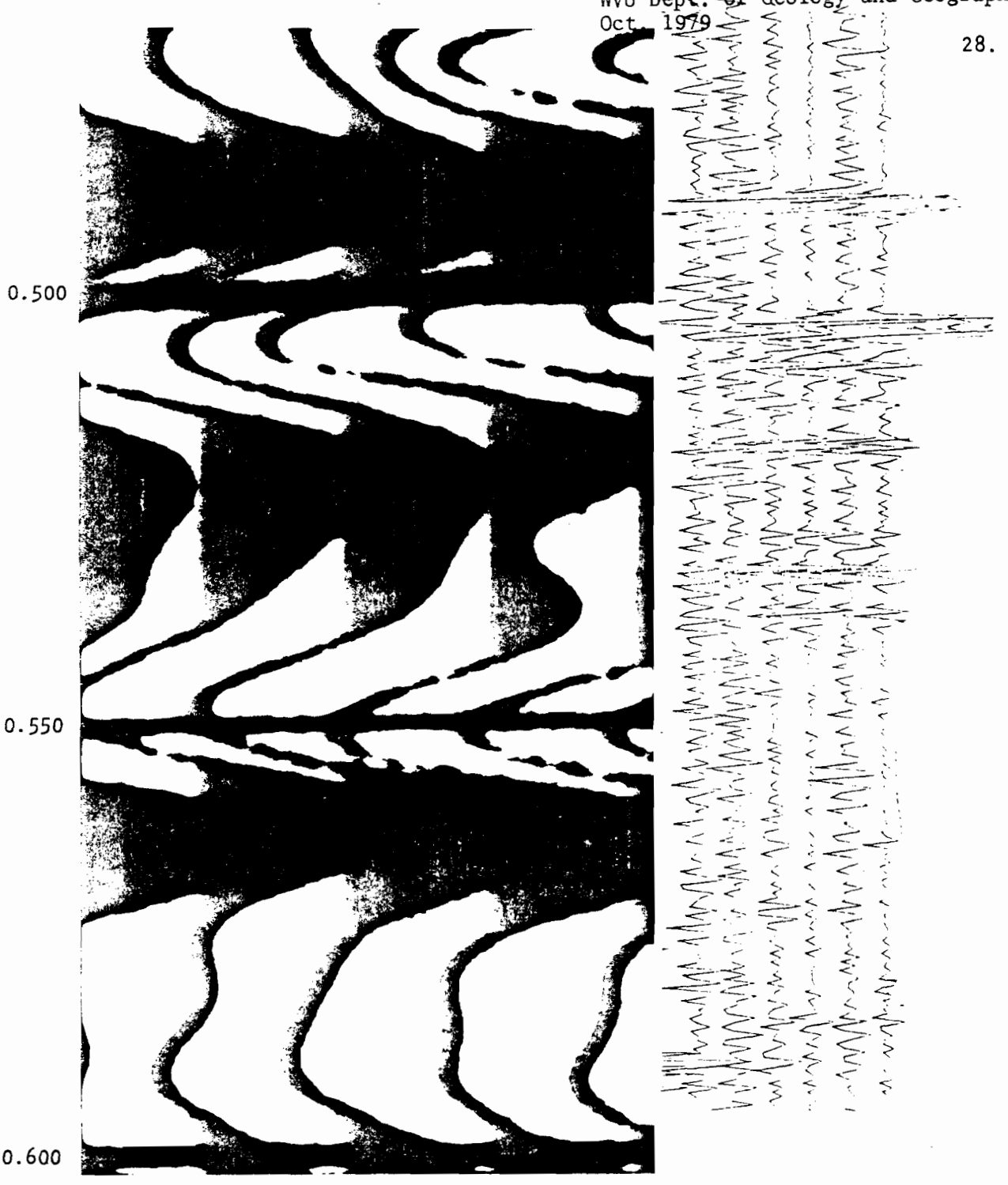
range limits the range of depths that can be investigated. There are other considerations, and in practice the depth range is somewhat site-dependent. Experiments at the Pricetown site indicate that adequate data may be obtained at depths from 350 to 1000 feet, although that is an estimate, yet to be confirmed.

The second class of problems relates to data analysis. The detection of fracture zones, and the presence of gas in the pore-space by seismic methods depends on the detection of reduced acoustic velocity, or a characteristic change in the wave form of the seismic pulse within the target area. Either of these will require the most sophisticated methods of seismic data processing. Since March, much time has been spent evaluating the West Virginia computing network (WVNET) in anticipation of the data processing which will be required when the seismograph is ready for use. The results of that evaluation are very discouraging. WVNET is an antiquated system, organized primarily for administrative record keeping. It is entirely inadequate, under present operating policies, for the computations necessary in the analysis of even small seismic data sets. While a "major" system up-grade is presently underway, the changes presently contemplated are of little consequence in applications requiring large calculations and graphic data display. The new plotter has been made available to this project on an experimental basis, and has been tested using data from the Cottageville gas field. It is of an old design, and obsolete in geophysical terms. Also, when it is fully implemented the cost of using it will be very high, perhaps $20,000 for the plotting charges alone to process a seismic line from Cottageville, based on rates currently contemplated by WVNET. That amount exceeds the purchase price of the plotter, and the supplies necessary to operate it.

3.1.3 Work plan for fiscal year 1979-1980

After modifications are made to the input amplifiers of the Bison seismograph and several minor repairs are complete, the system will be field tested at the Pricetown II site (Wetzel County). Work at Pricetown is tentatively scheduled for October 13. Judgment will be made at that time on the capabilities of our current equipment. This will determine what work will be done at Cottageville. The field work at Cottageville (reflection survey, if feasible; refraction survey, if shown feasible by the model studies) will probably begin next spring. The problem of data processing will be further studied in anticipation of data being collected from the Pricetown test site and Cottageville.

* * * * * *



TWO WAY TRAVEL TIME (seconds)

GSI data

there are two reflection events between 0.490 to 0.550 seconds

WVU data

there are at least 5 reflection events between 0.490 to 0.550 seconds

Figure 3

3.1 Work Package 2100-2-2 STRUCTURE STUDIES — Thomas H. Wilson

3.1.1 Current status of work and scheduled deliverables

1. A three phase study of surface structures in Middle and Upper shales in the Middle Mountain syncline of the Valley and Ridge Province, Pendleton County, West Virginia, has been completed. The study included the following: 1) detailed mapping of the Middle Mountain syncline, 2) an analysis of bedding orientation contours of the syncline, and 3) a study of the orientations and spacings of systematic joints in the shales of the syncline. The studies were designed to characterize the Parsons cross-strike structural discontinuity in the Valley and Ridge Province in terms of observable structure.

2. Fifty five additional gravity stations were occupied in Pendleton County, Tucker County, Randolph County, and Grant County, West Virginia. These stations will be used in later gravity modeling of balanced cross sections along the length of the Parsons structural lineament.

3. Gravity modelling of existing cross sections has begun.

4. An analysis of the USGS's aeromagnetic data of West Virginia has been initiated.

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for fiscal year 1979-1980

1.) Balanced cross sections will be constructed through the Appalachian Plateau along the length of the Parsons structural lineament.

2.) The gravitational fields of these cross sections will be modeled and compared with the gravity survey of Byron Kulander and Stuart Dean.

3.) Second vertical derivatives of the magnetic intensity data will be calculated for West Virginia.

4.) Write final report on project.

* * * * * *

3.1 Work Package 2100-2-2 STRUCTURE STUDIES — Jeanette M. Dixon

3.1.1 Current status of work and scheduled deliverables

Parsons Lineament Fracture Study, Tucker County, West Virginia: From October, 1978, through April, 1979, analyses of joint data gathered in Tucker County were completed. The results were published as a deliverable and are on file under the title "A Method of Measuring Joint Intensity with Application to the Parsons Lineament."

Petersburg Lineament Fracture Study, Grant and Pendleton Counties, West Virginia: In June, 1979, joint data was gathered along the Allegheny Front to determine: (1) if rocks in the Petersburg Lineament are more intensely fractured, and (2) how the Lineament affects rocks with depth. Analysis of data has been completed and will be published in the final report in January, 1980.

Westward Extensions of Lineaments Study: Pennsylvanian rocks in Taylor, Barbour, and bordering counties were examined to determine whether or not the Parsons and the Petersburg Lineaments extended westward onto the Plateau. Results of this study will be published in the final report in January, 1980.

Coal Cleat Intensity Study: Two coal seams in a roadcut on Route 48, Monongalia County, West Virginia, were examined to determine: (1) if differences in cleat intensities could be measured and (2) what affect an overlying stream channel has on cleat intensities. Being able to detect variations in cleating intensity may be useful in mine roof falls, pillar strength, and other mining problems. Results of this study will be published in the final report in January, 1980.

Operator Variance Study: Four operators measured three outcrops for joint intensity in order to determine how much, if any, variation in measurements would exist between operators. The results of this study will be published as a deliverable item October, 1979.

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for fiscal year 1979-1980

Complete the final report due September, 1980.

* * * * * *

3.1 Work Package 2200-1-2 FRACTURE DENSITY AND ORIENTATION Mark A. Evans

3.1.1 Current status of work and scheduled deliverables

Examination of thirteen oriented Devonian shale cores from the Appalachian Plateau revealed considerable deformation at depth in the form of fracturing and shearing. The core wells are located in Mason County, WV; Monongalia County, WV; Jackson County, WV; Wetzel County, WV; two from Lincoln County, WV; Allegheny County, PA; Carroll County, OH; Washington County, OH; Wise County, VA; Perry County, KY; Johnson County, KY; and Martin County, KY. Fracture frequency and orientation measurements were made on the fractures in each core. Fractures were differentiated (when possible) into core-induced fractures, unmineralized natural fractures, mineralized natural fractures, slickensided fractures, and slickenlines.

Core-induced fracture orientations exhibit an extreme consistency with depth in a particular core. They are also quite consistent regionally in that they all generally have a northeast trend. This consistency indicates the presence of a stress or rock fabric anisotropy which in turn may be related to an east to northeast trending maximum in-situ compressive stress (Sbar and Sykes, 1973).

One natural fracture trend found in most of the cores studied is orthogonal to the Appalachian trend and swing with that trend into the Southern Appalachians. These fractures probably formed as extension fractures under tectonic compressive stresses. Another natural fracture set found in most of the cores parallels the core induced fractures and probably formed in relation to the same stress or fabric anisotropy. Other, less prevalent, natural fracture sets also exist but show relationship only to local structures.

The presence of slickensides in most cores studied is evidence for slip plane and decollement movement in the Plateau. Decollement movement was found to have occurred in Allegheny County, PA; Monongalia County, WV; Wetzel County, WV; Lincoln County, WV; Wise County, VA; and possibly in Johnson County, KY; Martin County, KY; and Perry County, KY. Most displacement can be related to Alleghenian deformation.

Fracture frequency between cores revealed the existence of several fracture facies. These fracture facies are generally stratigraphically controlled. Natural fracture facies are the Marcellus Shale, Tully Limestone, Geneseo Shale, West Falls Formation, and Lower Huron Member of the Ohio Shale. Slickenside fracture facies are usually decollement zones and include the Marcellus Shale, Tully Limestone, Geneseo Shale, West Falls Formation, base of the Java Formation, and Lower Huron and Cleveland Members of the Ohio Shale.

3.1 Work Package 2200-1-2 FRACTURE DENSITY AND ORIENTATION M.A. Evans

3.1.1 Current status of work and scheduled deliverables - continued

A small slip plane was found to exist near the base of the Lower Huron in nearly all cores which included this unit. Throughout most of the Plateau, displacement along this slip plane has a general northeast-southwest trend.

Dramatic differences in fracture patterns were found between two adjacent core wells in Lincoln County, WV. The wells are located over the Rome Trough and may have been under the influence of two different stress fields when fracturing occurred. This is consistent with the findings of Kulander and Dean (1978) who found chaotic fracturing in coals over a Rome Trough basement fault zone.

A core from a well located near a possible basement fault in Allegheny County, PA, exhibits a wide variety of fracture patterns that do not seem to be related to structures in that area. This anomolous fracture pattern is also consistent with the findings of Kulander and Dean (1978).

A final report on the fractures in the thirteen cores is nearly complete. A first draft is finished and drafting of illustrations has begun.

Kulander, B. R., and Dean, S. L., 1979, ms, Rome Trough Relationship to Fracture Domains, Regional Stress History and Decollement Structures: (in review for Proc. of the Southeast Section Geol. Soc. of America Symposium on Western Limits of Detachment and Related Structures in the Appalachian Foreland).

Sbar, M. L. and Sykes, L. R., 1973, Contemporary Compressive Stress and Seismicity in Eastern North America: an Example of Intro-Plate Tectoncs: Geol. Society of America Bull., v. 84, p. 1861-1882.

3.1.2 Problem areas and suggested improvements

No problems.

3.1.3 Work plan for fiscal year 1979-1980

Complete final report on fracturing in oriented Devonian shale cores from the Appalachian Plateau as well as complete drafting of illustrations. Two or more detailed reports on core fractures are also planned.

* * * * * *

3.1 Work Package 2200-1-2 FRACTURE STUDIES — Kevin D. Lee

3.1.1 Current status of work and scheduled deliverables

A report entitled "Fractures from Devonian Shale Outcrops Along the Pine Mountain Thrust" was completed using data collected during the summer of 1978.

More field work was done in the spring of 1979 at Jenkins, Kentucky, on joint occurrence in the thrust zone of Pine Mountain at the base of the Devonian shale. A postulated theory as a result of my field work is that joint occurrence in the thrust plane is derived from a combination of regional compression and local shearing.

The summer of 1979 was spent at Kentucky-West Virginia Gas Company in Prestonsburg, KY, recording structural tops from drillers' logs in the Big Sandy gas fields of eastern Kentucky. Approximately 4,500 drillers' logs were recorded. Work is now proceeding on three structure contour maps to be constructed from those drillers' logs.

3.1.2 Problem areas and suggested improvements

Finding a quicker way to get reimbursed for field expenses would be a blessing.

3.1.3 Work plan for fiscal year 1979-1980

Finish my maps by January 1, 1980, and complete my thesis by June 30, 1980.

* * * * * *

3.2 Work Package 3200-2-3 SUBSURFACE GEOLOGY — Henry W. Rauch

Subtask - Identify 3 areas in which to conduct ground water studies.

3.1.1 Current status of work and scheduled deliverables

Ground-water studies have been initiated and completed in two areas: the Cottageville area of Jackson County, West Virginia (see Annual Report for 1978 for results), and the Midway-Extra area of northern Putnam County, West Virginia (see the second Volume of this 1979 Annual Report for results).

3.1.2 Problem areas and suggested improvements

Our only problem is that METC-DOE failed to extend us continued support for fiscal year 1980, making it impossible to select a third area for a third ground water study.

3.1.3 Work plan for fiscal year 1980

No work is planned under U.S. government sponsorship. Instead, private funding has been arranged to carry on our research.

* * * * * *

3.2 Work package 3200-2-3 SURFACE RESISTIVITY — H. W. Rauch

Subtask - Conduct resistivity surveys over ground water study areas (defined under 3200-1-2).

3.2.1 Current status of work and scheduled deliverables

As was emphasized in previous reports, including that for fiscal year 1979, less stress has been put on resistivity surveying in favor of other more fruitful research aspects. Resistivity survey results have been accordingly included under other tasks: 3200-5-1 and 3200-5-3.

* * * * * *

3.3 Work Package 3200-5-1 STRUCTURE/PRODUCTION CORRELATION H. W. Rauch

Subtask - Correlate all data and attempt to establish a relationship between geologic features, lineaments, fractures, ground water, and oil and gas production.

3.3.1 Current status of work and scheduled deliverables

All work has been completed for the second ground-water study area - the Midway-Extra area of Putnam County, West Virginia. The final project report consists of Robert Beebe's M.S. thesis and a paper authored by Beebe and Rauch for the 3rd EGSP conference at Lakeview, Morgantown, West Virginia; copies of both are included in the second volume of this report.

3.3.2 Problem areas and suggested improvements

None. See task 3200-1-2 report above.

3.3.3 Work plan for fiscal year 1980

See report for task 3200-1-2 above.

* * * * * *

3.4 Work Package 3200-5-3 LINEAMENT/STRUCTURE CORRELATION H. W. Rauch

Correlate fractures and lineaments derived from photo analysis with results of ground water tests to determine if any relationship exists between ground water production and the occurrence of lineaments.

3.4.1 Current status of work and scheduled deliverables

See report for task 3200-5-1 above.

3.4.2 Problem areas and suggested improvements

None. See task 3200-1-2 report above.

3.4.3 Work plan for fiscal year 1980

See report for task 3200-1-2 above.

* * * * * *

UGR File #C048/A79, v.2
WVU Dept. of Geology & Geography
Oct. 1979
C048/A79, V.2

West
Virginia
University

AN ANALYSIS OF THE STRUCTURAL PARAMETERS THAT INFLUENCE GAS PRODUCTION FROM THE DEVONIAN SHALE

VOLUME II: DATA REPOSITORY AND REPORTS PUBLISHED DURING FISCAL YEAR 1978-1979

Dept. of Geology & Geography
College of Arts & Sciences
Morgantown, W. V. 26506

ANNUAL PROGRESS REPORT

October 1979

U.S. Department of Energy
Contract number ~~DE-AC21-76MC05194~~
formerly EY-76-C-05-5194

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Oct. 1979

DATA AND FIGURES OF ALL APPENDICES

ARE AVAILABLE IN ORIGINAL SCALE AT REQUEST

APPENDIX A

Regional Structure Data

1978 - 1979

Robert C. Shumaker

WVU Dept. of Geology & Geography
Oct. 1979

PARAMETERS OF GEOLOGIC STRUCTURE WHICH AFFECT DEVONIAN GAS SHALE PRODUCTION IN WEST VIRGINIA AND EASTERN KENTUCKY - A PROGRESS REPORT 1978-1979

by

R. C. Shumaker, Project Director
Devonian Shale Program

co-authored by

R. R. Beebe, J. Negus-de Wys, J. M. Dixon, M. A. Evans, K. G. Kirk,
K. D. Lee, B. R. Long, H. W. Rauch, J. E. Ruotsala, W. W. Schaefer,
R. L. Wheeler, R. T. Williams, T. H. Wilson

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Dr. Shumaker is director of the West Virginia University - Department of Energy contract investigating the structural parameters that influence Devonian shale gas production. Drs. Wheeler, Williams, and Rauch direct the surface structure studies, geophysical, and ground water studies of this program respectively. Dr. Wheeler is presently with the U. S. Geological Survey, Denver, Colorado. All principal investigators were enrolled in the graduate studies program at West Virginia University during the 1978-79 academic year.

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Robert R. Beebe, B.S. Northeastern University 1976, Boston, Massachusetts
- Hydrology (completed 2 years, M.S. candidate) presently with Exxon, Corpus Christi, Texas

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Jeanette M. Dixon, A.B. Baylor University 1970, Waco, Texas; M.S. University of Akron 1976, Ohio
- Surface Structure (2nd of 3 years, Ph.D. candidate)

Mark A. Evans, B.S. West Virginia University 1978, Morgantown, West Virginia
- Subsurface Fractures (1st of 2 years, M.S. candidate)

Keith G. Kirk, B.S. Penn State University 1973; M.S. West Virginia University 1976
- Geophysics (completed 3 years, Ph.D. candidate) presently with U.S.G.S., Denver, Colorado

Kevin D. Lee, B.S. West Virginia University 1978
- Regional Structure (1st of 2 years, M.S. candidate)

Brian R. Long, A.B. Alfred University 1971, Alfred, NY; M.S. West Virginia University 1979
- Fractures - Eastern Kentucky (completed 2 years, M.S.) presently with W. Va. Department of Natural Resources, Charleston, W. Va.

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ABSTRACT

Major accomplishments during 1978-1979 include:

1. Production studies: A recognition that the best production (fracture porosity) occurs in synclines, off structure, in two West Virginia fields. Two exploration rationales developed from this study. Continued accumulation of basic geologic, geochemical, and production data for the large Eastern Kentucky Shale Gas Field is in preparation for an integrated analysis.

   Studies using XRF and XRD on well cuttings from 14 wells in eastern Kentucky yielded elemental data for 12 elements and mineralogical data for 16 minerals. A high correlation was found between contoured averages of seven elements and density contours of high producing wells (final open flow).

2. Surface structure: A technique was developed to estimate the fracture intensity in areas of limited rock exposure, and a study continues of Devonian shale deformation along a cross-strike structural discontinuity that intersects an Appalachian Valley and Ridge fold.

3. Fracture studies: Surface fractures of eastern Kentucky showed diverse trends dependent on lithology. Predicting the trends of subsurface fractured reservoirs from surface fracture trends is hazardous in areas of detached deformation. Natural fractures and induced fractures were logged and summarized for Devonian shale oriented cores taken in Mason County and Monongalia Counties, West Virginia. Gas shows in these two wells relate to partially mineralized fractures. Some 13 Appalachian Basin cores are described.

4. Hydrology: The comparison of shallow ground water productivity and quality with production from shale gas wells within the Midway-Extra field was completed, and there is a correlation of gas production with one low-altitude photo lineament trend.

5. Geophysics: Several seismic and resistivity techniques were tested to evaluate what method can best detect shallow fractures. These techniques are being applied to the Cottageville, West Virginia, field area to determine if shallow geophysical techniques are useful in determining fracture production trends.

INTRODUCTION

Most of the research tasks in our program, outlined below, reached or exceeded a two year level of effort this October, so that we are now beginning to reap benefits from our research efforts concerning the origin of fracture porosity in the Devonian shale of the study area (Figure 1). By the time of this third annual meeting of the Eastern Gas Shales Project and the publication of the Preprint volume, we will have completed five separate studies which relate fracture porosity and structural parameters; these include: two production studies which document the effect of geologic structure on production in specific West Virginia shale gas fields, the Cottageville and Midway-Extra fields, a third study which documents surface fractures in eastern Kentucky, a hydrologic study which compares shallow water well productivity and quality with shale gas production from the Midway-Extra field, and finally we completed a study on fracture porosity related to tectonic thinning and shale flowage as studied in selected folds of the Appalachian Plateau and Valley and Ridge physiographic-structural Provinces.

In the first part of this report we introduce the objectives and organization of our contract for those unfamiliar with its background. We then briefly summarize progress made toward attaining these objectives.

One important subject not covered in a referred paper includes work which the senior author considers to be a major breakthrough in understanding the origin of the fracture porosity in commercial shale gas wells that are located near the periphery of commercial production in West Virginia (Figure 1). This understanding is most significant to the Eastern Gas Shale Program; so we will place our emphasis in this text on a description of the examples and the data on which we base our conclusions. We believe that the results of our work on fracture porosity in shale also have application to other tight reservoirs, particularly in exploration for fractured tight reservoirs of the mid-continent region, an area where basement tectonics dominates. The senior author emphasizes this model developed through an integrated approach where the efforts of the following people have been essential: Mr. E. B. Nuckols III's effort in collecting the data at the Cottageville field (1976[1] and 1978),[2] Mr. William W. Schaefer's investigation and report on the Midway-Extra field (1979),[3] Mrs. Jane Negus-de Wys' analysis of production data from the Cottageville field (de Wys and Shumaker, (1978)[4] and Mr. Glenn R. Sundheimer's excellent seismic interpretation of the Cottageville field area (1978).[5] This integration of work and the extrapolation of ideas is the responsibility of the senior author.

OBJECTIVES

The general objective of our research funded under United States Department of Energy Contract number DE-AC21-76MC05194 (formerly EY-76-C-05-5194) is to study the structural parameters of the Devonian shales that affect gas production in eastern Kentucky and West Virginia (Figure 1).

To that end our program is specifically designed to:

1. Collect, compile, and analyze geologic data to construct regional structure maps of eastern Kentucky and West Virginia.

2. Determine if structural types and styles affect production and influence production characteristics.

3. Determine if shallow seismic surveys can detect near-surface faults and fracture zones, and if such structures can be detected, to further determine how fractures relate to both production from the shale and to lineations observed on remotely sensed data.

4. Determine if a relationship exists between ground water movement and shale gas productivity.

Through the integration of our work with others, it is our ultimate goal to discover if relationships exist between Devonian shale gas production and geologic structure. If such a relationship is established, we will attempt to develop a method or methods for selecting favorable sites to drill shale wells that have a greater potential for gas production than the norm for that region.

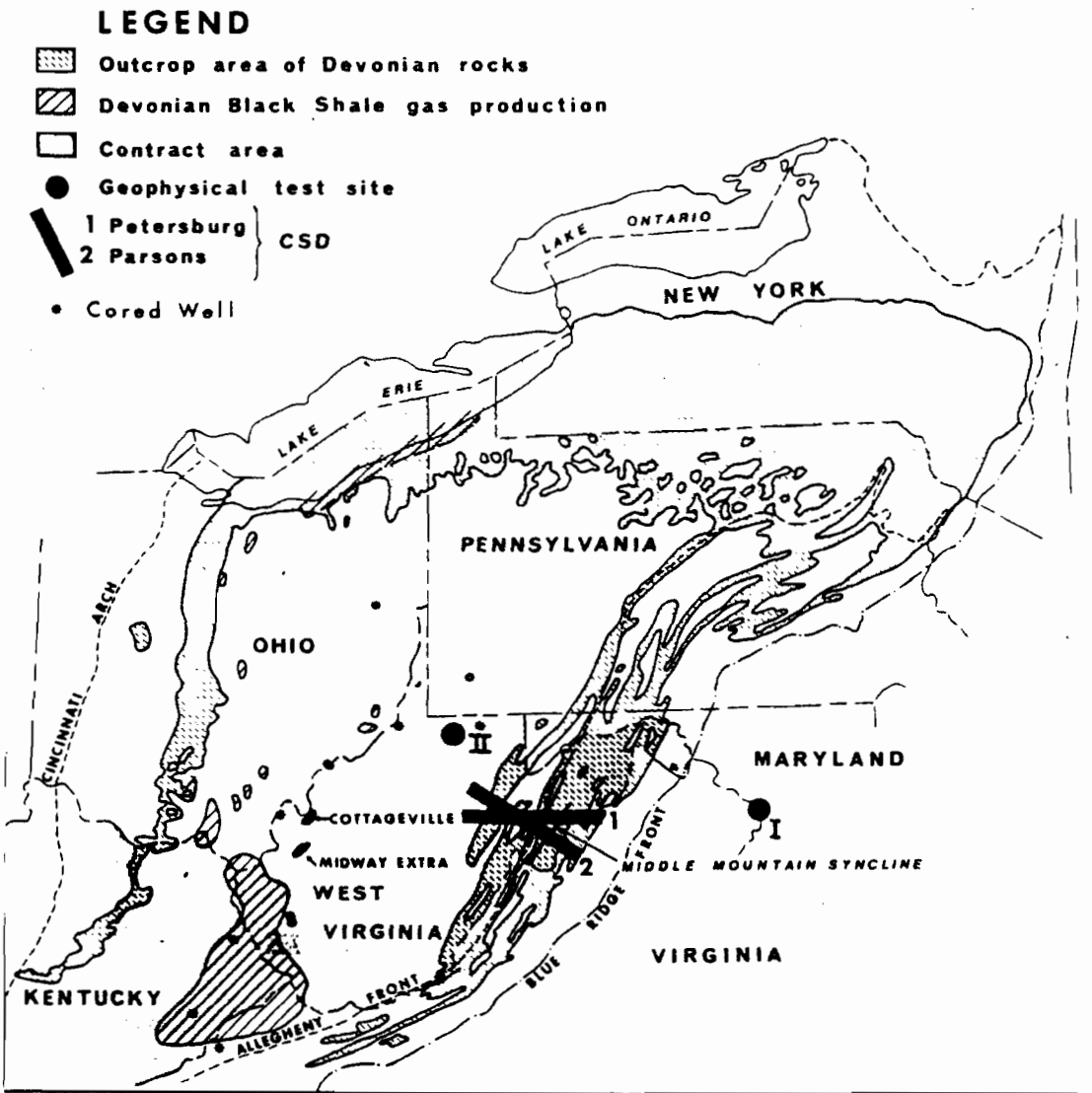


Figure 1 Index Map - Structural Parameters that Affect Devonian Shale Gas Production

ORGANIZATION

In order to attain the stated objectives we have designed several tasks which have been organized into five study groups. Four of these groups: regional structure studies, fracture studies, structural type studies, and production studies, are carried under the U.S.D.O.E.'s Resource Inventory Tasks. One group, geophysical studies, is carried under Shale Characterization Tasks.

In essence, the first two tasks, that is the regional structure and fracture studies, are designed to provide a regional structure base for the study area. The structural type studies seek to document, by analytical field work, details of structures which are either similar to structures producing gas or which are similar to those which we feel could be prospective. The production studies will seek out and study gas fields where detailed well production records are available that permit thorough analysis and documentation of the geologic parameters that influence gas production from the shale. The geophysical studies are charged with the task of developing inexpensive geophysical techniques that can locate shallow fracture zones of high permeability.

PROGRESS AND PLANS 1978-1979

Regional Structure Studies

The emphasis of our effort here has shifted from compilation of areal structure maps to the construction of detailed structure maps for specific areas. A shift in emphasis was made because results of our production studies show that the shale gas production is related to structures that have very low structural relief at the Devonian level, and that such prospective structures frequently can be located only through the construction maps with a contour interval of ten or twenty feet. We are applying this technique to areas adjacent to the Cottageville and Midway-Extra fields in West Virginia, and we are accumulating data for analysis and characterization of the largest shale gas field, the Big Sandy Gas Field, of eastern Kentucky. The object of these investigations is to test our ideas concerning the relationships between production and geologic structure, characterize relationships in other productive areas of the basin, and to define prospective shale gas trends so that industry will be challenged to use our work or ideas in field well step outs and wildcat exploration.

Production Studies

Detailed investigation of the Midway-Extra field of Putnam County, West Virginia, by William W. Schaefer (1979)[3] established a direct relationship between production from the lower Huron Devonian shale and the structural trend of that field. Schaefer was able to confirm that initial and final open flows from wells at Midway-Extra are greatest along the northwestern limb of the Midway anticline, that is, in the adjacent syncline, off structure. He also found a lesser increase on the southeastern limb. The striking similarity of high flow rates with structural position along the fold is forcefully brought out by comparing Figures 2 and 3 taken directly from Schaefer's text (1979)[3]. Furthermore, he showed that the thickening of the lower Huron shale, the primary reservoir, into the adjacent syncline (Figure 4) suggests growth of the structure during sedimentation. He interpreted this to mean that basement deformation is important in the formation of the Midway anticline. From these data (Figures 2, 3, 4, and 5) at the Midway-Extra field one cannot be absolutely certain if it is the over-thickened lower Huron-organic shale or if it is fractures associated with the folding which contributes most to the noted increase of off-structure flow rates. One also might argue that even if fractures are present, they are not necessarily structural in origin. They could be caused by other lithologic factors or even as a result of differential compaction between thin shale on and thick shale off structure. Regardless of the cause, an empirical exploration rationale was proposed based on Schaefer's study (1979).[3] Direct evidence for the exact underlying cause as well as the precise siting of wells expecting commercial production was still elusive even though Schaefer had made a major guiding breakthrough.

If, however, we combine what we learned at the Midway-Extra field with what we know of the Cottageville field, then additional insight is gained into the specific cause for shale gas production for that portion of West Virginia (Figure 1). At first glance, the similarity between Cottageville (Martin and Nuckols, 1976;[1] Nuckols, 1978;[2] and de Wys and Shumaker, 1978)[4] and the Midway-Extra field is not striking. Structurally, the Cottageville field appears to lie along a very low relief flexure on a southeast dipping regional slope. The cause for the flexure was inferred to be a basement fault (Martin and Nuckols, 1976[1] and Shumaker, unpublished maps).[7] Detailed interpretation of seismic data collected by Geophysical Services, Incorporated, by Glenn Sundheimer (1978[5]

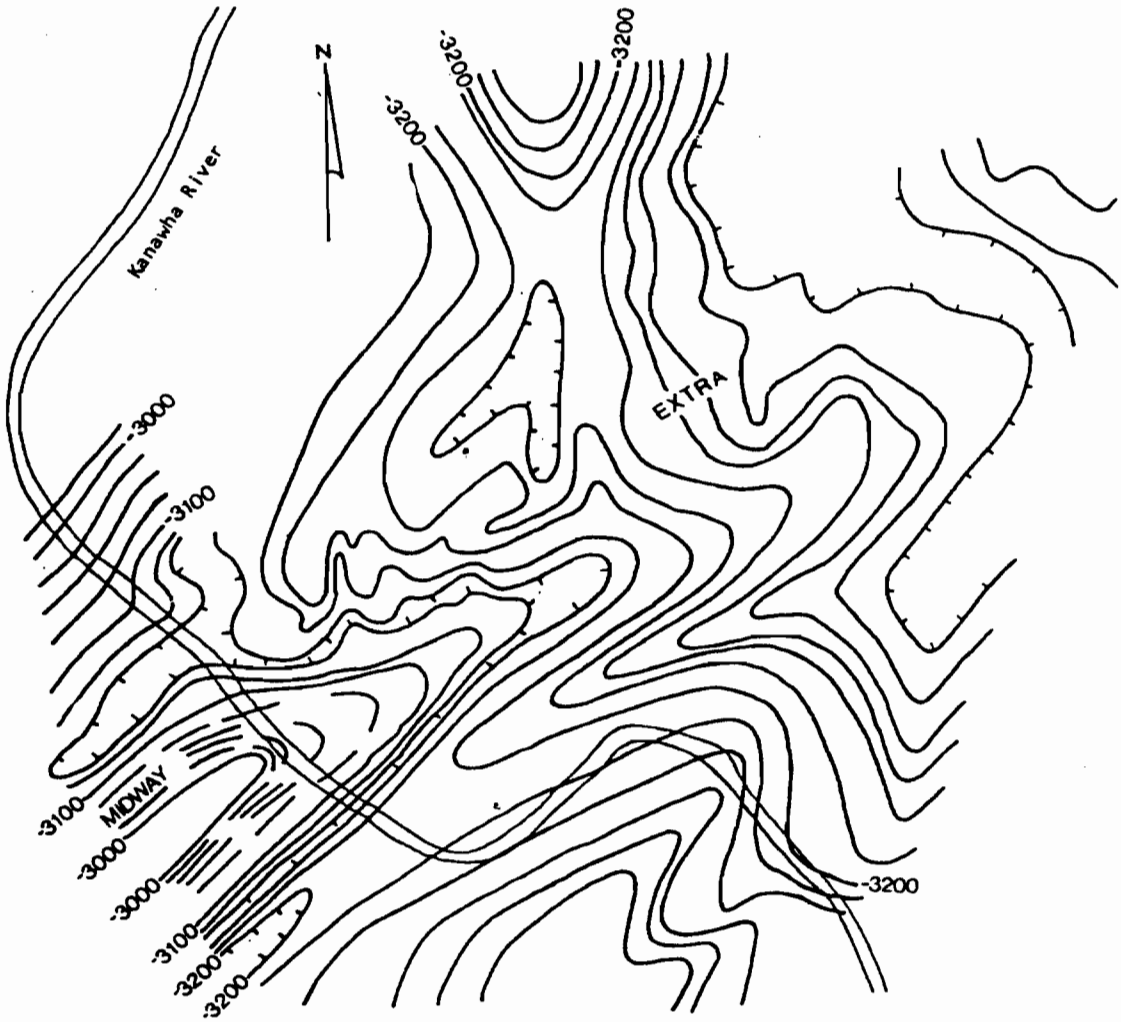


FIGURE 2
STRUCTURE-BASE OF BROWN SHALE (L.HURON)

Midway-Extra Field
Putnam County, W. Va.

0 1 2
MILES
C.I. = 20'
W. Schaefer, 1979

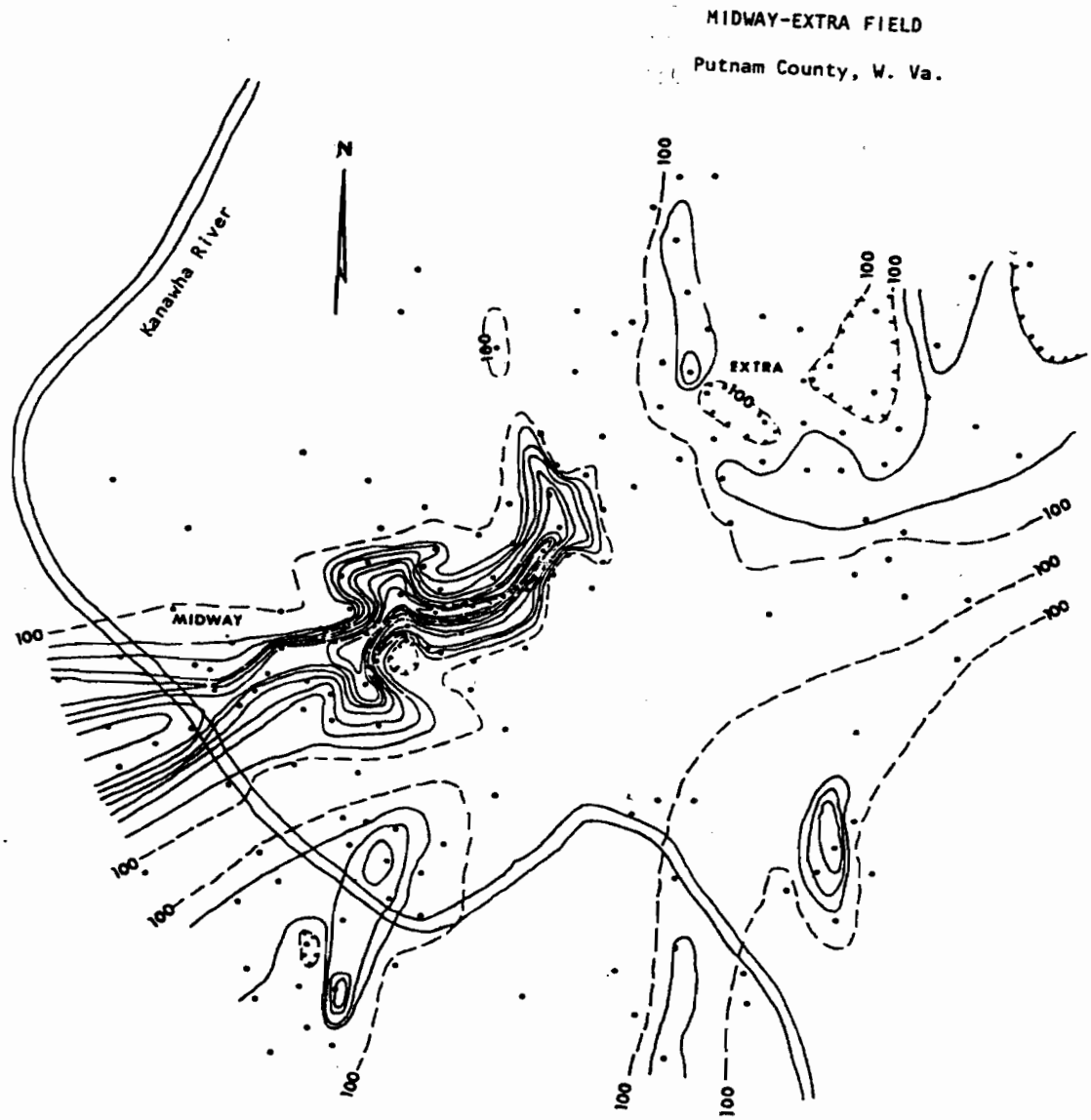


Figure 3

BROWN SHALE ISOPOTENTIAL
OPEN FLOW AFTER STIMULATION

0 1 2
MILES
C.I. = 100
MCF/D
W. Schaefer 1979

MIDWAY-EXTRA FIELD
Putnam County, W. Va.

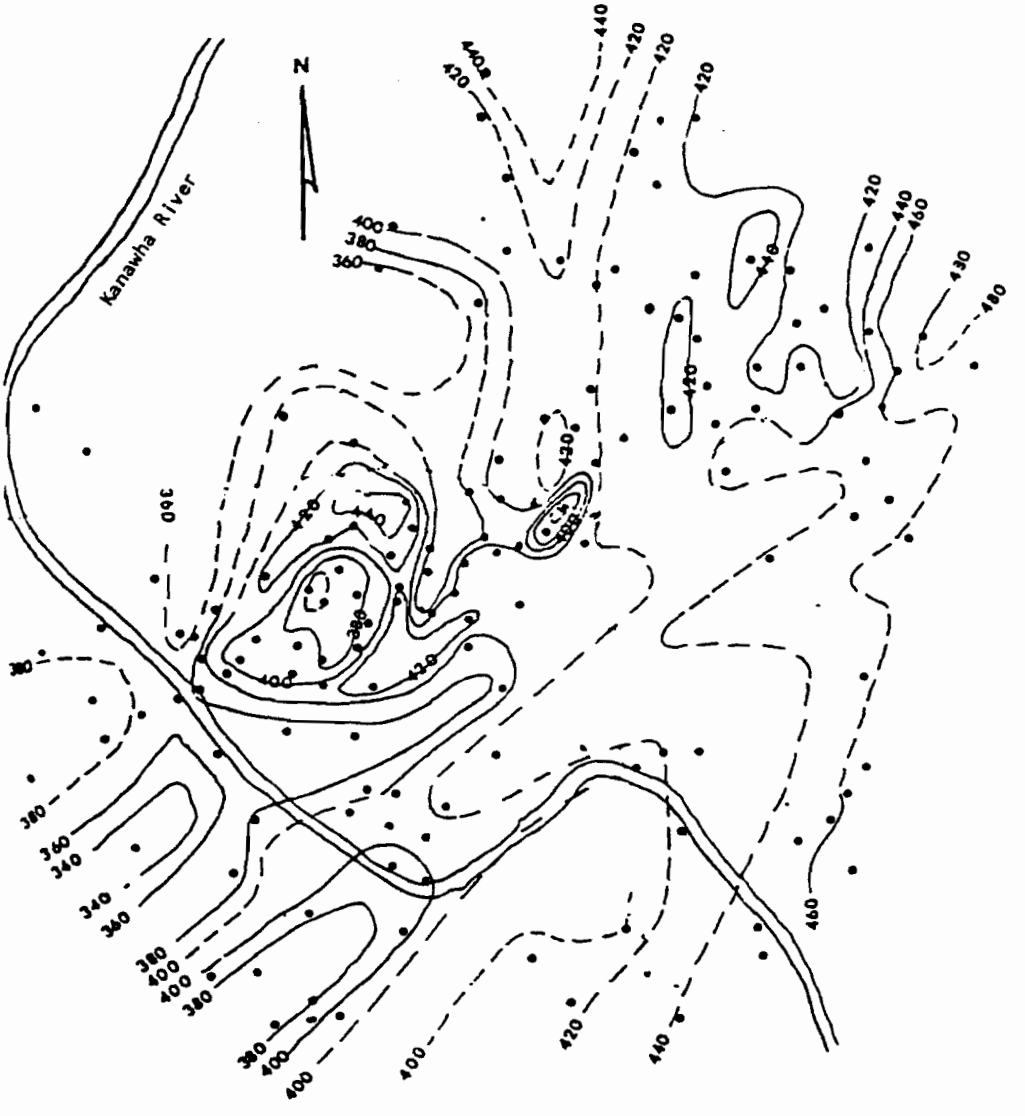
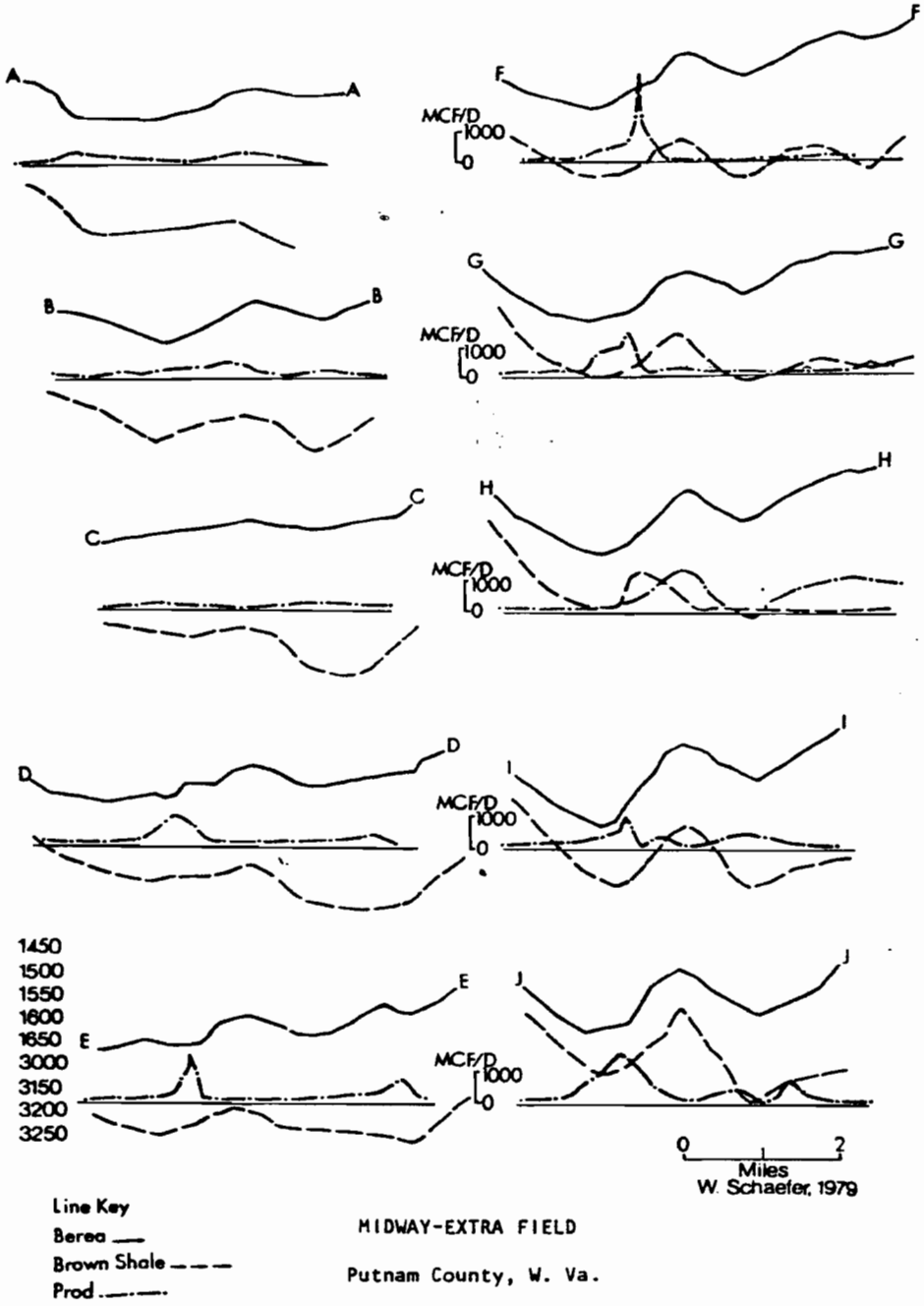


Figure 4

LOWER HURON ISOPACH MAP

W. Schaefer 1979

STRUCTURE AND ISOPOTENTIAL CROSS SECTIONS



MIDWAY-EXTRA FIELD

Putnam County, W. Va.

Figure 5

and 1979)[6] confirmed this interpretation, and his work further established that a basement fault directly underlies the trend of the most productive wells along the south flank of the Cottageville field (compare Figures 6 and 7). Please note the southeast regional dip, and also note that Sundheimer mapped a subdued flexure and syncline just updip from the fault (Figure 6), that is, northwest of the fault. These structures are similar to, although not identical to ones mapped by E. B. Nuckols III (Manuscript in preparation), from detailed subsurface geologic data. Nuckols has found that sedimentary patterns of the organic shales are complex around this structure. His unpublished maps also show that the best production does not uniquely follow the thickest lower Huron organic shale section. The best production lines up with the fault as mapped by Sundheimer. If one eliminates the regional dip from Sundheimer's isotime structure map (Figure 6), then the Cottageville field becomes a low fold with flanking synclines. It is only now that the Cottageville field appears similar to the Midway-Extra field, but Cottageville has far less relief. Keeping this in mind, compare the position of the fault, the fold crestal trace, and the trace of the flanking northern syncline with the production trends at Cottageville as mapped by de Wys and Shumaker (Figures 8, 9, and 10). There is a marked similarity of the final open flow map of the Midway-Extra field with production maps at Cottageville. This similarity is noted by lower productivity along the structural crest of both structures. In the case of Cottageville there is a near coincidence of productive trends shown on the summary trend map (Figure 11) above and parallel to the fault. The trends are not nearly as numerous for the northern syncline (Figures 6 and 11) which, incidentally, may be the southwest terminus of another buried fault. In the case of Cottageville, the comparison between structure and production seems far more conclusive than at Midway-Extra simply because of the greater quality and quantity of data. At Cottageville it is clear that better wells occur off-structure and that the best wells generally occur directly above the basement fault. De Wys and Shumaker (1978)[4] contoured the production data at Cottageville (Figures 7 thru 10) with a mechanical style, attempting to avoid bias in their contouring. Had they contoured the production data as Schaefer did, and if they had both Schaefer's results and Glenn Sundheimer's map, then the Cottageville production maps would be different, and the identity of structure with production trends would be more striking.

Using re-interpreted Cottageville as background, we can now go back to Midway-Extra and re-interpret the northwestern flank of the anticline suggesting that it is faulted at depth. The justification for this interpretation is that the high productivity wells at Cottageville are located along and above a fault.

Thus far we have pointed out the similarity between the fields, but there still is uniqueness to each field. This uniqueness is seen at Cottageville as we reimpose regional dip toward the southeast on that structure. We now have a logical reason for why the best producing wells occur near the western terminus of the fault and near the western terminus of the east plunging syncline on the north flank of the field. We interpret these areas as the updip end of fracture porosity associated with the structure. It is reasoned that the fracture porosity acts like a stratigraphic or diagenetic trap encased within the lower Huron shale (Shumaker 1978).[8] Shale gas has migrated up-plunge, westward, to the end of the fracture porosity. Furthermore this area appears to be along a change in the regional dip, a line of change or flexure from the broad flat Parkersburg syncline to the steeper slope leading toward the Cincinnati Arch. The significance of this observation remains unaccessed until we have more regional data, but it may be a key to why the Cottageville field produces compared with Devonian shale above other basement faults.

If we carefully study the Midway-Extra field we note a uniqueness there; the high flow wells align into minor north trending patterns (Figure 3) parallel to minor structural trends and an intersecting structural trend at the northeastern end of that field (Figure 2). We reason that these better wells occur at the intersection of the two fault trends. This, again, is a logical extension of the interpretation given above. We hypothesize that, if one fault yields good porosity, then the intersection of two should yield more porosity and therefore excellent production. This observation leads to a second substantive rationale for exploration; drill on the intersection of fault trends - on the low side.

There are a multitude of methods to develop fractures and thereby potential fracture permeability, that is, by: basement structure, detached structure, compaction, sedimentary diagenesis, overburden removal, etc., it is the senior author's conclusion that basement growth structure is the most effective means of producing commercially effective porosity within this area of West Virginia. The importance of this understanding and the application of these exploration guidelines to southwestern West Virginia are heightened by a similar observation made by Don Neal (manuscript in preparation) of the West Virginia Geological and Economic Survey concerning the coincidence of higher initial flow from gas wells located on the flanks of geologic structures. This conclusion is based on his work in

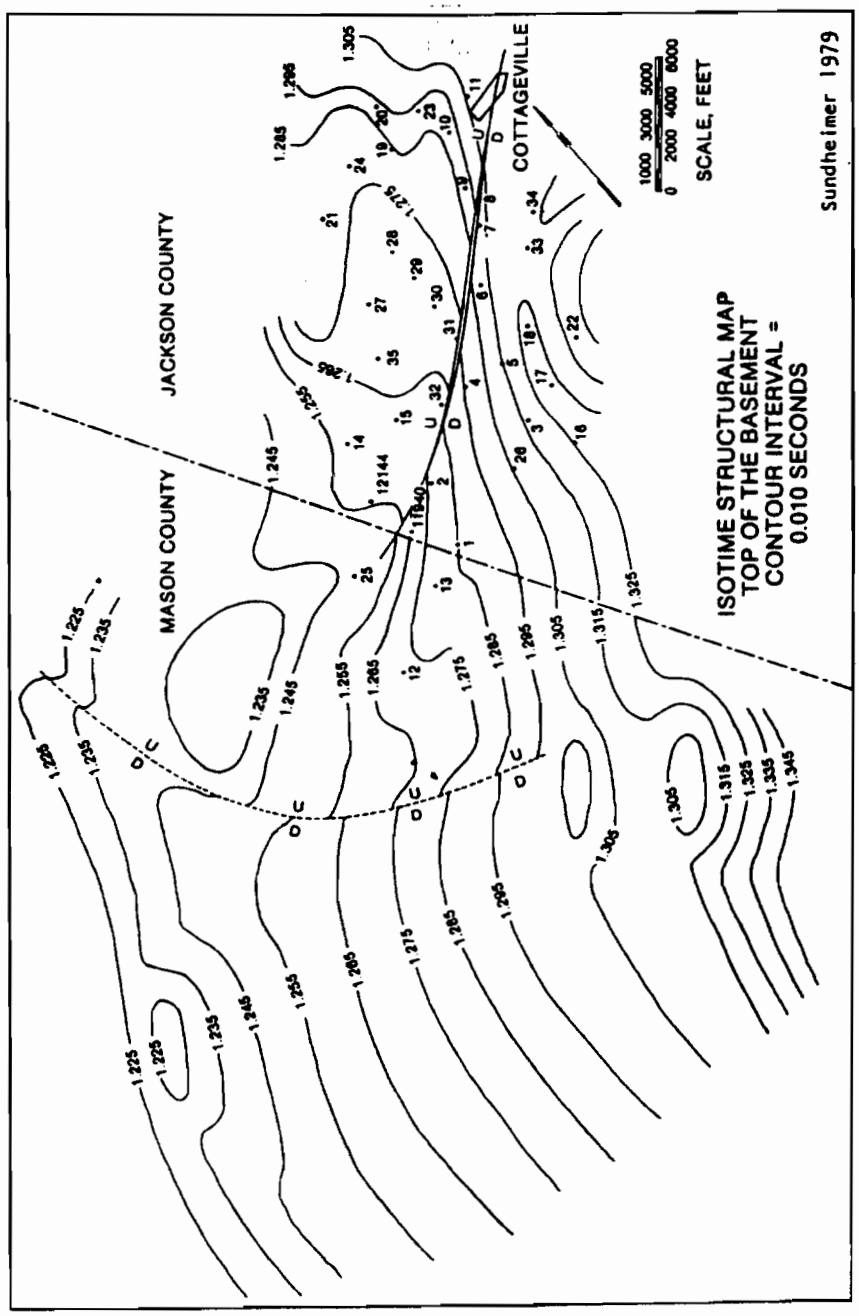

JACKSON COUNTY
MASON COUNTY
COTTAGEVILLE
ISOTIME STRUCTURAL MAP
TOP OF THE BASEMENT
CONTOUR INTERVAL =
0.010 SECONDS
SCALE, FEET
1000 3000 5000
0 2000 4000 6000
Sundheimer 1979

Figure 6

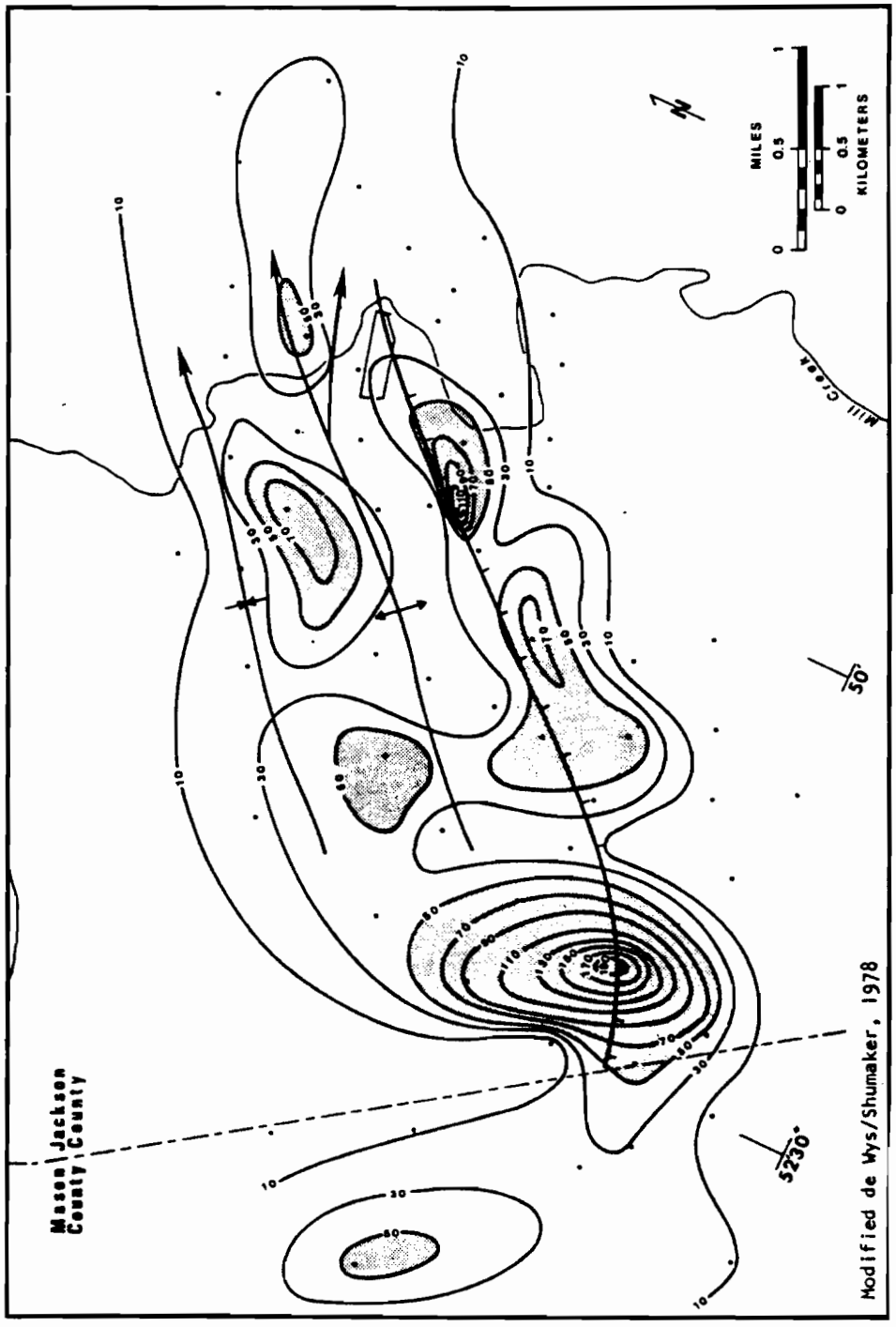


Figure 7 Isocontours of Highest Annual Production (1st or 2nd year production). Contour Interval = 20MMcf/yr.

Fault and Fold Axes from Seismic - Sundheimer, 1978 (personal communication)

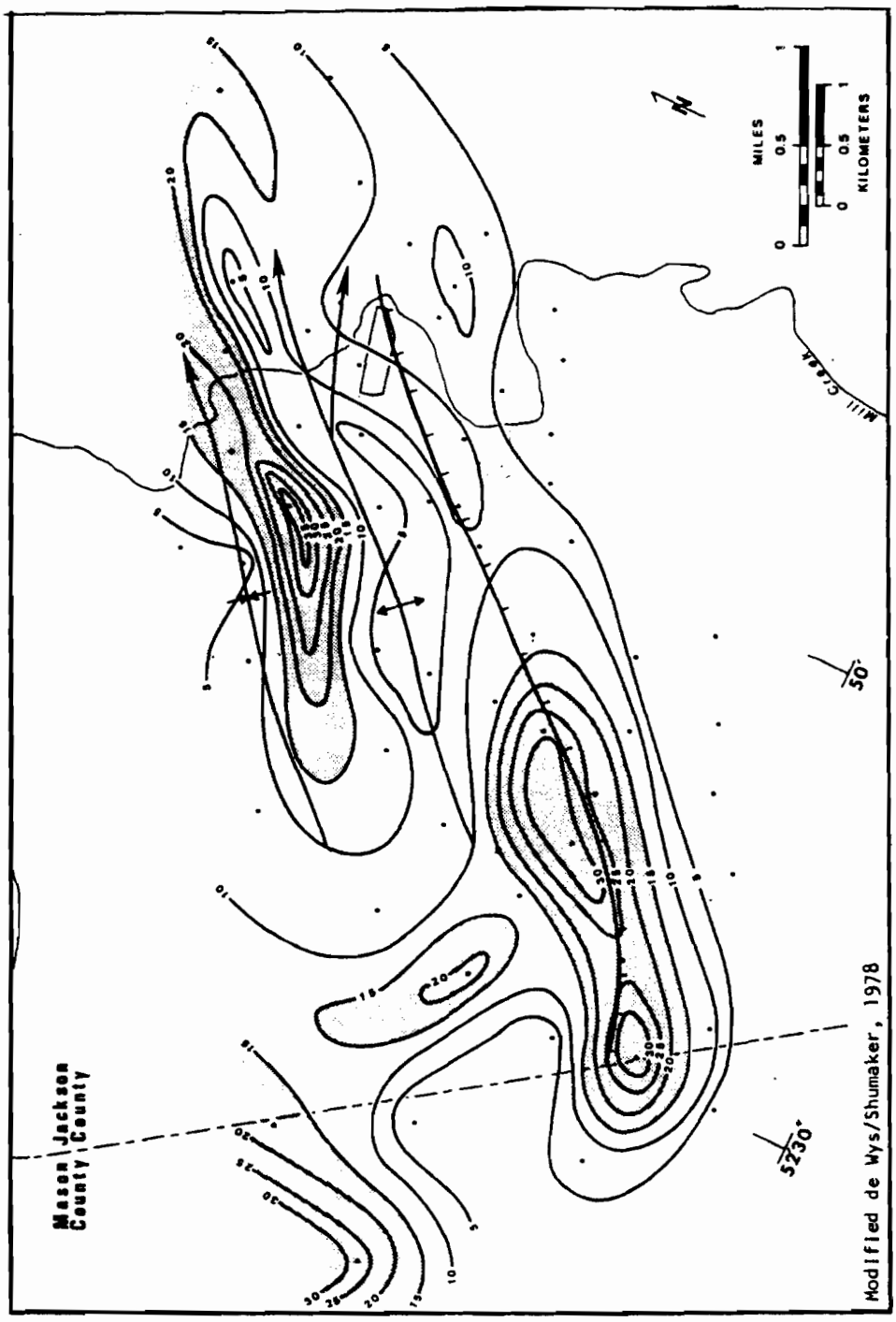
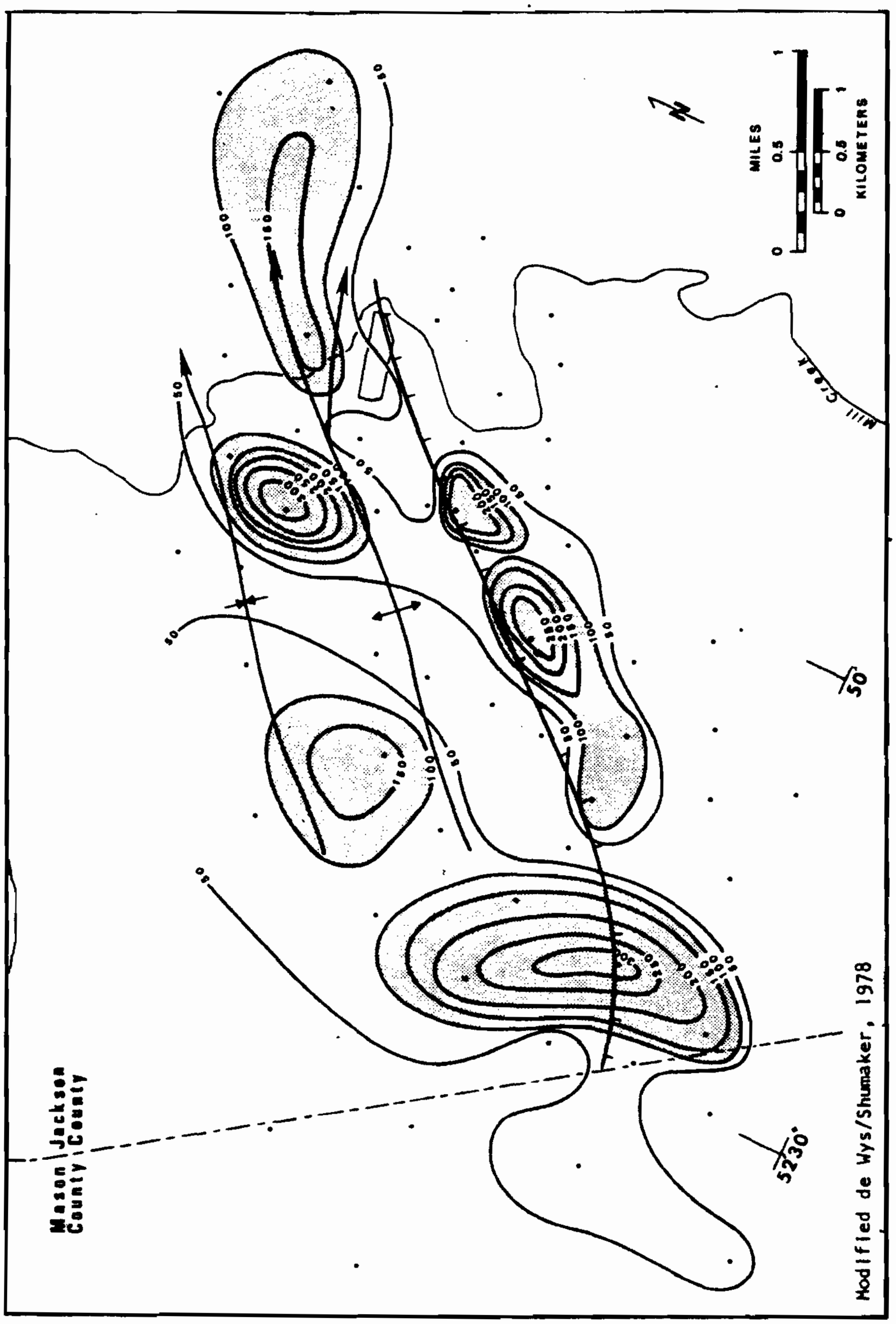


Figure 8 Isocontours of Mean Annual Gas Production. Contour Interval = 5MMcf

Fault and Fold Axes from Seismic - Sundheimer, 1978 (personal communication)



Modified de Wys/Shumaker, 1978

Figure 9 Isocontours of First Five Years Accumulated Gas Production. Contour Interval = 50MMcf/yr.

Fault and Fold Axes from Seismic - Sundheimer, 1978 (personal communication)

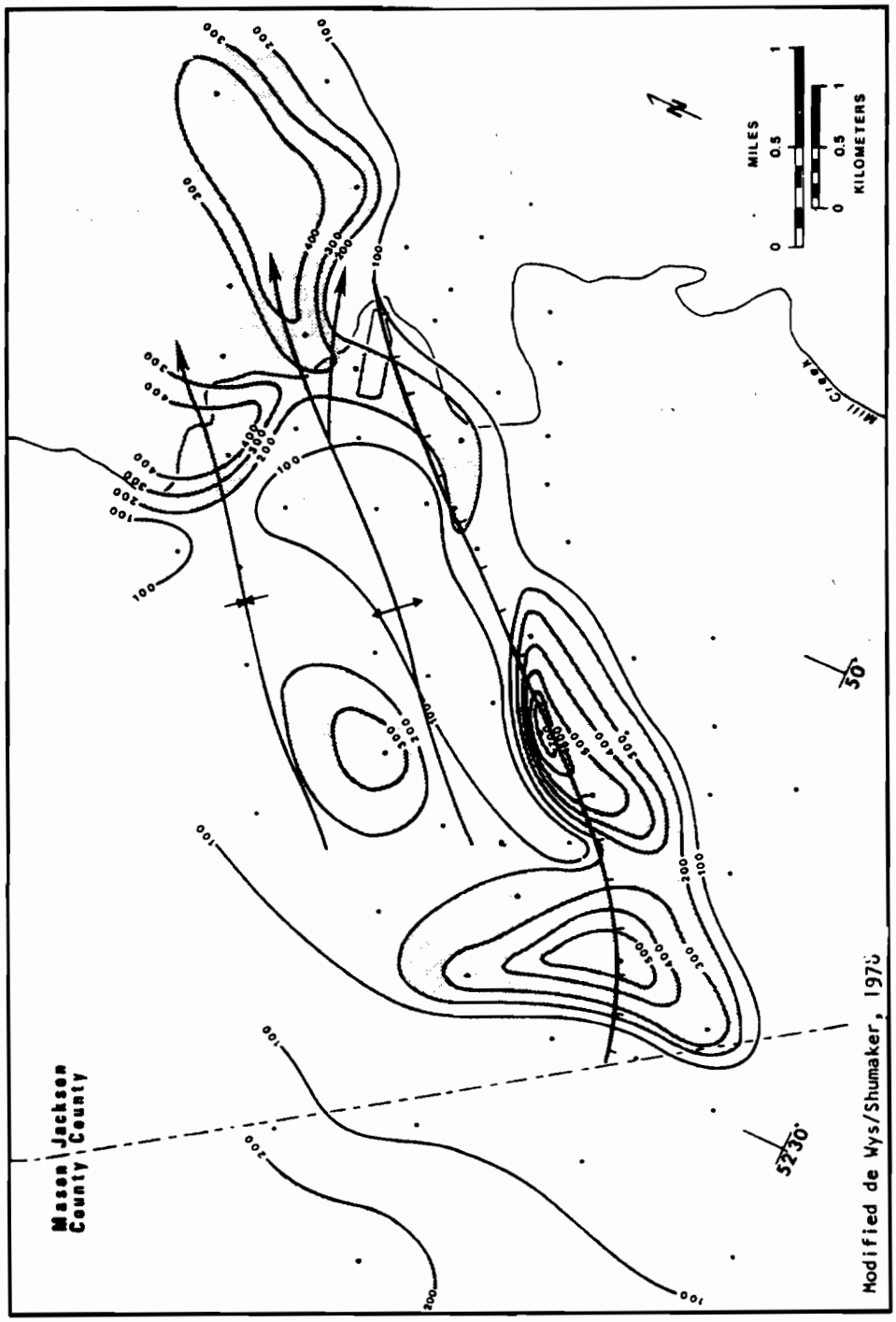


Figure 10 Isocontours of Total Accumulated Production. Contour Interval = 100MMcf

Fault and Fold Axes from Seismic - Sundheimer, 1978 (personal communication)

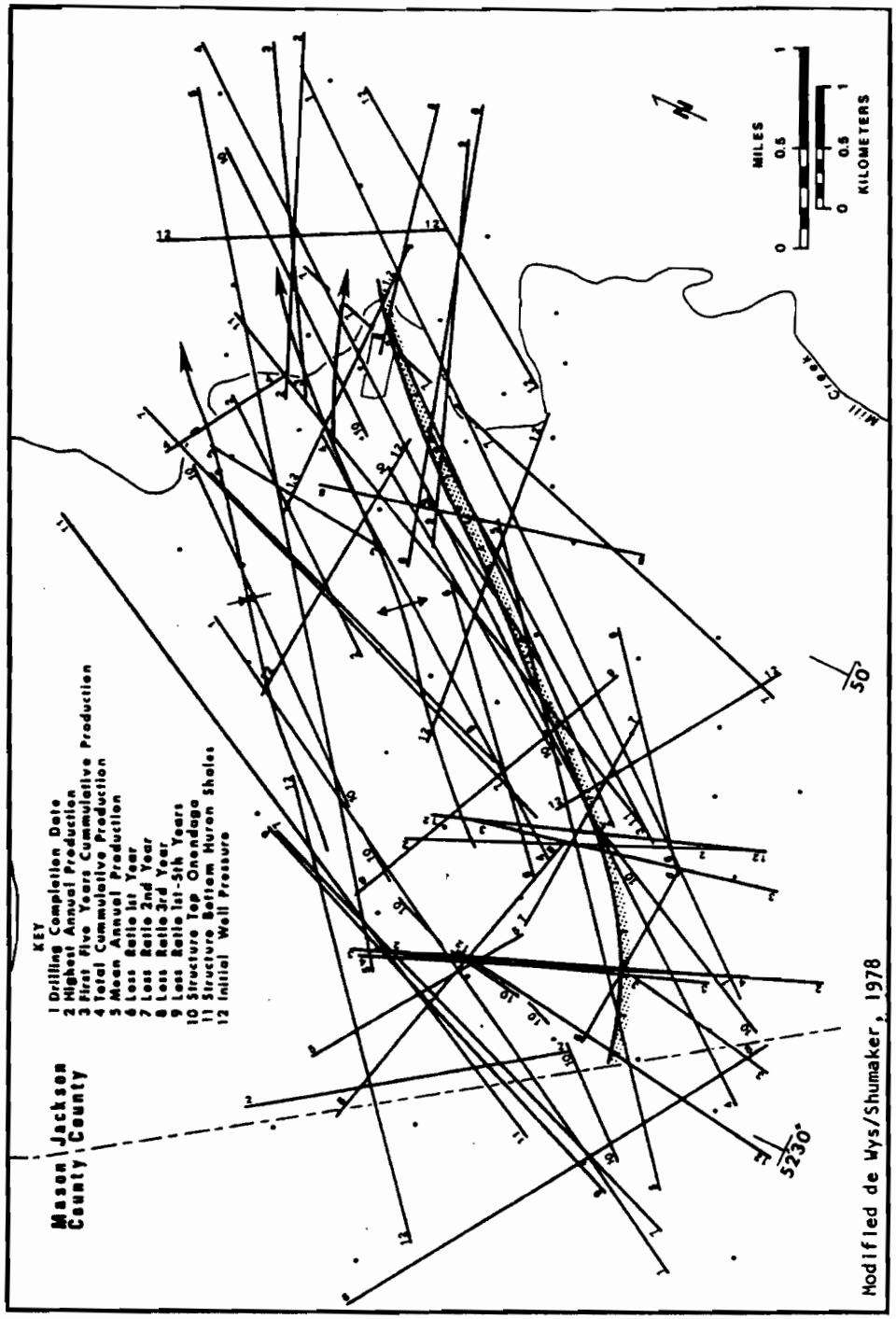


Figure 11 Axial Trends of Contours from Production Maps.

Shading on down side of fault.

the adjacent area of West Virginia to the south. It therefore seems likely that these rationales can be extended southward into adjacent counties of southern West Virginia.

As to why the fractures select the lower Huron shale section as the host unit, one can only speculate. The physical response of the lower Huron to deformation must be related to its lithology, but the exact nature and origin of the stress field creating the fractures still remains uncertain. Vertical basement tectonics seems to be an important source of that stress within the area described, but one cannot eliminate the importance of a horizontally directed stress field modifying and intensifying the local stress field (Advani 1978[9] and Shumaker 1978).[8]

A word of caution regarding the model and rationales described in this paper. The model was developed as a result of our characterization of structural parameters that affect shale production in southwestern West Virginia, and therefore it should not be applied indiscriminately or universally as a unique solution to other areas. It clearly is not a unique solution for fracture porosity. Certainly there are numerous ways to produce open fractures and therefore potentially productive shale gas areas in the multitude of tectonic environments and structural styles within the Appalachians. Our interpretations do not deny the existence or the influence of other fracture types on production even within these southwestern West Virginia shale gas fields, for we know that other genetic fracture types, which may be significant to production, are present within the Devonian shale (Shumaker 1978).[8]

The model described above obviously has its greatest application to southern West Virginia, but we believe it also has application to the mid-continent area. This area is largely undeformed. The prevailing structure is systematic, largely orthogonal, joints; but where the flat lying sediments are deformed, it is generally by basement deformation and often recurrent basement deformation (Shumaker 1979).[10] We suggest for your consideration that a reason for lack of shale production within this immense mid-continent area may relate to the position of most wells on structural prospects. They clearly are not drilled on the flanks of structures, down-dip from the crest, unless there is a stratigraphic reason. We may have a reason for such exploration: structurally controlled fracture facies.

The Eastern Kentucky Gas Field is the third field selected for detailed analysis. We are presently in the midst of our work. Well cuttings (500+) from 14 wells in the Eastern Kentucky Gas Field have been examined and described. Cross sections are being constructed to study details of lithological changes in the Berea-Huron stratigraphic sequence.

Graphs, computer maps, and statistical analyses are in progress on a geochemical study of well cuttings from 14 wells in the Eastern Kentucky Gas Field (same wells as lithology studies with one exception). Fourteen elemental oxides (except Sulphur) and sixteen minerals are under examination. Certain maps show a high degree of correlation to density contours of high producing wells (based on 5000 wells).

Final stages of the study of the Eastern Kentucky Gas Field are commencing. Final open flow data are being compared to structural depths, shale thickness, lithological changes, evidence of fracture occurrence, high organic content, and geochemistry. Results of this phase of the field study will be presented at a later date.

Structural Type Studies

Analysis of the Parsons and Petersburg cross-strike structural lineaments (Figure 1) in the high plateau country of West Virginia have been conducted to determine: (1) joint intensity within and adjacent to the lineaments, (2) the nature of joint intensity with depth, and (3) the westward extent of the two lineaments. Rock is found to be more intensely jointed within the Parsons lineament in the Upper Devonian Chemung siltstones, mudstones, and shales of Tucker County, West Virginia, (Dixon, 1979a,[11] 1979b[12] Dixon and Wilson)[13] The lineament extends northwest and terminates in Taylor County. It is expressed in Lower and Middle Pennsylvanian sandstones as two zones of intense jointing (Dixon and Wilson)[13] The Petersburg lineament was studied along the Allegheny Front to determine the effect of joint intensity with depth. Joints in Devonian shales, siltstones, and sandstones and Lower Mississippian sandstones were measured. The width of the zone of intense jointing does not vary with depth. However, intensity is significantly

greater in the Middle Devonian black shales than in other lithologies (Figure 12). The Petersburg lineament extends west-southwest to the Randolph-Upshur County line where it is disrupted or terminates. This lineament is manifest in Lower and Middle Pennsylvanian sandstones with intensities similar to those in Parsons lineament.

A three phase study of surface structures in Middle and Upper Devonian shales in Middle Mountain syncline (Figure 1) of the Valley and Ridge province, Pendleton County, West Virginia, has been completed. The study included the following: 1) detailed mapping of the Middle Mountain syncline, 2) an analysis of bedding orientation contours of the syncline (Wilson, 1979a[14] and 1979b),[15] and 3) a study of the orientations and spacings of systematic joints in the shales of the syncline. The studies were designed to characterize the Parsons cross-strike structural discontinuity (PCSD) in terms of faulting, folding and jointing in the exposed Devonian shale sequence. The PCSD is found to coincide with a zone in which structural shortening is taken up by smaller folds and more abundant thrust faults. In consequence, the shales within this zone are also more intensely jointed.

Fracture Studies

A regional survey of eastern Kentucky surface joints was completed to determine if surface fracture trends or domains, areas of similar trending joints, relate to high producing trends or high producing areas within the eastern Kentucky shale gas fields. Maps of joint strikes plotted as rose diagrams show that coal has the most consistent regional orientations of joints in the lithologies studied. Joints in black shale, brown shale, gray shale, and sandstone have varying angular relationships to regional coal cleat strikes. This dissimilarity between trends associated with each surface lithology makes prediction of subsurface fracture trends in the Devonian shale reservoir hazardous. Coal face cleats and coal structure form-lines change trend to become sub-parallel to the trace of the Pine Mountain thrust fault (Figure 13). Regardless of its origin, this gradual change in trend of face cleat trends is coincident with the most productive area in the eastern Kentucky shale gas field. The precise significance of this coincidence has not been determined as shale gas production extends into the areas of usual face cleat trend, that is, perpendicular to Appalachian fold axes.

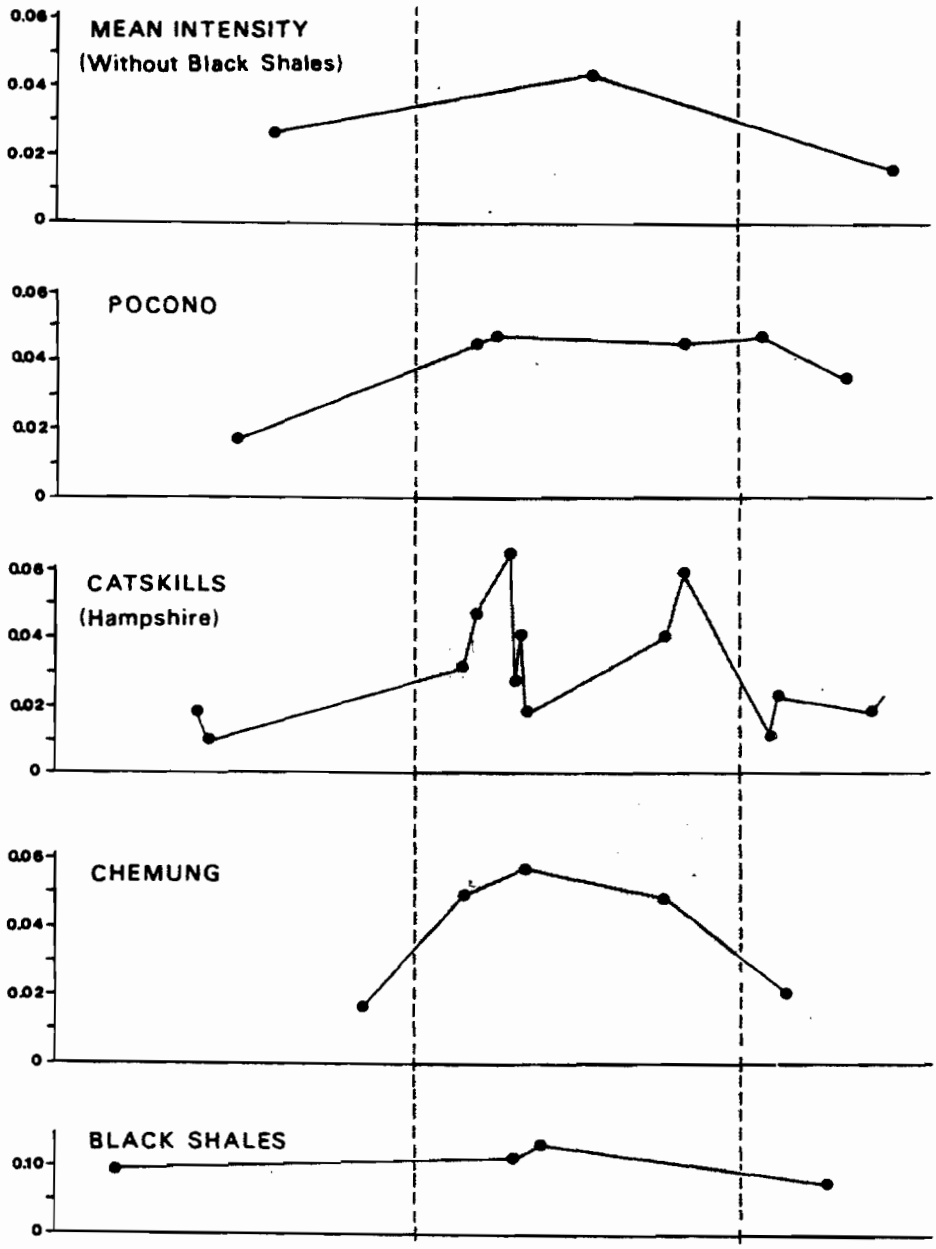
Outcropping Devonian shales along the east flank of the Cincinnati Arch show consistent joint strikes of N25E, N45E and N65W. First-formed and second-formed joints strike northeast and northwest, respectively. This is opposed to the coal cleat trend over the eastern Kentucky gas field where face cleats (first-formed) strike northwest and change to become nearly E-W in the Pine Mountain thrust area.

Thirteen oriented Devonian shale cores from the Appalachian Plateau of West Virginia, Kentucky, Ohio, Virginia, and Pennsylvania have been examined for fractures (Figure 1). The orientation, type of mineralization (if any), and presence of fractographic features, i.e., plume, hackle, and arrest lines, were recorded for each fracture. Fractures were differentiated into three types: natural, core induced and slickenside. Frequency and orientation for each type of fracture have been plotted against core depth to determine the existence of possible fracture facies and decollement zones as well as changes in current in-situ stress and paleo stress as a function of depth or lithology. Regional subsurface fracture patterns are plotted and are being examined for comparison with the regional structure. Open file reports are available for two of the cores studied, Mason County #3 D/K core, West Virginia, and Monongalia County MERC #1 core, West Virginia. Reports on the other cores examined will be available in early 1980.

Ground Water

A hydrogeologic characterization study was done in the Midway-Extra Devonian shale gas field (Figure 1) of northern Putnam County, West Virginia. Lineaments were mapped and water wells were surveyed for physical and chemical parameters to compare with initial yield of nearby shale gas wells.

Northwest trending short straight photolineaments are significantly associated with water-well yield. Water wells located within 200 feet of a lineament's center line have significantly higher yields. Gas wells located near short photolineaments of the same trend had significantly higher initial open flows (both before and after stimulation) than wells located near other photolineaments. Gas wells also had significantly higher initial open flows when located in areas where photolineament density is high. Gas wells located near the most certain photolineaments had higher initial open flows than wells near less certain photolineaments. Landsat lineaments appear to be poor locations for gas



Joint Intensity of Petersburg Lineament
along Allegheny Front

Figure 12

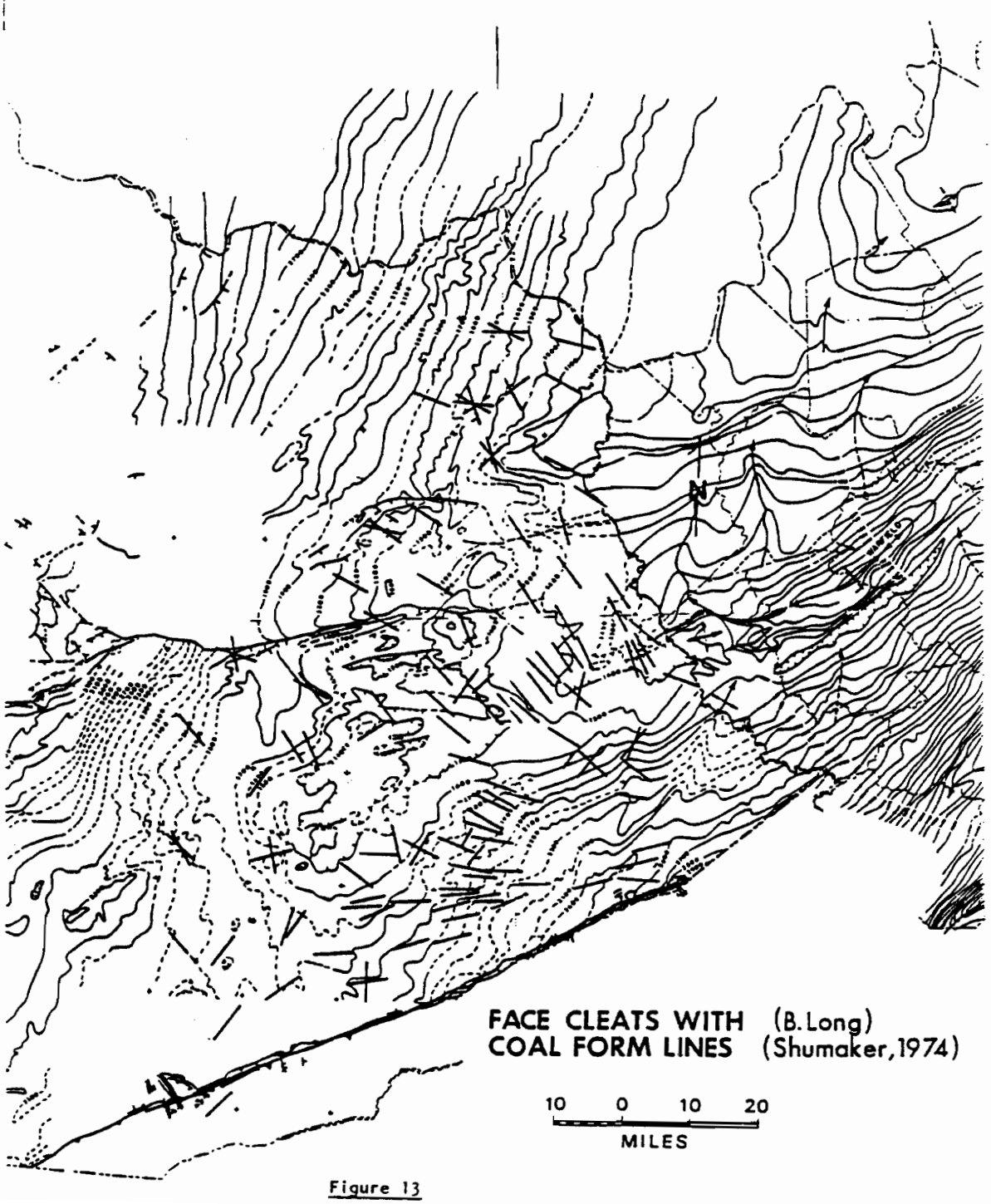

FACE CLEATS WITH (B.Long)
COAL FORM LINES (Shumaker,1974)
10 0 10 20
MILES

Figure 13

wells, and they do not overlap the high gas-producing areas.

Certain water-well parameters are also associated with initial gas well yield. Water wells located within high initial gas flow areas (over 100 MCF/day after stimulation) have significantly higher bicarbonate and nitrate concentrations than wells in low producing gas areas.

The results of our analyses here at Midway-Extra are similar to those found at Cottageville (Jones and Rauch, 1978)[16] except that at Cottageville the trend of gas associated short lineaments is west-northwest.

Geophysical Studies

The main thrust of the geophysical effort at West Virginia University is the characterization of some of the acoustic properties of both the fractured and unfractured zones. The hope, of course, is to determine which properties may serve as reliable exploration criteria.

Refraction seismic surveying will be used for shallow studies of lateral velocity changes. The nature of both the method and our equipment limits the depth of investigation to ±800 feet. Since we will record waveforms (as well as travel times) attenuation anomalies may be observed.

High resolution reflection seismic surveying will provide data on small scale structures, attenuation anomalies, and acoustic velocity at depths greater than is possible with our refraction method. Our high resolution reflection seismic method uses an explosive source in a 7 foot deep shot hole. The geophones are in 4 foot deep holes. Since attenuation of high frequency acoustic energy is most severe in the weathered, near surface material, this procedure results in band width wider than that of more conventional techniques; and shot and geophone ground coupling are improved. Surface waves are eliminated from the records by burial of the geophones and high pass input filters. Burying the geophones also attenuates noise from other sources (e.g., wind, traffic, etc.). Signal to noise ratio is thus improved. Our signal band appears to be ±300 hz to ±1 khz resulting in vertical resolution of a few feet.

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APPENDIX B

Surface Structure Studies

1978 - 1979

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EXTENSION STRUCTURES

IN THE CENTRAL APPALACHIANS

by

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1978

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Oct. 1979

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ABSTRACT

Late tectonic extension faults and extension fractures may form abundantly in steep limbs of detached anticlines. The Devonian Brallier formation of the central Appalachians is the unit that has undergone the greatest amount of extension faulting and fracturing, among Upper Ordovican to Lower Mississippian units exposed and studied on the northwest limb of the Wills Mountain anticline. Gravity data and analogy with exposures on the northwest limb of the Wills Mountain anticline indicate that the Blackwater and Glady anticlines may also have thinned and fractured Brallier on their northwest limbs in the subsurface. Given the underlying dark shale source and updip thickened shales as a seal, these volumes may contain gas in a fractured reservoir.

INTRODUCTION

Fracture is defined by Dennis (1967) as a surface along which loss of cohesion has taken place. Therefore, unless the term is restricted by use of a modifier or used in conjunction with the term fault, fracture as used herein, will include faults, joints, and fissures. When used in conjunction with the term fault, fracture is defined as a surface along which little or no slip has occurred (joint or fissure). When used with a prefix, such as extension fracture, then the term is restricted to those fracture surfaces formed by bed-parallel extension, as defined and characterized in the main text of this thesis.

The purpose of the thesis is to investigate a particular class of bed-extending brittle structures known as extension faults and extension fractures. These formed late during the growth of anticlines in the detached tectonics characteristic of the central Appalachians. A specific goal of this investigation is to develop a predictive tool for the subsurface locations of unusually fractured rock in the Middle and Upper Devonian clastic sequence.

The field area investigated in this thesis was primarily the northwest limb of the Wills Mountain anticline, which extends through Pennsylvania, Maryland, West Virginia and Virginia. Other map-scale anticlines near the Wills Mountain anticline were examined, as well

as localities in Pennsylvania that expose outcrop-scale kink folds or kink-bands and which were suggested by Dr. R. T. Faill (written communication, 1978). Conclusions and speculations apply to these areas and to larger parts of the central Appalachians, chiefly in West Virginia.

The thesis is composed primarily of four short manuscripts, each having separate title, authors and abstract, and each building on or extending the last. The references and acknowledgements are a combined list from all four manuscripts. There is a separate section containing conclusions based on the work reported in the four manuscripts. Each manuscript has been or will be submitted for publication.

Each manuscript addresses the problem of predicting where the greatest amount of bed extension occurs. The first manuscript introduces the concept of fold-related brittle extension structures. It presents a relative time sequence for typical central Appalachian faulting and associated fracturing, and describes general field criteria for differentiating between earlier faults and the later extension faults. This manuscript refines a three stage model originally conceived by Dr. William J. Perry, Jr., of the U. S. Geological Survey, Reston, Virginia. Field work was done by all three authors, but most of the manuscript is based on a term paper written by

the senior author and his field work at Pinto, Maryland.

The second manuscript develops an approximate mathematical model using measured values of horizontal shortening to estimate the minimum bed dip at which extension structures will occur. This information places geographical constraints on areas which may be investigated for gas-bearing porosity or permeability produced as extension fractures or extension faults. The equations in this manuscript were developed by Dr. Russell. L. Wheeler.

The third manuscript concentrates on extension faults, as described and defined in the first manuscript, and represents the result of field investigations in the area delineated in the second manuscript. The third manuscript describes the stratigraphic distribution of extension faults in and near the Devonian clastic sequence and especially relates abundance of extension faults to structural position. It is also concerned with the relationship between the extension faults and large fold-related splay faults rising from deeper detachments. The manuscript estimates the contribution of extension faulting to anticlinal growth and estimates relative amounts of extension in fold limbs so that limbs may be selected which are most likely to contain gas in fractured reservoirs. The equations in the manuscript were derived by Dr. Russell L. Wheeler.

The fourth manuscript uses a kink-band model of fold development to estimate the amount of extension in the kink-band or in the more rotated limb of a kink fold. The extension can occur as porosity and permeability producing fractures or faults as described in the first and third manuscripts. The kink-band model of fold development is probably the best explanation for the observed geometric form of major folds in the central Appalachians. Field criteria are given for differentiating between folds of kink-band origin and those of buckling origin. The map distribution of gravity lows is used to explain the distribution of extension faulting from manuscript three in a kink fold model. Drilling areas are suggested for fractured reservoirs.

Three-Stage Model of Brittle Deformation in the Central Appalachians

Philip S. Berger[1], William J. Perry, Jr.[2], and Russell L. Wheeler[1]

ABSTRACT

Recent fieldwork in the central Appalachians shows the applicability of a three-stage model of brittle deformation. Distinct minor structures form at specific times during overall horizontal shortening and map-scale folding. Stage I contraction faults shorten horizontal or gently dipping beds and are closely associated with wedging. Stage II uplimb thrust faults shorten folded beds hingeward. Stage III extension faults and extension fractures lengthen steeply dipping to overturned beds. Opening or shearing directions of fractures and crosscutting relationships of faults, other fractures, and stylolites allow distinction of the three stages. Stage III may have produced fracture porosity and permeability on steep limbs of anticlines. We propose a three- stage model of outcrop-scale fault and other fracture development for steeply dipping to overturned beds in

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eastern West Virginia and adjacent areas. Less rotated beds may show at least two of the stages. Kinematic analysis of faults and other fractures allows differentiation of the three stages.

Structural Style

The central Appalachian foreland has many detached anticlines but few outcropping major thrust faults. The anticlines are interpreted as active features generated mainly by duplication of strata by ramping of underlying thrust faults, by splay faults, and by ductile flow of shale-rich intervals into anticlinal crests (Perry and de Witt, 1977, Perry, 1978, Wheeler, 1975). The synclines are regarded as passive features resulting from anticlinal growth in adjacent rocks, rather than from active downbuckling (Gwinn, 1964).

We deal with the sequence of outcrop-scale structures that formed at specific times during overall southeast-northwest horizontal shortening and vertical extension. We assume that each individual structure formed in an orientation that allowed it to accommodate some of that horizontal shortening, or vertical extension, or both.

The first-order anticlines (Nickelsen, 1963, p. 16) of the western Valley and Ridge and the Allegheny Plateau provinces formed predominantly by flexural slip folding

(Faill, 1969), rather than by passive or flexural flow folding (Gair, 1950). Interlayering of shales and evaporites with sandstones, siltstones or limestones allows slip between units of low relative ductility. Stage I structures form before folding, or early during folding, when the angle between bedding and the maximum principal compressive stress is less than about 10 degrees. Experiments at room temperature and confining pressures to 2000 bars (equivalent to about 6 km in depth) suggest that slip parallel to bedding is possible when the angle between the maximum principal compressive stress and bedding ranges from 10 to 60 degrees (Price, 1967). Stage II structures form in this range of limb dips (see below). Stage III structures form in response to additional horizontal shortening, late in or after folding, when steep limb dips preclude further slip parallel to bedding. These structures form when the angle between bedding and the maximum principal compressive stress exceeds about 60 degrees. These conclusions are reinforced by the finite-element derived stress-history of folding (Dieterich and Carter, 1969).

Price (1967) described extension and contraction structures from the Canadian Rocky Mountains using the fault terminology of Norris (1958). We report the same types of structures from the central Appalachians, placing

them in a relative time sequence and describing simple field criteria for differentiating among stages.

STAGE I STRUCTURES.--Cloos (1964) first recognized and named the prefolding wedges common in the central Appalachians. Wedges are the wedge-shaped ends of small fault blocks in which the bounding contraction faults (Norris, 1958) form angles of 30 degrees or less to bedding. Examples provided by Cloos (1964, figs. 2, 3, 4 and 6) involve brittle layers (sandstone and limestone) which have been "sheared, wedged, and telescoped together" in a more ductile medium (shale). This process of contraction faulting shortened the stratigraphic section in a northwest-southeast direction and thickened it perpendicular to bedding prior to or early during folding. Such contraction faults can form dipping in either direction (northwest or southeast).

Concerning the Canadian Rockies, Price (1967) writes that if layering was planar and inclined at a low angle to the maximum principal compressive stress, that stress' trajectories would tend to parallel layering, and subsequent failure would take the form of contraction faults acting to shorten layers. The resulting geometry of brittle beds in a more ductile matrix is that of Cloos' wedges. Compound wedges involving a series of brittle beds which have been telescoped together are shown by Cloos

(1964, fig. 7) and Perry and de Witt (1977, fig. 10). Price (1967) used the term contraction faults to include all faults that produce a shortening in the plane of the bedding, thus including uplimb thrust faults (see below).

In wedged beds later rotated to vertical by folding, the bounding contraction faults record normal-fault separation at a low angle to bedding. In cratonward-facing folds (asymmetric to the northwest in the Appalachians), such stage I faults normally show a downlimb sense of displacement (fig. 1). They did not form as normal faults in their present orientation, because (1) the necessary northwest-southeast horizontal extension is inconsistent with central Appalachian structural style, and (2) their formation in a contractional regime is indicated by drag features and absence of associated extension features.

Prefolding fractures have been recognized in the central Appalachians (Dean and Kulander, 1977). These fractures may predate the contraction faults, because such fractures are offset by these faults and by bed-parallel compaction stylolites that are inferred to have formed under overburden stress equal to maximum principal compressive stress, when bedding was horizontal.

Prefolding calcite-filled fractures can be recognized if orientations of calcite fibers record shearing on the fractures. If the fractures are rotated to their original

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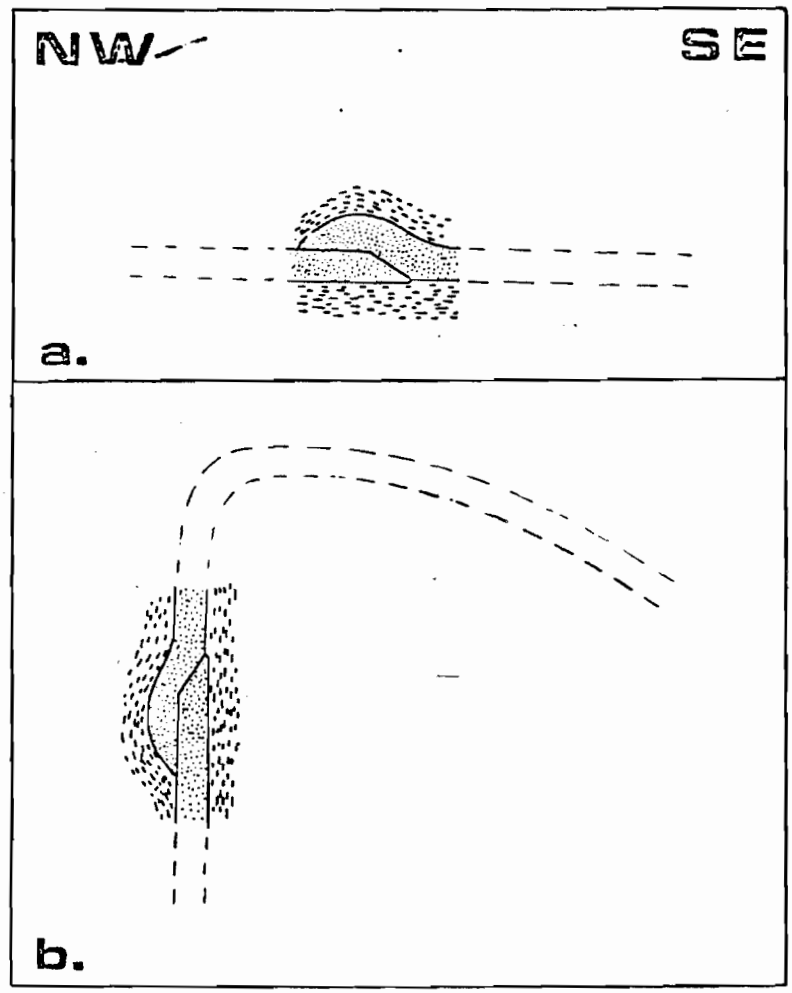
Figure 1. Contraction fault (stage I) formed wedges prior to folding: (a) prefolding attitude, (b) postfolding attitude on northwest limb of west-facing anticline, The angles between the bedding and fault planes and the size of the associated fold are variable.


NW
SE
a.
b.

(prefolding) orientations, the net growth direction of the fibers should be about 30 degrees from the (horizontal) maximum principal compressive stress.

STAGE II STRUCTURES.--Stage II structures formed during folding. They record relative reverse movement toward the anticlinal hinge as part of the Appalachian fold's internal adjustments to southeast-northwest horizontal shortening, and to fold growth by flexural mechanisms. Perry and de Witt (1977) describe and define uplimb thrust faults, the hanging walls of which move up the limb of the anticline and away from the axis of the adjacent syncline (figure 2). Similarly, Gair's (1950) out-of-syncline thrusts, and Gwinn's (1964) symmetrical thrust faults are northwest- and southeast-dipping reverse faults that resolve space problems in cores of anticlines. In concentric folding, upward and inward motion on anticlines' flanks, and flexural slip above ductile rocks, thrust strut-like brittle beds of the limbs over passive anticlinal crests where flexural slip is inhibited. Perry (1971) mapped southeast-dipping apparent normal faults at a low angle to bedding in vertical beds on the northwest limb of the Wills Mountain anticline in Pendleton County, West Virginia. He interprets these as originally northwest-dipping uplimb thrust faults (Perry, 1971, 1978), later rotated by continued growth and asymmetric

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Figure 2. Southeast- and northwest-dipping uplimb thrust faults (stage II).

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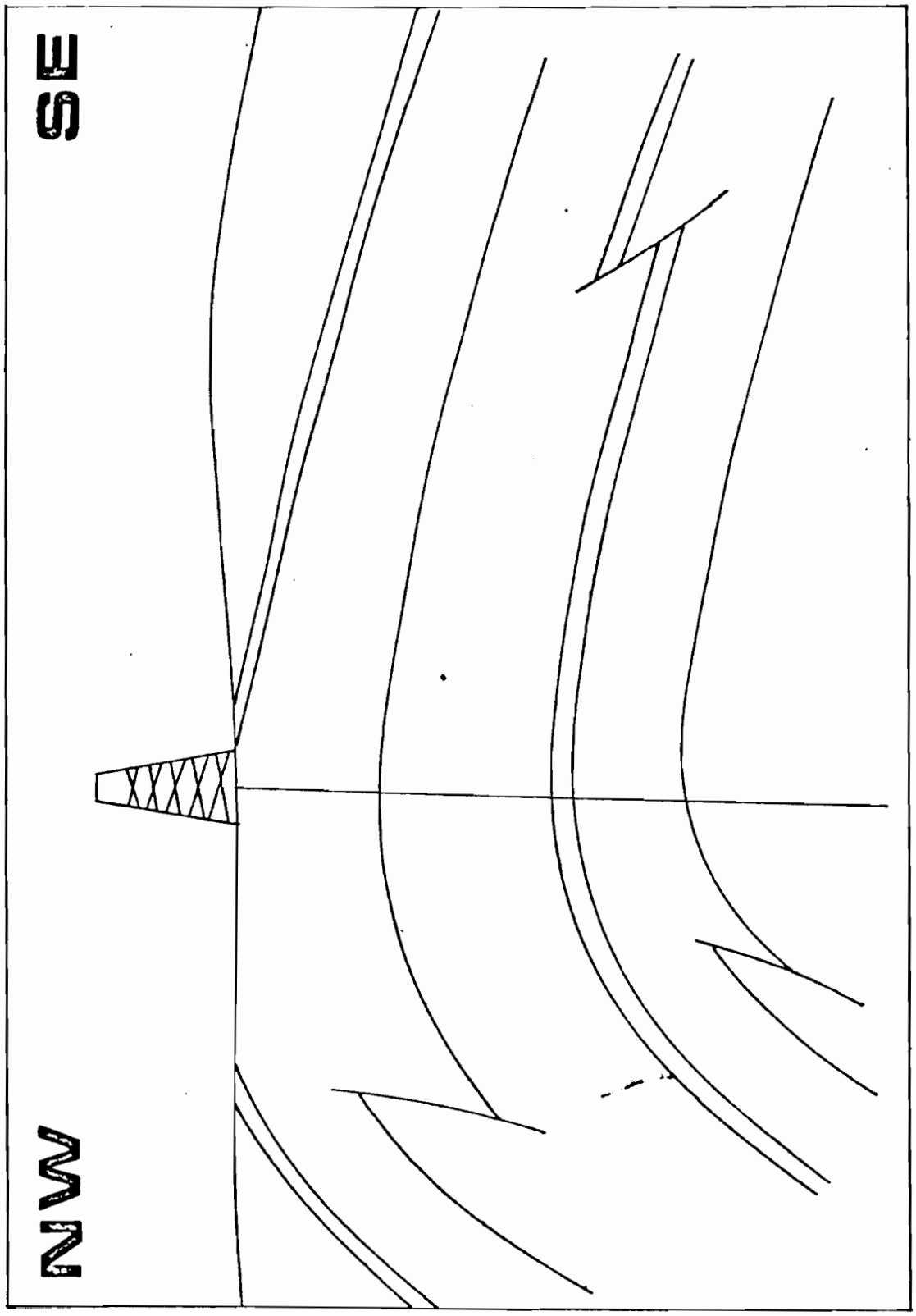

development of the anticline. Rotated uplimb thrust faults are also present on the nearly vertical northwest limb of the Cacapon Mountain anticline in Maryland (Perry and de Witt, 1977. p. 32).

Stage II structures shorten beds and facilitate anticlinal growth. Both can occur contemporaneously in a planar, mechanically anisotropic medium if net transport is mostly toward the anticlinal hinge. Some rotation of stage II structures occurs if they form early, at low limb dips (Root, 1973). Uplimb thrusts also show a wedge-like geometry and may be difficult to distinguish from stage I wedges. Uplimb thrusts tend to cut many beds and die out in shale flowage (Gair, 1950), folds (Gwinn, 1964), or bed parallel slip (Price, 1964). Wedges tend to be small because they represent the adjustment to shortening of a single or a few strut-like beds. Wedges can show a downlimb sense of displacement on northwest limbs of anticlines. Uplimb thrusts tend to cut more beds because they represent adjustment to shortening of the entire fold. Uplimb thrusts always show hingeward displacement of the upper (or outer) fault block.

As uplimb thrust faults on limbs steepen during growth of the anticline, the normal stress across the thrust surface and the resulting friction increase until the fault locks (Gwinn, 1964). Further tightening of the

anticline can produce another fault or faults on the limbs. Continued growth of the anticline, beyond that which flexural slip is capable of relieving, causes onset of stage III.

STAGE III STRUCTURES.--Stage III structures begin to form when beds rotate so far towards the vertical that the effect of vertical extension exceeds that of horizontal shortening. Further growth of the anticline can then only occur by bed-parallel extension. Stages I and II both involve bed-parallel contraction, and so can overlap in time. Because the change from bed-parallel contraction to bed-parallel extension is a discrete event, stages II and III are unlikely to overlap, and their structures should be readily distinguishable. Stage III structures are most easily recognized on and are especially characteristic of steeply dipping to overturned beds.

Norris (1958, 1964) defined extension faults as those that result in elongation in the plane of the layering. He reported extension faulting in otherwise ductile beds (carbonaceous shales) dipping 10 to 25 degrees. Price (1964, 1967), Perry (1971, 1978) and this paper describe extension faults in brittle, steeply dipping beds. Norris and Price noted that if the layering rotated externally in the course of flexural-slip folding until it was at a high angle to the maximum principal compressive stress, then

the trajectories of that stress would tend to become perpendicular to the layering and subsequent brittle failure would take the form of extension faults. This rotation of the stress trajectories is shown by the finite-element modelling of Dieterich and Carter (1969). Price (1967) has found that extension faults tend to intersect bedding at about 70 degrees.

Extension faults show net bed-parallel lengthening unique in the kinematic history of a fold, thus allowing easy recognition. Characteristically, extension faults are low-angle, northwest- or southeast-dipping reverse faults on steep or overturned limbs (figure 3). Extension fractures which show bed-parallel lengthening and form normal to bedding are stage III structures. Extension faults have not undergone a significant amount of later rotation. If they formed prior to folding, they would have formed as high angle normal faults, which are inconsistent with Appalachian contractional deformation. Specifically, extension faults cut contraction faults of stages I and II (Perry, 1971, Perry and de Witt, 1977) and are therefore later features. In extreme cases, map-scale extension faults can lead to overthrust west limbs of anticlines (Dennison, written communication, 1978).

With the possible exception of some systematic joints, stage III structures are the latest recognizeable

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Figure 3. Relationships of stage II uplimb thrust faults to stage III extension faults on an asymmetric fold (modified from Perry and de Witt, 1977, after Price, 1967). Extension fracturing may be associated with both stages II and III.

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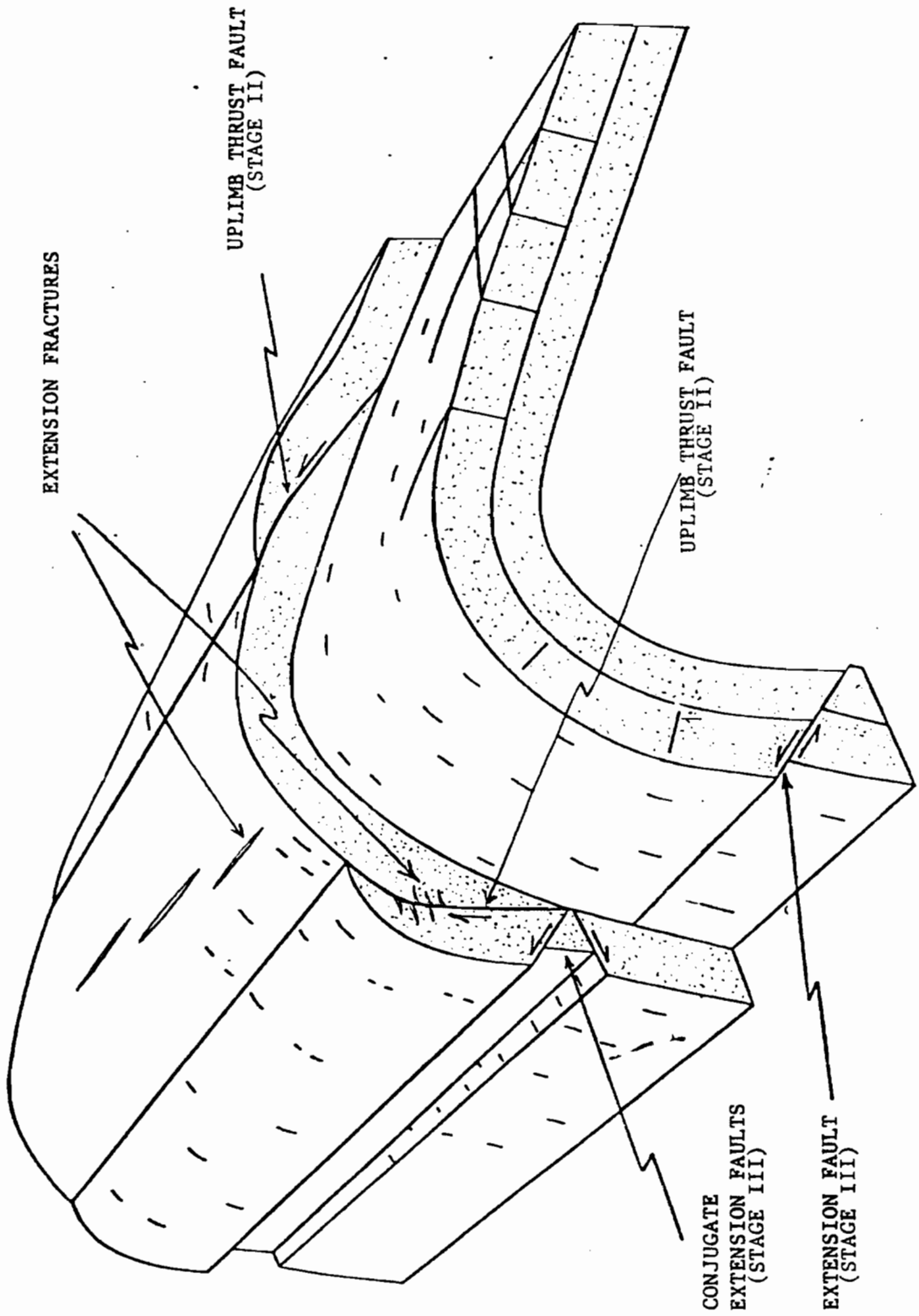

effects of brittle, fold-related deformation in the central Appalachians. Because they are least likely to be filled by vein material or closed during later deformation, they are a possible target for gas exploration in fractured rock.

Field Applications

Recent fieldwork has shown the applicability of our three-stage model of brittle deformation in steeply dipping beds in the central Appalachians. Nine exposures of Ordovician through Mississippian limestones, sandstones, siltstones, and shales of West Virginia, Maryland and Virginia have been interpreted in terms of the model to yield a sequence of events consistent with Appalachian structural style. Slip-senses of minor faults are usually apparent and show either stage I contraction faulting, stage II crestward slip, or stage III bed parallel extension, depending on the angle between beds and horizontal shortening when failure occurred. Directions of fracture openings are ambiguous unless the fractures are filled with fibrous calcite, cut across compaction or tectonic stylolites, or are slickensided. Durney and Ramsay (1973) showed that crystal fibers in calcite fracture-fillings track the direction of opening of the fracture. If the fracture opened by simple dilatancy, then succesive orientations of incremental

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extension during fiber growth can be determined. If the direction of fracture opening is parallel or at a small angle to bedding, then the fracture is unequivocally a stage III feature. Fractures whose opening directions have components of crestward shearing can be either stage I or stage II.

An excellent exposure showing examples of all three stages of brittle deformation is the cut in Silurian limestones along the Baltimore and Ohio Railroad, on the northwest flank of the Wills Mountain anticline at Pinto, Allegany County, Maryland.

Acknowledgements

We wish to thank Wallace de Witt, Jr. and Clinton D. A. Dahlstrom, among many others, with whom we have had useful discussions in the field. Comments of de Witt, M. T. Heald, and R. C. Shumaker improved the manuscript. Many of the concepts herein are influenced by the work of R. A. Price, who cannot be held acountable for our conclusions with respect to the Appalachians. Early versions of the manuscript were prepared with a modification of WYLBUR, a text-editing system developed at the Stanford University Computation Center.

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Western Limit of Extension Fracturing in West Virginia

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Abstract: Extension fractures can extend beds and create porosity, permeability or both where dips on anticlinal limbs are relatively steep (greater than 45 degrees if there is no strain parallel to hinge lines). Simple calculations and reasonable assumptions permit the conclusion that including the effect of hinge line parallel strain does not significantly alter the minimum bed dip at which extension fractures will open. Therefore the minimum conditions necessary for extension fracture formation are unlikely to occur west of Gwinn's (1964) high plateau, with the exception of the Burning Springs anticline, in Wood and Wirt Counties, West Virginia, where limb dips reach a maximum of 68 degrees.

INTRODUCTION

Detachment faults in ductile beds are the primary mechanism for map-scale deformation in the central Appalachian allochthon, and specifically for the Valley and Ridge and most of the Plateau provinces in West Virginia (Gwinn, 1964; Rodgers, 1963). The location of the

western limit of detachment in the central Appalachians is a matter of conjecture, although it may be significant in explaining the distribution or occurrence of gas production from the Middle and Upper Devonian clastic sequence (mostly shales). The purpose of this paper is to determine the western limit in West Virginia of detachment-related fracture porosity and permeability formed as folding rotates beds from low limb dips, where they are contracted, to high dips, where they are extended.

STRUCTURAL STYLE

The West Virginia allochthon has many detached anticlines but few outcropping major thrust faults. The major anticlines are interpreted as active features generated mainly by duplication of strata by ramping of underlying detachment faults, by splay faults, by kink band folding, and by ductile flow of shale rich intervals into anticlinal crests (Gwinn, 1964; Faill, 1969; Wheeler, 1975). The major synclines are regarded as passive features resulting from anticlinal growth in adjacent rocks, rather than from active downbuckling (Gwinn, 1964).

Location of the western limit of allochthonous anticlines involving the Devonian clastic sequence is ambiguous, because the folds generally become less distinctive towards the west. Limb dips and closure decrease westward. In some of the folds of central and

western West Virginia, such as the Arches Fork and Wolf Summit anticlines, closure is apparent below the Middle and Upper Devonian clastic sequence, on the Middle Devonian Onesquethaw Group (Cardwell, 1973), but not above the clastic sequence, on the Middle Mississippian Greenbrier Group (Haught, 1968). The limestones, sandstones, cherts, and thin shales of the Onesquethaw Group and the underlying Oriskany Sandstone, Helderberg Group, and Tonoloway Formation commonly form a single stiff unit about 600 to 1000 feet (180 to 300 meters) thick (Cardwell and others, 1968) in the mechanical stratigraphy of West Virginia. If the folds in the Onesquethaw are part of the allochthon, then a detachment below the Silurian Tonoloway and the thick Devonian clastic sequence (2600 to 7800 feet; 800 to 2400 meters) has absorbed the deformation by flow (Cardea, 1956) or upper detachment (Dahlstrom, 1969a). On the other hand, some folds show closure in the Mississippian Greenbrier Group but not in the Devonian Oriskany Sandstone, from which we infer that a detachment is above the Oriskany and probably in the ductile Middle Devonian black shales. Perry and Wilson (1977) describe an example of this on the Mann Mountain anticline.

We believe that extension fractures may form a significant part of gas-bearing fracture porosity and

permeability. Extension fractures that show bed-parallel extension are interpreted to be late tectonic, formed when folding beds rotated to such steep dips that the rocks were within the extensional, rather than contractional field of the strain ellipsoid (Berger, Perry and Wheeler, ms. in review). These extension fractures are unlikely to be filled by vein material or closed by later deformation and thus may produce gas. We attempt to locate the western limit of extension fracturing in the subsurface as part of a program to predict the location of more highly fractured rock for gas exploration.

In this paper we use the analytical and graphical techniques of Ramsay (1967) to determine the angle (θ) between the X strain axis (the direction of greatest lengthening: vertical) and the surface of no finite longitudinal strain. The surface of no finite longitudinal strain marks the boundary between the contractional and extensional fields in the strain ellipsoid and its dip increases with the horizontal contractional strain. Assuming that the maximum principal compressive stress and the Z strain axis (direction of greatest contraction) are horizontal and perpendicular to strike (Perry, 1971), then the minimum bed dip at which extension fractures can open is 90 - θ degrees. Using published values of shortening or values measured on published cross-sections, we calculate

the critical (minimum) bed dip at which extension fracturing will begin. Comparison of predicted values of critical dips with observed or estimated values of limb dips or shortening in anticlines allows us to predict the distribution of extension fracturing and related fracture porosity and permeability in West Virginia.

METHODS

Ramsay (1967, p. 128) determined the equation for the angle (θ) between the surface of no finite longitudinal strain and the X strain axis, assuming constant volume and no hinge line parallel strain ($e_2 = 0$)

$$\theta = \pm\cos^{-1}\sqrt{\frac{\lambda_3' - 1}{\lambda_3' - \lambda_1'}} \qquad (1)$$

where $\lambda_i' = 1/\lambda_i$

and $\lambda_i = (1+e_i)^2$, $i = 1,2,3$ (2)

Therefore to determine the minimum bed-dip at which extension fractures will begin to open for a given anticline and its estimated shortening value, we need values of λ_1 and λ_3.

λ_3 measures length change parallel to the X (contractional) strain axis. λ_2 measures length change parallel to the hinge line of the fold (intermediate strain axis: Y) and is assumed to be equal to 1. λ_1 measures strain parallel to the Z (extensional) strain axis. λ_3 is found by measuring the amount of shortening for a given anticline by the sinuous bed or equal area method,

after removal of synfolding or postfolding slip on faults that changed bed length but did not rotate beds. We shall regard folding of a stiff layer within a volume of softer rock as grossly approximating overall homogenous nonrotational strain. We assume that the volume of rock containing the rotating stiff bed is not cut by through-going detachments and thus has not been deformed by shear on or near the detachment. That assumption is reasonable within a single anticline (Kulander, oral communication, 1978). Then by the sinuous bed method after restoration of fault slip, the shortening strain is

$$e_x = (\ell - \ell_o)/\ell_o \qquad (3)$$

where ℓ_o = the arc length of a stiff unit like the Onesquethaw-Tonoloway sequence, and

ℓ = the linear distance between the two inflection points of the anticline (the distance into which ℓ_o has shortened).

The sinuous bed method is valid for stiff units that have buckled, kinked, or faulted, but have not flowed internally or pressure-dissolved. The values of shortening in this paper are determined by the sinuous bed method but are consistent with values determined by the equal area method (Gwinn, 1970), which does not assume that there has been no internal flowage or mass-removing

pressure solution.

Our values of shortening need not include shortening by layer parallel penetrative strain (Engelder and Engelder, 1977) or by formation of pressure solution cleavage (Geiser, 1977), because most of this shortening appears to have formed early, prior to folding (Geiser, 1970; Nickelsen, 1976, 1978; Berger, Perry and Wheeler, ms. in review).

λ_1 can be calculated as follows. For a unit sphere deforming at constant volume to a strain ellipsoid

$$V(\text{sphere}) = 4/3\pi r^3 = 4/3\pi$$

$$V(\text{ellipse}) = 4/3\pi(1+e_1)(1+e_2)(1+e_3)$$

Substituting equation (2) and setting V(sphere) equal to V (ellipsoid)

$$\lambda_1 = 1/\lambda_2\lambda_3 \qquad (4)$$

Therefore to determine λ_1 we need only λ_3, which we estimate from shortening, and λ_2, which we assume is equal to 1. Therefore

$$\theta = \pm\cos^{-1}\sqrt{\frac{1/\left[\left(1+\frac{l-l_0}{l_0}\right)^2 - 1\right]}{1/\left[\left(1+\frac{l-l_0}{l_0}\right)^2 - \left(1+\frac{l-l_0}{l_0}\right)^2\right]}} \qquad (5)$$

If we take into account hinge line parallel strain, then λ_2 will be close to but not equal to 1. We assume that e_2 will be no more than ± 10 percent of e_3. This figure is arbitrary but is probably in excess of the true value in

most places, especially where large folds are straight in map view. There is no doubt that strain parallel to hinge lines occurs. The existence of cross joints in folded rocks demonstrates hinge line parallel extension, although hinge line parallel contraction may be equally likely in folded rocks. The arcuate trends in parts of the central Appalachians may help determine whether hinge line parallel contraction or extension has occurred. Where the Appalachians are convex toward the craton, as in central Pennsylvania, hinge line parallel extension may be more likely. Where the Appalachians are concave cratonward, as in southern West Virginia and western Virginia, hinge line parallel contraction is more likely.

Using our values of shortening, and reasonable estimates of λ_2, the angle (θ) between the vertical X strain axis and the surface of no finite longitudinal strain is determined graphically using a Mohr diagram for three-dimensional strain (Ramsay, 1967, p. 152). The points along the line $\lambda' = 1$ on the Mohr diagram yield values of points on the surface of no finite longitudinal strain, in degrees from the X and Y strain axes. These values can be plotted in equal area projection to determine the shape of the surface of no finite longitudinal strain: conical with hinge line-parallel strain, planar without (Ramsay, 1967, fig. 4-21). The

minimum bed dip at which extension fractures will open is measured along the east-west axis of the projection.

RESULTS

Table 1 lists the predicted bed dips at which extension fractures will begin to open for given values of shortening and $\lambda_2 = 1$. These values were calculated using equation (5) and are the complements of the angles (θ) between the X strain axis and the surface of no finite longitudinal strain. Some of the predicted dips were checked by Mohr diagrams for three-dimensional strain. With no change in length parallel to the hinge line, the minimum bed dip at which extension fractures will begin to open is 45 degrees. That finding is consistent with the results of finite-element modeling of viscous layers (Dieterich and Carter, 1969), and other work summarized by Perry (1978, p. 524). Where there is $\pm .1(e_3)$ hinge line parallel strain, the minimum bed dip at which extension fractures will open does not differ significantly from the values in Table 1.

Table 2 lists measurements of shortening for anticlines in West Virginia, determined from cross-sections by the sinuous bed method or from estimates in the literature. With the exception of the Burning Springs anticline, in Wood and Wirt Counties, West Virginia, no anticlines west of Gwinn's (1964) high

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TABLE 1

PERCENT SHORTENING	MINIMUM LIMB DIP
1%	45 degrees
2%	45 degrees
3%	46 degrees
4%	46 degrees
5%	46 degrees
10%	48 degrees
15%	50 degrees
20%	51 degrees
25%	53 degrees
30%	55 degrees
35%	57 degrees
40%	59 degrees
45%	61 degrees
50%	63 degrees

plateau, which have structural relief less than 300 feet (90 meters), should show extension fracturing unless faulting in the subsurface has created abnormally high limb dips. Fault imbrication in the subsurface of the Burning Springs anticline has caused dips as steep as 68 degrees (Shockey, 1954). The Arches Fork and Wolf Summit anticlines may also show extension fracturing, since Gwinn (1964) indicates that they have between 300 and 800 feet (90 and 240 meters) of relief, intermediate between anticlines of the high plateau and those of western West Virginia.

ACKNOWLEDGEMENTS

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Table 2.

Anticline	Location	Shortening	Maximum Limb Dip	Source
RELIEF GREATER THAN 800 FEET (240 METERS)				
Burning Spgs.	Wood/Wirt Co.	2%	68 degrees	Shockey (1954)
Briery Mtn.	Preston Co.	6%	45 degrees	Cardea (1959)
Chestnut Rdg.	Monongalia Co.	3%	12 degrees	Mitchell (1960)
Wills Mtn.	Pendleton Co.	20%	overturned	Perry (1971)
Browns Mtn.	Pocahontas Co.	16%	overturned	Kulander and Dean (1972)
RELIEF BETWEEN 300 and 800 FEET (90 and 240 METERS)				
Wolf Summit	Lewis Co.	<1%	5 degrees	Milner (1968)
Hiram	Harrison Co.	<1%	<1 degree	Cardwell (1973)
Arches Fork	Doddridge Co.	<1%	<1 degree	Cardwell (1973)
Warfield	Logan Co.	<1%	<1 degree	Cardwell (1973)
RELIEF LESS THAN 300 FEET (90 METERS)				
Mann Mtn.	Fayette Co.	<1%	<1 degree	Perry and Wilson (1977)

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Late-Tectonic Extension Faulting in the Central Appalachians

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Abstract: Examination of outcrops in parts of the western Valley and Ridge and eastern Allegheny Plateau provinces of Maryland, Pennsylvania, Virginia and West Virginia located 227 bed-extension faults of which 115 had measurable separation at 24 stations. Previous work showed the faults formed late during folding when beds were steeply dipping, and not by early normal faulting when beds were horizontal. The distribution and amount of extension faulting have implications bearing on tectonic development and gas potential. First, outcrop-size and larger extension faults contribute significantly to anticlinal growth in more brittle units when external rotation steepens fold limbs. Second, stratigraphic localization of extension faulting suggests that reported thinning of brittle units on steep limbs of anticlines may be partly due to late-tectonic extension faulting, rather than wholly to splay faults rising from detachment surfaces. Third, measured values of bed-parallel extension for packets of especially brittle rocks indicate

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significant amounts of fracture potentially suitable for gas reservoirs.

INTRODUCTION

The western Valley and Ridge and eastern Allegheny Plateau provinces of Maryland and West Virginia are characterized by anticlines with the greatest amounts of structural relief within their respective provinces. In the Valley and Ridge province, the Wills Mountain anticline (Fig. 4) has approximately 4000 m of structural relief (Perry, 1975). In the Plateau province, the Browns Mountain anticline may have structural relief as great as 2500 to 3000 m (Kulander and Dean, 1972). The Elkins Valley anticline also exposes vertical beds and may have structural relief of almost 3000 m (Rodgers, 1970). Northwest limbs of these folds are steeply dipping and locally overturned. Other eastern Plateau anticlines are characterized by more steeply dipping rocks in the subsurface than at the surface, at least to the level of the Lower Devonian (Rodgers, 1970), and may be asymmetric with more steeply dipping southeastern limbs at least to the level of the Oriskany (Gwinn, 1964).

The steeply dipping limbs of map-scale anticlines in the central Appalachians are due primarily to external rotation of stiff beds (mostly sandstones and limestones) during folding. The map-scale folding is caused by

stepwise westward rise (ramping) of detachment surfaces or by splay faulting from nearly horizontal detachment surfaces (Rodgers, 1963; Gwinn, 1964). In most places in the central Appalachians, the detachment surface or splay fault does not reach the surface. As bed rotation and accompanying horizontal shortening and vertical extension continued, anticlinal growth in stratigraphic units above the detachment involved flow of shaly sequences out of anticlinal limbs and into crests (Wheeler, 1975) and bed-parallel extension in steeply dipping to overturned beds (Perry, 1971).

This study is based on outcrop examination of bed-parallel extension structures, primarily faults, which begin to form when beds rotate sufficiently toward the vertical that the effect of vertical extension exceeds that of horizontal shortening. Extension faults can form at any bed orientation, depending on the attitude of the local maximum principal compressive stress (Norris, 1958, 1964). However in the central Appalachians, analysis of structural style and field investigation both indicate that extension faults form when the dip of beds exceeds 45 degrees (Berger and Wheeler, in review), and mostly as reverse faults, serving to thin the beds. Cloos and Broedel (1943) and Root and Wilshusen (1977) described faults with similar structural style in other parts of the

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central Appalachians. Perry and de Witt (1977), Perry (1978), and Berger, Perry and Wheeler (in press) recognize these reverse faults as extension faults, analogous to those described from the Canadian Rockies by Norris (1958, 1964) and Price (1964, 1967).

With the possible exception of some systematic joints, these extension faults are the latest recognized effects of brittle but fold-related deformation in the central Appalachians (Berger, Perry and Wheeler, in press). Because they are formed late during deformation, they are least likely to be filled by vein material or closed during later deformation. If sufficiently numerous and extensive they are an excellent target for gas exploration assuming the presence of a gas-bearing source and reservoir seal. In particular, they may form permeable fractured reservoirs in the Middle and Upper Devonian clastic sequence. This paper attempts to evaluate that hypothesis.

FIELD METHODS

More than 100 large exposures of steeply dipping or overturned beds were examined in the western Valley and Ridge and eastern Allegheny Plateau provinces in parts of Maryland, Pennsylvania, Virginia and West Virginia (Fig. 4). Of these exposures, 24 were intersected by at least one measurable extension fault. Each fault was identified

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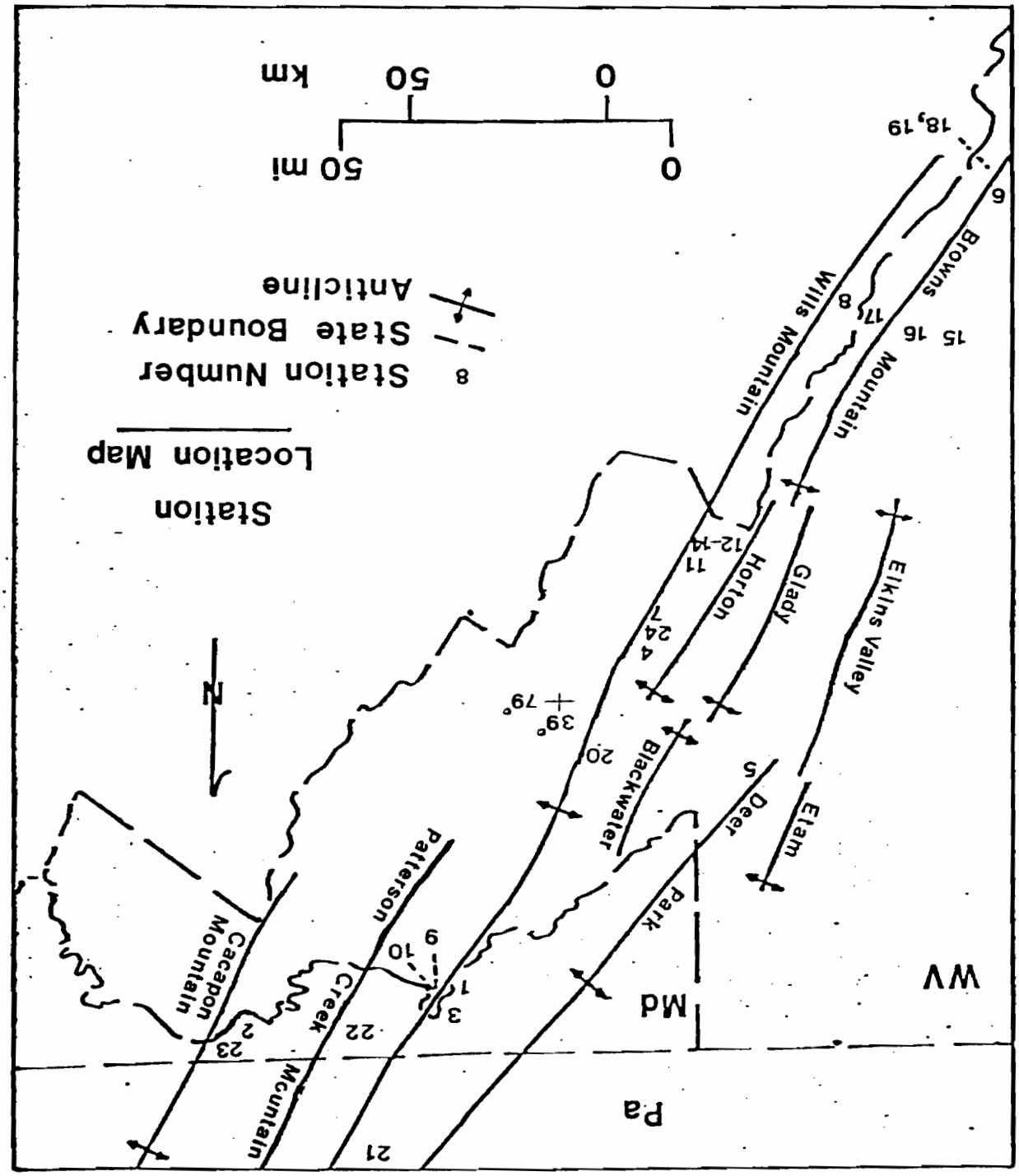

Figure 4. Map showing major anticlines in the study area. Numbers show locations of stations listed in Table 4.

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either by the senses of asymmetry of associated drag folds or by matching of beds across the fault. The following were measured or calculated for each fault: vertical separation, horizontal separation, dip separation, bed-parallel extension (separation measured parallel to the beds, not defined by Dennis, 1972), and the thickness of the packet of beds affected by the fault. For each station, the exposure length and thickness of each stratigraphic unit present were measured. In exposures with variable dip, only beds dipping more than 45 degrees were included, because only there are extension faults expected (Berger and Wheeler, in review).

At a few places in the exposures, zones of en echelon filled feather fractures with sigmoidal habit were presumed to mark incipient extension faults. The dip separation was calculated as the sum of the zone-parallel thicknesses of the fracture fillings and the other separation values were calculated accordingly. Styles of terminations of the fault surfaces were noted, as were spatial relations to folds and to contraction faults (faults that shortened beds: Norris, 1958, 1964).

STRUCTURAL STYLE

Perry (1971) recognized 31 extension faults on the northwest limb of the Wills Mountain anticline in Pendleton County, West Virginia. He (unpublished notes,

1965-1967) found extension faults in the Silurian Tuscarora quartzite, Rose Hill formation, Keefer sandstone, Williamsport sandstone and Tonoloway limestone and the Devonian Oriskany sandstone. Table 3 details the number of extension faults recognized in our study. Extension faults were found in many of the same units in the study area in which de Witt and Dennison (1972) noted minor faulting and Perry (1971) noted minor extension faults. Extension faults were found as well in other units.

Outside the study area, Cloos and Broedel (1943, their Plate 1) show 27 extension faults in 180 m of outcrop in the Hamilton Group near Harrisburg, Pennsylvania. Not all the reverse faults reported by Cloos and Broedel (1943) are extension faults. Many are fractures with unmeasurable amounts of offset or are contraction faults. However, the number and distribution of faults and other fractures (843 fractures in 12 stations) led Cloos and Broedel (1943) to conclude that reverse faults in steeply dipping beds are widespread and characteristic of Appalachian folding (p. 1388).

Some extension faults occur singly. Others are conjugate pairs with associated synthetic and antithetic extension faults. Numerous other fractures were observed, especially in the shaly parts of the Brallier Formation,

Table 3.

STRATIGRAPHIC UNIT	NO. OF EXTENSION FAULTS	NO. OF MEASURABLE EXT. FAULTS	CUMULATIVE THICKNESS OF SECTION: OUTCROPS WITH MEAS. EXT. FAULTS	FAULTS PER M OF SECTION
Mississippian				
Pocono Formation	9	4	266 m	0.034
Devonian				
Hampshire Formation	1	0	--	--
Chemung Group	8	6	308 m	0.026
Brallier Formation	104	43	1251 m	0.063
Millboro Formation	1	1	75 m	0.01
Marcellus Formation	4	0	--	--
Silurian				
Tonoloway Formation	35	24	200 m	0.175
Wills Creek Formation	1	1	159 m	0.006
Bloomsburg Formation	7	2	94 m	0.074
McKenzie Formation	27	17	148 m	0.182
Rochester Shale	14	14	139 m	0.101
Keefer Sandstone	2	1	6 m	0.3
Rose Hill Formation	4	2	7 m	0.6
Tuscarora Formation	7	4	82 m	0.08
Ordovician				
Juniata Formation	3	2	40 m	0.08
Total	227	115		

many with slickenside, slickenline, or apparent dip orientations similar to those of nearby extension faults but not showing drag folding or matchable beds. The number of extension faults recognized, as well as the numerous undifferentiated fractures, indicates to us that extension faults are an important and little recognized component of, and are indeed characteristic of, certain stratigraphic units where those units are rotated to steep dips. Thus field observations indicate that in the Devonian clastic sequence, the Brallier Formation may form unusually many extension faults when bed dips increase into the extensional field.

Field observations indicate that the extension faults may terminate against each other, or against a thick bed of siltstone or limestone. In some places the thick bed is broken by a fracture zone along the continuation of the extension fault, and the fractures may show small amounts of slip. An extension fault may die out as a single fault or by distributing its slip among several splays in shales. At many places the extension faults curve upwards or downwards into surfaces of bedding-plane slip (Price, 1964).

Extension faults may form and have been recognized on limbs of folds ranging in size from typical outcrop-scale to map-scale. Therefore they represent a

common response to the local maximum principal compressive stress, which tends to be roughly parallel to beds until dips reach 45 to 60 degrees, and then tends to be perpendicular to the beds (Dieterich and Carter, 1969). Previous workers have shown that most extension faults form at high angles to beds, although they can form at lower angle (Norris, 1958; Price, 1967; Perry, 1971).

Price (1964) writes that in less steeply dipping beds in the Canadian Rockies, extension faults tend to show a uniform dip direction and commonly begin and terminate in a bedding-plane slip surface. With increased bed rotation, he noted that extension faults form conjugate sets. We have not found this to be generally true in the central Appalachians. An extension fault that terminates in a bedding-plane slip surface may be part of a conjugate set of extension faults. Overturned beds in the central Appalachians show both single faults and conjugate sets of extension faults.

Because some extension faults are found to begin or terminate in bedding planes, earlier flexural slip folding may still have been active at the time of extension faulting. We propose that extension faulting can occur during flexural-slip folding if the contacts within a packet of beds become locked, perhaps around small folds, so that the shear strength at a bed contact exceeds the

tensile strength of the bed or beds. The slip surface may then cut across the locked beds, forming an extension fault. Some subsequent external rotation of those extension faults by further folding is likely (Price, 1964), especially where beds are now overturned.

Other extension structures found include boudinage of thin siltstone or limestone beds, abundant lenticular extension fractures oriented roughly perpendicular to bedding, and three normal faults of small displacement. There is a strong positive association between exposed fault length and amount of dip separation (for 119 observations, Spearman's correlation coefficint (Siegel, 1956) gives a significance level of .0001.

RESULTS

Table 4 summarizes the results of our field investigations for the 24 stations that showed measurable separation. Below, we suggest that useful conclusions of regional applicability can be reached by extrapolating our data into the subsurface. Inferences about fold growth and tectonic thinning of the limbs can be made from compilation of the vertical and horizontal separation data, respectively. Estimates of gas potential are based on the amount of bed parallel extension.

It must be emphasized that measurements reported here are minimum values. Only definite extension faults

Table 4.

STATION NO. AND NAME	E/R	T/R	F/R	LOCATION	STRATIGRAPHIC UNITS(S)
1 Pinto, Md	27.0%	1.6%	30.0%	NW limb, Wills Mt. ant.	Rose Hill/Keyser
2 Woodmont, Md	2.9%	0.4%	3.7%	NW limb, Cacapon Mt. ant.	Mahantango/Brallier
3 La Vale, Md	4.0%	0.5%	3.0%	NW limb, Wills Mt. ant.	Mahantango/Hampshire
4 Ketterman's Knob, WV	40.0%	0.1%	14.4%	NW limb, Wills Mt. ant.	Brallier
5 Parsons, WV	2.6%	3.5%	3.6%	axial region, Deer Park ant.	Chemung
6 White Sulfur Springs, WV	40.0%	0.1%	14.4%	NW limb, Browns Mt. ant.	Chemung/Pocono
7 Judy Gap-a, WV	<.1%	0.2%	-----	NW limb, Wills Mt. ant.	Tonoloway
8 Ryder Gap, VA	23.0%	3.7%	25.0%	NW limb, Wills Mt. ant.	Brallier/Chemung
9 Cedar Cliffs, Md	1.0%	0.6%	1.3%	SE limb, Wills Mt. ant.	Bloomsburg/McKenzie
10 Rose Hill, Md	0.5%	0.2%	0.2%	SE limb, Wills Mt. ant.	Rose Hill/McKenzie
11 Teeter Hollow, WV	<.1%	0.1%	<.1%	NW limb, Wills Mt. ant.	Rochester
12 Snowy Mt. Rd.-a, WV	2.0%	0.4%	2.4%	NW limb, Wills Mt. ant.	Rochester/Keefer
13 Snowy Mt. Rd.-b, WV	3.0%	2.9%	2.3%	NW limb, Wills Mt. ant.	Rochester/Keefer
14 Snowy Mt. Rd.-c, WV	1.0%	1.9%	2.3%	NW limb, Wills Mt. ant.	Rochester/Keefer
15 Huntersville, WV	0.1%	<.1%	0.6%	NW limb, Browns Mt. ant.	Bloomsburg
16 Rte. 39, WV	3.4%	<.1%	0.6%	axial region, Browns Mt. ant.	Tuscarora
17 Minnehaha Springs, WV	0.5%	0.8%	0.4%	SE limb, Browns Mt. ant.	Juniata/Tuscarora
18 I-64-a, WV	<.1%	0.1%	<.1%	SE limb, Browns Mt. ant.	Brallier
19 I-64-b, WV	<.1%	0.2%	<.1%	axial region, Browns Mt. ant.	Harrell/Brailler
20 North Fork Gap, WV	0.2%	0.3%	<.1%	NW limb, Wills Mt. ant.	Tuscarora
21 Wolf Camp Run, Pa	<.1%	0.1%	<.1%	NW limb, Wills Mt. ant.	Mahantango/Brallier
22 Martin Mt., Md	<.1%	0.3%	<.1%	NW limb, Patterson Ck. Mt. ant.	Tonoloway
23 Hancock, Md	<.1%	0.1%	<.1%	SE limb, Cacapon Mt. ant.	Bloomsburg
24 Judy Gap-b, WV	31.0%	3.1%	34.8%	NW limb, Wills Mt. ant.	Brallier

E = anticlinal growth; T = tectonic thinning; F = amount of extension; R = structural relief

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were measured. All measurements were taken in 2 to 3 m high strips along the accessible basal segments of exposures. The larger the displacement along the fault the less the chance of matching beds across the fault. The extrapolations into the subsurface could be maximum values because they assume the same intensity of faulting throughout the vertical extent of the fold limb as that measured in our selected exposure. However, because it seems unlikely that the present erosion level preferentially exposes unusually extended rocks, the true values may approach our extrapolated values. Thus the results reported here are conservative (minimum) but probably roughly accurate values for the amount of fold growth by extension faulting.

FOLD GROWTH

The major anticlines of the central Appalachians are active structures generated mainly by duplication of strata by ramping of underlying detachment faults, by splay faulting, and by ductile flow of shale or evaporite sequences into anticlinal crests (Gwinn, 1964; Faill, 1969; Wheeler, 1975). The major synclines are passive structures resulting from anticlinal growth in adjacent rocks, rather than from active downbuckling (Gwinn, 1964). We propose that extension faulting late during folding provides an important contribution to anticlinal growth.

At Station 1, near Pinto, Maryland on the northwest limb of the Wills Mountain anticline (Fig. 4, Table 4), the amount of growth by bed-parallel extension may be as much as 27% of the entire structural relief of the fold. This value is based on data from a single exposure on the limb of the anticline and is extrapolated into the subsurface by

$$E = V(BPT/ET)(R/2.5) \qquad (1)$$

where E = the amount of anticline growth by extension, in meters,

V = the sum of the amounts of vertical separation of measured extension faults,

BPT = the sum of the thicknesses of the packets of beds containing the extension faults,

ET = the present (post-extension) length of the exposure measured perpendicular to beddinig,

R = the structural relief of the anticline, and

2.5 = the height of accessible exposure in meters.

Estimates of structural relief are: Wills Mountain anticline - 4000 m (Perry, 1971), Browns Mountain anticline - 3000 m (Kulander and Dean, 1972), Deer Park anticline, 3000 m (Gwinn, 1964), Cacapon Mountain

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anticline - 4000 m (Perry and de Witt, 1977), and Patterson Creek Mountain anticline - 2500 m (Cardwell, 1975). The amount of structural relief of the Wills Mountain anticline in Maryland and Pennsylvania is equal to or greater than the amount measured by Perry (1971) in Pendleton County, West Virginia, because although the anticline appears to lose structural relief northeastward into Maryland (Cardwell and others, 1968), that is compensated by increasing depths to basement from southwest to northeast along the strike of the Wills Mountain anticline (Kulander and Dean, 1978).

Using equation (1), values of E have been determined for each station in which extension faulting was measurable. Similar results have been obtained by Cloos and Broedel (1943), using a similar method of extrapolation. They estimated that the reverse faults contribute 10% to the structural relief of the anticline they studied. Table 4 lists our percentages of anticline growth by extension. The contribution of extension to fold growth is significant in many exposures, especially considering that extension does not begin until late in folding when the limbs are steeply dipping and the fold may have already attained considerable relief. The widespread stratigraphic and geographic distribution of extension faults in steeply dipping beds (Tables 3 and 4,

Fig. 4) supports our suggestion that our results have regional applicability.

TECTONIC THINNING

Tectonic thinning of measured stratigraphic sequences has been reported in the study area (Dennison and Naegele, 1963; Dennison, Travis and Ferguson, 1965; de Witt and Dennison, 1972; de Witt, 1974) and was used as a guide by us in locating exposures that have undergone extension faulting. We hoped to be able to recognize enough extension faults to account for a large proportion of the tectonic thinning. The amount of tectonic thinning (T) is determined using equation (2)

$$T = H/ET \qquad (2)$$

where H = the sum of the amounts of horizontal separation of measured extension faults.

At Station 4, near Ketterman's Knob, Pendleton County, West Virginia (Fig. 4, Table 4), Dennison and Naegele (1963) report that approximately 60 m of the Brallier formation is absent (about 25% tectonic thinning). Outcrop examination at Station 4 indicates a minimum of .1% tectonic thinning by extension faulting. Here Dennison and Naegele (1963) write that tectonic thinning was probably accomplished by minor faulting within a fault zone in the Brallier Formation.

To the north along strike, Dennison, Travis and

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Ferguson (1966) infer the presence of four major fault zones in the Brallier Formation (Kittlelick, Dawson, Cresaptown [station 3], and Hyndman [station 21] faults) largely from geomorphic evidence of a narrow strike valley, but also from measured stratigraphic sections. Dennison, Travis and Ferguson (1966) infer that these fault zones are splay faults rising from a deep detachment, probably located in the Ordovician Reedsville Formation. De Witt (1974 and written communication, 1978) proposes on the basis of seismic data that the Hyndman fault is a large splay fault with associated extension faults in the fault zone, particularly in the vicinity of the village of Hyndman.

We believe that the tectonic thinning reported by Dennison and Naegele at our stations 3 (La Vale) and 4 (Ketterman's Knob) was accomplished more by small and medium size late tectonic extension faults than by the single splay faults envisioned by Dennison and Naegele (1963) and de Witt and Dennison (1972) (Fig. 5). Our arguments are three. First, all four inferred splay faults crop out in and thin the Brallier Formation. This requires a fortuitous coincidence of erosion level with the intersection of the Brallier Formation and the fault surface and must occur for all four faults. If a fault is a splay and thus not confined to the Brallier, then it is

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Figure 5. Contrasting models of tectonic thinning by faulting on the northwest limb of the Wills Mountain anticline. No vertical exaggeration. A. Splay fault interpretation modified from Dennsion and Naegele (1963), Dennison and others (1966) and de Witt and Dennsion (1972). B. Extension fault interpretation modified from Perry (1971). Dashed lines are decollement or splay faults. Short solid lines in upper left of section B are extension faults. Cross-sections are not to the same scale.

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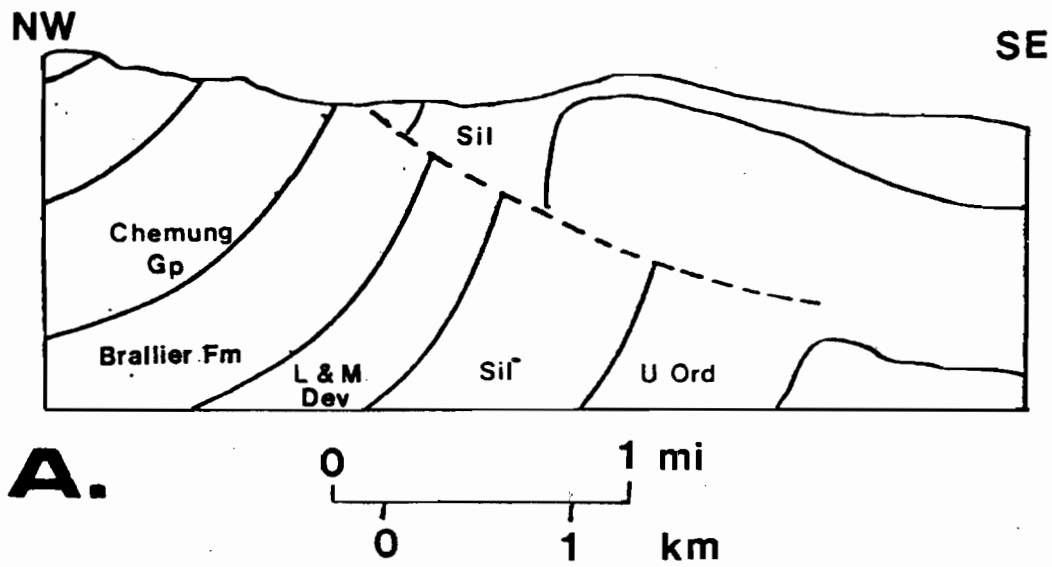
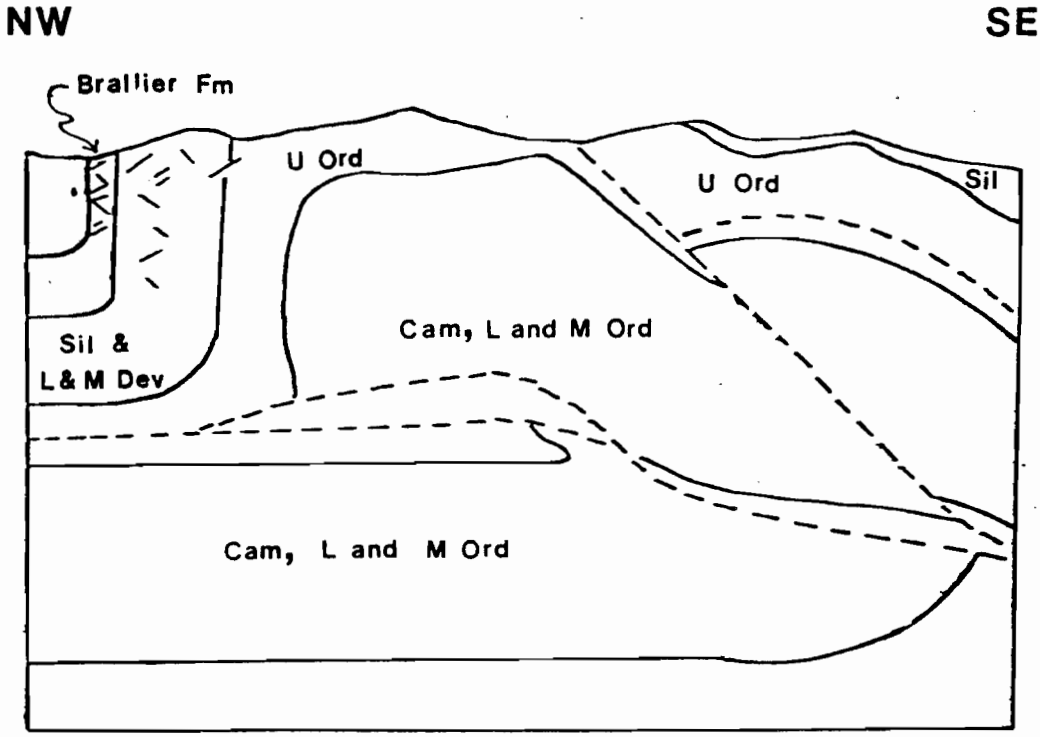


A.

0 1 mi

0 1 km



B.

0 1 mi

0 1 km

about equally likely to crop out stratigraphically above, within, or below that unit. Second, as shown in Table 3, the Brallier Formation shows more extension faults than does any other Devonian unit examined. Third, as noted above under "Field Methods", the Brallier contains more minor faults, many unclassifiable, than does any other unit examined. We suggest a simpler explanation that the Brallier Formation localizes extension faulting in our study area (Fig. 5). These small extension faults may not descend to the detachment in the Reedsville Formation, but could have considerable slip. Perry (1971) has recognized a map-scale extension-like fault on the Wills Mountain anticline (see also de Witt, 1974).

We suggest that the Dawson thrust of Dennison and Naegele (1963) and de Witt and Dennison (1972) is a large extension fault because we observed few minor extension faults in the outcrop belt of the fault zone (station 21 and in exposures near station 1).

The thinning in the Hyndman fault zone is more likely to be due to splay faulting than to the associated extension faults (de Witt, written communication, 1978) on the basis of confidential seismic data available to de Witt. However, the thinning mapped at the surface (de Witt, 1974) may not be clearly connected with the splay fault observed on the seismic section at depth because

poor reflections are usually received in such areas of steep dips.

The Kittlelick fault is thought to be a fault zone by Dennison, Travis and Ferguson (1966). We agree but suggest that the thinning along the Kittlelick fault is due to a zone of extension faulting similar to the zone of numerous extension faults observed along the Cresaptown fault and near Ketterman's Knob. We also suggest that thinning of stratigraphic units adjacent to the Kittlelick and Hyndman faults as reported by Dennison and others (1966) and de Witt and Dennison (1972) may also be due in part to extension faulting as well as to branches from splay faults.

PERCENT EXTENSION

Maximum possible amount of extension due to faulting (F) is estimated by

$$F = BPE(BPT/ET)(R/2.5) \qquad (3)$$

where BPE = the sum of the amounts of bed-parallel extension of measured extension faults.

The value (F) is the amount of extension for a limb of a fold based on extrapolation of measured values of bed-parallel extension. The greater the (F) value the greater the possibility of a fold being suitable for gas in fractured reservoirs. This estimate is a maximum because the extension is generated as beds are faulted

apart in directions parallel to bedding but the resultant voids are simultaneously reduced by tectonic thinning.

As shown in Table 4, the (F) value due to bed-parallel extension on the Wills Mountain anticline can be locally almost 35% of total structural relief. We have noted that extension faults are always associated with extension fractures. We suggest that qualitative estimates of the relative amounts of fracture porosity and permeability in the subsurface can be made by comparison of bed-parallel extension values (F).

Murray (1968) obtained a value of .05 percent fracture porosity from a geometric analysis of bed curvature in a producing field with very low primary porosity. We believe there occur zones or patches of concentrated fracture porosity, or permeability, or both, depending on the response of a particular stratigraphic unit to the local maximum principal compressive stress. Where many small measurable faults extend the beds, rather than one or a few larger unmeasurable extension faults, then our data will show a higher percent extension. Along the Allegheny Front in southern Pennsylvania, Maryland and northern West Virginia (Dennison and Naegele, 1963), these faulted zones vary in intensity northeast and southwest along strike of the Brallier Formation. It is also possible that faulted zones vary vertically throughout the

limb in the subsurface. More detailed stratigraphic work is necessary before drilling targets can be selected. However, estimates of tectonic thinning by Dennison and Naegele (1962), Dennison and others (1966), and de Witt and Dennison (1972), values in our Table 3, and the abundant unclassified fractures observed in the shaly parts of the Brallier Formation all suggest to us that the Brallier may be the most highly extension-fractured and -faulted unit in the subsurface.

Extension faulting is usually restricted to a relatively brittle bed or beds bounded by more ductile shaly beds. Thick-bedded brittle units do not show well developed extension faults, nor do ductile black shales that we examined. Results consistent with these statements have been obtained in experimental work (Griggs and Handin, 1959). We suggest that the 0.3 to 0.7 m thick, shale-bounded siltstones near the base of the Brallier Formation would be the most likely candidates for production controlled by extension faults. They may be the equivalent of the Sycamore sandstone or siltstone (Patchen, 1977), a unit recognized only in the subsurface of central West Virginia and which produces small amounts of gas.

Any patchy distribution of tectonic thinning may be due to the presence or absence of lubrication between beds

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(see Reches and Johnson, 1976). Where the bed packets are unlubricated, they may lock and fail by extension, as described above. Where they are lubricated, they may undergo flexural slip without extension. The type and distribution of lubrication is beyond the scope of this paper. Alternatively, there exists the possibility that the zones of intense extension fracturing and extension faulting may be due to the presence of a nearby large splay fault.

GAS POTENTIAL

Any potential fractured reservoir whose porosity and permeability are partly or wholly due to extension fracturing would be located in folds of the eastern or High Plateau (Gwinn, 1964) or Valley and Ridge province where dips greater than 45 degrees allow extension fracture formation (Berger and Wheeler, ms. in review). If the Brallier Formation is selected as the target gas bearing formation, then the Glady, Horton, Blackwater and Deer Park anticlines would be the best potential sites in the High Plateau because the Brallier is not exposed but is present at shallow depths and may contain steeply dipping beds. In the Valley and Ridge province the Broadtop synclinorium also offers steeply dipping Brallier Formation in subsurface anticlines (Jacobeen and Kanes, 1974). If the source of gas in the Brallier is the

underlying dark, kerogen-rich shales, then the prime drilling targets would be off the crests of the anticlines on the steep, extended limbs. Drilling targets on the limbs have not been adequately tested in the past (R. Shumaker, oral commuication, 1978). Here thinned, steeply dipping, extended Brallier rocks may overlie dark shales thinned by flowage toward cores of detached anticlines that grew over imbricated stacks of Oriskany Sandstone and older rocks. The presence of gravity lows near the crests of anticlines indicates shale flowage (Kulander and Dean, 1978).

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Extension in Kink-Bands and on the Limbs of Kink Folds

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ABSTRACT: Beds in kink-bands can undergo bed-parallel extension when the angle between the kink surface and the kink-band is less than the angle between the kink surface and the enveloping beds. Field investigations in the Middle and Upper Devonian clastic sequence of the central Appalachians indicate that the kink-band undergoes more extension fracturing and jointing and shows more twist hackle than the enveloping beds. However, comparison of measured values of extension with predicted volume increases in kink-bands indicates that only about 10 percent of the volume change is translated into extension fractures.

The intersection of two inclined kink-bands produces a kink fold that is identical in gross form to a chevron fold formed by buckling, but can be distinguished by associated fold forms. The geometry of second order folds (Nickelsen, 1963) of the central Appalachians can best be accounted for by a kink fold model (Faill, 1969, 1973).

Gravity lows indicate thickened low density shale on

the northwest limbs of the Blackwater and Glady anticlines. We suggest that there exist thinned and extended units downdip from the thickened shale sections. Therefore, map-scale kink folds should have the most thinning by extension fracturing and faulting low on the steep limb in the subsurface. There, such folds are more likely to contain gas in fractured reservoirs.

INTRODUCTION

Dennis (1967) defines kink-band as a tabular zone along which foliation is deflected. A kink fold is formed from the intersection of two kink-bands. A kink fold may be in the form of a box fold or may have planar limbs and narrow hinges similarly to a chevron fold (Fig. 6B).

Recent work by Faill (1969, 1973) has shown that the typical map-scale folds of Pennsylvania have planar limbs and narrow hinges that can best be explained by kink-band deformation. The geometric and kinematic similarities between map- and outcrop-scale kink-bands suggest to Faill that the processes and mechanisms that gave rise to the large folds were identical to those that produced the small folds.

In this paper, we use outcrop-scale folds to provide information about relative amounts of bed extension on limbs in map-scale folds. Anticlines with large amounts of extension may contain suitable exploration targets for

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gas in fractured reservoirs.

KINK-BANDS AND KINK FOLDS

Faill (1969, 1973) is able to explain most attributes of central Appalachian fold style by using the intersection of two kink-bands inclined toward each other with opposite senses of rotation and divergent kink axes. However, Johnson (1977) argued from elastic theory that folds with planar limbs and narrow hinges also can arise from another sequence of development (Fig. 6A). Johnson proposed that hinges can narrow and limbs straighten progressively during folding, thus transforming a concentric-like fold into a chevron fold. Conceivably, tension fractures may form due to initial bending and later straightening of the limb (B. Kulander, oral communication, 1978). These chevron folds can appear almost identical in outcrop to kink folds formed by the intersection of two inclined kink-bands. The kink-bands tend to form when the beds are lubricated (separated by very weak interbeds) and when the maximum principal compressive stress is at a small angle to beds (Johnson, 1977). Chevron folds formed from concentric-like folds are most likely to occur when the beds are not lubricated, when the surrounding medium is softer than the folded beds and when the maximum principal compressive stress parallels the beds. However, Chapple (1978) notes that

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Figure 6. Contrasting models of formation of chevron and kink folds. Horizontal lines at left are selected beds. A. Sequence from sinusoidal to concentric-like to chevron forms. B. Sequence from low, sinusoidal forms to kink forms, with local chevron forms (after Johnson, 1977). Dashed lines denote kink surfaces.

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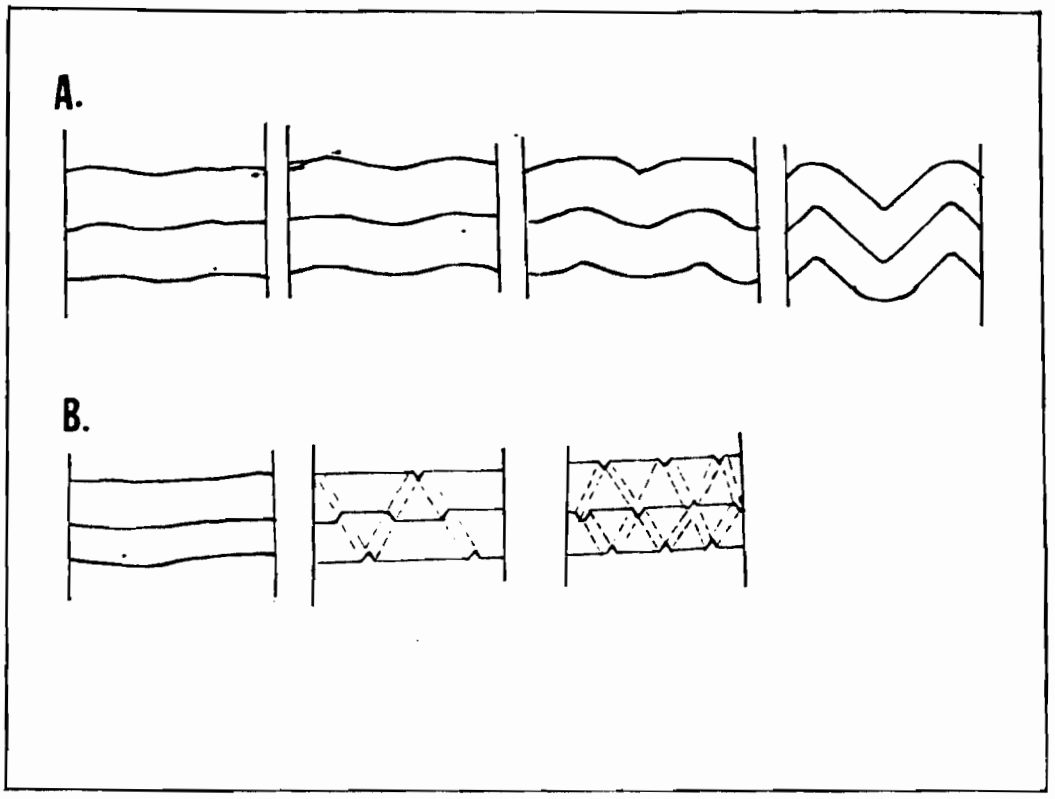

the applicability of Johnson's elastic theory to folding is not entirely clear.

We have tried to discriminate in the field between chevron folds (Fig. 6A) and kink folds formed from the intersection of two kink-bands (Fig. 6B). Johnson (1977) suggests that chevron folds may have vestiges of their earlier concentric-like form (Fig. 6A). The combination of concentric-like and chevron forms causes no room problem in the cores of folds. The folds are similar in style and can extend indefinitely parallel to the axial surface. On the other hand, Berger has observed that many kink-bands and kink folds die out in either direction parallel to the kink surface. If the fold is asymmetric, then it is probably a kink fold formed by the intersection of two kink-bands of unequal width (Faill, 1969). The chevron folds of Johnson (1977) are usually symmetrical. Although these diagnostic criteria are not infallible, they can indicate the affinity of the fold.

Ramsay (1967, p. 450) concludes that less work is expended to shorten a layer by the production of kink-bands or paired conjugate kinks than by the formation of symmetrical chevron folds. Thus it seems logical to conclude that kink folds will be more prevalent in nature. Planar-limbed folds of uncertain affinity are thus more likely to be kink folds.

EXTENSION IN KINK-BANDS

Ramsay (1967, p. 449) uses a geometric model to predict the amount of dilation (Δ) in a kink-band (Fig. 7). The amount of dilation $\Delta = (\sin \beta_2 / \sin \beta_1) - 1$ (1) where β_1 is the angle between the axial surface and the enveloping beds, and β_2 is the angle between the axial surface and the kink-band. If $\beta_1 > \beta_2$, then $\Delta < 0$ and the layers thin and extend parallel to bedding. Kulander and Dean (in review) use this method to predict the amount of porosity in kink bands. They estimate that 10 percent porosity can occur when the beds separate ($\beta_1 < \beta_2$ and $\Delta > 0$). They determine that porosity can also occur as the beds separate in the hinges of kink-bands if $\beta_1 = \beta_2$, but that the amount of such hinge porosity depends on the thickness to length ratio of the beds composing the kink band.

In this study, we are interested in kink folds where $\Delta < 0$, so that one limb is extended. Generalizing this model to central Appalachian folds that have planar limbs and narrow hinges, β_1 is the angle between the axial surface and the shallow limb.[4] β_2 is the angle between the axial surface and the steeper dipping limb. We have investigated several planar-limbed folds to try to observe more extension in the kink-band or in the steep limb. We compare the measured amount of extension with the amount of extension predicted by equation (1), and assume to

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Figure 7. Kink-band model of fold development showing relationship of P_1 and P_2 to the kink surface and thinning and extension of beds in the kink-band (A) or steep limb of a kink fold (B). t_1 is original bed thickness, t_2 is thinned bed thickness.

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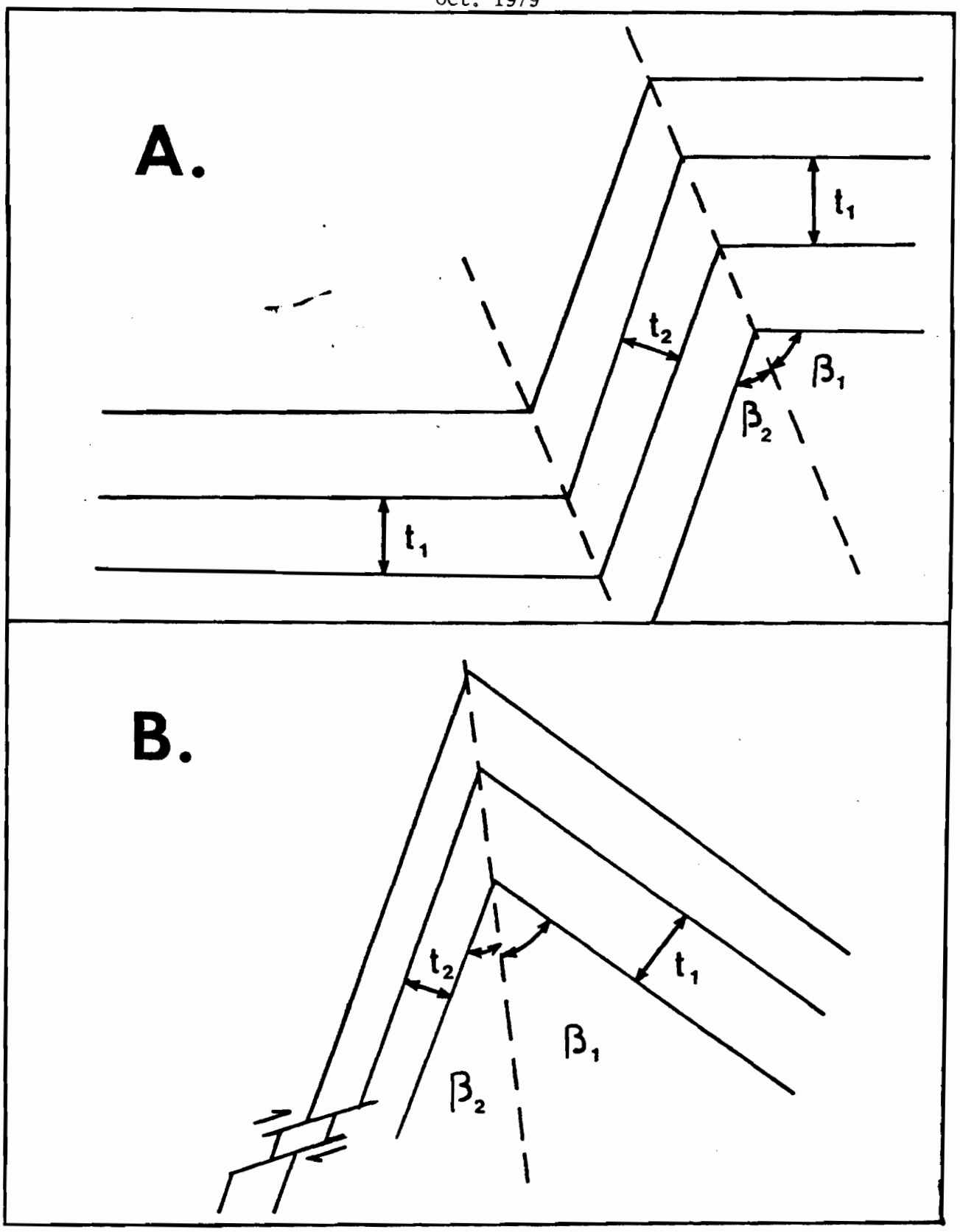

start that the dilation is completely translated into extension fractures. As we shall see, that assumption is overly optimistic, but that will not change the validity of the following analysis.

FIELD INVESTIGATIONS

Tipton, Pennsylvania (Fig. 8, 9). This fold is a northeast-plunging kink-band in the steeply dipping Devonian Brallier Formation on the northwest limb of the Nittany Arch. The shallow limb is the kink-band. the steep limb is the enveloping bedding and $\Delta < 0$. As shown in Figure 9, there are more joints, unclassified fractures, extension fractures, and twist hackle (Kulander, Dean and Barton, 1977; Kulander, Barton and Dean, in review) in the kink-band than in the enveloping bedding. Berger measured 1.7 percent extension by fracturing in the kink-band. The amount of extension by fracturing is the sum of the amounts of separation of all fractures in a measured length of a single bed. Equation (1) predicts 19.5 percent extension in the kink-band.

Watts, Pennsylvania (Fig. 8). This kink-band in the Devonian Trimmers Rock Formation (Faill, written communication, 1978) dies upward in the exposure, parallel to the kink surface. In this case, the steep limb is the kink-band and $\Delta < 0$. Berger measured 3.0 percent extension by fracturing in the kink-band. Equation (1) predicts 35.8

Figure 8. Location map showing exposures and significant tectonic elements. Dashed lines are anticlines, arrows denoting plunge. Dotted line marks boundary of the Broadtop synclinorium. Hachured line is a thrust fault. Circles are exposures.

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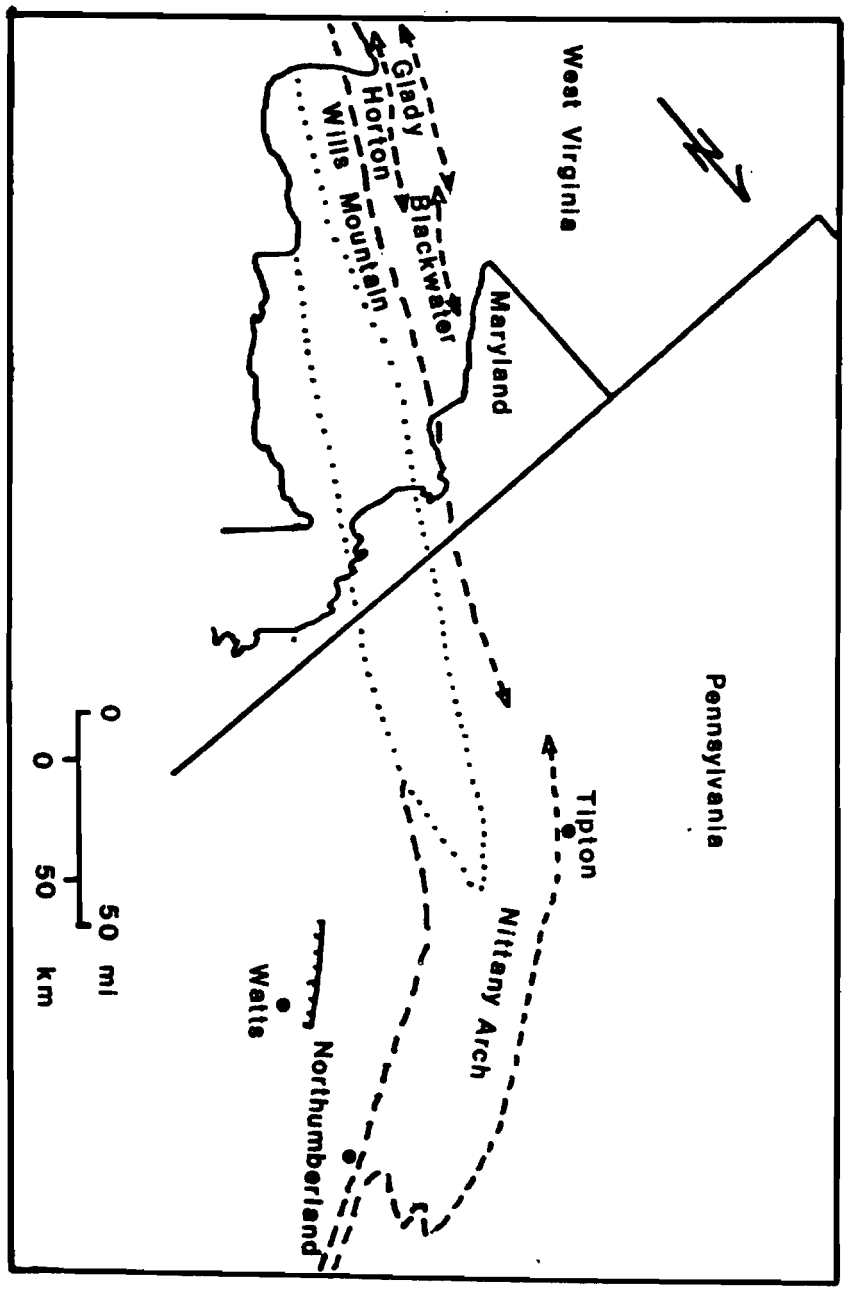
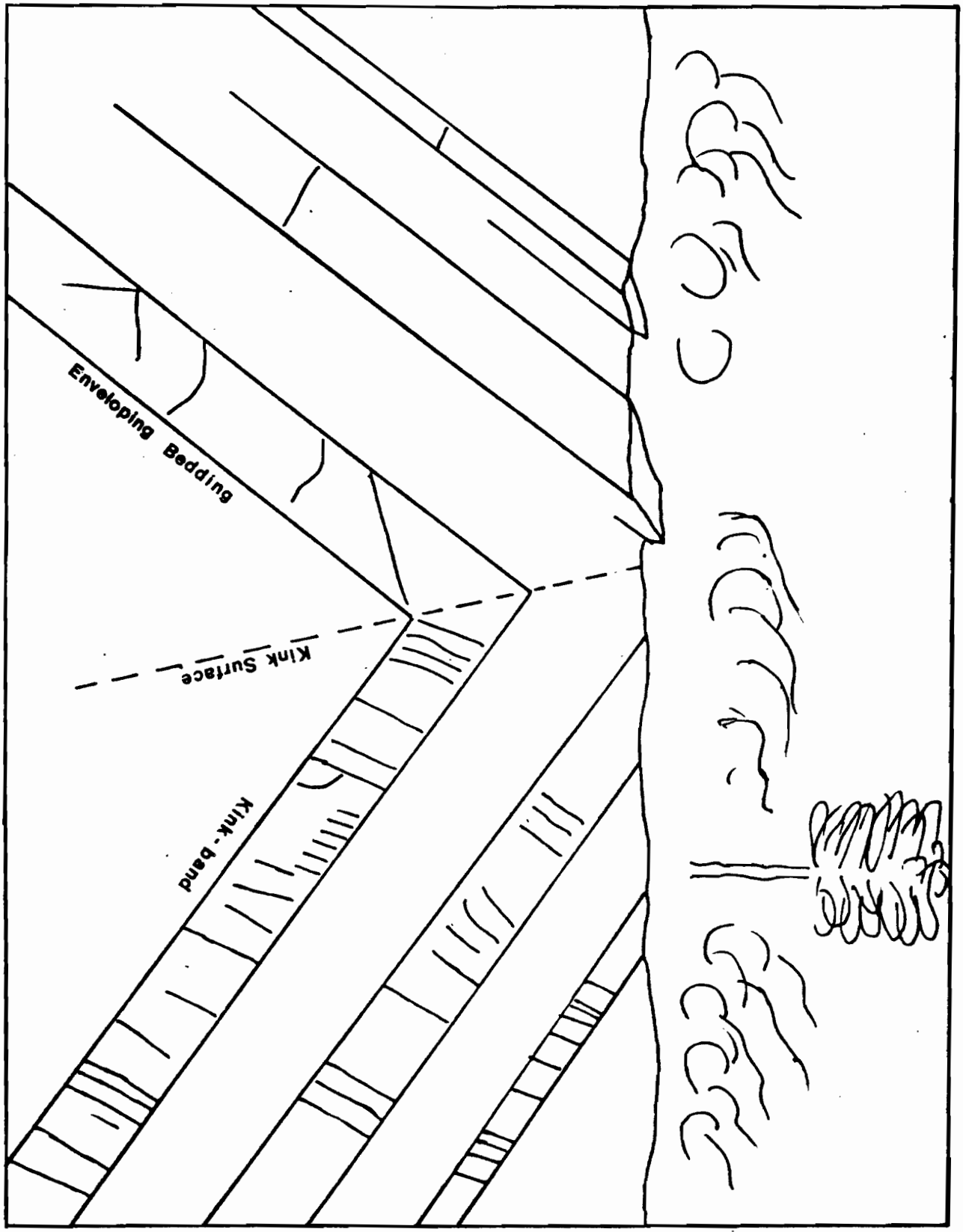


Figure 9. Outcrop at Tipton, Pennsylvania in the Devonian Brallier Formation on the northwest limb of the Nittany Arch. Siltstones show more fracturing in the kink-band than in the enveloping bedding. Schematic sketch from a photograph, looking northeast. Outcrop width about 15 m.


Enveloping Bedding
Kink Surface
Kink-band

percent extension.

Northumberland, Pennsylvania (Fig. 8). This large kink-band in nearly horizontal beds of the Devonian Catskill Formation (Faill, written communication, 1978) has $\Delta > 0$ so that we would expect shortening and separation of beds rather than extension. However, the kink-band showed excellent extension fractures (Berger and Wheeler, ms. in review) that produced 1.6 percent extension.

The results of our field investigations indicate that extension by fracturing amounting to approximately ten percent of the predicted value is likely in kink-bands. Berger noted as predicted that beds at Tipton, Pennsylvania are more extended in the kink-band than in the enveloping bedding. This is consistent with the Ramsay (1967) model of beds undergoing extension in the kink-band, if $\Delta < 0$. Results more consistent with predicted values might be found in thinner bedded units than we examined, because thicker units are extended a lesser amount, proportionally to their thickness (Ramsay, 1967, p. 451).

MAP-SCALE FOLDING

Anticlines in the central Appalachians can grow by crestward flowage of shale and mudstone units (Wheeler, 1975; Perry and de Witt, 1977; Kulander and Dean, 1978). For more brittle units, Berger and Wheeler (in preparation) show that extension faults can thin and

extend beds on the steep limbs of asymmetrical anticlines, providing a significant contribution to anticlinal growth. The presence of gravity lows on the northwest (steeper dipping) limbs of the Wills Mountain, Blackwater, Browns Mountain and Glady anticlines indicates to us one or both of (1) flowage of low density shale from low on the steep limbs to high on those limbs, or (2) thickened or repeated shale sections due to (a) detachment-related, pre-folding thrusting (Kulander and Dean, 1978; stage I of Berger and others, in press), or to (b) vertically dipping low density shales (B. Kulander, oral communication, 1978).

We would expect gravity lows that are detachment-related to extend parallel to the anticlinal axis until the detachment surface changes level along a transverse step. Thus the relatively long, linear gravity lows on the northwest limbs of the Wills Mountain and Browns Mountain anticlines (Kulander and Dean, 1978, plate 2) are probably more the result of fault repetition and thickening of the Ordovician Martinsburg Formation and Devonian shales than to lobate crestward flow of ductile rocks (B. Kulander, oral communication, 1978). In contrast, the circular lows on the northwest limbs of the Blackwater and Glady anticlines are more likely due to lobes of uplimb flowage in the ductile units of the Middle and Upper Devonian clastic sequence. On the northwest limb of the Wills

Mountain anticline, the discontinuous strike-parallel linear gravity lows terminate within a few kilometers along strike of the discontinuous strike-parallel linear belts of thinned Devonian Brallier Formation mapped by Dennison and Naegele (1963). The gravity lows are caused by thickening of Ordovician Martinsburg formation and the vertical beds of the Middle and Upper Devonian clastic sequence and the thinned outcrop belt is caused by extension and other tectonic thinning of the Devonian Brallier formation (Berger and Wheeler, in preparation; Dennison and Naegele, 1963). On the Blackwater and Glady anticlines the inferred thickened shale lobes suggest that there exists a thinned Brallier formation lower on the limb that is subjected to extension faulting (Berger, Perry and Wheeler, in press) in the brittle units and flowage in the ductile units. This thinning would be similar to that observed in outcrop in the Devonian Brallier Formation (Dennison and Naegle, 1963; Berger and Wheeler, in preparation) and could indicate gas potentially in a fractured reservoir. The source beds could be the Devonian black shales (the Marcellus and Harrell formations) and the flowed, thickened, perhaps heavily slickensided shale updip could seal the reservoir. We suggest further exploration for thinned and fractured shales down-dip of the buried, thickened shales that we

infer to lie beneath the observed gravity lows (Fig. 10). For steep northwestward dips, the suggested exploration target would lie roughly under the northwestern boundary of a circular gravity low. Additional gravity measurements and modeling of the gravity lows mapped by Kulander and Dean (1978), guided by construction of balanced cross sections (Dahlstrom, 1969b; Perry, 1971), should define those targets more exactly.

The kink fold model of folding also implies that thinning by extension can occur on the northwest (steep) limb (Figure 2B). Folds thickened near the crest and thinned lower on the limb can still have planar limbs and narrow hinges consistent with a kink-fold model of map-scale folds.

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Figure 10. Relationship of gravity low to anticline.

A. Original thickness. B. Siltstone and shale thickened by uplimb flow of shale. C. Siltstone and shale thinned by uplimb flow of shale and thinning by extension faulting of siltstones and and shales.

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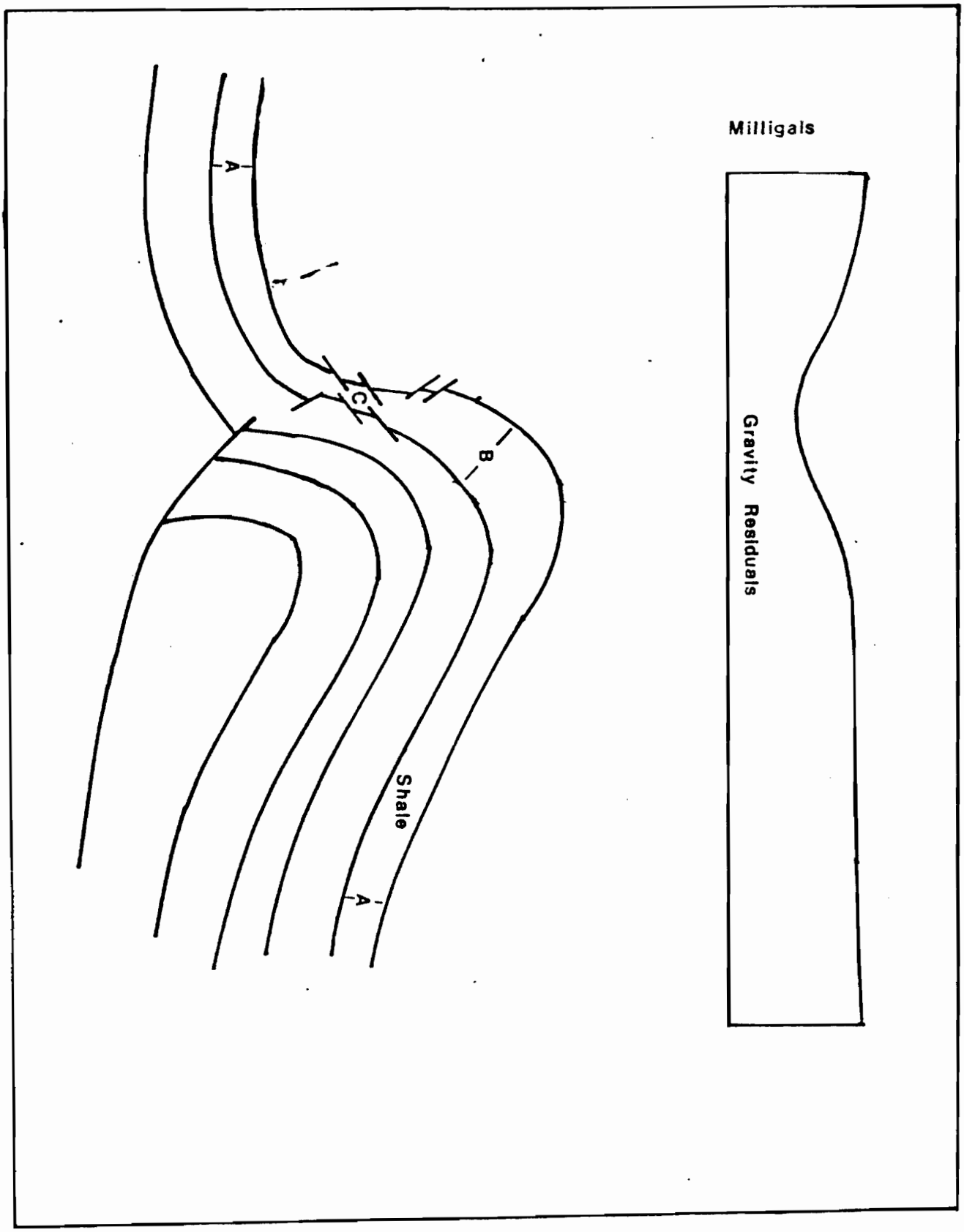

CONCLUSIONS OF ENTIRE THESIS

1) Outcrop-scale and map-scale faults that formed during overall horizontal shortening and associated detached folding can be placed in a three-stage relative time sequence.

2) Wedge-shaped contraction faults form early (stage I) when beds are nearly horizontal. These faults may have associated anticlines and may be smaller versions of the detachment and ramp systems characteristic of allochthonous fold belts. In beds later rotated to steep dips by folding, contraction faults will show normal fault separation at a low angle to bedding. In cratonward-facing folds, contraction faults will show a downlimb sense of displacement.

3) Uplimb thrusts form during folding (stage II) and record relative reverse movement toward the anticlinal hinge. These faults serve to raise the limbs of anticlines to solve space problems.

4) Extension faults and extension fractures form late in folding (stage III) when beds rotate so far towards the vertical that the effect of vertical extension exceeds that of horizontal shortening. Extension faults are reverse faults formed at high angles to beds and rotated

little or not at all. Unequivocal extension fractures are lenticular and form normal to beds.

5) Extension fracturing will begin when bed dips reach 45 degrees assuming that there is no more than $\pm .1(e_3)$ hinge line parallel strain.

6) Extension faults and associated fractures provide a significant contribution to: a) anticlinal growth, b) unit thinning, and c) bed extension thus favoring formation of fractured gas reservoirs.

7) The Dawson, Cresaptown, and Kittlelick thrusts of Dennison and Naegle (1963) are more likely zones of extension faulting than single detachment-related splay faults. The Hyndman fault is more likely a splay fault but has associated extension faults.

8) The Brallier Formation is the Devonian unit most intensely deformed by extension faulting and extension fracturing. Given a gas source (the underlying Marcellus and Harrell Formations) and a seal, it may be a shallow gas exploration target on the northwest limbs of the Glady, Horton, Blackwater and Deer Park anticlines.

9) Limbs of kink folds and beds in kink bands can undergo extension parallel to the beds when the angle between the kink surface and the Kink-band is less than the angle between the kink surface and the enveloping beds.

10) Although kink-bands show evidence of more extension than do the enveloping beds, the amount of extension measured is less than the amount predicted. Only about 10 percent of the predicted volume change is translated into extension fractures.

11) Circular gravity lows on the northwest limbs of the Blackwater and Glady anticlines can be due to lobate thickening of shales high on the limbs and thinning low on the limbs. Thinning can occur in the Brallier formation similarly to that measured on the northwest limb of the Wills Mountain anticline by Dennison and Naegele (1963). We suggest exploration under the northwestern boundaries of the mapped gravity lows to intersect the inferred thinned shale sections, which may contain gas in fractured reservoirs.

SUGGESTIONS FOR FUTURE WORK

1) In many instances, contraction faults (stage I) have associated anticlines. These form over smaller versions of the ramps with which major detachment surfaces change stratigraphic level. I have identified many contraction fault localities. These are listed in Appendix IV. Study of these faults as well as those from other localities can give insights into relative ductilities of rocks involved in ramp formation, ratios of length of ramp to height of associated anticline, initiations and terminations of ramps, terminations of associated anticlines, problems of conservation of space, and the nature of the most energy efficient structures.

2) An outcrop study of uplimb thrust faults (stage II) would probably not be feasible because these faults are rarely exposed and are usually so large so as to be unidentifiable on outcrop scale. However, I found one uplimb thrust that is classic in form, but it may also be a shear zone associated with an igneous intrusion. Petrographic work in the fault zone to determine if the cataclastic material had igneous or sedimentary affinities would answer this question. The zone in question crops out in Ryder Gap, Bath County, Virginia (Station 8 of manuscript three, Appendix I).

3) Kink folds are formed by a different process than

are chevron folds (see Manuscript four). Kink folds are products of shearing and chevron folds, of buckling. Examination of strain markers such as burrows, fossils or oolites or analysis of quartz deformation lamellae and calcite twin lamellae can yield information on the origin of the fold.

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APPENDIX I

Location of field stations: "Late-tectonic extension faulting in the central Appalachians"

Station 1 - West side of the railroad tracks, .1 km north of Pinto, Allegany County, Maryland (outcrop described in Swartz, 1923).

Station 2 - North side of the C & O Canal, 10 km south of the intersection of U. S. 40 and Woodmont Road, Woodmont, Allegany county, Maryland. Outcrop is 1 km east of Woodmont Road on Deneen Road and is described in Perry and de Witt (1977), p. 33-39.

Station 3 - North side of U. S. 40 in La Vale, Maryland. Outcrop is east of the La Vale Plaza shopping center and is described by de Witt and Dennison (1972) p. 63-68.

Station 4 - East side of U. S. 33, 4 km north of Riverton, West Virginia. Outcrop is across the road from the stream that drains the south side of Ketterman's Knob and is described in Dennison and Naegele (1963), p. 37-39.

Station 5 - North side of Holly Meadows Road, 5 km north of Parsons, West Virginia at bench mark 1579.

Station 6 - Along the north side of I-64, 8 km west

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of White Sulphur Springs, West Virginia. First outcrop past west bound entrance to I-64 from U. S. 60 at the bridge over Wolf Creek.

Station 7 - In an abandoned quarry, .1 km east of the intersection of U. S. 33 and W. Va. 28, Pendleton county, West Virginia.

Station 8 - Along Va. 39, Bath County, Virginia, .1 km east of the Virginia/West Virginia border.

Station 9 - West side of the railroad tracks, 3 km south of Cumberland, Maryland, .1 km north of the Amcelle Corp. plant (outcrop described in Swartz, 1923).

Station 10- West side of the railroad tracks, 3 km south of Cumberland, Maryland, .3 km south of the Allegany County Fairgrounds, Allegany County, Maryland (outcrop described by Swartz, 1923).

Station 11- North side of Teter Run, 3 km south of Circleville, West Virginia and .5 km east, up the dirt road into Teter Gap, .1 km east of the first cattle guard.

Station 12 - East side of secondary W. Va. 17, first exposure east (.8 km) of intersection

with secondary W. Va. 19, Pendleton County, West Virginia.

Station 13- East side of secondary W. Va. 17, second exposure east (1 km) of intersection with secondary W. Va. 19, Pendleton County, West Virginia.

Station 14- East side of secondary W. Va. 17, third exposure east (1.1 km) of intersection with secondary W. Va. 19, Pendleton County, West Virginia.

Station 15- First outcrop on the south side of W. Va. 39, 1 km east of Huntersville, West Virginia at the spring.

Station 16- North side of W. Va. 39, 1.1 km west of Minnehaha Springs, West Virginia. Outcrop is .1 km east of the bridge over the stream flowing through Buzzard Hollow and is pictured on the cover of Cardwell (1975).

Station 17- North side of W. Va. 39, first outcrop (.3 km) west of Minnehaha Springs, West Virginia.

Station 18- along the south side of I-64, 4 km southeast of White Sulphur Springs, West Virginia. Third outcrop east of the bridge

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over the railroad tracks (outcrop described by King, 1973).

Station 19- Along the south side of I-64, 3.5 km east of White Sulphur Springs, West Virginia. Fourth outcrop east of the bridge over the railroad tracks.

Station 20- North side of W. Va. 28, 4 km north of Hopeville, West Virginia, .2 km east of Smoke Hole caverns (North Fork Gap). Outcrop figured in Sites (1978).

Station 21- South side of Wolf Camp Run, .3 km west of the intersection of Wolf Camp Run Road and Pa. 96. Outcrop described in de Witt and Dennison (1972), p.72-73. Outcrop is .5 km north of Madley, Pennsylvania.

Station 22- North side of U. S. 40, 1 km east of the crest of Martin Mountain, Allegheny County, Maryland.

Station 23- On the south side of the exit ramp, at the juncture of U. S. 40 and U. S. 522, on the exit ramp of U. S. 40 for eastbound traffic. Outcrop is 1 km west of Hancock, Maryland.

Station 24- West side of U. S. 33, first outcrop (1 km) north of the juncture of U. S. 33 and W. Va. 28, Pendleton County, West Virginia.

APPENDIX II

Location of field stations: 'Extension in kink-bands and on the limbs of kink folds'

Tipton, Pennsylvania - This outcrop is located on the north side of the Pennsylvania secondary road that extends from U. S. 220 northwest through Tipton, Pennsylvania. It is the first west of the town of Tipton.

Watts, Pennsylvania - This outcrop is located on the west side of U. S. 322, 3 km north of Amity Hall, Pennsylvania, .1 km north of the entrance ramp from the secondary road through Watts, Pennsylvania. this is the first entrance ramp north of Amity Hall.

Northumberland, Pennsylvania - This outcrop is located on the west side of U. S. 11, .1 km south of the bridge across the west branch of the Susquehanah River into Northumberland, Pennsylvania. The outcrop is overgrown but is identifiable by the words "Susan + Matt" spray painted on the outcrop.

Appendix III

A note on the size of extension faults.

Map-scale extension faults are large enough that body forces (gravity) become significant relative to the surface forces that form outcrop-scale extension faults. Mechanics of faulting may differ between the two scales. Accordingly, the term extension fault and its companion term contraction fault may be limited to outcrop scale structures (W. Perry, Jr., oral communication, 1978). Although the size at which gravity becomes significant is approximately 50 m (R. Wheeler, oral communication, 1978) I do not restrict usage in this thesis because I am not sure of the significance of this difference in mechanics of faulting.

A note on the stratigraphy and sedimentology of the Brallier Formation

Lundegard and others (1978) characterize the Brallier Formation as part of an overall thickening- and coarsening-upward sequence, containing megasequences from 3 to 51 m thick. They recognize six facies of the Brallier, of which three constitute 80 percent of the areal extent of the formation and contain lithologies I observed to contain extension faults and fractures. These three facies are: A) Alternating beds of siltstone, shale or mudstone; B) Bundles of siltstone and fine-grained sandstone with minor interbeds of shale or mudstone; C) Olive-gray mudstone or shale.

APPENDIX IV

Contraction Fault Localities

1) West side of the railroad tracks, .1 km north of Pinto, Allegany County, Maryland.
2) West side of the railroad tracks, 3 km south of Cumberland, Maryland, .3 km south of the Allegany County Fairgrounds, Allegany County, Maryland (two contraction faults).
3) North side of Holly Meadows Road, 5 km north of Parsons, West Virginia at bench mark 1579.
4) East side of secondary W. Va. 17, 1 km east of intersection with secondary W. Va. 19, Pendleton County, West Virginia (two contraction faults).
5) North side of W. Va. 39, first outcrop west of Minnehaha Springs, West Virginia.
6) North side of W. Va. 28, 4 km north of Hopeville, West Virginia, .5 km east of Smoke Hole Caverns (North Fork Gap).
7) West side of U. S. 33, 4 km north of Riverton, West Virginia. Outcrop is across the road from Station 4.
8) East and west sides of U. S. 322, 3 km north of Amity Hall, Watts, Pennsylvania.

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BEDDING ORIENTATION CONTOURS OF MIDDLE DEVONIAN SHALES EXPOSED IN THE MIDDLE MOUNTAIN SYNCLINE, VALLEY AND RIDGE PROVINCE, WEST VIRGINIA

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ABSTRACT

Bedding orientation contours have been used to estimate the effect of the Parsons structural lineament on exposed Middle Devonian shales in the Middle Mountain syncline of the Valley and Ridge province, Pendleton County, West Virginia. Models are developed which permit the interpretation of bedding orientation contours in terms of fold geometry and faulting. Patterns in the contours of bedding strike and dip have been related to: 1) the regional structure of the syncline, and 2) internal faulting and folding related to structure in the underlying Devonian Oriskany Sandstone (Wilson, 1979). The analysis shows that the strike line map and contours of standard deviations in bedding dip are most useful as a tool to locate structure.

Deformation domains defined as areas of high standard deviation in bedding dip have been used to locate and define the extent of faulting. Deformation domains are found to be larger and more numerous within the Parsons structural lineament where it intersects the exposed Middle Devonian shales of the syncline. These deformation domains contain more intensely jointed shale, and are directly related to faults and folds in the underlying Devonian Oriskany Sandstone. Deformation domains therefore represent a small scale analogue to Shumaker's (1978) fracture facies. Thus information on the Oriskany structure can be used to predict the location of intensely fractured reservoirs. Structural shortening in the Parsons structural lineament is taken up by more numerous faults and low amplitude folds, and thus more numerous

fractured reservoirs. Future exploration for fractured gas reservoirs can then be optimized by concentrating subsurface studies along cross-strike structural discontinuities (such as the Parsons structural lineament), and determining their westward extent into the Plateau.

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BACKGROUND

The present paper is part of a study designed to characterize the structural effects of a cross-strike structural discontinuity (the Parsons structural lineament) on the exposed Middle Devonian shales of a Valley and Ridge structure, the Middle Mountain syncline. The difficulty faced in mapping these poorly exposed shales has been lessened through use of the techniques presented herein. It is hoped that some of the results of this study will be of use in the current exploration efforts to locate gas producing Devonian shales in the Appalachian Basin.

STUDY AREA

The regional locations of the Parsons and Petersburg structural lineaments are shown in Figures 1 and 2. The maps presented in this study are constructed from data collected in the Middle Mountain syncline of the Valley and Ridge province in Pendleton County, West Virginia (Figures 2 and 3). The Middle Mountain syncline exposes Middle and Upper Devonian formations (Figure 3). The geologic map (Figure 3) is modified from Tilton and others (1927). The area is of particular interest in that the less competent organic-rich Middle Devonian shales exposed in this syncline are intersected by the Parsons structural lineament (Figures 2 and 3). Only the northern boundary of the Parsons structural lineament is shown in Figure 3.

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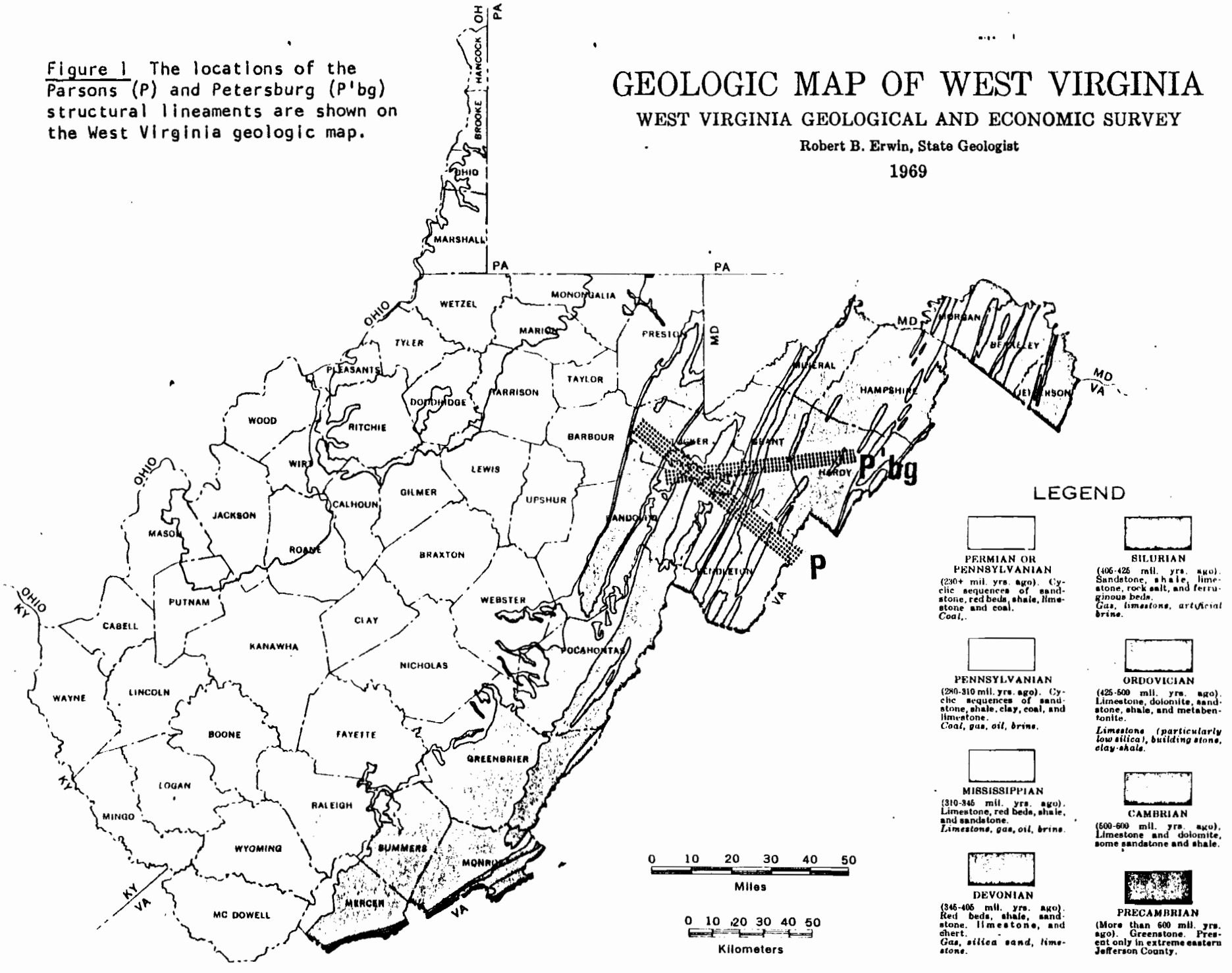
Figure 1 The locations of the Parsons (P) and Petersburg (P'bg) structural lineaments are shown on the West Virginia geologic map.



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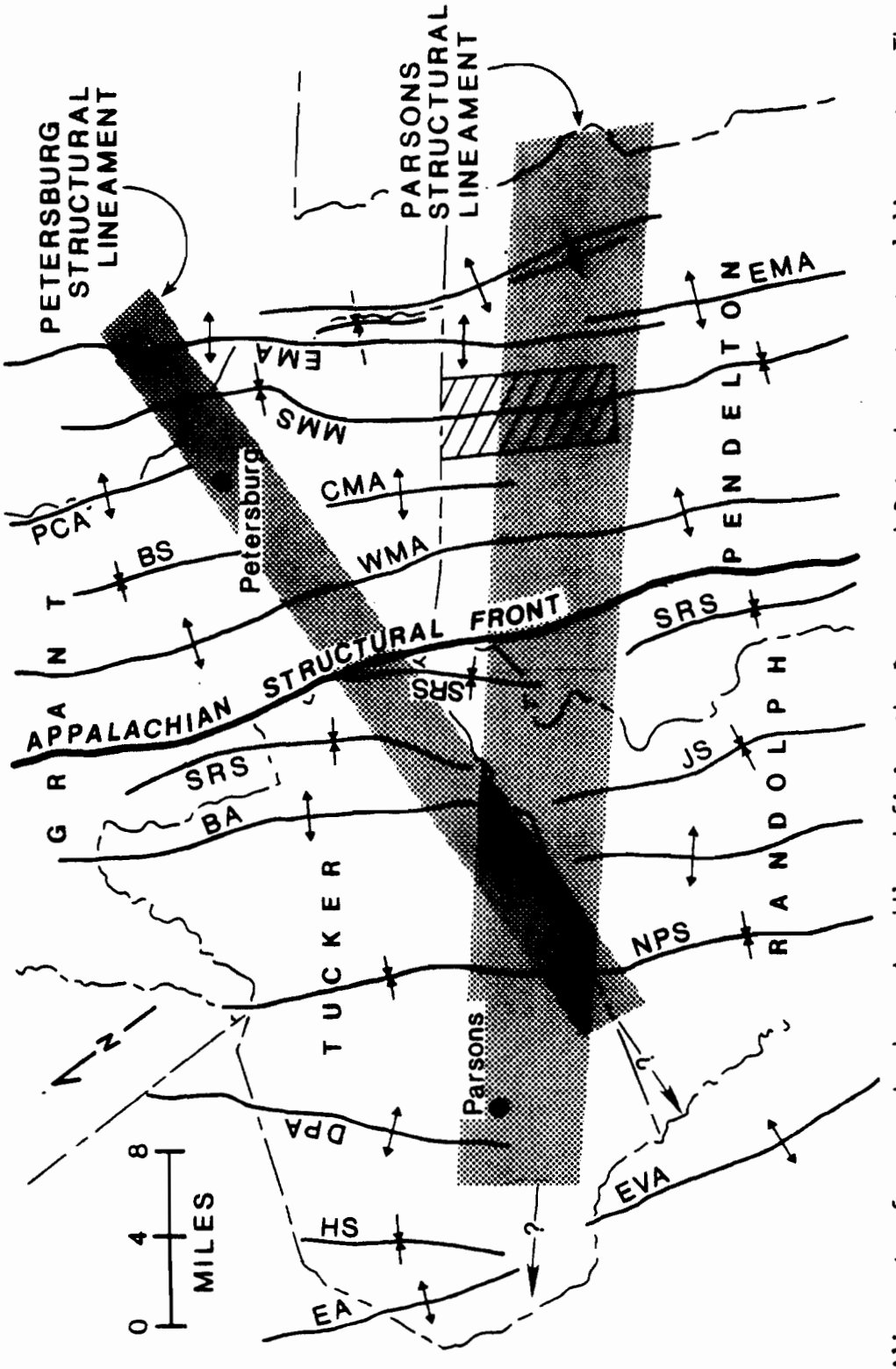

Figure 2 Alignments of noses, bends, and saddles defining the Parsons and Petersburg structural lineaments. The study area along the Middle Mountain syncline is enclosed in the hachured rectangle. Abbreviations: EMA - Elkhorn Mountain anticline, MMS - Middle Mountain syncline, CMA - Cave Mountain anticline, WMA - Wills Mountain anticline, SRS - Stoney River syncline, JS - Job syncline, BA - Blackwater anticline, NPS - North Potomac syncline, EVA - Elkins Valley anticline, HS - Hannahsville syncline, EA - Etam anticline.

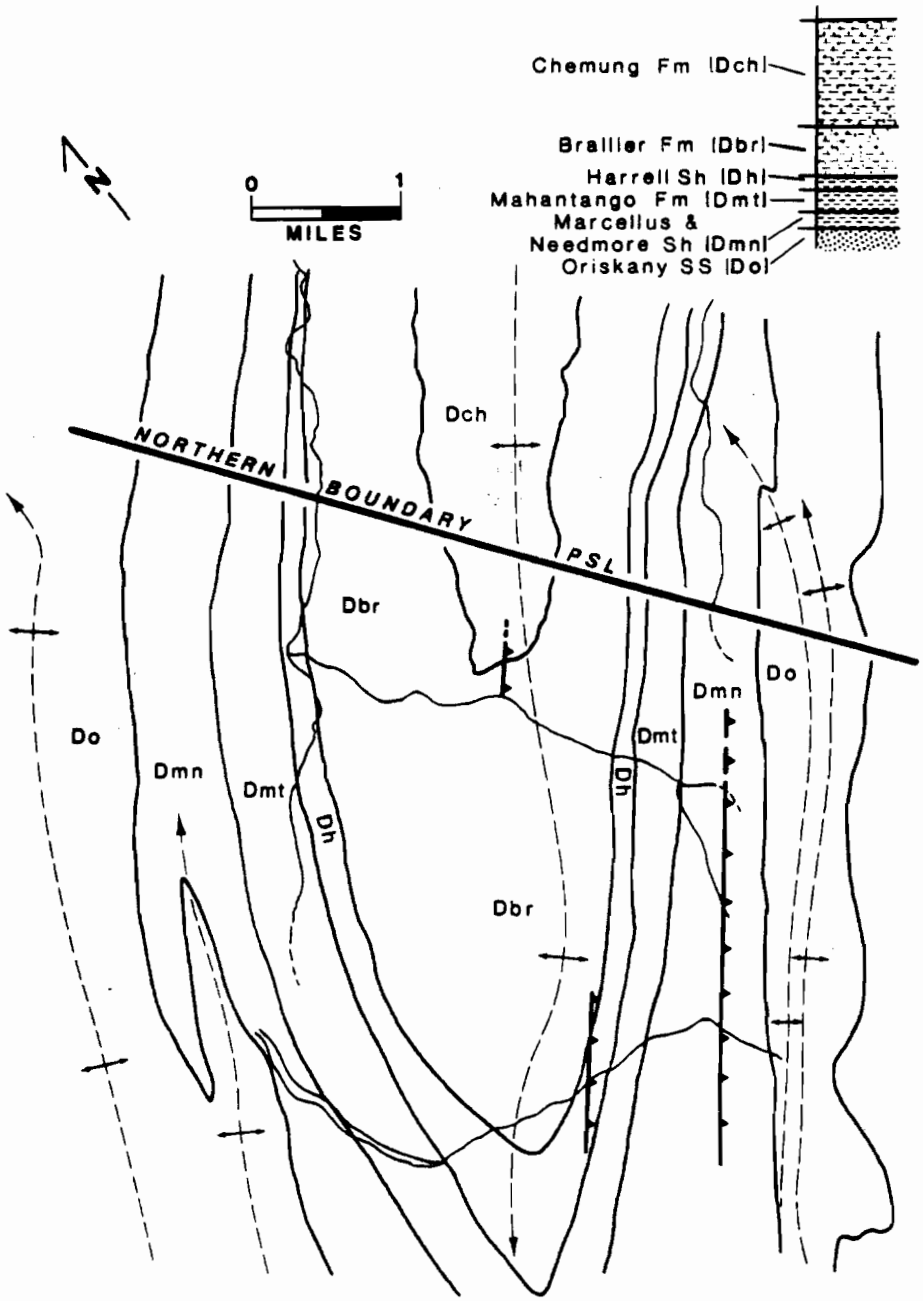

Figure 3 Geology and structure of the Middle Mountain syncline in the Valley and Ridge Province in Pendleton County, West Virginia. (taken from Tilton and others, 1927)

INTRODUCTION

The present work is stimulated by recent detailed mapping of structures in the Allegheny Plateau (Henderson, 1973; Mullennex, 1975; Trumbo, 1976; LaCaze, 1978) and Valley and Ridge Provinces (McColloch, 1976; Sites, 1978). These studies made use of bedding orientation contours in the structural analysis of the Parsons and Petersburg cross strike structural discontinuities (Figures 1 and 2) (Wheeler and others, 1979). Alignments of disruptions in bedding orientation contours often form zones colinear to these discontinuities. The widths of these zones are often cited as defining the widths of structural discontinuities (Wheeler and others, 1974; Sites and others, 1976; Wheeler and others, 1979).

During the present mapping and structural analysis of the Middle Mountain syncline (Valley and Ridge Province in the Central Appalachians of West Virginia) methods were developed which permit the interpretation of bedding orientation contours in terms of fold geometry and internal structure. The present study is similarly concerned with structural relationships between the Middle Mountain syncline and a structural discontinuity referred to locally as the Parsons structural lineament (PSL) (Figures 1, 2 and 3). The physical significance of zones of disruption in bedding orientation contours and their relationship to the PSL will be examined in detail.

MAP CONSTRUCTION

The bedding orientation contours are constructed from detailed measurements of bedding strike and dip. The map area is divided into a regularly spaced square grid. The contoured values of strike or dip are the mean of several measurements contained in each square grid division of the map area. The center of each square represents a control point. The control points and individual measurements are shown as large and small dots respectively on the enclosed acetate overlay.

Sampling

The effects of averaging and resolution should be considered in the interpretation of the actual data. Station spacing within the study area is determined by accessibility, the aims of the study, and the limitation of available time. The spacing of control points is ideally based on the structural variability of the area: a high rate of structural change requires a greater density of control points (Elliott, 1967). However, such an approach is infeasible in a study where contour maps are constructed specifically for the purpose of detecting unknown structure. A regular grid spacing then makes optimum use of the data. The choice of the grid spacing is determined by the sample density. A 0.38 mile grid spacing was chosen for use in constructing the contour maps from the Middle Mountain syncline.

Sample Distributions

Strike and dip values are members of directional distributions. Directional distributions have an angular period which repeats

any given attitude at cyclic intervals of 180 degrees (Elliott, 1965). Statistical treatment is thus complicated because there can be no unique origin or baseline to the distribution and the linear models of distribution such as the Gaussian (normal) are invalid (Elliott, 1965; Jizba, 1953; Chayes, 1954; Mardia, 1970). Normal statistics, however, can be applied to sample distributions of directional data having standard deviations less than 60 degrees (Chayes, 1954).

Sample distributions from each cell in the Middle Mountain area have standard deviations that are in all cases less than 60 degrees. The mean for the sample distribution in each cell was chosen as the mean value about which the standard deviation of the sample values was a minimum. This procedure is illustrated in Figure 4. In the example, north is chosen as the origin for the values of strike with east equal to 90 degrees and west equal to -90 degrees. It is customary to read values from the compass as so many degrees east or west of north. This confines the distributions to the northwest and northeast quadrants of the diagram. However, since the data is cyclical, the value 11 is the same as -179, 41 the same as -139, and so on. The mean of the distribution will be different depending on which value is chosen to represent the measurement. The distribution which minimizes the standard deviation is easily determined by inspection: the minimum standard deviation occurs for the most clustered grouping of values. The mean of the distribution in Figure 4A is 25 degrees, and its standard deviation is 57 degrees. The value A = -83 degrees in Figure 4A is clearly

an outlier. Choosing the supplement of this value A' = 97 degrees clusters the distribution about a mean of 55 degrees and minimizes the standard deviation at 29 degrees (Figure 4B).

The assumption that the distributions are normal is implicit in the use of the mean and standard deviation to characterize these distributions. Several of the sample distributions were tested for normality using the Kolmogorov-Smirnov test for goodness of fit (Siegel, 1959). The distributions were found in all cases to be normally distributed. Some bimodal distributions are very likely non-normal. However, the assumption of normality is in general valid.

MODELS (Figure 5)

Dip

The interpretation of dip contours is considerably simplified if the magnitude of the dip is plotted and no distinction between dip direction is made. This permits the dip values associated with a particular structure to be contoured as a continuous field. Contours drawn through points having the same magnitude of dip outline structures much the same as do structure contours. A series of confocal ellipses (Figure 5-B) is suggested to represent the pattern formed by dip contours of a symmetrical doubly plunging anticline or syncline. The trough line of the fold is drawn as a line connecting points of greatest curvature in the dip contours. Steeper limb dips show as more closely spaced contours.

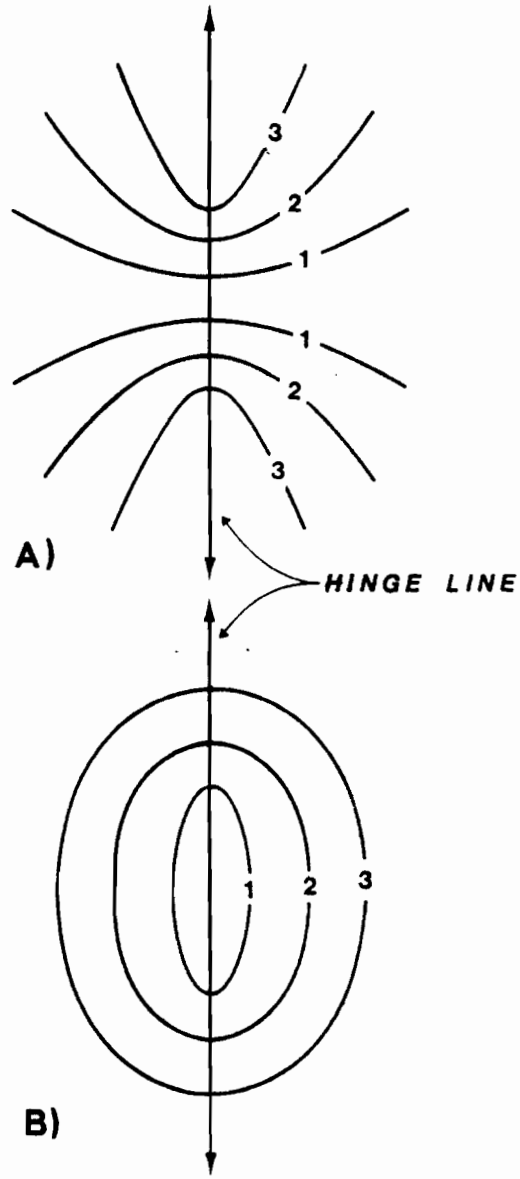

Figure 5 Theoretical bedding orientation contours for a doubly plunging symmetrical fold. A) Strike B) Dip. C1 = 10°

Strike

Choice of the mean trend of the fold hinge line or the regional trend of the structure under investigation as an origin for distributions of strike simplifies structural interpretation of strike contours. Modeling the contours of strike as a continuous field is possible only if the absolute value of the residuals from the regional trend is plotted. Contours of strike from a doubly plunging symmetrical anticline or syncline transformed in this manner will appear as a family of elliptic hyperbolae (Figure 5-A), with each hyperbola representing an isopleth of constant strike. The elliptic hyperbolae can be thought of as connecting points on the confocal ellipses, tangents to which make equal angles (strike) with the major axis of the ellipse. Assymmetry in the fold would be indicated by a closer spacing of contours on one limb. As with the dip contours, the crest line can be approximated by connecting points of greatest curvature in the contours. This model assumes that the hinge line of the fold has the regional trend to which all values of strike are reduced. Contours of strike associated with subsidiary folds whose hinge lines do not parallel that of the major fold will produce patterns that deviate from those of the model.

The models are based on an ideal conception of fold geometry. Since structures encountered in the field are never so simple, the patterns observed in contour maps of actual data should be considered with care. Although a pattern might appear quite similar to that suggested for a doubly plunging fold, it could be related to faulting,

statistical fluctuations in the data, to the resolution determined by cell spacing, or all three. The maps do permit the forming of preliminary hypotheses about the presence of subtle structures in a specific area, particularly if mappable marker units or distinct contacts are too few to outline structure.

Strike and Dip Standard Deviation Contours

The value of strike or dip plotted at a control point is a mean value calculated from samples collected in the cell containing that control point. The precision with which this value is representative of the parent population within a cell can be estimated as the standard deviation of values in the cell sample.

The standard deviations can also be thought of as a measure of the reliability of the contours drawn on the basis of those values. Perhaps a more reliable contouring method would be to use a contour interval equal to the 95% confidence interval of the values within a certain area (Elliott, 1967). However, since there is considerable variation in the standard deviations of samples over the entire map area, the standard deviations of each cell sample are contoured.

The contours of standard deviation not only provide a measure of the reliability of the strike and dip contours but are directly related to internal structure of the cell mass. A band of high standard deviations in strike will parallel the fold hinge line, fanning outward in the plunging nose. The high standard deviations near the crest line or trough line reflect the large errors present in the measurement of strike of low-dipping beds (Woodcock, 1976). The noseward

fanning of the high standard deviation band results from increased bedding curvature in the nose as well as from the measurement error. Disruption near faults will also produce high standard deviations in strike.

Dip values are not affected by the large measurement errors associated with strike. The standard deviations of bedding dip within a certain area are thus a measure of the intensity of deformation of that area. High standard deviation areas (referred to below as deformation domains) result from faulting and folding of the bedding in those areas.

BEDDING ORIENTATION CONTOURS OF THE MIDDLE MOUNTAIN SYNCLINE

Strike Contours (Figures 6A and 7A)

Contours of strike used by previous workers have been constructed with north or east as an origin for values of strike (see Sites, 1978). There are two shortcomings in this method: 1) the contours cannot be modelled as a continuous field; and 2) although the values of strike can be contoured as a continuous field, the resultant patterns are confusing to interpret structurally. However, such contours do permit general statements about relative amounts of structurally related disruption in an area. This leads to the question of the validity and the nature of associations between disrupted contours and actual structure.

The strike contours in Figure 6A have north as an origin (north = 0°, east = 90°, and west = -90°). Quite pronounced changes in

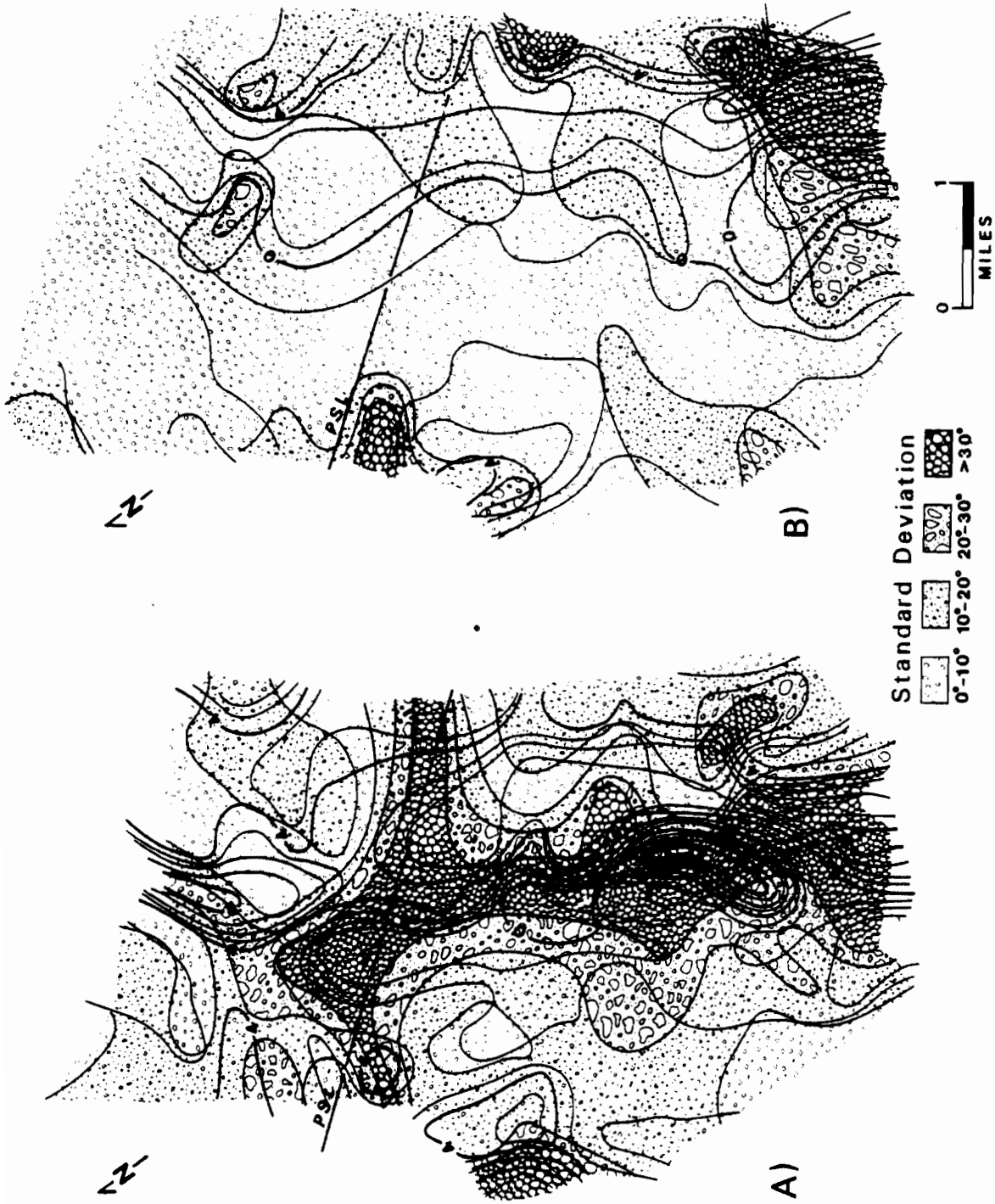

Figure 6 A) Average strike from samples taken in 0.38 mile square divisions of the map area overlies standard deviations of sample strike from each division, B) average dip overlies standard deviation of dip. C1 =10°

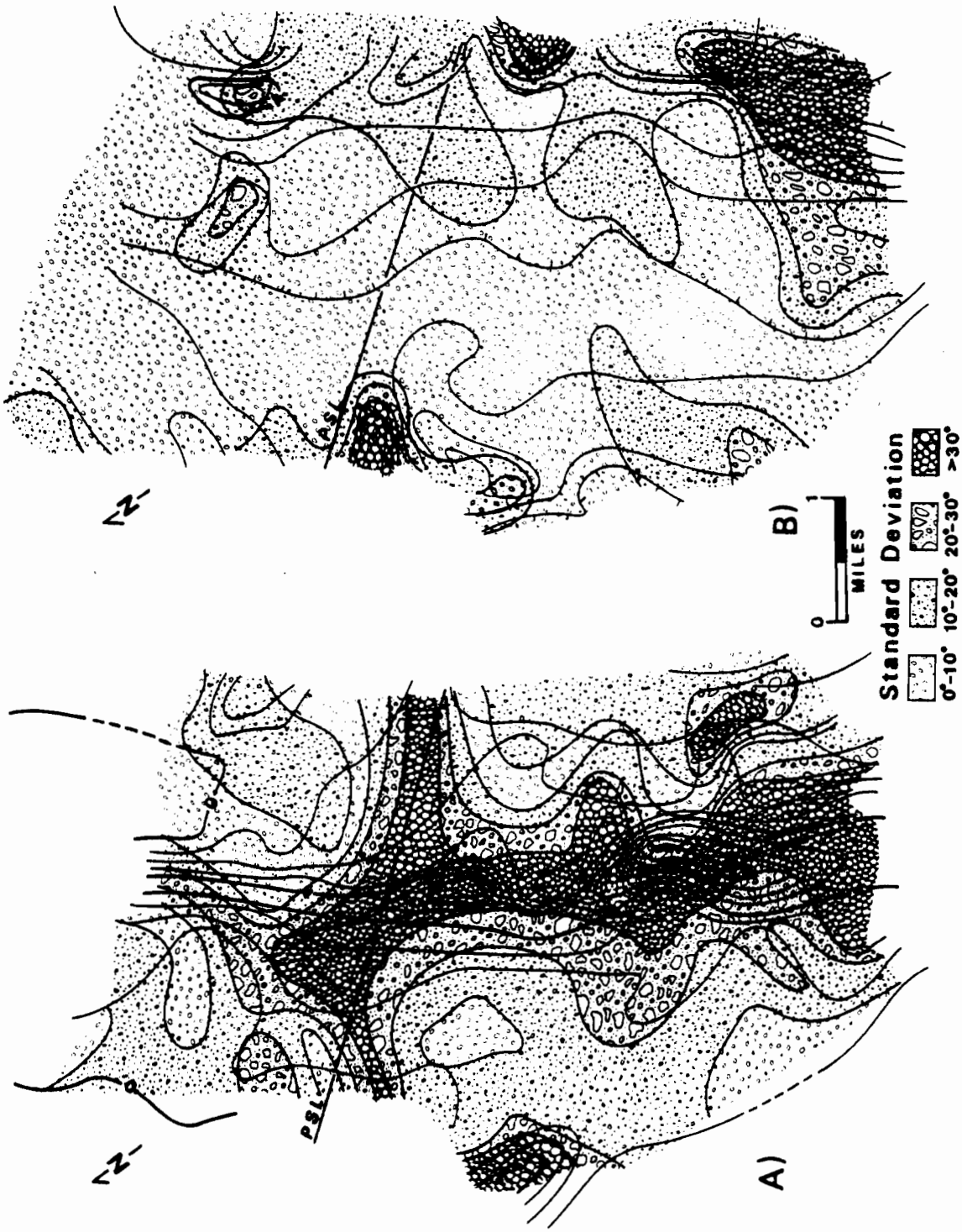

Figure 7 A) Absolute value of (strike -35°) overlies standard deviation of strike, B) absolute value of dip overlies standard deviation of dip. C1 = 10°

the orientation of strike are associated with the bullseye in the lower central portion of this figure. Changes in strike are also seen to the left and right of this bullseye. Contours of the absolute values of the residuals of bedding strike from the regional structural trend (Figure 7A) considerably simplify the appearance of the contours from this area. Comparison of these contours with the model (Figure 5A) suggests that most of the changes in strike occurring in the map area are associated with the swing in bedding strike across the fold axis.

If two models of strike contours (Figure 5A) are placed nose to nose, a region of closed contours centers over the saddle formed by the plunging noses. The values of strike increase toward the center of this bullseye. This closed pattern is apparent in the contours of strike in the Middle Mountain syncline (Figures 6A and 7A) and locates the area across which there is a northeastward plunge.

The compressed appearance of the contours toward the trough line indicates that the Middle Mountain syncline is more elongate or eccentric than the model fold. Changes in the orientation of the crest line observed in these contours may be the result of increased measurement error in the values of strike of these low-dipping beds. The changes may result from sampling older and softer units to the southwest, where the syncline may have a different orientation.

The nose of contours on the central northwest border of the map area (Figures 6A and 7A) occurs on the northeast plunging nose of an anticline (Figure 3). Structural interpretation of the contours from an area this small is restricted since the pattern is drawn from

only three or four control points. Resolution limits imposed by grid spacing require field verification of interpretations of small disruptions.

The analysis illustrates that many of the irregularities, bullseyes, and offsets observed in Figure 6A are purely an artifact of the north justified assignment of strike values. It further illustrates that shifting zero to the regional trend and contouring only the absolute values of the residuals of strike from this value produce patterns which can be interpreted in terms of actual structure.

Dip Contours (Figures 6B and 7B)

Contours of the absolute value of dip (Figure 7B) are considerably simplified in comparison to those for dip (Figure 6B). As discussed earlier, contours of absolute value of dip associated with a given structure can be modeled as a continuous field thus facilitating structural interpretation of the contours.

The trough line of the Middle Mountain syncline lies within the band of low dipping beds shown in Figure 7B. There is good agreement between the position of the trough line defined by strike contours (Figure 7A) with the position defined by contours of dip. The absence of closure in the contours in the southwest of the map area indicates that the change in structural level is gradual and at no point dips more steeply than 10°. The lack of closure at either end also implies that the Middle Mountain syncline is more elongate than the model fold in agreement with the strike contours and field observations.

The nose-like pattern in the southern corner of the map area (Figure 7B) is similar to that suggested for the plunging nose of a fold (see dip model, Figure 5A). An anticline in the Devonian Oriskany Sandstone plunges out beneath the Middle Devonian shales just to the southwest of this area and may in part explain this pattern. However, field investigation reveals that the area is thrust faulted with steeply dipping to overturned bedding present in the hanging wall. This fault splays off a major ramp beneath the Elkhorn Mountain anticline east of the map area (Figure 2) and dies out in the Middle Devonian shales of the Middle Mountain syncline. The pattern in dips is then related in part to both these structures. Other dip disruptions northeast of this area are related primarily to the faulting.

The disturbance in dip on the central northwest border of the map area just southwest of the PSL (Figure 7B) is in part related to the plunge-out of an anticline in this area. It is not understood why this pattern extends further to the northeast than that for strikes (Figure 7A). Examination of this area revealed faulting to the southwest, and it is expected that this faulting continues further to the northeast.

As with the contours of strike, the interpretation of contours of absolute value of dip must consider the effects of resolution and statistical error in the data.

STRIKE LINE MAP (Figure 8)

The strike line map is easily constructed by plotting the mean value of strike from each cell as a vector and approximating the continuous outline of the structure by drawing lines tangent to these vectors.

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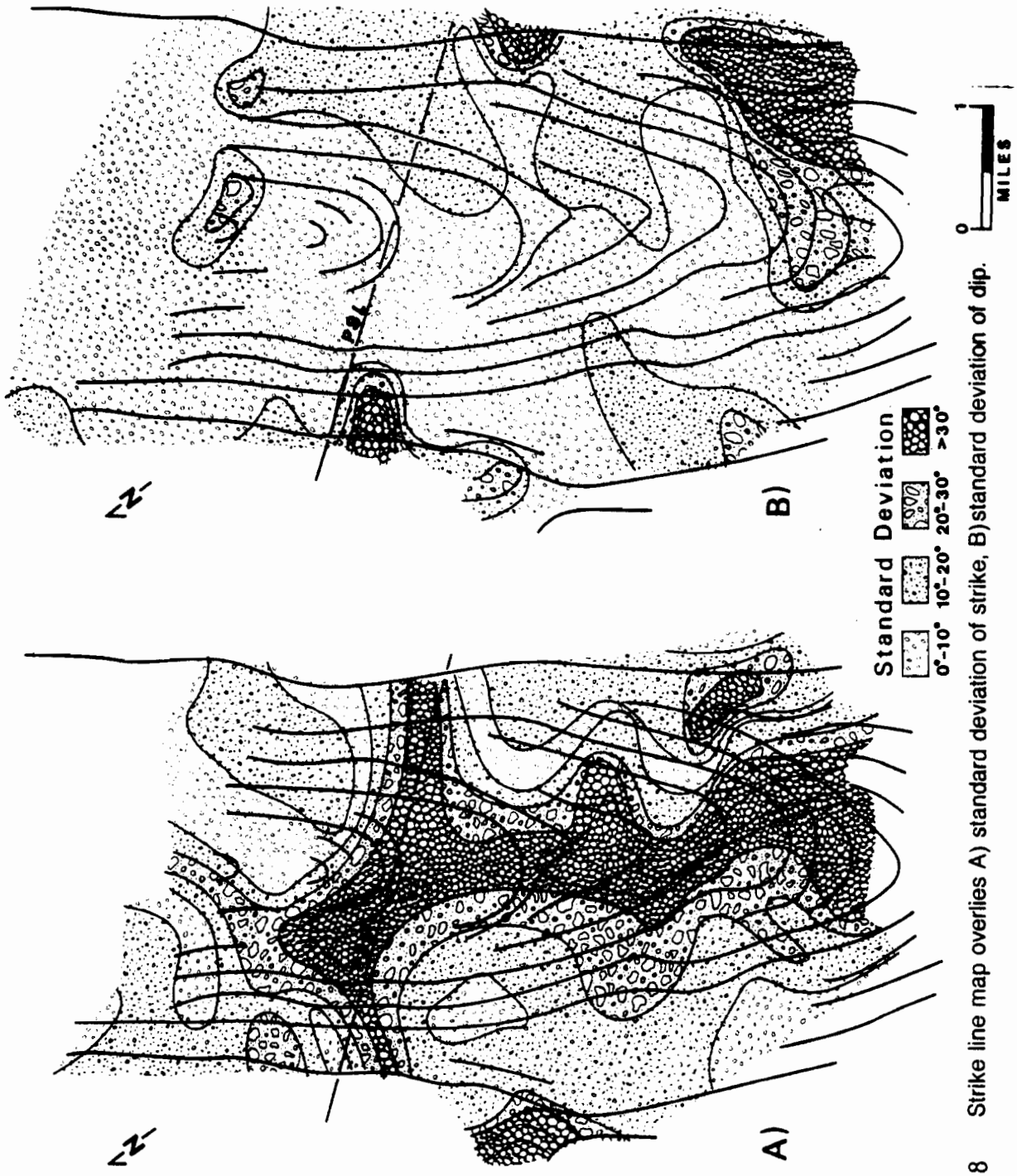

Figure 8 Strike line map overlies A) standard deviation of strike, B) standard deviation of dip.

The strike line map (Figures 8A and 8B) is easily interpreted and clearly illustrates the basic structural elements of the Middle Mountain syncline discussed in the previous sections. Elliott (1965) has examined the interpretation and use of lineation isogonic maps in structural interpretation of various metamorphic fabrics, and similarly finds that the strike line map is "probably the clearest way of showing the structural geometry of the lineation surface." This map is combined with the contours of standard deviations of strike and dip (Figures 8A and 8B) to provide a structural reference and to illustrate structural correlation with these contours.

STANDARD DEVIATION CONTOURS

Resolution and the effects of resolution on data interpretation are predetermined by the choice of cell spacing. However, statistical errors of various origins need to be broken down, and their effects on interpretation considered in detail. This problem has been approached in several ways, one of which was to examine the continuous field of statistical error associated with the data sets, by contouring the standard deviations of the cell samples (see patterned contours in Figures 7A, 7B, 8A, and 8B).

Standard Deviations of Strike Contours (Figures 6A, 7A, and 8A)

One of the obvious characteristics in the contours of standard deviations in strike is the high s. d. (standard deviation) zone following the crest line of the Middle Mountain syncline.(Figures 7A and 8A). Association of this zone with low dipping and curved bedding

(see dip contours Figure 7B, and strike line map Figures 8A and 8B) indicates that the large standard deviations are due, respectively, to increased measurement error of strikes in low dipping beds (Woodcock, 1976) and to actual structural variation within each cell. The significance of structural variation in the area is obscured by the much larger measurement errors (see subsection on Strike Contours above).

The arm-like high s.d. appendages extending to the borders across the north central part of the map area and along the northern boundary of the PSL are largely related to measurement error in low dipping beds (Figure 7A and 8A) although there may be some faulting to the northwest.

Dispersion related to map scale structures is found in high s.d. areas on the west central border and south corner of the map area. The high s.d. area on the west central border is in part due to measurement error in the low dipping bedding (Figure 7B) but also coincides with the plunging nose of an anticline discussed earlier (Figure 3). The strike line map clearly illustrates this structural involvement (Figures 8A and 8B). The high s.d. area in the south corner of the map results from thrust faulting.

Standard Deviation of Dip Contours (Figures 6B, 7B, and 8B)

The measurement error in dip is a constant for all values of dip. Systematic errors, such as errors in calibration, personal errors, experimental conditions, or technique (Beers, 1953) can be disregarded since discrepancy with other determinations of dip is of no concern here. Random errors such as errors in judgement probably

contribute no more than $\pm$ 5° in error. Standard deviations in dip greater than five or ten degrees are therefore structural in origin.

The high s.d. zone in the south corner of the map area (Figures 7B and 8B) coincides with the nose-like pattern of dips (Figure 7B) and the disrupted area on the strike line map (Figures 8A and 8B). With standard deviations in dip due primarily to structure, high s.d. areas provide reliable evidence of the existance and extent of structural disruption. Northeast of this zone the s.d.'s decrease and then increase (Figures 7B and 8B). Additional field work in this area along with records of cuttings from water wells support an extension of the faulting into this area at least to the northern boundary of the PSL (Figure 3). The high s.d. area in the south corner extends across the axis of the syncline. This area is also faulted, and represents branches of the major splay rising from the southeast as it dies out in the Middle Devonian shales. The northern border of this high s.d. area (>20 degrees) coincides roughly with the contact between the siltstone-rich Braillier Formation and the Harrell shales, illustrating the pronounced differences in the mechanical strengths of the Middle and Upper Devonian lithologies.

The small area in the west corner of the map area with standard deviations between 20 and 30 degrees is not associated with any mapped structures; however, the South Branch of the North Fork of the Potomac River bends sharply across strike in this area before turning along strike into the faulted core of the Cave Mountain anticline (Sites, 1970) and may represent the effect of a transverse fault.

Contours of standard deviation in dip locate areas of bedding disruption, defined as deformation domains, that are the result of faulting and folding. As a field tool these contours were found to be the most useful and reliable for locating internal structures of the Middle Mountain syncline. Although these contours do not define structures, they define areas of deformation associated with the structures.

CONTOURS OF RANDOM NUMBERS AND REPRESENTATIVE SAMPLING

It has been suggested that the patterns observed in the contours of strike and dip are similar to the patterns observed in the contours of random numbers, and that consequently structural interpretations of these maps are of questionable significance. This criticism is no longer valid in view of the correlation of contour patterns with the models and observable structure. However, useful information concerning the question of representative sampling, and the characteristics of the underlying population distribution(s) can be gained by contouring random numbers generated from a population(s) having a specified distribution(s).

In a non-plunging cylindrical fold, for instance, the bedding strike will equal the fold trend. If the fold is not complicated by internal structures, measured values of strike differing from the regional trend will be due to measurement error and surface irregularities resulting from sedimentary structures.

As a simple case, in a low amplitude fold, standard deviations in observed strike could be roughly 30 degrees over the entire structure. The regional trend of the Middle Mountain syncline is N35E.

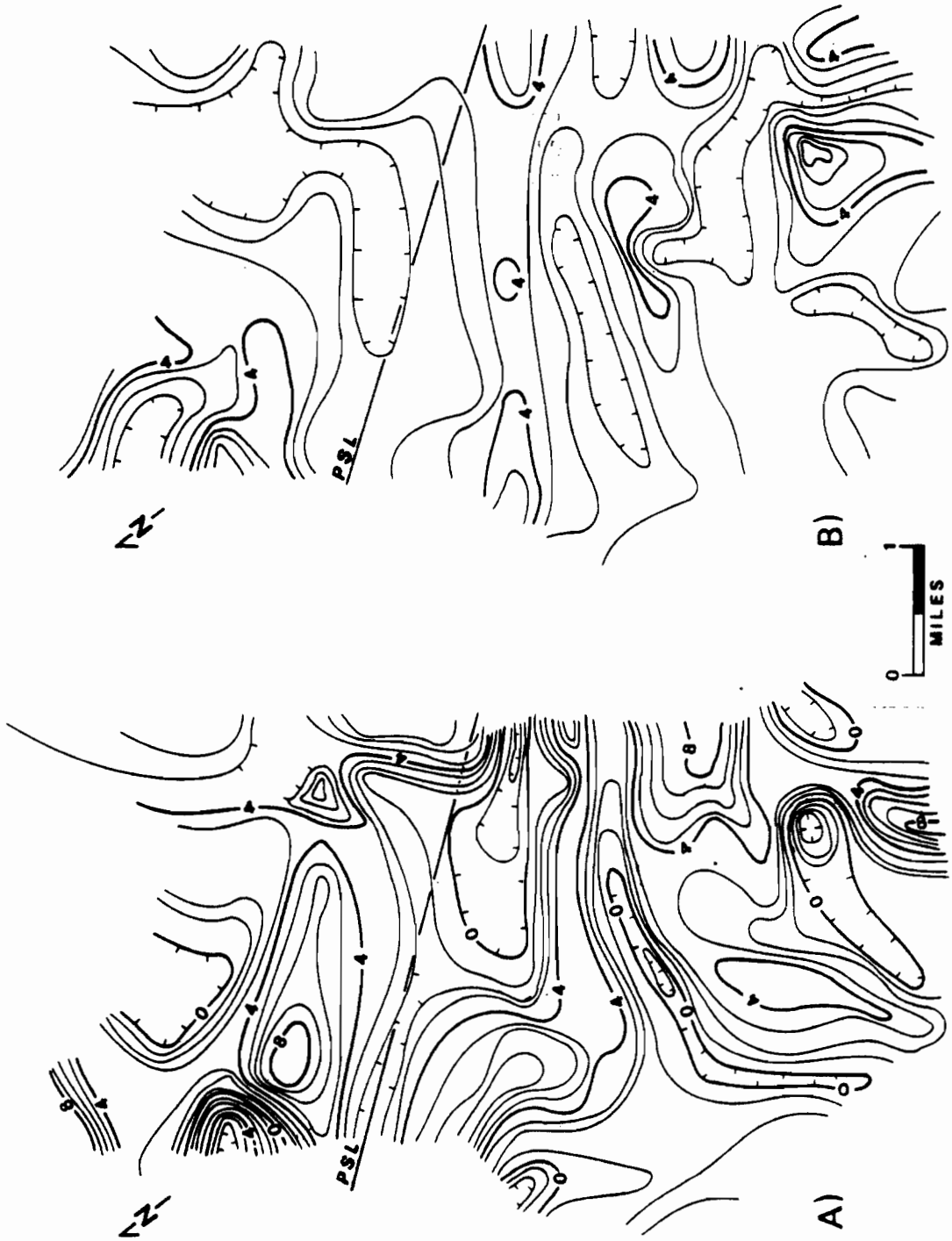

Figure 9 A) Strike values of 82 control points are drawn randomly from a population with mean =35 degrees (the regional structural trend) and standard deviation = 30°, B) absolute value of (random strike-35°). C1 = 10°

It would be instructive to examine the patterns in contours of strikes drawn randomly from a population having these parameters (i.e., mean = 35 degrees, and standard deviation = 30 degrees). To do this a number for each of the 82 control points was drawn randomly from a normally distributed population with the above parameters. Contours of north justified strikes are shown in Figure 9A. The absolute value of the residuals from regional strike are contoured in Figure 9B. The resultant patterns are not those expected for a cylindrical non-plunging fold, and further, they do not suggest the presence of structures that are in any way consistent with known regional structure. The presence of such a large standard deviation (30 degrees) of non-structural error would thus require that the values assigned to each control point be an average of several measurements from the surrounding area.

Additional numbers were generated from this population to match the sample density associated with each control point in the Middle Mountain syncline. Contours of the absolute values of the residuals and the standard deviations of the samples from the control areas are shown in Figures 10A and 10B. Again, it is not apparent from the contours that this is a cylindrical non-plunging fold. However, it is apparent that if non-structural error in the measured values of bedding strike from the Middle Mountain area is comparable to that in the random example, then structural interpretation of those data is meaningless.

The large non-structural error requires that an even greater number of measurements be made to yield a value that is representative of the population mean. The required number of measurements will

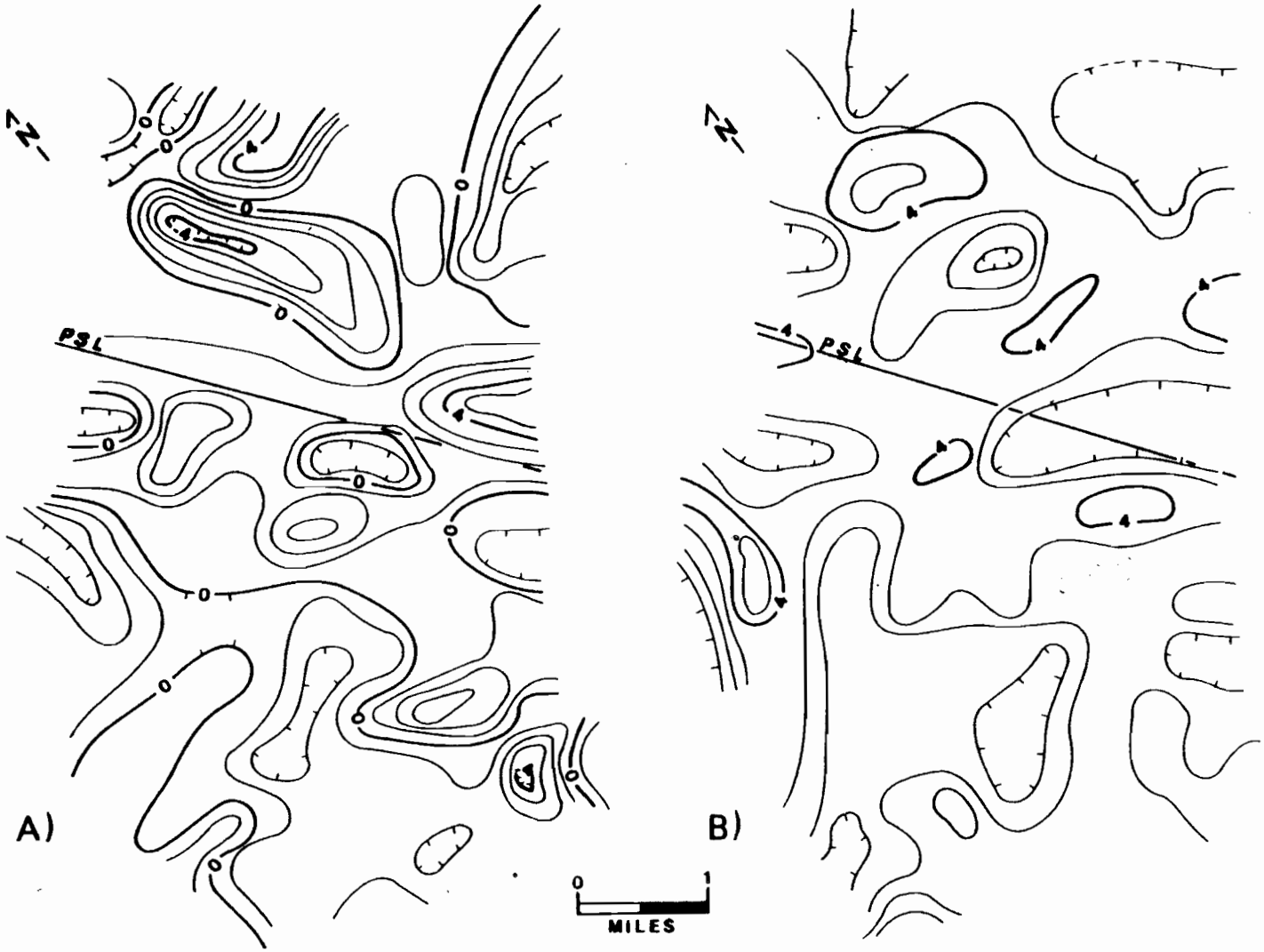

Figure 10 Stations within each cell division of the map area were assigned values drawn randomly from a population having a mean of 0 degrees and standard deviation of 30 degrees. A) Average value of the samples within each cell division, B) their standard deviation. C1 = 10°

depend on the desired precision of the sample average. For instance, to produce a value that is within 5 degrees of the population mean 95% of the time, can be determined by setting the expression for the 95% confidence interval equal to 5 degrees and then solve for the required number of samples. To reach this desired precision requires the measurement of 138 values of strike for each control point, and an extreme waste of field time.

It is particularly apparent from this discussion that structural interpretation of strike contours is least reliable since measurement error in a value of strike often exceeds 30 degrees (Woodcock, 1976).

The representativeness of the sampling in the Middle Mountain area has been examined more specifically by drawing values randomly from normally distributed populations having cell sample statistics as the population parameters for each cell in the map area. Contours of the means and standard deviations of these random numbers are shown in Figures 11A and 11B. The control values from the original data were averaged from two to eleven samples. The standard deviations of the samples in each control division are quite variable from cell to cell (see Figures 7 and 8). Structural and non-structural errors in the measured values of strike and dip were discussed earlier (see STANDARD DEVIATION CONTOURS). The presence of high standard deviation areas raises the doubt that, particularly in these areas, the means and thus the contours may not be representative of the parent populations of bedding orientations. However, the structural elements observed in

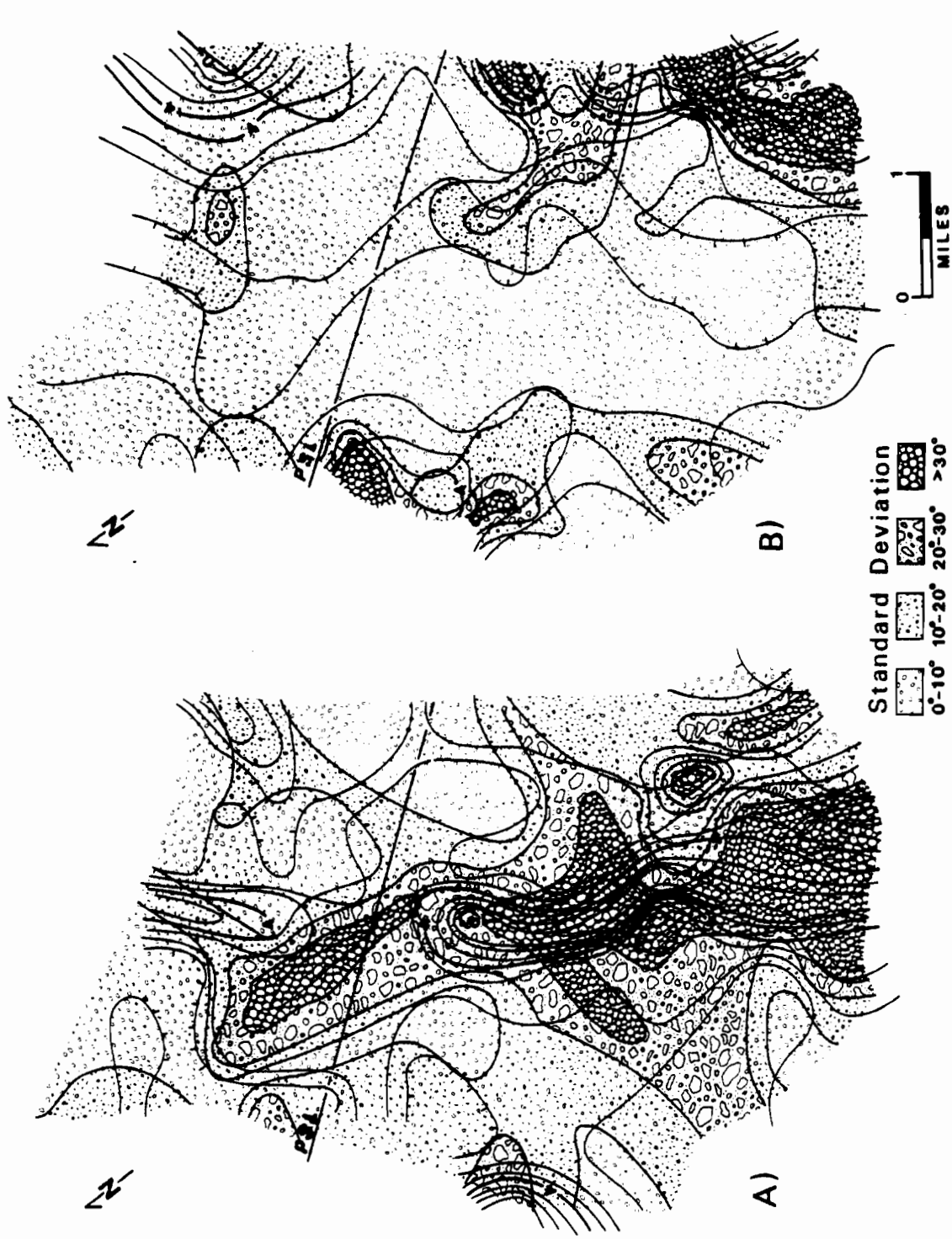

Figure 11 Strike and dip values were drawn randomly from normally distributed populations having cell sample statistics for parameters. A) Absolute value of (random strike -35 degrees) overlies their standard deviations, B) absolute value of random dip overlies their standard deviations. C1 = 10°

the contours of the Middle Mountain data (see BEDDING ORIENTATION CONTOURS OF THE MIDDLE MOUNTAIN SYNCLINE and STANDARD DEVIATION CONTOURS above) are also present in the random contours (Figures 11A and 11B). The differences in the patterns are quite apparent but do not significantly alter the interpretation. More pronounced differences result in areas of poor control, such as the disappearance of the arm-like appendages in the contours of standard deviations of strike discussed earlier (see Figures 7A, 8A and 11A).

The deformation domains defined by areas of high standard deviation in bedding dip retain the greatest similarity to the original contours (Figures 7B and 8B). With the exception of the 20 to 30 degree high standard deviation area present in the northeast quadrant of the original contours, every high standard deviation area present in the original contours is also present in the random contours.

The small non-structural errors in measurement of bedding dip and the reproducibility of the contours again support the usefullness of contours of standard deviations in bedding dip in detecting structural disruption.

The assumption of normality (see SAMPLE DISTRIBUTIONS above) is further supported by the similarity of the contours of the original data to those generated from normally distributed populations.

DEFORMATION DOMAINS AND FRACTURED GAS RESERVOIRS

Much of the current research in the D.O.E.'s Eastern Gas Shales project is directed toward predicting the locations of fractured

reservoirs in the gas producing Devonian shales. The Middle Devonian shales that crop out in the Valley and Ridge province belt are the mechanical equivalent of the Upper Devonian Brown Shale beneath the Allegheny Plateau province. The current work in the Middle Mountain syncline is aimed at determining the effects of cross-strike structural discontinuities (in this case the Parsons structural lineament) on the organic-rich Middle Devonian shales exposed in this area, and to suggest an exploration rationale for locating fractured gas reservoirs associated with structural discontinuities in the Allegheny Plateau.

The effects of structural lineaments on the characteristics of jointing have been examined previously (Wheeler, 1979a; LaCaze, 1978; Dixon, 1979a & b; Wheeler, 1978a; Wheeler and Holland, 1977). A method for estimating fracture intensity (Vialon and others, 1976) has been used to determine the effects on systematic joint intensity of the Parsons and Petersburg structural lineaments in the Plateau (Wheeler and Dixon, 1979; Dixon, 1979a and b). The results show that the Parsons and Petersburg structural lineaments represent zones of increased joint intensity.

The Parsons structural lineament is expressed on a regional scale as a cross-strike alignment of noses, bends and saddles of major folds in the Valley and Ridge and Plateau provinces (Wheeler and others, 1974) (see Figure 2). Structural shortening within the Parsons structural lineament in the Middle Mountain syncline is in general taken up by smaller folds and more abundant thrust faults than outside this structural lineament. The increase in minor folding and

particularly the increased number of thrust faults in the Middle Devonian shales of the Middle Mountain syncline result in the increase in size and number of deformation domains. Preliminary results (Wilson and Wheeler, in prep.) show that the intensity of systematic jointing is greater within the deformation domains. Thus the Parsons structural lineament in the Middle Mountain syncline is a zone of greater fracture intensity because it is also a zone of larger and more numerous deformation domains.

A thrust fault is more likely to flatten out as it propagates into a weak layer, although higher angle faulting is possible (Rodgers and Rizer, 1979a and b). As the fault propagates into the weak layer, secondary structures and fractures will remain in the region initially near the fault tip, after the fault tip has propagated out of that region (Rodgers and Rizer, 1979a and b; Rodgers, oral communication, 1979). Relic secondary faults observed in the Upper Devonian Lower Huron Shale member of the Ohio Shale Formation were used to identify the interval of detachment in the Pine Mountain thrust sheet (Wilson and others, 1978). An increased intensity of jointing was also observed in the interval of detachment (Wilson and others, 1978). Secondary faulting will also deform the area in advance of the leading edge of a thrust fault (Anderson, 1951; Hafner, 1951; Chinnery, 1966; Rodgers and Rizer, 1979). Northwest trending slickenlines observed in the Brown Shales of the Nicholas Combs #7239 core (Kulander, Dean and Barton, 1977) and slickenlines observed in the Martin County core were explained in this way (Wilson and others, 1978) and were suggested to represent the porous fracture facies discussed by Shumaker (1978).

Bedding-transverse thrust faults cut across the Devonian Oriskany Sandstone on the northwest limb of the Elkhorn Mountain anticline and probably represent secondary splay thrusts off a major splay that rises from a decollement in the Ordovician Reedsville Formation and above which the Elkhorn Mountain anticline is formed. The deformation domains on both limbs of the Middle Mountain syncline are interpreted as a direct result of the thrust faults and associated folding in the underlying Devonian Oriskany Sandstone. The association of deformation domains with mapped faults and more intensely jointed shales suggests that the deformation domain is a small analogue of the fracture facies. Although the presence of shear surfaces may act to decrease the porosity of these shales (Bagnell and Ryan, 1976) the documented presence of more intense jointing in these shales may increase the porosity and the permeability producing a fractured gas reservoir.

RECOMMENDATIONS FOR FUTURE EXPLORATION EFFORTS

The increased abundance of deformation domains in the Parsons structural lineament and their relationship to Oriskany structure suggest an exploration rationale:

I. Concentrate subsurface studies in the Appalachian Plateau on Oriskany-Onondaga structures.

II. Exploration efforts should be most productive if subsurface studies of Oriskany-Onondaga structure are concentrated in cross-strike structural discontinuities (for example the Parsons structural lineament).

Work currently under way will recommend sites as primary exploration targets.

CONCLUSIONS

The strike line map and contours of standard deviations in bedding dip are of considerable value in mapping structures in poorly exposed, mechanically incompetent shales, where exposure is often limited and structural interpretation highly speculative.

Deformation domains are more intensely fractured and represent small analoques of Shumaker's (1978) fracture facies.

The relationship of deformation domains to Oriskany structure, and the presence of more numerous larger deformation domains in cross strike structural discontinuities are important factors to consider in developing an exploration rationale to locate fractured gas reservoirs.

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· Station Location
● Grid Control Point

Overlay is registered by North arrow and PSL boundary.

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A METHOD TO IDENTIFY ZONES OF INTENSE JOINTING

WITH APPLICATION TO THE PARSONS LINEAMENT, WEST VIRGINIA

by

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ABSTRACT

A METHOD TO IDENTIFY ZONES OF INTENSE JOINTING WITH APPLICATION TO THE PARSONS LINEAMENT, WEST VIRGINIA

Studies of water well yields, of three roadcuts, and of field observations indicate that the Parsons lineament in eastern West Virginia is a broad, cross-strike zone of unusually intense jointing. To test this hypothesis, strike, dip, exposed length, exposed depth, and spacing of 1594 joints were measured in interbedded siltstones, mudstones, and shales in the Upper Devonian Chemung facies. Joint sets were determined to strike N 35-55° W, N 25-45° E, and N 80° E - N 80° W. SYMAPS show more intense jointing within the Parsons lineament with the northeast-trending set contributing most to the increase. Identification of zones of intense jointing could be useful in hydrocarbon exploration, mine design, construction, and water-well siting.

INTRODUCTION

Anomalously intense jointing has often been cited as a reason for some gas production from fractured shales, coal mine roof falls, construction problems, and increased water-well yields. Accordingly, a method for measuring joint intensity and locating areas of intense fracturing would be generally useful. As part of the Eastern Gas Shales Project, funded by the Department of Energy, such a method was developed (Wheeler and Dixon, 1979). This paper reports a field test and application of the method. My purpose is to characterize exposed systems of natural fractures that are considered to be analogues of fractured gas reservoirs still buried further west, in central West Virginia (Wheeler, 1978a; 1978b).

SETTING

The Parsons lineament in the Plateau Province in eastern West Virginia was chosen for this study because previous studies (Wheeler and others, 1978; Wheeler and Holland, 1978a; 1978b) indicated that rocks in the lineament are more intensely jointed than rocks juxtaposed to the lineament. The lineament is a northwest trending band, from 7 to 10 km wide, of disruptions in the regular northeast-trending folds and detachments characteristic of the eastern Plateau Province (Gwinn, 1964; Cardwell and others, 1968). The lineament extends at least 55 km, according to terrain corrected gravity, topographic, and LANDSAT data. This paper deals with systematic joints in interbedded siltstones, mudstones, and shales of the Upper Devonian

Chemung facies. Only the Chemung was studied in order to reduce the effects of differing lithologies. Bed thicknesses range from 0.2 to 200 cm, and typically are 10 to 30 cm. In Tucker County, the Parsons lineament crosses the outcrop belt of Chemung rocks exposed in the cores of the northeast-trending Deer Park and Elkins Valley anticlines (Cardwell and others, 1968; Gwinn, 1964).

METHOD

A total of 1594 joints were measured at 143 stations in the Chemung facies (Figure 1). As many as possible of strike, dip, exposed depth, exposed length, spacing, and bed thickness were measured on each joint. Exposed depth is the total exposed extent of a joint in the direction perpendicular to bedding, and exposed length, parallel to bedding; spacing is the perpendicular distance to the adjacent joint in the same set (Stubbs and Wheeler, 1975; Wheeler and Stubbs, 1979). Bed thickness is a measurement of the thickest bed through which the joint penetrates. Exposure size, regularity or irregularity of spacing, and number of joint sets exposed determined the number of measurements taken per station. Fifty-four percent of the joints were measured in roadcuts; the rest in streamcuts and stream pavements. Statistical analyses and contour maps of joint intensity and spacing were done with local modifications of the Statistical Analysis System and of the SYMAP program.

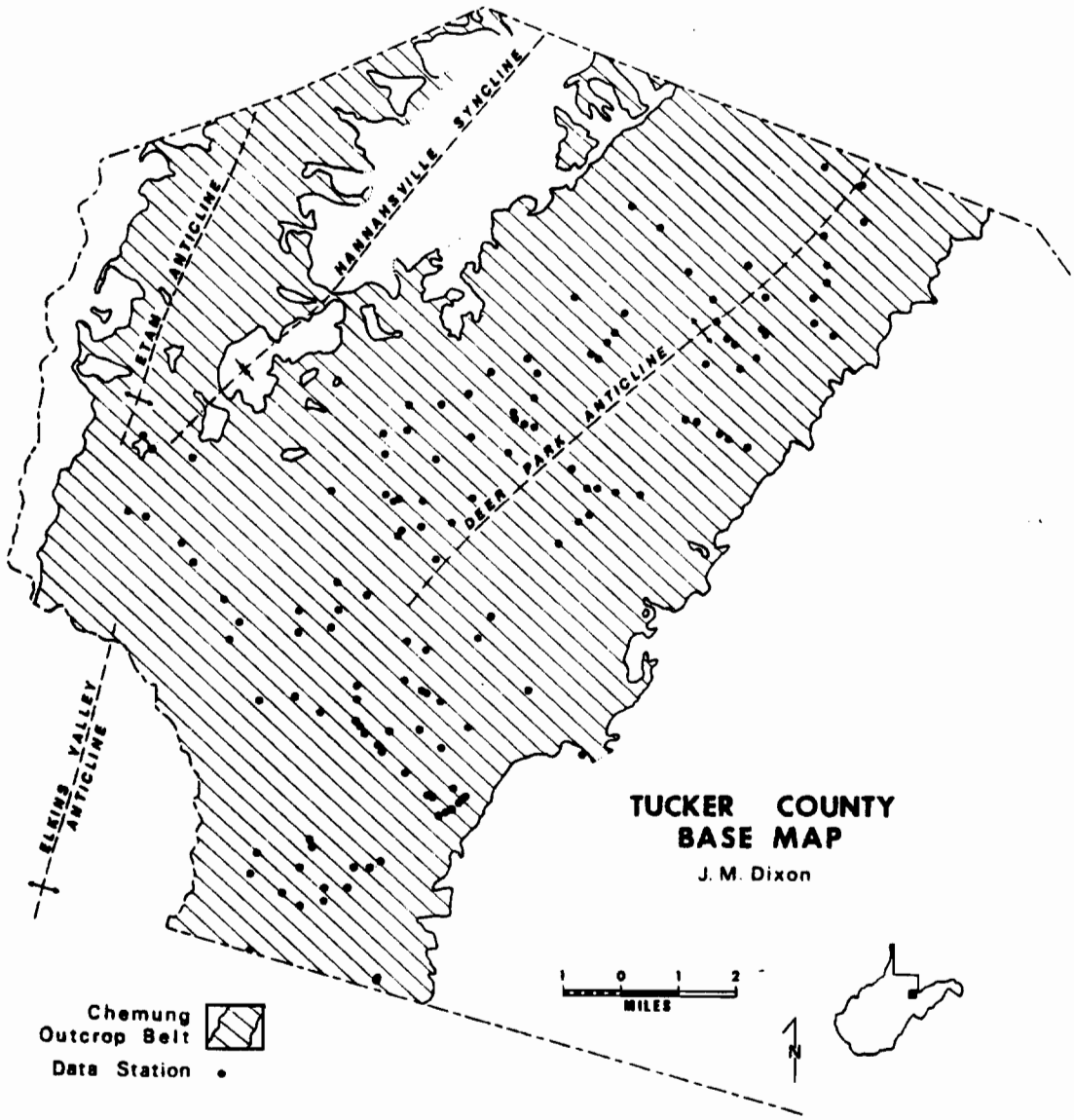


Figure 1. Index map showing the extent of the Chemung Outcrop belt and station locations.

RESULTS

A circular histogram of all measured joints shows three sets: N 35-55° W (transverse to folds), N 25-45° E (longitudinal), and N 80° E - N 80° W (diagonal), with the northwest set dominating (Figure 2). Roadcuts and stream exposures each show all three sets (Figure 3). All three sets appear north, within, and south of the lineament, but in different abundances (Figures 2a, b, c). In addition, a N 05-10° W set appears south of the lineament (Figure 2c).

A measurement of joint intensity, joint surface area per unit volume of rock (Wheeler and Dixon, 1979; Wheeler, 1979), was made using inverses of average spacings, summed over all sets in an exposure (Vailon and others, 1976; Wheeler, 1979; Dixon, 1979). SYMAP shows areas of more intense jointing within the lineament (Figure 4). The map was shown to five people: independently, each chose the boundaries of the lineament where shown in Figure 4. SYMAPS of average spacing for individual sets indicate that the northeast-striking set contributes most to the increased intensity inside the lineament, the northwest-striking set contributes slightly, and the east-striking set contributes little, if at all (Figures 5, 6, and 7). Mean spacings of each set support that (Table 1).

A SYMAP of average bed thickness shows a northeast-trending band of thin beds, reflecting the thinner beds of the lower Chemung facies exposed along the crest of the Deer Park and Elkins Valley anticlines (Figure 8). The trends found in the spacing and intensity

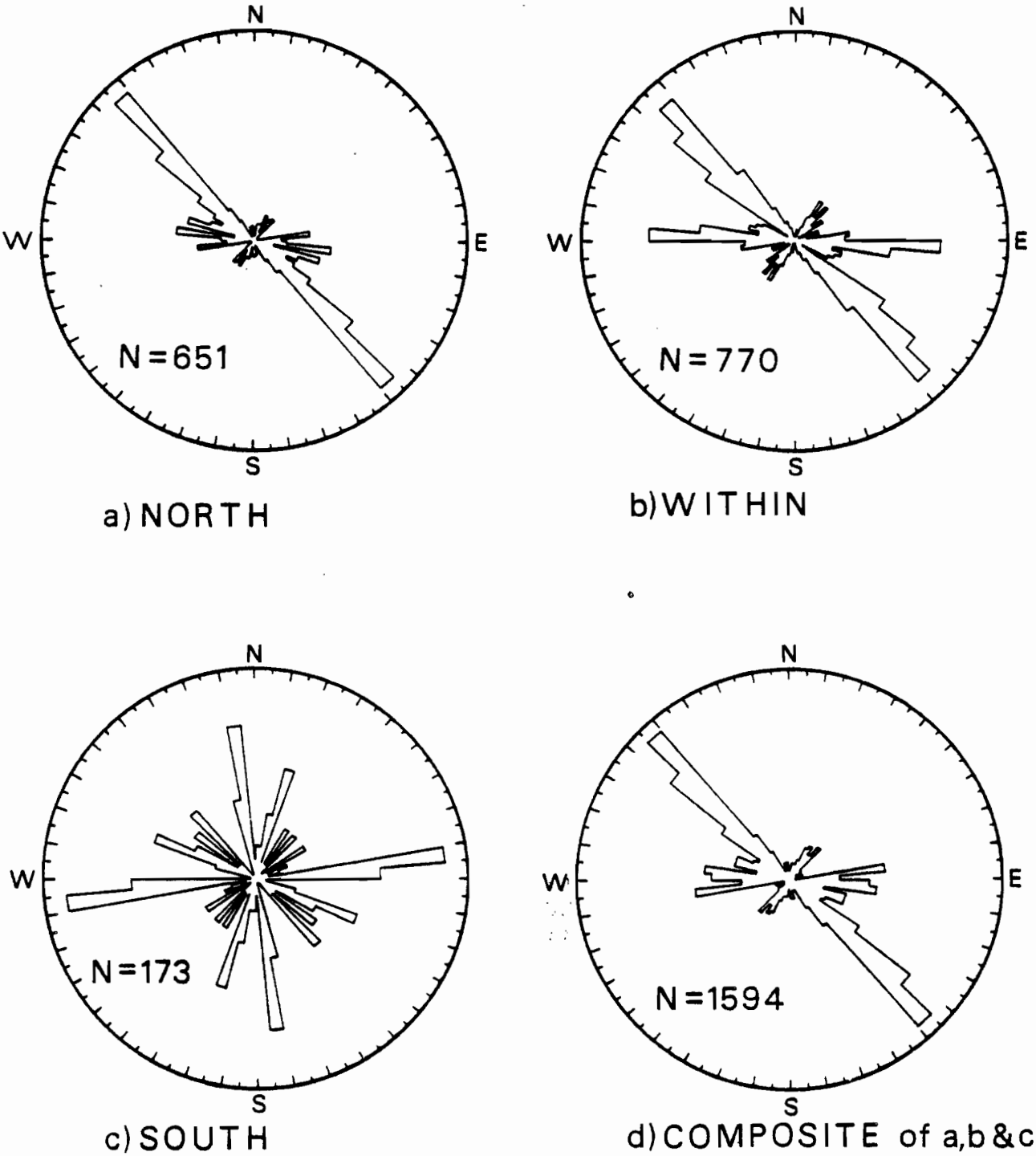
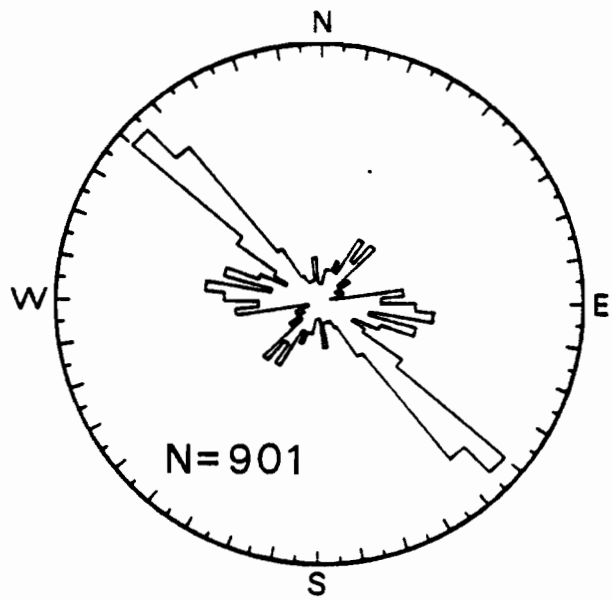
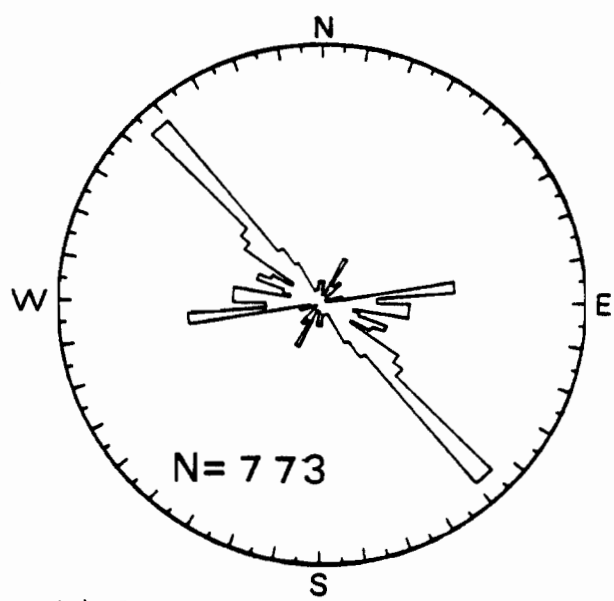


Figure 2. Circular histograms of joints taken north, within, and south of Parsons lineament and a composite of all joints measured.



a) ROADCUT JOINTS



b) STREAM JOINTS

Figure 3. Circular histograms of joints taken (a) along road cuts, (b) along streamcuts and stream pavements.

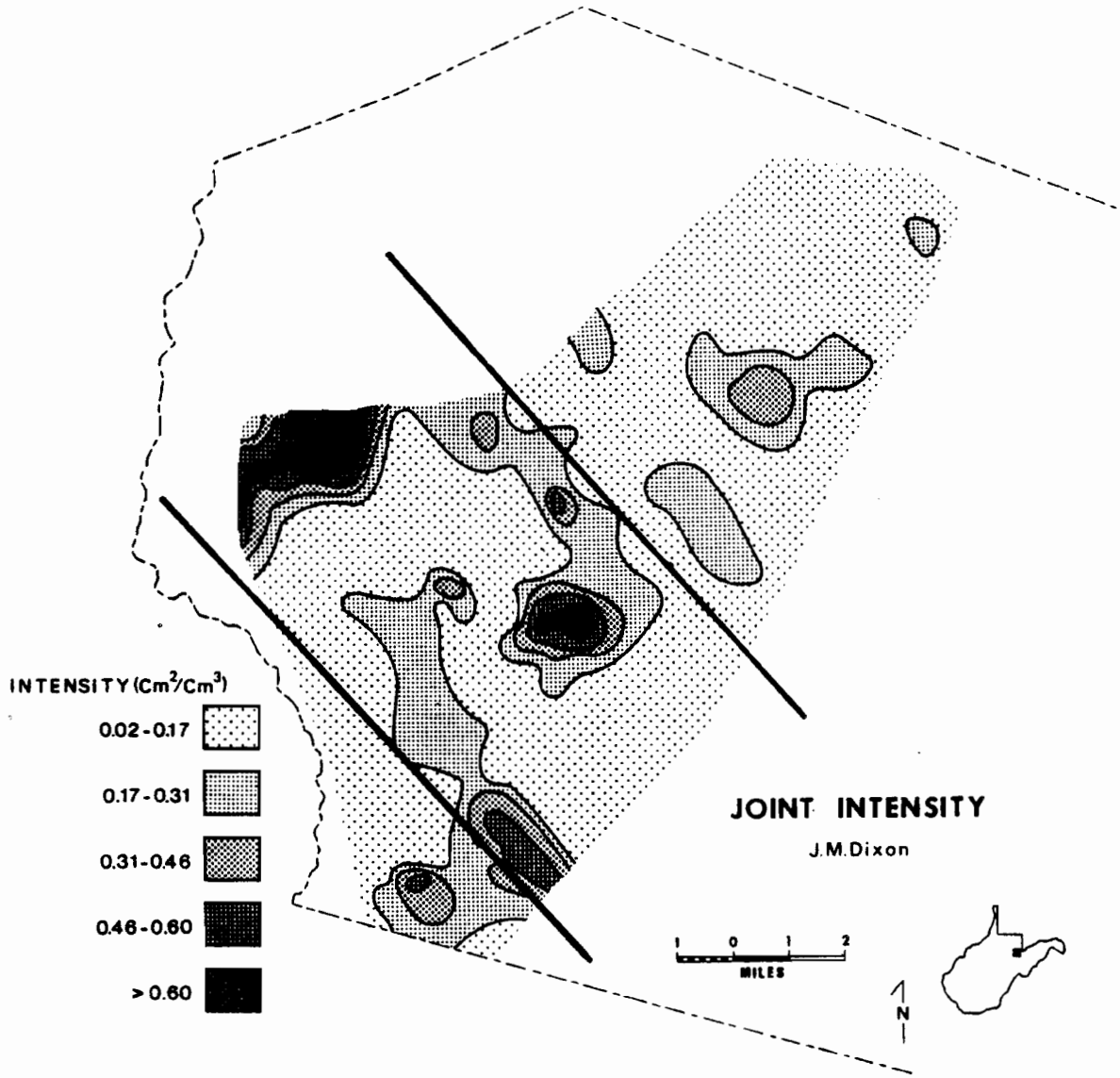


Figure 4. Contour map showing joint intensity, plotted at each station.

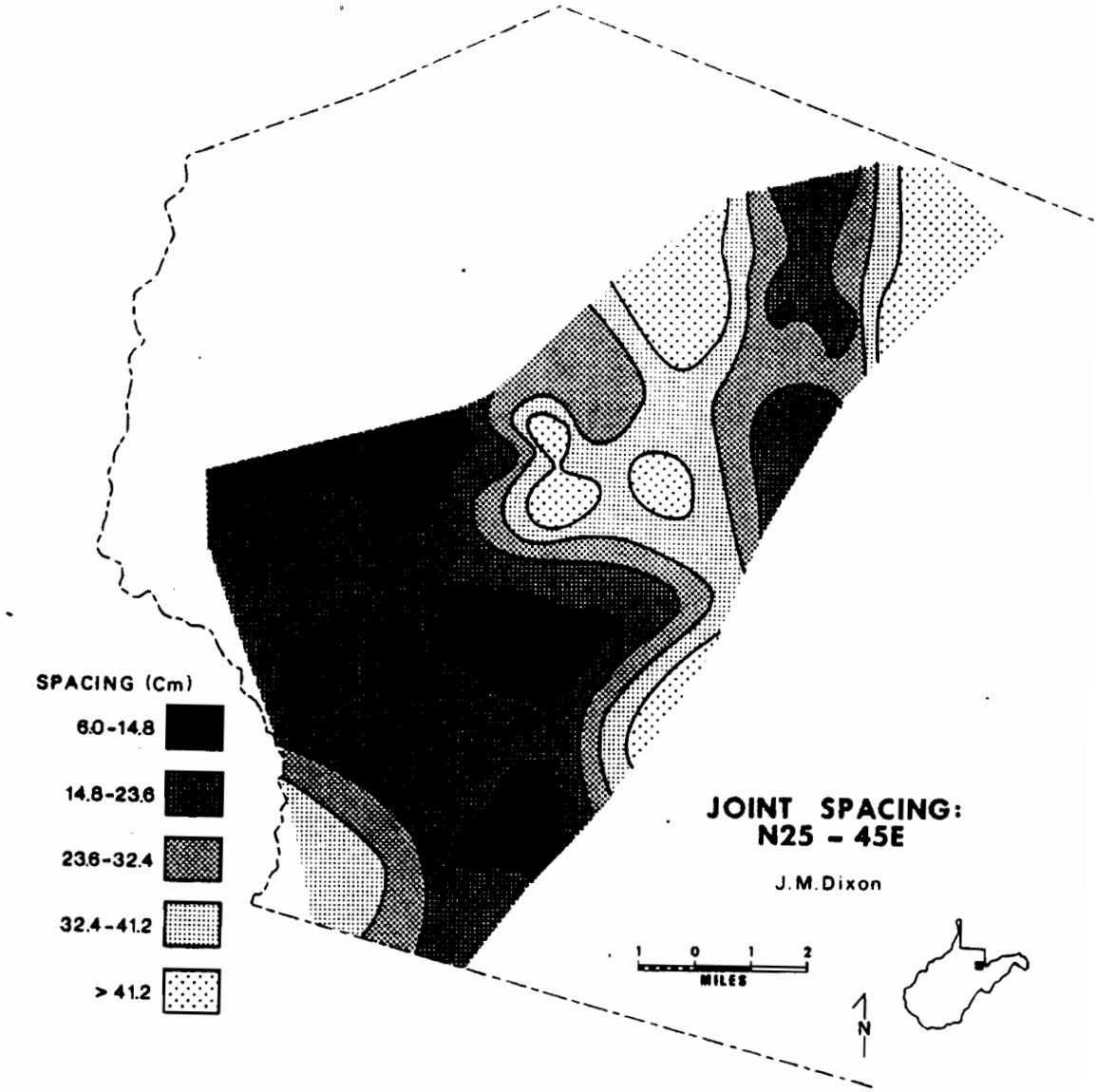


Figure 5. Contour map of the mean spacing, plotted at each station, of the northeast trending joint set.

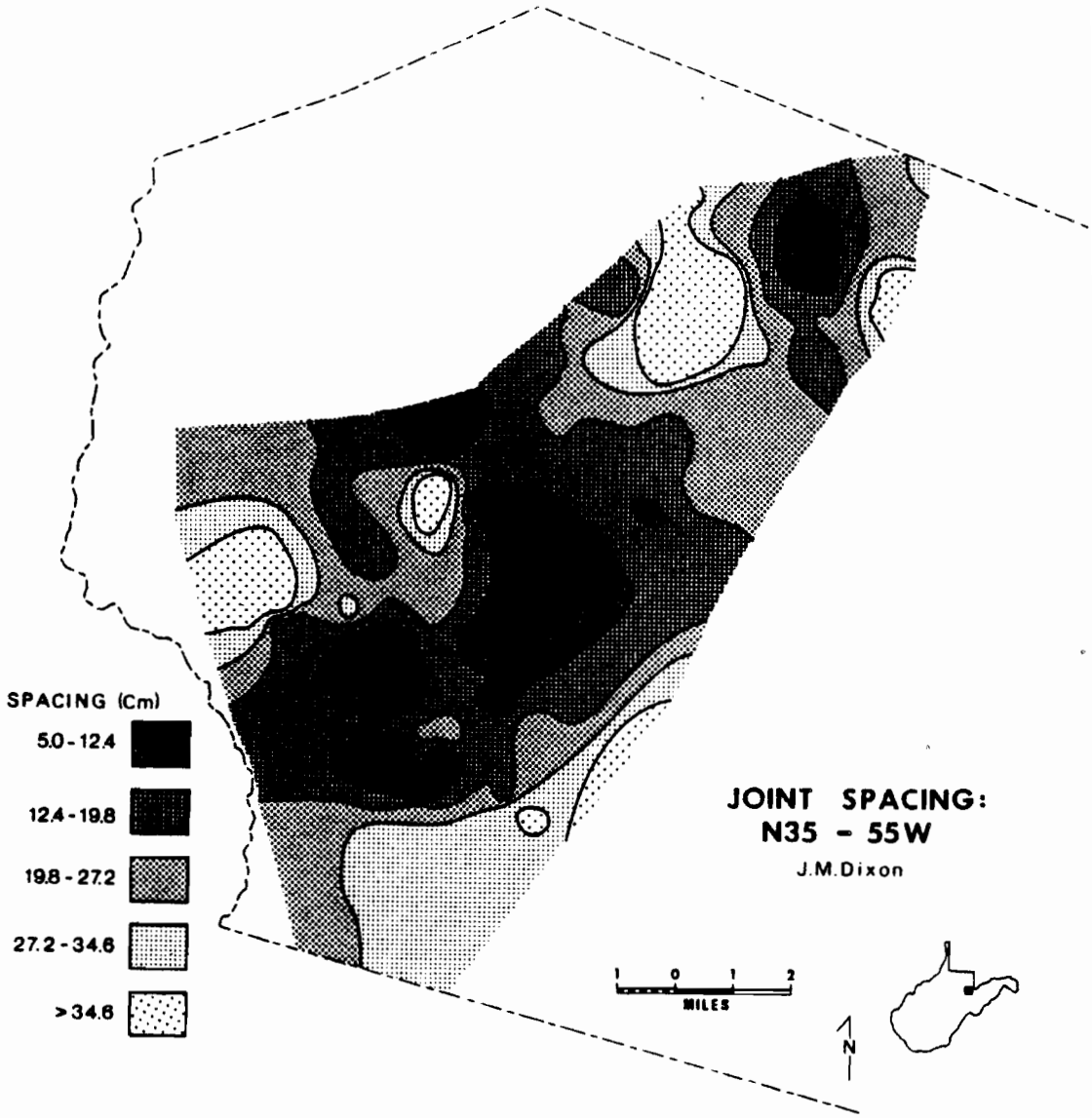


Figure 6. Contour map of mean spacing, plotted at each station, of the northwest-trending joint set.

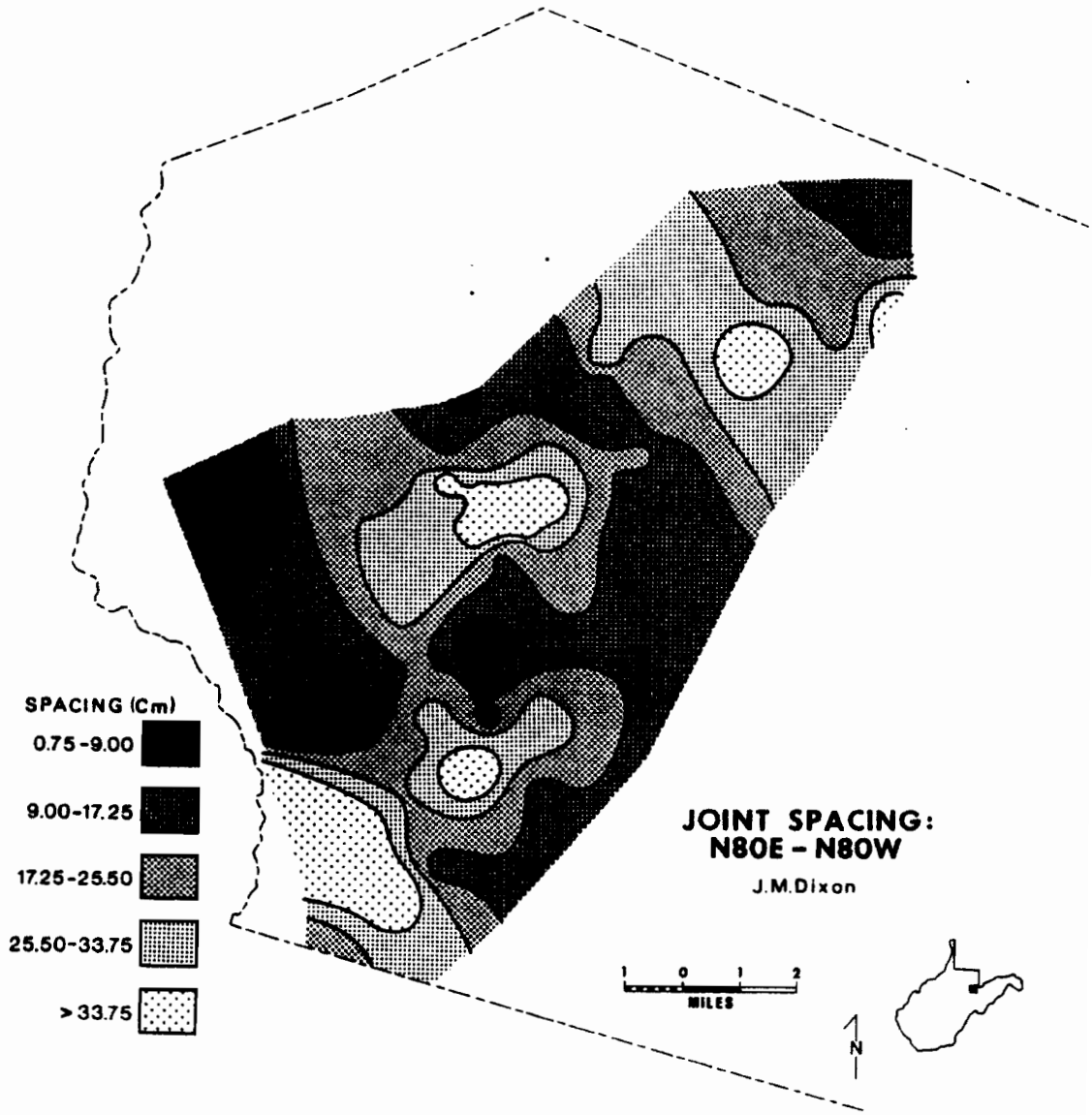


Figure 7. Contour map of mean spacing, plotted at each station, of the east-trending joint set.

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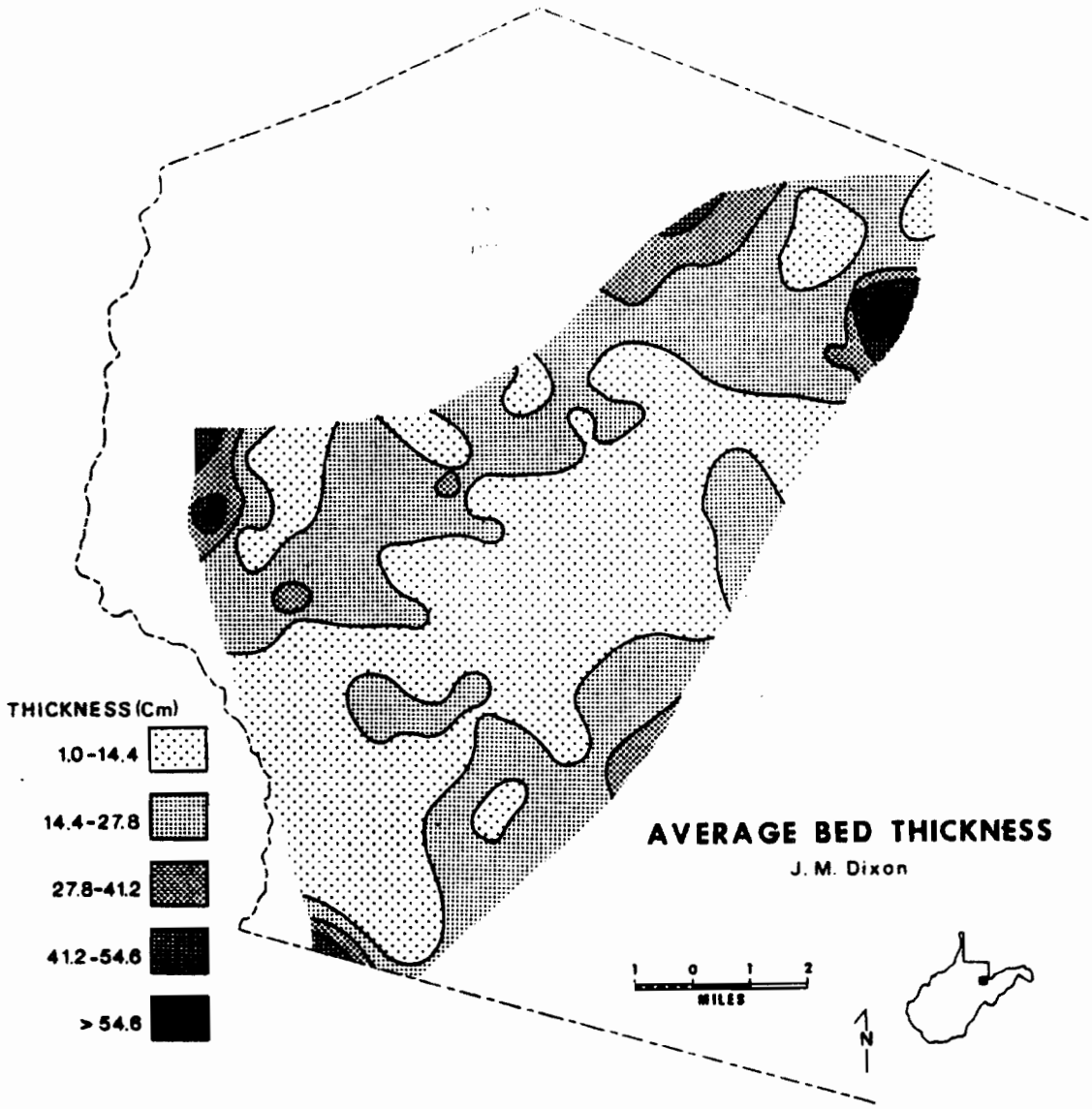

Figure 8. Contour map of the mean bed thickness, plotted at each station.

Location	Joint Set								
	Northeast			Northwest			East-West		
	n	$\bar{s}$	σ_s	n	$\bar{s}$	σ_s	n	$\bar{s}$	σ_s
North	50	31	29.8	232	22	19.8	136	22	14.5
Within	79	17	16.3	270	19	18.9	172	25	23.6
South	15	28	13.2	18	30	27.0	36	42	39.9

Table 1. Mean spacing in cm ($\bar{s}$), number of observations (n), and standard deviations in cm (σ_s) of each joint set north, within, and south of Parsons lineament.

maps are northwest to north, from which I conclude that a factor other than bed thickness controls joint intensity. (Statistical tests show only a minor correlation between bed thickness and joint spacing.) That factor apparently is the Parsons lineament.

Large, northeast-trending anticlines plunge into the Parsons lineament (Figure 1; Cardwell and others, 1968), which may have increased the intensity of the transverse joint set on the anticlinal noses. Smaller, northeast-trending anticlines with wavelengths on the order of half a kilometer are more numerous in the lineament (Trumbo, 1976), and may increase the intensity of the longitudinal set.

CONCLUSIONS

1. The Upper Devonian Chemung facies shows three well-developed, systematic joint sets: N 35-55° W, N 25-45° E, and N 80° E - N 80° W, with the northwest set dominating.

2. Rocks within the Parsons lineament are more intensely jointed than rocks juxtaposed.

3. SYMAPS and statistics show the northeast-trending set contributes most to joint intensity, the northwest-trending set slightly contributes, and the east-trending set contributes little or not at all to increased joint intensity within the Parsons lineament.

4. Joint spacing was found to be the most useful measurement in determining joint intensity.

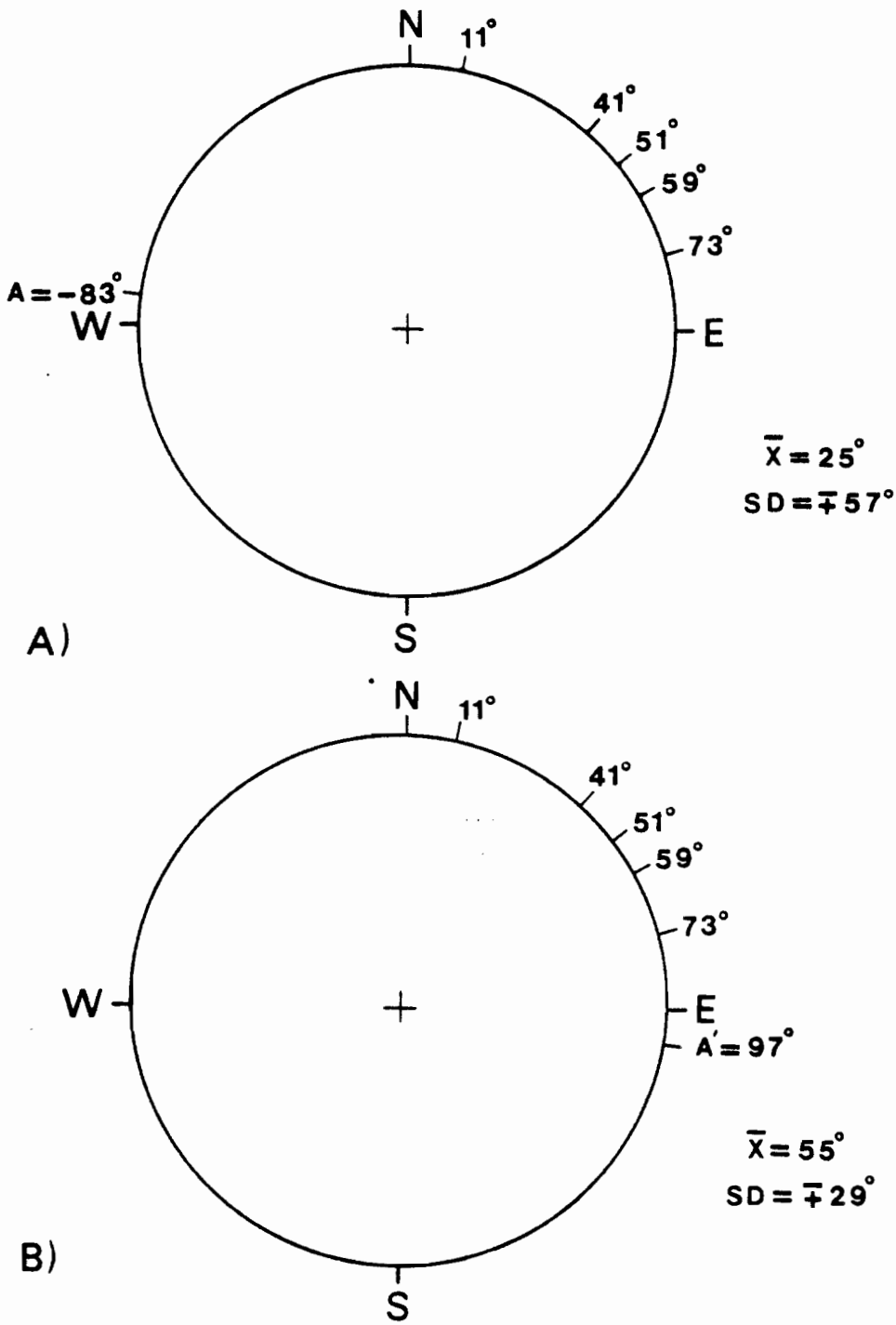

Figure 4 Sample distribution of strike illustrates the method for determining the mean of a directional distribution by minimizing the standard deviation.

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APPENDIX A

STATION LOCATION OF UTM COORDINATES

STA	LONG	LAT	STA	LONG	LAT
001	4328.28	615.12	076	4336.54	613.30
002	4329.71	613.71	077	4337.21	613.89
003	4330.34	614.08	078	4333.23	616.75
004	4330.80	610.53	079	4333.02	616.46
005	4329.34	612.22	080	4332.42	615.92
006	4325.48	613.10	082	4326.50	616.70
007	4325.20	612.50	083	4332.90	612.91
008	4325.87	611.72	084	4334.70	612.43
009	4327.03	611.25	085	4335.52	611.59
010	4326.43	611.07	086	4335.39	610.92
011	4326.92	610.60	087	4334.81	610.98
012	4323.35	611.10	088	4333.73	609.50
013	4323.17	610.80	089	4330.37	609.76
014	4322.60	610.18	090	4329.88	609.59
015	4329.56	611.70	091	4330.32	608.65
016	4330.60	606.53	092	4329.73	608.64
017	4328.02	603.70	093	4329.95	606.99
018	4325.61	602.99	094	4329.45	606.72
019	4324.87	602.92	095	4331.60	605.67
020	4323.48	602.57	096	4332.16	605.30
021	4319.75	602.58	097	4332.87	604.30
022	4319.98	611.05	098	4332.96	603.77
023	4320.06	611.07	099	4335.13	604.14
024	4322.17	609.52	100	4334.77	604.43
025	4322.02	608.87	101	4334.58	605.56
026	4327.13	610.47	102	4327.19	613.48
027	4327.27	610.34	103	4327.88	612.70
028	4327.50	609.30	104	4328.09	612.32
029	4327.92	608.60	105	4328.47	611.66
030	4327.80	607.57	106	4328.17	612.15
031	4333.67	611.01	107	4327.11	612.15
032	4333.48	611.25	108	4326.60	612.76
033	4332.48	611.38	109	4327.87	610.34
035	4331.16	609.72	110	4328.22	610.35
036	4326.64	610.97	111	4332.66	611.48
037	4325.27	612.38	112	4332.78	612.03
038	4325.21	612.49	113	4333.50	612.08
040	4324.70	612.70	114	4333.54	611.40
041	4324.80	612.88	115	4331.86	612.48
042	4324.88	613.08	116	4338.61	621.52
043	4325.06	613.23	117	4339.48	621.58
044	4325.12	613.30	118	4340.37	621.09
045	4325.18	613.35	119	4338.45	621.62
046	4325.25	613.42	120	4338.15	620.74
047	4334.54	616.24	021	4338.78	620.22
048	4334.00	616.68	123	4337.58	619.92
049	4333.98	616.96	124	4335.95	619.72
050	4333.90	617.47	125	4335.62	620.39
051	4333.79	618.17	126	4335.48	620.62
052	4334.94	614.42	127	4335.23	621.17
054	4333.60	613.45	128	4335.38	613.38
055	4338.43	623.52	129	4335.68	615.17
056	4338.78	622.98	130	4335.77	614.90
057	4338.28	620.51	131	4335.92	614.58
058	4339.40	620.08	132	4336.11	614.55
059	4340.17	619.37	133	4336.51	615.13
060	4341.34	618.56	134	4337.23	615.22
061	4341.94	617.73	135	4323.16	610.33
062	4339.50	622.92	136	4323.69	609.17
063	4339.92	623.30	137	4323.90	609.10
064	4340.42	623.31	138	4320.77	607.49
065	4343.18	623.17	139	4323.12	608.84
066	4342.68	624.21	140	4322.55	609.54
067	4341.22	623.18	141	4322.37	608.36
068	4341.65	624.31	142	4323.48	607.63
069	4337.77	621.36	143	4322.87	607.46
070	4337.48	620.91	144	4323.01	604.68
071	4335.99	619.44	145	4338.96	617.63
072	4337.62	614.91	146	4338.43	617.36
073	4339.38	616.18	147	4338.11	617.15
074	4336.20	611.61	148	4337.66	616.91
075	4336.27	612.53	149	4337.80	616.69

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APPENDIX B

TUCKER COUNTY DATA

KEY TO ABBREVIATIONS

STA = station number

STRI = joint strike

DIP = joint dip

LNG = joint length

DPT = joint depth

SPA = joint spacing

BED = bed thickness

EXP = type of exposure: R = roadcut, S = stream pavement, SC = streamcut

SET = indicates into which of the three main joint sets the joint falls: NW = northwest, NE = northeast, EW = east-west.

LOC = location with respect to the Parsons lineament: IN = within, NT = north, SO = south.

STA	STRI	DIP	LNG	DPT	SPA	BED	EXP	SET	LOC
001	N45W	88SW	106	048	060	020	R	NW	IN
001	N46E	90NW	004	022	013	015	R		IN
001	N45W	88SW	148	020	002	015	R	NW	IN
001	N46E	90NW	007	017	044	017	R		IN
001	N46E	90NW	027	029	060	020	R		IN
001	N45W	88SW	084	021	007	021	R	NW	IN
001	N45W	88SW	074	022	002	022	R	NW	IN
001	N45W	88SW	075	039	005	020	R	NW	IN
001	N46E	90NW	007	015	014	015	R		IN
001	N46E	90NW	009	008	014	008	R		IN
001	N46E	90NW	012	008	022	008	R		IN
002	N84W	81SW	013	002	007	002	R	EW	IN
002	N30E	90NW	026	003	003	003	R	NE	IN
002	N84W	81SW	005	002	005	002	R	EW	IN
002	N45W	90SW	010	125		003	R	NW	IN
002	N20E	90NW	110	070	010	004	R		IN
002	N20E	90NW	087	065	003	004	R		IN
002	N78W	90SW	007	005		005	R		IN
002	N60W	90SW	023	010	007	010	R		IN
002	N60W	90SW	063	011	015	011	R		IN
002	N45W	90SW	027	007		007	R	NW	IN
002	N45W	90SW	035	007	002	007	R	NW	IN
002	N80E	80SE	040	012	045	012	R	EW	IN
002	N30E	90NW	024	001	008	001	R	NE	IN
002	N30E	90NW	020	001	005	001	R	NE	IN
002	N30E	90NW	021	001	008	001	R	NE	IN
002	N30E	90NW	018	001	004	001	R	NE	IN
002	N45W	90SW	100	010	016	010	R	NW	IN
002	N70W	90SW	027	005	016	005	R		IN
002	N30E	90NW	016	001	008	001	R	NE	IN
002	N30E	90NW	005	001	006	001	R	NE	IN
002	N84W	81SW	022	003	016	003	R	EW	IN
002	N84W	81SW	036	002	015	002	R	EW	IN
002	N84W	81SW	020	004	010	004	R	EW	IN
002	N84W	81SW	010	004	004	004	R	EW	IN
002	N84W	81SW	023	004	010	004	R	EW	IN
003	N34E	90NW	028	015	033	015	R	NE	IN
003	N34E	90NW	035	015	017	015	R	NE	IN
003	N34E	90NW	055	015	020	015	R	NE	IN
003	N34E	90NW	045	015	008	015	R	NE	IN
003	N34E	90NW	054	015	024	015	R	NE	IN
003	N87E	80NW	153	015	030	015	R	EW	IN
003	N87E	80NW	055	015	020	015	R	EW	IN
003	N87E	80NW	036	015	022	015	R	EW	IN
003	N87E	80NW	070	015	020	015	R	EW	IN
003	N87E	80NW	033	015	016	015	R	EW	IN
003	N87E	80NW	078	015	016	015	R	EW	IN
003	N34E	90NW	012	003	007	003	R	NE	IN
003	N34E	90NW	010	003	004	003	R	NE	IN
003	N34E	90NW	007	006	008	006	R	NE	IN
003	N87E	80NW	013	006	011	006	R	EW	IN
003	N60W	85SW	105	044	030	006	R		IN
004	N45W	88NE	135	048	050	010	R	NW	IN
004	N45W	88NE	107	020	020	010	R	NW	IN
004	N45W	88NE	175	015	005	010	R	NW	IN
004	N50E	90NW	001	008	036	008	R		IN
004	N50E	90NW	003	026	035	010	R		IN
004	N50E	90NW	020	010	007	010	R		IN
004	N50E	90NW	025	010	012	010	R		IN
005	N55W	73NE	007	005	011	005	R	NW	IN

STA	STRI	DIP	LNG	DPT	SPA	BED	EXP	SET	LOC
005	N40E	15SE	007	007	007	007	R	NE	IN
005	N55W	73NE	015	007	008	007	R	NW	IN
005	N40E	15SE	005	007	003	007	R	NE	IN
005	N40E	15SE	005	005	004	005	R	NE	IN
005	N40E	15SE	001	005	002	005	R	NE	IN
005	N55W	73NE	011	005	005	005	R	NW	IN
005	N55W	73NE	020	006	007	006	R	NW	IN
005	N84E	77SE	022	014	005	014	R	EW	IN
005	N84E	77SE	042	003	005	003	R	EW	IN
005	N84E	77SE	019	008	010	008	R	EW	IN
005	N84E	77SE	024	010	002	010	R	EW	IN
005	N50W	70NE	021	008	011	008	R	NW	IN
005	N50W	70NE	026	015	007	019	R	NW	IN
005	N50W	70NE	045	024	012	024	R	NW	IN
005	N40E	15SE	025	024	033	024	R	NE	IN
005	N40E	15SE	027	030	039	024	R	NE	IN
005	N60W	70NE	032	016	003	010	R		IN
005	N55W	73NE	022	010	008	010	R	NW	IN
005	N40E	15SE	018	020	005	005	R	NE	IN
006	N45W	82NE	007	012	015	012	R	NW	IN
006	N45W	82NE	018	014	020	012	R	NW	IN
006	N45W	82NE	009	020	015	010	R	NW	IN
006	N45W	82NE	009	020	022	010	R	NW	IN
006	N45W	82NE	007	017	012	010	R	NW	IN
006	N45W	82NE	006	021	023	010	R	NW	IN
006	N45W	82NE	035	021	016	011	R	NW	IN
006	N45W	82NE	012	050	009	011	R	NW	IN
006	N45W	82NE	005	020	007	011	R	NW	IN
006	N45W	82NE	050	033	023	033	R	NW	IN
006	N45W	82NE	022	006	010	006	R	NW	IN
006	N45W	82NE	030	006	013	006	R	NW	IN
006	N45W	82NE	031	006	012	006	R	NW	IN
006	N45W	82NE	012	006	011	006	R	NW	IN
006	N40E	56SE	010	006	010	006	R	NE	IN
006	N40E	56SE	011	006	023	006	R	NE	IN
006	N40E	56SE	010	010	011	010	R	NE	IN
006	N40E	56SE	033	014	003	014	R	NE	IN
007	N23W	90SW	104	019	023	019	R		IN
007	N23W	90SW	033	019	022	019	R		IN
007	N23W	90SW	016	019	017	019	R		IN
007	N23W	90SW	001	019	010	019	R		IN
007	N23W	90SW	018	019	011	019	R		IN
007	N23W	90SW	012	019	022	019	R		IN
007	N23W	90SW	022	019	017	019	R		IN
007	N69E	90NW	260	090	048	025	R		IN
007	N69E	90NW	250	048	017	017	R		IN
007	N23W	90SW	010	005	012	005	R		IN
007	N23W	90SW	008	005	014	003	R		IN
007	N23W	90SW	001	008	002	003	R		IN
007	N23W	90SW	001	020	005	005	R		IN
007	N69E	90NW	043	021	011	021	R		IN
007	N69E	90SE	001	034	015	034	R		IN
007	N69E	90NW	015	007	040	007	R		IN
007	N69E	90NW	007	007	041	007	R		IN
007	N69E	90NW	002	007	060	007	R		IN
007	N69E	90NW	002	007	065	007	R		IN
007	N69E	90NW	032	010	010	010	R		IN
007	N69E	90NW	010	010	009	010	R		IN
008	N35E	90NW	010	011	010	011	R	NE	IN
008	N75W	90SW	600	070	055	038	R		IN

STA	STRI	DIP	LNG	DPT	SPA	BED	EXP	SET	LOC
008	N35E	90NW	011	011	028	011	R	NE	IN
008	N35E	90NW	011	011	015	011	R	NE	IN
008	N35E	90NW	012	011	035	011	R	NE	IN
008	N35E	90NW	009	011	021	011	R	NE	IN
008	N85W	56NE	038	020	048	020	R	EW	IN
008	N85W	56NE	165	011	050	011	R	EW	IN
008	N35E	90NW	015	004	013	004	R	NE	IN
008	N35E	90NW	001	004	013	004	R	NE	IN
008	N35E	90NW	001	004	010	004	R	NE	IN
008	N35E	90NW	017	007	014	007	R	NE	IN
008	N35E	90NW	016	007	007	007	R	NE	IN
008	N35E	90NW	014	015	020	015	R	NE	IN
008	N53W	90SW	500	115		060	R	NW	IN
008	N53W	90SW	500	233		085	R	NW	IN
009	N74E	90NW	060	013	008	013	S		IN
009	N74E	90NW	080	013	034	013	S		IN
009	N74E	90NW	080	013	017	013	S		IN
009	N74E	90NW	065	013	020	013	S		IN
009	N74E	90NW	070	013	010	013	S		IN
009	N74E	90NW	051	013	007	013	S		IN
009	N74E	90NW	040	013	020	013	S		IN
009	N74E	90NW	041	013	030	013	S		IN
009	N74E	90NW	007	008	020	008	S		IN
009	N35W	90SW	040	008	030	008	S	NW	IN
009	N35W	90SW	063	013	037	013	S	NW	IN
009	N35W	90SW	042	013	013	013	S	NW	IN
009	N35W	90SW	043	013	021	013	S	NW	IN
009	N35W	90SW	070	013	021	013	S	NW	IN
010	N52W	90SW	105	007	010	007	R	NW	IN
010	N52W	90SW	125	007	002	007	R	NW	IN
010	N52W	90SW	029	007	009	007	R	NW	IN
010	N52W	90SW	040	011	006	011	R	NW	IN
010	N52W	90SW	022	011	010	011	R	NW	IN
010	N52W	90SW	228	070	003	011	R	NW	IN
010	N52E	90NW	001	007	043	007	R		IN
010	N52E	90NW	001	007	011	007	R		IN
010	N52E	90NW	001	007	023	007	R		IN
010	N52E	90NW	010	007	026	007	R		IN
010	N52E	90NW	001	007	043	007	R		IN
010	N52E	90NW	005	007	024	007	R		IN
010	N52E	90NW	009	007	046	007	R		IN
010	N52E	90NW	001	007	038	007	R		IN
010	N52E	90NW	001	007	031	007	R		IN
010	N52E	90NW	001	007	030	007	R		IN
010	N52E	90NW	001	010	021	010	R		IN
010	N52E	90NW	001	010	020	010	R		IN
010	N52E	90NW	001	010	024	010	R		IN
011	N46W	87SW	057	018	030	018	R	NW	IN
011	N46W	87SW	161	030	028	030	R	NW	IN
011	N46W	87SW	022	009	028	009	R	NW	IN
011	N46W	87SW	022	009	018	009	R	NW	IN
011	N46W	87SW	105	030	025	030	R	NW	IN
011	N46W	87SW	098	023	054	023	R	NW	IN
011	N46W	87SW	050	023	020	023	R	NW	IN
012	N48W	90SW	025	105	012	012	R	NW	IN
012	N48W	90SW	020	057	012	012	R	NW	IN
012	N48W	90SW	020	012	030	012	R	NW	IN
012	N48W	90SW	120	130	080	012	R	NW	IN
012	N65E	90NW	075	012	035	012	R		IN
012	N65E	90NW	016	013	014	013	R		IN

STA	STRI	DIP	LNG	DPT	SPA	BED	EXP	SET	LOC
012	N21E	86SE	045	037		012	R		IN
012	N46E	73NW	047	024	009	017	R		IN
012	N46E	73NW	088	017	011	017	R		IN
012	N48W	90SW	160	060	018	030	R	NW	IN
012	N48W	90SW	015	028	022	011	R	NW	IN
012	N48W	90SW	002	030		010	R	NW	IN
012	N30E	90NW	057	020	004	008	R	NE	IN
012	N28E	84NW	023	027	030	012	R	NE	IN
012	N88W	90SW	030	002	005	002	R	EW	IN
012	N88W	90SW	013	007	010	007	R	EW	IN
012	N88W	90SW	014	007	025	007	R	EW	IN
012	N55E	90NW	180	040		040	R		IN
012	N55W	90SW	079	112		040	R	NW	IN
012	N55W	90SW	150	040		040	R	NW	IN
012	N55W	90SW	200	080	060	040	R	NW	IN
013	N68W	90SW	039	058	023	047	R		IN
013	N86W	90SW	038	038	043	038	R	EW	IN
013	N68W	90SW	001	027	003	027	R		IN
013	N68W	90SW	001	047	046	047	R		IN
013	N68W	90SW	003	055	012	055	R		IN
013	N68W	90SW	001	055	023	055	R		IN
013	N68W	90SW	042	018	043	018	R		IN
013	N68W	90SW	027	018	040	018	R		IN
013	N68W	90SW	010	027	037	018	R		IN
013	N68W	90SW	030	018	020	018	R		IN
013	N68W	90SW	005	018	022	018	R		IN
013	N78W	90SW	023	026	028	007	R		IN
013	N78W	90SW	014	005	020	005	R		IN
013	N78W	90SW	010	005	016	005	R		IN
013	N20W	81SW	052	010		010	R		IN
014	N75W	85NE					R		IN
015	N73W	55NE	096	015	029	003	R		IN
015	N73W	55NE	040	006		003	R		IN
015	N73W	55NE	020	007	012	003	R		IN
015	N73W	55NE	012	007	013	003	R		IN
015	N73W	55NE	020	007	022	003	R		IN
015	N73W	55NE	045	007	011	003	R		IN
015	N73W	55NE	045	010	028	003	R		IN
015	N73W	55NE	045	010	038	003	R		IN
015	N73W	55NE	037	010	040	003	R		IN
015	N73W	55NE	035	010	033	003	R		IN
015	N73W	55NE	029	010	025	003	R		IN
016	N49W	76SW	060	050	074	050	R	NW	IN
016	N46W	75SW	138	120	052	065	R	NW	IN
016	N46W	75SW	092	055	049	055	R	NW	IN
016	N46W	75SW	061	040	037	040	R	NW	IN
016	N46W	74SW	064	065	024	060	R	NW	IN
016	N46W	75SW	034	051	026	051	R	NW	IN
016	N46W	75SW	071	035	033	035	R	NW	IN
016	N46W	75SW	045	022	035	022	R	NW	IN
016	N46W	75SW	070	054	078	054	R	NW	IN
016	N46W	75SW	101	075	116	045	R	NW	IN
016	N46W	75SW	083	052	077	052	R	NW	IN
016	N46W	75SW	105	038	045	038	R	NW	IN
016	N46W	75SW	095	038	029	038	R	NW	IN
016	N46W	75SW	010	038	045	045	R	NW	IN
016	N60E	78SE	014	008	021	008	R		IN
016	N60E	72SE	003	008	028	008	R		IN
017	N62E	78SE	006	008	041	008	R		BR
017	N62E	78SE	018	008	057	008	R		BR

STA	STRI	DIP	LNG	DPT	SPA	BED	EXP	SET	LOC
017	N62E	78SE	018	012	039	010	R		BR
017	N62E	78SE	001	012	026	010	R		BR
017	N62E	78SE	014	010	046	010	R		BR
017	N62E	78SE	008	010	030	010	R		BR
017	N62E	78SE	014	006	038	003	R		BR
017	N62E	78SE	014	006	035	006	R		BR
017	N62E	78SE	002	006	040	006	R		BR
017	N62E	78SE	001	006	035	006	R		BR
018	N42W	75SW	061	004	055	004	R	NW	BR
018	N42W	75SW	024	004	028	004	R	NW	BR
018	N42W	75SW	034	012	045	012	R	NW	BR
018	N42W	75SW	012	010	030	010	R	NW	BR
018	N13E	90NW	043	004	018	004	R		BR
018	N42W	75SW	020	014	014	004	R	NW	BR
018	N42W	75SW	075	004	024	004	R	NW	BR
018	N42W	75SW	028	008	028	008	R	NW	BR
018	N42W	75SW	102	016	044	016	R	NW	BR
018	N13E	90NW	058	016		016	R		BR
018	N87E	90NW	015	001	007	001	R	EW	BR
018	N87E	90NW	012	001		001	R	EW	BR
018	N25E	90NW	087	005	052	005	R	NE	BR
018	N45W	74SW	065	010	060	010	R	NW	BR
018	N45W	75SW	059	049	040	005	R	NW	BR
018	N45W	74SW	030	005	067	005	R	NW	BR
018	N45W	74SW	050	005	059	005	R	NW	BR
019	N33E	73NW	026	005	012	005	R	NE	BR
019	N33E	73NW	013	005	010	005	R	NE	BR
019	N33E	73NW	014	005	010	005	R	NE	BR
019	N33E	73NW	026	005	013	005	R	NE	BR
019	N33E	73NW	019	005	010	005	R	NE	BR
019	N33E	73NW	015	004	005	004	R	NE	BR
019	N33E	73NW	016	004	007	004	R	NE	BR
019	N33E	73NW	016	004	010	004	R	NE	BR
019	N33E	73NW	012	004	007	004	R	NE	BR
019	N33E	73NW	012	003	008	003	R	NE	BR
019	N33E	73NW	001	003	005	003	R	NE	BR
019	N33E	73NW	015	005	012	005	R	NE	BR
019	N33E	73NW	018	005	005	005	R	NE	BR
019	N50W	88SW	005	004	023	004	R	NW	BR
019	N50W	88SW	007	005	015	005	R	NW	BR
019	N50W	88SW	001	005	015	005	R	NW	BR
019	N50W	88SW	001	006	016	006	R	NW	BR
019	N50W	88SW	001	006	014	006	R	NW	BR
019	N50W	88SW	006	002	015	002	R	NW	BR
019	N50W	88SW	007	002	011	002	R	NW	BR
019	N50W	88SW	009	003	010	003	R	NW	BR
019	N50W	88SW	006	003	007	003	R	NW	BR
020	N24E	68SE	048	004	007	004	R		BR
020	N35E	67SE	075	009		009	R	NE	BR
020	N35E	66SE	010	007	003	007	R	NE	BR
020	N49W	75SW	007	023	030	004	R	NW	BR
020	N49W	75SW	017	011	065	004	R	NW	BR
020	N49W	75SW	001	013	048	008	R	NW	BR
020	N49W	75SW	001	013	050	008	R	NW	BR
020	N24E	68SE	183	013	003	008	R		BR
020	N24E	68SE	103	008		008	R		BR
020	N05E	58NW	089	026		015	R		BR
020	N05E	58NW	089	014	008	005	R		BR
020	N05E	58NW	035	019	007	008	R		BR
020	N05E	58NW	053	054	019	008	R		BR

STA	STRI	DIP	LNG	DPT	SPA	BED	EXP	SET	LOC
020	N05E	58NW	057	041		005	R		BR
020	N05E	58NW	024	007	005	007	R		BR
021	N37W	85SW	048	024	025	024	R	NW	BR
021	N12E	67NW	066	026	023	026	R		BR
021	N12E	67NW	064	023	004	023	R		BR
021	N12E	67NW	119	023		023	R		BR
021	N12E	67NW	078	023	030	023	R		BR
021	N12E	67NW	045	023	004	023	R		BR
021	N12E	67NW	078	023		023	R		BR
021	N37W	85SW	035	010	024	010	R	NW	BR
021	N37W	85SW	032	012	032	012	R	NW	BR
021	N37W	85SW	006	011	016	001	R	NW	BR
021	N37W	85SW	032	019	031	019	R	NW	BR
021	N37W	85SW	070	023	030	023	R	NW	BR
021	N37W	85SW	037	011	029	011	R	NW	BR
021	N37W	85SW	037	022	026	022	R	NW	BR
021	N37W	85SW	034	022	019	022	R	NW	BR
021	N70W	90SW	007	021	006	021	R		BR
021	N70W	90SW	001	024	004	024	R		BR
021	N70W	90SW	001	024	003	024	R		BR
021	N70W	90SW	001	024	007	024	R		BR
021	N70W	90SW	001	024	008	024	R		BR
021	N70W	90SW	001	024	009	024	R		BR
021	N70W	90SW	001	024	008	024	R		BR
021	N70W	90SW	001	024	026	024	R		BR
022	N57E	78NW	062	039	029	039	R		SO
022	N16E	77SE	040	039	084	039	R		SO
022	N57E	78NW	050	039		039	R		SO
022	N57E	78NW	125	028	025	028	R		SO
022	N57E	78NW	012	037	044	037	R		SO
022	N57E	78NW	027	037	057	037	R		SO
022	N57E	78NW	038	037	018	037	R		SO
022	N16E	77SE	003	007	029	007	R		SO
022	N16E	77SE	030	007	018	007	R		SO
022	N57E	78NW	055	025		025	R		SO
022	N16E	77SE	045	025	075	025	R		SO
022	N16E	77SE	080	025	052	025	R		SO
023	N10E	90NW	025	005	018	005	R		SO
023	N10E	90NW	014	005	028	005	R		SO
023	N10E	90NW	012	005	028	005	R		SO
023	N10E	90NW	009	005	014	005	R		SO
023	N40E	90NW	017	005	023	005	R	NE	SO
023	N40E	90NW	019	005	024	005	R	NE	SO
023	N40E	90NW	014	005	030	005	R	NE	SO
023	N45W	73SW	071	012		012	R	NW	SO
023	N45W	73SW	087	009		009	R	NW	SO
023	N13W	75SW	030	006	013	006	R		SO
023	N13W	75SW	005	006	015	006	R		SO
023	N40E	90NW	017	007	023	007	R	NE	SO
023	N40E	90NW	007	007	005	007	R	NE	SO
023	N40E	90NW	017	007	015	007	R	NE	SO
023	N40E	90NW	010	007	015	007	R	NE	SO
023	N45W	73SW	200	050	025	007	R	NW	SO
024	N08W	70SW	020	007	022	007	R		SO
024	N08W	70SW	021	007	022	007	R		SO
024	N08W	70SW	020	010	022	010	R		SO
024	N08W	70SW	020	002	020	002	R		SO
024	N08W	72SW	044	009	043	009	R		SO
024	N28E	90NW	015	003	025	003	R	NE	SO
024	N28E	90NW	007	005	027	005	R	NE	SO

STA	STRI	DIP	LNG	DPT	SPA	BED	EXP	SET	LOC
024	N08W	72SW	010	006	014	006	R		SO
024	N08W	72SW	017	008		008	R		SO
024	N08W	72SW	049	014	.022	014	R		SO
024	N08W	72SW	026	014	018	004	R		SO
024	N10E	65NW	014	005	023	005	R		SO
024	N20E	77NW	007	007	002	007	R		SO
024	N20E	77NW	010	008	008	008	R		SO
025	N10W	69SW	012	017	008	017	R		SO
025	N02E	69SE	006	017	005	017	R		SO
025	N07W	69SW	002	017	008	017	R		SO
025	N07W	69SW	010	017	013	017	R		SO
025	N07W	69SW	010	010	023	010	R		SO
025	N07W	69SW	017	010	014	010	R		SO
025	N07W	69SW	040	025	052	025	R		SO
025	N07W	69SW	057	025	018	025	R		SO
025	N07W	69SW	047	110	026	025	R		SO
025	N07W	69SW	023	004	008	004	R		SO
025	N07W	69SW	009	004	018	004	R		SO
025	N18E	61NW	027	006	006	006	R		SO
025	N18E	61NW	010	006	004	006	R		SO
025	N18E	61NW	017	006	007	006	R		SO
025	N18E	61NW	010	006	004	006	R		SO
025	N18E	61NW	020	008	004	008	R		SO
025	N18E	61NW	007	008	005	008	R		SO
025	N18E	61NW	001	008	008	008	R		SO
025	N18E	61NW	001	008	009	008	R		SO
025	N18E	61NW	001	008	009	008	R		SO
026	N38W	90SW	413	018	010	018	R	NW	IN
026	N80E	60SE	001	018	042	018	R	EW	IN
026	N80E	60SE	001	018	057	018	R	EW	IN
026	N80E	60SE	001	018	029	018	R	EW	IN
026	N80E	60SE	001	018	059	018	R	EW	IN
026	N35W	90SW	057	019	023	029	R	NW	IN
026	N35W	90SW	048	019	013	019	R	NW	IN
026	N35W	90SW	099	019	013	019	R	NW	IN
026	N35W	90SW	099	019	012	019	R	NW	IN
026	N35W	90SW	090	019	014	019	R	NW	IN
026	N35W	90SW	057	019	010	019	R	NW	IN
026	N35W	90SW	056	019	018	019	R	NW	IN
026	N35W	90SW	120	019	024	019	R	NW	IN
026	N80E	60SE	009	009	028	009	R	EW	IN
026	N80E	60SE	003	009	026	009	R	EW	IN
026	N80E	60SE	003	009	015	009	R	EW	IN
026	N80E	60SE	001	009	012	009	R	EW	IN
026	N80E	60SE	003	009	035	009	R	EW	IN
026	N80E	60SE	016	009	013	009	R	EW	IN
026	N80E	60SE	003	009	032	009	R	EW	IN
026	N80E	60SE	003	009	035	009	R	EW	IN
026	N38W	90SW	014	006	019	006	R	NW	IN
026	N38W	90SW	008	103	015	006	R	NW	IN
026	N38W	90SW	005	006	015	006	R	NW	IN
027	N71W	90SW	114	012		012	R		IN
027	N06W	90SW	127	010		010	R		IN
027	N71W	90SW	022	007		007	R		IN
027	N71W	90SW	032	011		011	R		IN
027	N45E	90NW	038	013		013	R	NE	IN
028	N50W	90SW	075	015	009	015	R	NW	IN
028	N50W	90SW	078	017	014	017	R	NW	IN
028	N50W	90SW	075	013		013	R	NW	IN
028	N50W	90SW	091	008		008	R	NW	IN

STA	STRI	DIP	LNG	DPT	SPA	BED	EXP	SET	LOC
028	N50W	90SW	020	010	015	010	R	NW	IN
028	N50W	90SW	025	008		008	R	NW	IN
028	N50W	90SW	129	006		006	R	NW	IN
028	N77W	74NE	050	013	027	013	R		IN
028	N75W	75NE	072	014	011	014	R		IN
028	N77W	78NE	025	009	011	009	R		IN
028	N77W	78NE	001	009	005	009	R		IN
028	N77W	78NE	030	009	003	009	R		IN
028	N77W	78NE	022	004	011	004	R		IN
028	N77W	78NE	048	004	016	004	R		IN
028	N77W	78NE	020	004	008	004	R		IN
028	N77W	78NE	015	004	006	004	R		IN
028	N77W	78NE	015	003	009	003	R		IN
028	N77W	78NE	028	015	022	004	R		IN
029	N85E	85NW	139	021		021	R	EW	IN
029	N45W	78SW	094	011		011	R	NW	IN
029	N40W	80SW	083	032	008	032	R	NW	IN
029	N40W	80SW	036	032	010	032	R	NW	IN
029	N40W	80SW	042	032	031	032	R	NW	IN
029	N40W	80SW	037	025	005	025	R	NW	IN
029	N40W	80SW	154	025		025	R	NW	IN
029	N40W	80SW	041	012	009	012	R	NW	IN
029	N40W	80SW	047	012	013	012	R	NW	IN
029	N40W	80SW	070	018	020	018	R	NW	IN
029	N40W	80SW	015	012	008	012	R	NW	IN
029	N40W	80SW	074	012		012	R	NW	IN
029	N85E	85NW	052	019	011	007	R	EW	IN
029	N85E	85NW	100	018	004	018	R	EW	IN
029	N85E	85NW	195	030		030	R	EW	IN
030	N59W	90SW	017	003	020	003	R		IN
030	N59W	90SW	019	002	012	002	R		IN
030	N59W	90SW	021	002	027	002	R		IN
030	N59W	90SW	020	003	020	003	R		IN
031	N42W	83SW	058	046	103	046	R	NW	IN
031	N87W	85SW	045	069		033	R	EW	IN
031	N65W	89NE	054	028	016	028	R		IN
031	N65W	89NE	012	028		028	R		IN
031	N87W	85SW	030	036	057	036	R	EW	IN
031	N87W	85SW	010	050		050	R	EW	IN
031	N87W	85SW	010	022	045	022	R	EW	IN
031	N87W	85SW	017	024	022	024	R	EW	IN
031	N87W	85SW	005	050		050	R	EW	IN
031	N87W	85SW	017	101	044	050	R	EW	IN
031	N38W	88SW	102	078	058	078	R	NW	IN
031	N42W	83NE	120	078	076	078	R	NW	IN
031	N42W	83NE	078	043	037	043	R	NW	IN
031	N42W	83NE	045	042	044	042	R	NW	IN
031	N42W	83NE	047	026	050	026	R	NW	IN
032	N89E	83NW	024	020	028	020	R	EW	IN
032	N89E	83NW	011	019		019	R	EW	IN
032	N89E	83NW	011	008	017	008	R	EW	IN
032	N89E	83NW	010	002	017	002	R	EW	IN
032	N89E	83NW	005	005	013	005	R	EW	IN
032	N89E	83NW	012	003	007	003	R	EW	IN
032	N89E	83NW	022	013	034	013	R	EW	IN
032	N89E	83NW	010	022	075	022	R	EW	IN
032	N89E	83NW	015	022	048	022	R	EW	IN
033	N83W	90SW	037	018	025	018	R	EW	IN
033	N83W	90SW	012	018	020	018	R	EW	IN
033	N83W	90SW	021	014	014	014	R	EW	IN

STA	STRI	DIP	LNG	DPT	SPA	BED	EXP	SET	LOC
033	N83W	90SW	007	006	011	006	R	EW	IN
033	N83W	90SW	021	006	012	006	R	EW	IN
033	N83W	90SW	006	010	008	010	R	EW	IN
033	N83W	90SW	027	016	018	016	R	EW	IN
033	N83W	90SW	087	019	024	019	R	EW	IN
033	N83W	90SW	053	018	024	018	R	EW	IN
033	N83W	90SW	056	025	032	025	R	EW	IN
035	N47W	90SW	300				SC	NW	IN
035	N24E	45SE	200		090		SC		IN
035	N24E	45SE	200		059		SC		IN
035	N24E	45SE	040		029		SC		IN
035	N02E	45SE	040		021		SC		IN
035	N02E	45SE	016		031		SC		IN
035	N02E	45SE	023		011		SC		IN
035	N55W	90SW	048	017	047	010	SC	NW	IN
035	N55W	90SW	017	010	009	010	SC	NW	IN
035	N55W	90SW	030	010	025	010	SC	NW	IN
035	N55W	90SW	039	010	035	010	SC	NW	IN
035	N85W	90SW	020	010	036	010	SC	EW	IN
035	N85W	90SW	047	010	029	010	SC	EW	IN
035	N85W	90SW	036	010	016	010	SC	EW	IN
035	N85W	90SW	036	010	037	010	SC	EW	IN
035	N68W		077				SC		IN
036	N48W	84SW	029	018	010	007	R	NW	IN
036	N81E	82SE	002	007	011	007	R	EW	IN
036	N43E	57NW	012	007	017	007	R	NE	IN
036	N48W	84SW	001	018	020	007	R	NW	IN
036	N48W	84SW	029	018	016	007	R	NW	IN
036	N48W	84SW	021	007		007	R	NW	IN
036	N81E	82SE	012	007	010	007	R	EW	IN
036	N81E	82SE	017	007	055	007	R	EW	IN
036	N48W	84SW	086	019	022	007	R	NW	IN
036	N48W	84SW	035	007	008	007	R	NW	IN
036	N48W	84SW	001	007	008	007	R	NW	IN
036	N48W	84SW	001	007	008	007	R	NW	IN
036	N81E	82SE	010	007		007	R	EW	IN
036	N43E	57NW	001	007	037	007	R	NE	IN
036	N43E	57NW	001	007	005	007	R	NE	IN
036	N43E	57NW	001	007	018	007	R	NE	IN
036	N48W	84SW	015	003	009	003	R	NW	IN
036	N48W	84SW	003	003	005	003	R	NW	IN
036	N48W	84SW	001	003	010	003	R	NW	IN
036	N48W	84SW	001	003	003	003	R	NW	IN
036	N43E	57NW	019	005	013	005	R	NE	IN
036	N43W	57NW	015	005	014	005	R	NW	IN
036	N81E	82SE	014	005	021	005	R	EW	IN
036	N81E	82SE	018	016	009	005	R	EW	IN
037	N65W	90SW					R		IN
037	N18E	90NW					R		IN
038	N57W	90SW	500	019		019	R		IN
038	N57W	90SW	043	006	012	006	R		IN
038	N57W	90SW	014	006	015	006	R		IN
038	N57W	90SW	007	006	012	006	R		IN
038	N57W	90SW	019	006	010	006	R		IN
038	N57W	90SW	052	006	006	006	R		IN
038	N57W	90SW	250	008	023	008	R		IN
038	N57W	90SW	117	016	020	016	R		IN
039							R		IN
040	N53W	90SW					R	NW	IN
040	N46W	90SW					R	NW	IN

STA	STRI	DIP	LNG	DPT	SPA	BED	EXP	SET	LOC
040	N45W	90SW					R	NW	IN
040	N72W	88NE		150			R		IN
040	N51W	90SW					R	NW	IN
040	N80W	90SW					R	EW	IN
040	N73W	90SW					R		IN
040	N74W	90SW					R		IN
040	N80W	90SW		150	015		R	EW	IN
041	N80W	88NE		150			R	EW	IN
041	N25E	90NW					R	NE	IN
041	N25E	90NW	180	090		090	R	NE	IN
041	N25E	90NW		200			R	NE	IN
042	N53W	90SW	035	006	020	006	R	NW	IN
042	N55W	90SW	010	025	028	012	R	NW	IN
042	N53W	90SW	020	150		012	R	NW	IN
042	N53W	90SW	029	048		012	R	NW	IN
042	N53W	90SW	015	012	020	012	R	NW	IN
042	N53W	90SW	050	120	057	020	R	NW	IN
042	N53W	90SW	020	110	040	020	R	NW	IN
042	N53W	90SW	015	050	040	020	R	NW	IN
043	N46W	90SW	005	064	020	020	R	NW	IN
043	N46W	90SW	005	065	050	020	R	NW	IN
043	N46W	90SW	012	063	027	020	R	NW	IN
043	N46W	90SW	063	051		051	R	NW	IN
043	N46W	90SW	012	006	016	006	R	NW	IN
043	N46W	90SW	009	006	018	006	R	NW	IN
043	N46W	90SW	004	058	029	058	R	NW	IN
043	N46W	90SW	029	019	023	019	R	NW	IN
044	N48W	90SW	210	185		025	R	NW	IN
044	N48W	90SW	104	100		025	R	NW	IN
044	N48W	90SW	200	101		050	R	NW	IN
044	N48W	90SW	500	050		030	R	NW	IN
044	N48W	90SW	001	062	005	026	R	NW	IN
044	N48W	90SW	001	062	075	026	R	NW	IN
045	N65W	90SW	125	092	030	015	R		IN
045	N65W	90SW	025	149		015	R		IN
045	N65W	90SW	003	010	006	003	R		IN
045	N65W	90SW	003	010	005	003	R		IN
045	N65W	90SW	001	010	007	003	R		IN
045	N65W	90SW	001	010	010	003	R		IN
045	N65W	90SW	001	010	006	003	R		IN
046	N85W	90SW	012	182	052	020	R	EW	IN
046	N85W	90SW	007	190	028	020	R	EW	IN
046	N85W	90SW	015	146	007	020	R	EW	IN
046	N85W	90SW	001	097	007	020	R	EW	IN
046	N85W	90SW	002	097	002	020	R	EW	IN
046	N85W	90SW	003	096	002	020	R	EW	IN
046	N85W	90SW	002	092	003	020	R	EW	IN
046	N85W	90SW	002	093	005	020	R	EW	IN
047	N26E	83SE	083	057	065	001	R	NE	NT
047	N26E	83SE	041	059	020	001	R	NE	NT
047	N85W	86SW	014	007	020	007	R	EW	NT
047	N85W	86SW	006	010	013	007	R	EW	NT
047	N85W	86SW	007	006	006	006	R	EW	NT
047	N85W	86SW	010	011	029	011	R	EW	NT
047	N85W	86SW	014	015	017	009	R	EW	NT
047	N85E	86SW	023	009	026	009	R	EW	NT
047	N85E	86SE	009	010	014	010	R	EW	NT
048	N33W	55SW	146	070		003	R		NT
048	N83E	90NW	006	004	007	004	R	EW	NT
048	N83E	90NW	006	004	005	004	R	EW	NT

STA	STRI	DIP	LNG	DPT	SPA	BED	EXP	SET	LOC
048	N83E	90NW	001	004	011	004	R	EW	NT
048	N30W	62SW	012	004		004	R		NT
048	N30W	62SW	009	004		004	R		NT
048	N45W	62SW	010	004	005	004	R	NW	NT
049	N46W	71SW	165	027		027	R	NW	NT
049	N88W	76NE	121	028		028	R	EW	NT
049	N88W	76NE	034	004	008	004	R	EW	NT
049	N46W	71SW	066	016	028	016	R	NW	NT
049	N46W	71SW	050	016	011	016	R	NW	NT
049	N46W	71SW	035	010	011	010	R	NW	NT
049	N88W	76NE	028	018	030	018	R	EW	NT
049	N88W	76NE	036	013	015	013	R	EW	NT
049	N46W	71SW	015	016	014	016	R	NW	NT
049	N12W	28SW	010	022	019	022	R		NT
049	N12W	28SW	012	017		017	R		NT
049	N12W	28SW	005	007	005	007	R		NT
049	N12W	28SW	001	006	006	006	R		NT
049	N12W	28SW	012	027	040	027	R		NT
049	N46W	71SW	028	027	021	027	R	NW	NT
049	N46W	71SW	025	027	013	027	R	NW	NT
049	N46W	71SW	065	027	014	027	R	NW	NT
049	N12W	28SW	010	015	013	015	R		NT
049	N12W	28SW	003	015	020	015	R		NT
049	N88W	76NE	033	017	021	017	R	EW	NT
049	N88W	76NE	023	025	012	025	R	EW	NT
050	N21W	90SW	500		096	001	S		NT
050	N21W	90SW	500				S		NT
050	N05W	90SW	386		122	001	S		NT
050	N05W	90SW	238			001	S		NT
050	N05W	90SW	120		025	001	S		NT
050	N05W	90SW	293		036	001	S		NT
050	N05W	90SW	251		037	001	S		NT
050	N03W	90SW	450		150		SC		NT
050	N03W	90SW	223				SC		NT
050	N45W	90SW	048	007	015	007	SC	NW	NT
050	N45W	90SW	061	007	018	007	SC	NW	NT
050	N45W	90SW	081	007	025	007	SC	NW	NT
050	N45W	90SW	105	007	018	007	SC	NW	NT
050	N45W	90SW	014	007	017	007	SC	NW	NT
050	N45W	90SW	015	007	015	007	SC	NW	NT
050	N45W	90SW	028	007	036	007	SC	NW	NT
051	N48W	88SW	081	029	027	029	SC	NW	NT
051	N48W	88SW	081	029	025	029	SC	NW	NT
051	N48W	88SW	078	029	021	029	SC	NW	NT
051	N48W	88SW	066	029	005	029	SC	NW	NT
051	N48W	88SW	048	029	032	029	SC	NW	NT
051	N48W	88SW	049	029	015	029	SC	NW	NT
051	N83W	90SW	130	025	038	025	SC	EW	NT
051	N43W	90SW	072	025	030	025	SC	NW	NT
051	N43W	90SW	086	025	062	025	SC	NW	NT
051	N43W	90SW	090	025	034	025	SC	NW	NT
051	N48W	88SW	035	025		025	SC	NW	NT
051	N48W	88SW	056	005	015	005	SC	NW	NT
051	N48W	88SW	085	005	006	005	SC	NW	NT
051	N48W	88SW	056	005	006	005	SC	NW	NT
051	N48W	88SW	061	005	015	005	SC	NW	NT
051	N48W	88SW	046	005	010	005	SC	NW	NT
051	N48W	88SW	067	005	055	005	SC	NW	NT
052	N58W	75SW	150	080			R		NT
053							R		NT

STA	STRI	DIP	LNG	DPT	SPA	BED	EXP	SET	LOC
054	N66W	90SW			032	013	R		IN
054	N66W	90SW			027	013	R		IN
054	N66W	90SW			021	013	R		IN
054	N66W	90SW			028	013	R		IN
054	N66W	90SW			016	013	R		IN
054	N66W	90SW			015	013	R		IN
054	N66W	90SW			028	013	R		IN
054	N66W	90SW			022	013	R		IN
054	N42E	45NW			059		R	NE	IN
054	N42E	45NW			053		R	NE	IN
054	N42E	45NW			081		R	NE	IN
054	N42E	45NW			068		R	NE	IN
054	N42E	45NW			016		R	NE	IN
054	N42E	45NW			027		R	NE	IN
054	N42E	45NW			038		R	NE	IN
054	N42E	45NW			021		R	NE	IN
054	N88W	90SW			067		R	EW	IN
054	N88W	90SW			030		R	EW	IN
054	N88W	90SW			020		R	EW	IN
054	N88W	90SW			071		R	EW	IN
054	N88W	90SW			027		R	EW	IN
054	N88W	90SW			026		R	EW	IN
054	N88W	90SW			030		R	EW	IN
054	N88W	90SW			009		R	EW	IN
055	N46W	89SW	109	047	019	047	R	NW	NT
055	N87W	89NE	075	034	038	047	R	EW	NT
055	N87W	89NE	138	028	069	028	R	EW	NT
055	N42E	85NW	010	056		001	R	NE	NT
055	N36E	90NW	050	028	130	028	R	NE	NT
055	N46W	89SW	013	019		028	R	NW	NT
055	N25E	90NW	012	006	009	001	R	NE	NT
055	N25E	90NW	001	006	019	001	R	NE	NT
055	N25E	90NW	001	006	020	001	R	NE	NT
055	N36E	90NW	050	027	092	027	R	NE	NT
055	N46W	89SW	048	027		027	R	NW	NT
055	N87W	89NE	030	008	015	008	R	EW	NT
055	N87W	89NE	010	008		008	R	EW	NT
056	N45W	90SW	034	043	036	043	R	NW	NT
056	N45W	90SW	010	043	062	043	R	NW	NT
056	N45W	90SW	120	134		100	R	NW	NT
056	N45W	90SW	038	123	015	100	R	NW	NT
056	N45W	90SW	146	200		200	R	NW	NT
056	N45W	90SW	180	220		200	R	NW	NT
057	N83W	83NE	073	026	018	026	R	EW	NT
057	N83W	84NE	001	026	018	026	R	EW	NT
057	N83W	83NE	020	026	054	026	R	EW	NT
057	N36W	83SW	041	021	016	021	R	NW	NT
057	N36W	83SW	028	021	025	021	R	NW	NT
057	N36W	83SW	033	021	024	021	R	NW	NT
057	N38E	33NW	016	021	046	021	R	NE	NT
057	N38E	33NW	025	021	029	021	R	NE	NT
057	N38E	33NW	024	021	029	021	R	NE	NT
058	N83E	49SE	057	067	006	001	R	EW	NT
058	N73W	75SW	173	049		058	R		NT
058	N83E	49SE	007	075	006	010	R	EW	NT
058	N83E	49SE	008	069	019	010	R	EW	NT
058	N83E	49SE	020	180	063	010	R	EW	NT
058	N83E	49SE	015	250		010	R	EW	NT
058	N83E	49SE	012	053	009	010	R	EW	NT
058	N83E	49SE	006	041	010	010	R	EW	NT

STA	STRI	DIP	LNG	DPT	SPA	BED	EXP	SET	LOC
059	N20E	90NW					R		NT
059	N80W	90SW					R	EW	NT
060	N49W	90SW	042	030	.025	030	R	NW	NT
060	N49W	90SW	031	030	036	030	R	NW	NT
060	N49W	90SW	029	030	006	030	R	NW	NT
061	N41W	77SW	019	061	051	061	R	NW	NT
061	N41W	77SW	038	061	041	061	R	NW	NT
061	N41W	77SW	049	061	058	061	R	NW	NT
061	N41W	77SW	033	038	024	038	R	NW	NT
061	N41W	77SW	028	038	023	038	R	NW	NT
061	N41W	77SW	021	038	037	038	R	NW	NT
062	N75W	90SW	300	104		083	R		NT
062	N45E	48NW					R	NE	NT
063	N47W	84NE	091	058	068	058	S	NW	NT
063	N75W	72NE	027	058		058	S		NT
063	N47W	84NE	050	058	064	058	S	NW	NT
063	N47W	84NE	080	047	021	044	S	NW	NT
063	N47W	84NE	087	047	060	044	S	NW	NT
063	N47W	84NE	020	058	037	058	S	NW	NT
063	N47W	84NE	008	058	035	058	S	NW	NT
063	N75W	72NE	001	078	088	058	S		NT
063	N75W	72NE	003	163	100	058	S		NT
063	N75W	72NE	008	080	025	020	S		NT
063	N47W	84NE	031	018	023	018	S	NW	NT
063	N47W	84NE	037	018	019	018	S	NW	NT
063	N75W	72NE	045	018	085	018	S		NT
063	N75W	72NE	060	018	031	018	S		NT
063	N75W	72NE	027	018	051	018	S		NT
064	N75W	80NE	029	005	014	005	R		NT
064	N45W	78SW	025	019	015	012	R	NW	NT
064	N45W	78SW	052	010	012	010	R	NW	NT
064	N75W	80NE	026	005	011	005	R		NT
064	N45W	78SW	022	012	020	012	R	NW	NT
064	N75W	80NE	046	010	007	010	R		NT
064	N45W	78SW	035	019	028	019	R	NW	NT
064	N45W	78SW	007	019	013	019	R	NW	NT
064	N45W	78SW	018	019	014	019	R	NW	NT
064	N45W	78SW	057	012	020	012	R	NW	NT
064	N87E	76NW	021	017	014	017	R	EW	NT
064	N87E	76NW	007	017	015	017	R	EW	NT
064	N87E	76NW	015	017	014	017	R	EW	NT
065	N44W	89SW	058	025	042	025	S	NW	NT
065	N44W	89SW	043	025	010	025	S	NW	NT
065	N44W	89SW	039	025	025	025	S	NW	NT
065	N44W	89SW	037	025	036	025	S	NW	NT
065	N44W	89SW	054	025	027	025	S	NW	NT
065	N44W	89SW	032	012	010	025	S	NW	NT
065	N44W	89SW	028	012	008	025	S	NW	NT
065	N44W	89SW	027	012	013	025	S	NW	NT
065	N44W	89SW	025	012	012	025	S	NW	NT
065	N89W	90SW	053	025	018	025	S	EW	NT
065	N89W	90SW	029	025	009	025	S	EW	NT
066	N72W	66SW	031	007	032	007	R		NT
066	N72W	66SW	011	012	026	012	R		NT
066	N58W	63SW	010	009	011	009	R		NT
066	N58W	63SW	025	009	014	009	R		NT
066	N58W	63SW	029	009	015	009	R		NT
066	N58W	63SW	020	009	012	009	R		NT
066	N49W	76SW	014	010	066	024	R	NW	NT
066	N49W	76SW	031	012	013	012	R	NW	NT

STA	STRI	DIP	LNG	DPT	SPA	BED	EXP	SET	LOC
066	N49W	76SW	026	012	017	012	R	NW	NT
067	N78W	69SW	026	019			R		NT
067	N78W	69SW	035	019			R		NT
068	N40W	90NW	016		065		S	NW	NT
068	N45W	90SW	067	017	020	007	S	NW	NT
068	N45W	90SW	040	027	024	007	S	NW	NT
068	N45W	90SW	058	009	011	009	S	NW	NT
068	N45W	90SW	060	009	026	009	S	NW	NT
068	N45W	90SW	055	009	022	009	S	NW	NT
068	N45W	90SW	072	009	042	009	S	NW	NT
068	N78W	69SW	250				S		NT
068	N78W	69SW	005	006	023	006	S		NT
068	N78W	69SW	008	007	009	006	S		NT
068	N78W	69SW	003	007	020	006	S		NT
068	N78W	69SW	002	009	010	006	S		NT
069	N46W	90SW	121	050	035	050	R	NW	NT
069	N46W	90SW	093	042		042	R	NW	NT
069	N46W	90SW	105	017		020	R	NW	NT
069	N46W	90SW	135	060	021	042	R	NW	NT
069	N46W	90SW	098	043		043	R	NW	NT
069	N46W	90SW	080	035		035	R	NW	NT
069	N34E	90NW	080	035		035	R	NE	NT
069	N64W	90SW	094	046		039	R		NT
069	N46W	90SW	109	053		053	R	NW	NT
069	N46W	90SW	068	025	034	025	R	NW	NT
069	N46W	90SW	055	025		025	R	NW	NT
069	N46W	90SW	025	012	005	012	R	NW	NT
069	N46W	90SW	012	012	007	012	R	NW	NT
069	N46W	90SW	013	012	009	012	R	NW	NT
070	N32E	81NW	461	020	000	032	R	NE	NT
070	N36E	82NW	479	012	000	032	R	NE	NT
070	N41W	90SW	015	006	000	006	R	NW	NT
070	N48E	65NW	025	006	000	006	R		NT
070	N46W	90SW	016	008	009	008	R	NW	NT
070	N41W	90SW	004	008	013	008	R	NW	NT
070	N41W	90SW	022	010	018	010	R	NW	NT
070	N41W	90SW	023	010	000	010	R	NW	NT
070	N43W	90SW	006	013	006	013	R	NW	NT
070	N41W	90SW	005	013	006	013	R	NW	NT
070	N41W	90SW	015	013	009	013	R	NW	NT
070	N41W	90SW	006	010	010	010	R	NW	NT
070	N41W	90SW	007	010	011	010	R	NW	NT
070	N41W	90SW	019	010	007	010	R	NW	NT
070	N41W	90SW	011	017	060	017	R	NW	NT
070	N41W	90SW	011	017	015	017	R	NW	NT
071	N71W	84SW	005	008	011	008	R		NT
071	N71W	84SW	008	008	016	008	R		NT
071	N71W	84SW	001	008	010	008	R		NT
071	N71W	84SW	019	008	013	008	R		NT
071	N71W	84SW	022	008	010	008	R		NT
071	N71W	84SW	004	009	001	009	R		NT
071	N71W	84SW	001	009	012	009	R		NT
071	N71W	84SW	008	009	015	009	R		NT
071	N71W	84SW	003	009	014	009	R		NT
071	N71W	84SW	003	009	002	009	R		NT
071	N11E	59NW	033	010	006	010	R		NT
071	N11E	59NW	028	010	000	010	R		NT
071	N42W	77SW	033	023	017	017	R	NW	NT
071	N42W	77SW	027	027	009	018	R	NW	NT
071	N42W	77SW	010	017	000	022	R	NW	NT

STA	STRI	DIP	LNG	DPI	SPA	BED	EXP	SET	LOC
071	N78W	81SW	007	013	008	013	R		NT
071	N78W	81SW	008	013	010	013	R		NT
071	N78W	81SW	027	013	011	013	R		NT
071	N42W	77SW	025	030	032	030	R	NW	NT
071	N42W	77SW	039	055	032	030	R	NW	NT
072	N60W	90SW	055	018	000	023	R		NT
072	N25E	90NW	039	010	000	010	R	NE	NT
072	N55W	90SW	020	028	000	021	R	NW	NT
072	N60W	90SW	032	032	000	030	R		NT
072	N60W	90SW	027	020	026	020	R		NT
072	N85E	90NW	020	042	000	003	R	EW	NT
072	N70W	83SW	020	083	000	007	R		NT
072	N55W	90SW	038	080	000	015	R	NW	NT
073	N85W	84SW	093	041	000	041	R	EW	NT
073	N31W	79SW	045	036	099	036	R		NT
073	N31W	79SW	039	036	099	036	R		NT
073	N31W	79SW	010	036	000	036	R		NT
073	N85W	84SW	044	020	000	020	R	EW	NT
073	N41W	69SW	036	053	023	029	R	NW	NT
073	N41W	69SW	043	060	000	020	R	NW	NT
074	N87W	76SW	122	134	000	134	R	EW	NT
074	N87W	76SW	070	027	000	023	R	EW	NT
074	N87W	76SW	037	007	018	007	R	EW	NT
074	N87W	76SW	031	007	010	007	R	EW	NT
074	N87W	76SW	053	033	000	007	R	EW	NT
074	N05E	79NW	046	007	000	007	R		NT
075	N70E	60NW	165	010	000	005	R		NT
075	N82E	90NW	135	015	035	015	R	EW	NT
075	N82E	90NW	058	015	000	015	R	EW	NT
076	N15E	90NW	076	012	076	012	S		NT
076	N15E	90NW	050	012	037	012	S		NT
076	N15E	90NW	086	012	047	012	S		NT
076	N15E	90NW	094	012	049	012	S		NT
076	N15E	90NW	080	012	000	012	S		NT
076	N85E	90NW	157	012	000	012	S	EW	NT
077	N22E	90NW	048	019	016	019	S		NT
077	N45E	85NW	071	018	064	018	S	NE	NT
077	N46W	90SW	051	025	019	019	S	NW	NT
077	N87W	90SW	082	000	010	009	S	EW	NT
077	N22E	90NW	037	019	016	019	S		NT
077	N46W	90SW	053	019	014	019	S	NW	NT
077	N45E	85NW	109	034	000	019	S	NE	NT
077	N87W	90SW	110	009	011	009	S	EW	NT
077	N87W	90SW	049	009	011	009	S	EW	NT
078	N63W	90SW	206	034	065	034	R		NT
078	N63W	90SW	101	015	080	015	R		NT
078	N63W	90SW	080	015	000	015	R		NT
078	N63W	90SW	278	034	000	034	R		NT
078	N48W	90SW	050	008	017	008	R	NW	NT
078	N55W	90SW	045	001	008	008	R	NW	NT
078	N55W	90SW	086	001	008	008	R	NW	NT
078	N55W	90SW	088	003	006	008	R	NW	NT
078	N55W	90SW	098	002	005	008	R	NW	NT
078	N55W	90SW	068	001	011	008	R	NW	NT
078	N55W	90SW	062	004	013	008	R	NW	NT
079	N47W	82SW	013	016	014	016	R	NW	NT
079	N47W	82SW	039	019	000	019	R	NW	NT
079	N47W	82SW	008	006	015	006	R	NW	NT
079	N82W	87SW	020	016	038	016	R	EW	NT
079	N82W	87SW	010	014	011	014	R	EW	NT

STA	STRI	DIP	LNG	DPI	SPA	BED	EXP	SET	LOC
079	N82W	87SW	015	014	003	014	R	EW	NT
079	N82W	87SW	018	014	012	014	R	EW	NT
079	N82W	87SW	017	014	024	014	R	EW	NT
079	N47W	82SW	003	017	018	017	R	NW	NT
079	N47W	82SW	018	018	013	018	R	NW	NT
079	N47W	82SW	018	014	015	014	R	NW	NT
079	N82W	87SW	009	014	017	014	R	EW	NT
079	N82W	87SW	032	014	019	014	R	EW	NT
079	N47W	82SW	017	018	012	018	R	NW	NT
079	N47W	82SW	027	020	018	017	R	NW	NT
079	N12W	70SW	043	013	000	013	R		NT
079	N07E	59NW	018	018	001	018	R		NT
079	N12E	48NW	033	013	014	013	R		NT
080	N72W	84SW	033	008	008	008	R		NT
080	N21E	84NW	017	008	018	008	R		NT
080	N72W	84SW	007	008	013	008	R		NT
080	N72W	84SW	024	008	018	008	R		NT
080	N72W	84SW	044	009	015	009	R		NT
080	N72W	84SW	018	009	009	009	R		NT
080	N72W	84SW	018	009	018	009	R		NT
080	N72W	84SW	018	009	011	009	R		NT
080	N21E	84NW	017	008	029	008	R		NT
080	N21E	84NW	001	009	013	009	R		NT
080	N21E	84NW	015	009	012	009	R		NT
080	N21E	84NW	024	009	025	009	R		NT
080	N21E	84NW	010	009	018	009	R		NT
080	N21E	84NW	019	010	017	010	R		NT
082	N23E	74NW	049	026	080	026	R		IN
082	N48W	88SW	064	027	065	027	R	NW	IN
082	N48W	88SW	100	026	000	026	R	NW	IN
082	N48W	88SW	020	036	039	036	R	NW	IN
082	N48W	88SW	060	040	050	040	R	NW	IN
082	N48W	88SW	062	046	067	046	R	NW	IN
082	N84W	87SW	053	040	025	033	R	EW	IN
082	N84W	87SW	005	040	020	033	R	EW	IN
082	N84W	87SW	027	026	000	026	R	EW	IN
082	N23E	74NW	058	030	063	030	R		IN
082	N23E	74NW	072	033	000	033	R		IN
083	N70W	87SW	020	015	000	013	R		IN
083	N46W	88SW	012	004	010	008	R	NW	IN
083	N46W	88SW	003	003	013	008	R	NW	IN
083	N46W	88SW	005	004	010	008	R	NW	IN
083	N70W	87SW	014	009	007	009	R		IN
083	N21E	73NW	129	022	011	007	R		IN
083	N21E	73NW	063	018	012	005	R		IN
084	N85W	88SW	075	142	030	020	R	EW	IN
084	N89W	90SW	034	034	044	034	R	EW	IN
084	N89W	88SW	028	029	021	022	R	EW	IN
084	N89W	88SW	035	056	041	022	R	EW	IN
084	N89W	88SW	015	018	013	006	R	EW	IN
084	N89W	88SW	012	026	014	006	R	EW	IN
084	N89W	88SW	005	005	008	005	R	EW	IN
084	N35E	84NW	015	019	006	019	R	NE	IN
084	N35E	84NW	024	019	023	019	R	NE	IN
084	N42W	71SW	024	014	000	014	R	NW	IN
084	N89W	88SW	010	014	021	014	R	EW	IN
084	N89W	88SW	010	014	022	014	R	EW	IN
084	N89W	88SW	019	017	016	017	R	EW	IN
084	N45W	84SW	146	018	015	018	R	NW	IN
084	N42W	71SW	105	020	000	020	R	NW	IN

STA	STRI	DIP	LNG	DPT	SPA	BED	EXP	SET	LOC
084	N89W	88SW	216	020	015	012	R	EW	IN
085	N54W	90SW	205	013	000	013	R	NW	IN
085	N30E	51NW	005	036	030	036	R	NE	IN
085	N30E	51NW	047	036	042	036	R	NE	IN
085	N30E	51NW	012	036	023	036	R	NE	IN
085	N30E	51NW	107	048	000	036	R	NE	IN
085	N54W	90SW	102	013	000	013	R	NW	IN
085	N54W	90SW	056	013	000	013	R	NW	IN
086	N33E	90NW	046	005	000	005	S	NE	IN
086	N47E	67NW	034	010	000	010	S		IN
086	N47E	67NW	029	008	000	008	S		IN
086	N33E	90NW	026	006	015	006	S	NE	IN
086	N40W	90SW	030	007	000	007	S	NW	IN
086	N40W	90SW	019	007	016	007	S	NW	IN
086	N40W	90SW	013	007	000	007	S	NW	IN
087	N87W	90SW	008	020	018	010	SC	EW	IN
087	N51W	90SW	034	033	000	013	SC	NW	IN
087	N87W	90SW	022	005	008	005	SC	EW	IN
087	N87W	90SW	015	007	012	007	SC	EW	IN
087	N87W	90SW	015	009	024	009	SC	EW	IN
087	N87W	90SW	005	010	038	011	SC	EW	IN
087	N87W	90SW	014	010	009	010	SC	EW	IN
087	N87W	90SW	007	005	017	007	SC	EW	IN
087	N87W	90SW	010	007	017	007	SC	EW	IN
087	N87W	90SW	015	013	034	007	SC	EW	IN
087	N87W	90SW	018	003	000	007	SC	EW	IN
087	N51W	90SW	010	070	000	010	SC	NW	IN
087	N51W	90SW	010	056	000	010	SC	NW	IN
087	N43W	90SW	070	061	000	010	SC	NW	IN
087	N51W	90SW	197	050	007	015	SC	NW	IN
087	N51W	90SW	040	012	026	012	SC	NW	IN
087	N84E	90NW	182	057	011	007	SC	EW	IN
087	N84E	90NW	085	043	011	007	SC	EW	IN
087	N84E	90NW	063	038	000	007	SC	EW	IN
087	N87W	90SW	047	067	006	007	SC	EW	IN
087	N73W	90SW	124	073	032	006	SC		IN
087	N73W	90SW	117	060	031	006	SC		IN
088	N45W	90SW	050	019	030	019	S	NW	IN
088	N45W	90SW	043	019	033	019	S	NW	IN
088	N45W	90SW	047	019	000	019	S	NW	IN
088	N86W	75SW	142	022	039	022	S	EW	IN
088	N86W	75SW	062	022	031	022	S	EW	IN
088	N86W	75SW	032	020	000	022	S	EW	IN
089	N62W	72SW	060	039	038	039	SC		IN
089	N62W	72SW	077	039	009	039	SC		IN
089	N62W	72SW	045	039	005	039	SC		IN
089	N62W	72SW	035	039	011	039	SC		IN
089	N62W	72SW	064	039	007	039	SC		IN
089	N03E	52NW	060	019	008	019	SC		IN
089	N03E	52NW	043	014	004	007	SC		IN
089	N28E	44NW	025	010	000	007	SC	NE	IN
089	N62W	72SW	040	039	007	039	SC		IN
089	N62W	72SW	038	039	006	039	SC		IN
089	N28E	44NW	015	014	011	014	SC	NE	IN
089	N28E	44NW	010	008	008	008	SC	NE	IN
089	N28E	44NW	020	005	001	005	SC	NE	IN
090	N43W	90SW	020	009	003	009	SC	NW	IN
090	N43W	90SW	016	009	009	009	SC	NW	IN
090	N43W	90SW	011	009	003	009	SC	NW	IN
090	N43W	90SW	012	009	010	009	SC	NW	IN

STA	STRI	DIP	LNG	DPI	SPA	PED	EXP	SET	LOC
090	N43W	90SW	018	017	005	009	SC	NW	IN
090	N43W	90SW	018	013	006	009	SC	NW	IN
090	N43W	90SW	018	017	010	009	SC	NW	IN
090	N43W	90SW	018	013	014	009	SC	NW	IN
090	N43W	90SW	010	017	007	009	SC	NW	IN
090	N43W	90SW	012	017	015	009	SC	NW	IN
090	N43W	90SW	010	017	013	009	SC	NW	IN
090	N43W	90SW	010	017	010	009	SC	NW	IN
091	N36W	87SW	180	025	068	025	S	NW	IN
091	N36W	87SW	130	025	025	025	S	NW	IN
091	N36W	87SW	103	025	012	025	S	NW	IN
091	N36W	87SW	090	025	039	025	S	NW	IN
091	N36W	87SW	087	025	014	025	S	NW	IN
091	N36W	87SW	085	025	040	025	S	NW	IN
091	N36W	87SW	080	025	055	025	S	NW	IN
092	N55W	74SW	017	007	016	007	SC	NW	IN
092	N55W	74SW	020	007	000	007	SC	NW	IN
092	N55W	74SW	005	002	022	002	SC	NW	IN
092	N55W	74SW	005	002	000	002	SC	NW	IN
092	N87E	90NW	051	030	004	004	SC	EW	IN
093	N25E	90NW	206	005	029	005	SC	NE	IN
093	N25E	90NW	174	005	043	005	SC	NE	IN
093	N25E	90NW	355	012	000	005	SC	NE	IN
093	N25E	90NW	089	015	020	010	SC	NE	IN
093	N49W	88SW	039	013	000	013	SC	NW	IN
093	N40W	72SW	043	012	000	012	SC	NW	IN
093	N40W	72SW	031	012	005	012	SC	NW	IN
093	N40W	72SW	011	012	013	012	SC	NW	IN
093	N85W	84SW	021	006	000	006	SC	EW	IN
093	N85W	84SW	043	015	023	015	SC	EW	IN
093	N40W	72SW	010	005	017	005	SC	NW	IN
093	N40W	72SW	014	007	015	008	SC	NW	IN
093	N40W	72SW	011	007	010	008	SC	NW	IN
093	N40W	72SW	008	007	008	009	SC	NW	IN
093	N40W	72SW	004	007	016	010	SC	NW	IN
094	N76W	80SW	020	010	043	010	S		IN
094	N76W	80SW	015	010	050	010	S		IN
094	N76W	80SW	020	010	055	010	S		IN
094	N76W	80SW	022	009	017	009	S		IN
094	N35E	78NW	050	010	015	010	S	NE	IN
095	N36W	84SW	320	014	006	014	R	NW	IN
095	N36W	84SW	340	015	000	015	R	NW	IN
095	N36W	84SW	310	008	000	008	R	NW	IN
095	N36W	84SW	010	010	040	010	R	NW	IN
096	N43W	88SW	073	005	000	005	R	NW	IN
096	N25E	90NW	015	008	026	008	R	NE	IN
096	N25E	90NW	024	008	021	008	R	NE	IN
096	N43W	88SW	050	007	000	007	R	NW	IN
097	N76E	74NW	242	102	008	102	R		IN
097	N76E	74NW	171	102	000	102	R		IN
097	N76E	74NW	190	039	004	039	R		IN
097	N76E	74NW	187	015	000	015	R		IN
098	N84E	75NW	078	026	003	016	R	EW	IN
098	N84E	75NW	196	021	000	011	R	EW	IN
098	N84E	75NW	132	007	000	007	R	EW	IN
098	N84E	75NW	106	007	000	007	R	EW	IN
098	N40E	68NW	053	013	008	013	R	NE	IN
098	N40E	68NW	045	013	007	013	R	NE	IN
099	N10W	69SW	110	046	014	046	R		IN
099	N10W	69SW	040	046	000	046	R		IN

STA	STRI	DIP	LNG	OPT	SPA	BED	EXP	SET	LOC
099	N45W	90SW	055	072	000	072	R	NW	IN
099	N45W	90SW	016	046	048	046	R	NW	IN
100	N72W	76SW	224	011	000	011	R		IN
100	N72W	76SW	133	017	000	017	R		IN
101	N33W	70SW	019	006	012	006	R		IN
101	N33W	70SW	021	006	000	006	R		IN
101	N42E	86NW	031	006	023	006	R	NE	IN
101	N42E	86NW	041	010	000	010	R	NE	IN
101	N77E	90NW	051	008	000	008	R		IN
101	N65W	87SW	094	023	004	023	R		IN
101	N65W	87SW	096	043	000	023	R		IN
102	N41W	85SW	084	014	032	005	S	NW	IN
102	N41W	85SW	109	013	052	005	S	NW	IN
102	N41W	85SW	045	005	008	005	S	NW	IN
102	N41W	85SW	109	005	013	007	S	NW	IN
102	N41W	85SW	034	012	036	007	S	NW	IN
102	N41W	85SW	108	015	000	015	S	NW	IN
102	N87W	84SW	142	023	042	023	S	EW	IN
102	N87W	84SW	035	012	012	012	S	EW	IN
102	N87W	84SW	024	012	019	012	S	EW	IN
102	N87W	84SW	048	014	054	014	S	EW	IN
102	N87W	84SW	092	021	000	021	S	EW	IN
102	N41W	85SW	174	011	025	006	S	NW	IN
102	N41W	85SW	153	013	012	006	S	NW	IN
102	N41W	85SW	085	009	032	006	S	NW	IN
102	N41W	85SW	174	013	038	006	S	NW	IN
102	N87W	84SW	092	010	051	010	S	EW	IN
102	N87W	84SW	095	009	040	009	S	EW	IN
102	N87W	84SW	057	005	034	009	S	EW	IN
103	N38W	84SW	014	008	007	008	S	NW	IN
103	N38W	84SW	013	008	012	008	S	NW	IN
103	N38W	84SW	023	007	009	007	S	NW	IN
103	N38W	84SW	017	007	011	007	S	NW	IN
103	N38W	84SW	013	008	000	008	S	NW	IN
103	N38W	84SW	010	010	009	010	S	NW	IN
103	N38W	84SW	012	010	008	010	S	NW	IN
103	N38W	84SW	016	010	010	010	S	NW	IN
103	N85E	58NW	022	006	008	006	S	EW	IN
103	N85E	58NW	015	014	006	006	S	EW	IN
103	N85E	58NW	011	007	003	003	S	EW	IN
103	N85E	58NW	005	004	009	006	S	EW	IN
104	N42W	86SW	057	012	012	012	S	NW	IN
104	N42W	86SW	030	012	014	012	S	NW	IN
104	N42W	86SW	039	009	007	009	S	NW	IN
104	N42W	86SW	053	009	010	009	S	NW	IN
104	N42W	86SW	058	009	007	009	S	NW	IN
104	N42W	86SW	115	007	032	007	S	NW	IN
104	N42W	86SW	042	008	004	008	S	NW	IN
104	N42W	86SW	021	008	006	008	S	NW	IN
105	N77W	75SW	045	023	015	023	S		IN
105	N77W	75SW	016	023	000	023	S		IN
105	N44W	85SW	023	022	040	022	S	NW	IN
105	N44W	85SW	020	022	040	022	S	NW	IN
105	N44W	85SW	010	014	025	014	S	NW	IN
105	N44W	85SW	023	012	016	012	S	NW	IN
105	N44W	85SW	012	012	012	012	S	NW	IN
105	N44W	85SW	015	022	029	022	S	NW	IN
105	N44W	85SW	016	018	023	018	S	NW	IN
105	N44W	85SW	030	016	009	016	S	NW	IN
105	N44W	85SW	038	023	019	012	S	NW	IN

STA	STRI	DIP	LNG	DPT	SPA	BED	EXP	SET	LOC
105	N44W	85SW	035	023	016	012	S	NW	IN
105	N44W	85SW	015	020	000	012	S	NW	IN
106	N51W	82SW	050	025	011	025	S	NW	IN
106	N51W	82SW	101	025	010	025	S	NW	IN
106	N51W	82SW	240	025	019	025	S	NW	IN
106	N51W	82SW	111	015	014	015	S	NW	IN
106	N51W	82SW	099	007	005	007	S	NW	IN
106	N51W	82SW	097	007	004	007	S	NW	IN
106	N51W	82SW	089	007	015	007	S	NW	IN
106	N51W	82SW	078	007	011	007	S	NW	IN
106	N32E	58NW	130	025	000	025	S	NE	IN
106	N32E	58NW	050	015	000	015	S	NE	IN
106	N01E	58NW	026	007	000	007	S		IN
106	N01E	58NW	019	015	000	015	S		IN
107	N82E	70NW	053	004	006	004	S	EW	IN
107	N82E	70NW	058	015	012	015	S	EW	IN
107	N82E	70NW	030	015	020	015	S	EW	IN
107	N46W	90SW	100	019	034	025	S	NW	IN
107	N46W	90SW	101	007	000	025	S	NW	IN
108	N88W	77SW	055	005	035	005	SC	EW	IN
108	N88W	77SW	047	005	027	005	SC	EW	IN
108	N88W	77SW	055	005	036	005	SC	EW	IN
108	N18W	80SW	033	045	006	045	SC		IN
108	N18W	80SW	073	045	030	045	SC		IN
108	N18W	80SW	065	045	000	045	SC		IN
108	N18W	80SW	075	007	006	007	SC		IN
108	N18W	80SW	052	008	000	008	SC		IN
108	N18W	80SW	062	045	037	045	SC		IN
108	N35E	90NW	044	045	038	045	SC	NE	IN
108	N35E	90NW	010	045	000	045	SC	NE	IN
109	N43W	83SW	044	012	012	012	SC	NW	IN
109	N43W	83SW	058	014	021	014	SC	NW	IN
109	N43W	83SW	055	021	014	021	SC	NW	IN
109	N43W	83SW	042	020	012	020	SC	NW	IN
109	N43W	83SW	020	020	012	020	SC	NW	IN
109	N43W	83SW	023	009	003	009	SC	NW	IN
109	N43W	83SW	023	009	009	009	SC	NW	IN
109	N43W	83SW	023	009	003	009	SC	NW	IN
109	N43W	83SW	025	009	007	009	SC	NW	IN
109	N43W	83SW	054	039	008	067	SC	NW	IN
110	N48W	90SW	020	053	020	007	S	NW	IN
110	N48W	90SW	021	054	029	007	S	NW	IN
110	N48W	90SW	005	008	009	008	S	NW	IN
110	N48W	90SW	006	008	004	008	S	NW	IN
110	N48W	90SW	005	008	004	008	S	NW	IN
110	N48W	90SW	005	008	010	008	S	NW	IN
110	N48W	90SW	002	008	008	008	S	NW	IN
110	N48W	90SW	002	008	007	008	S	NW	IN
111	N87W	85SW	144	012	025	012	SC	EW	IN
111	N87W	85SW	152	012	019	012	SC	EW	IN
111	N87W	85SW	178	014	024	014	SC	EW	IN
111	N87W	85SW	195	014	016	014	SC	EW	IN
111	N87W	85SW	117	014	013	014	SC	EW	IN
111	N87W	85SW	025	010	019	010	SC	EW	IN
111	N87W	85SW	057	010	020	010	SC	EW	IN
111	N87W	85SW	049	010	020	01	SC	EW	IN
111	N87W	85SW	070	010	010	010	SC	EW	IN
111	N08E	72NW	020	010	030	010	SC		IN
111	N08E	72NW	020	010	047	010	SC		IN
111	N08E	72NW	010	010	027	010	SC		IN

STA	STRI	DIP	LNG	DPT	SPA	EED	EXP	SET	LOC
111	N08E	72NW	022	015	047	015	SC		IN
111	N08E	72NW	013	015	025	015	SC		IN
112	N84W	87SW	728	020	085	020	S	EW	IN
112	N84W	87SW	720	020	123	020	S	EW	IN
112	N84W	87SW	320	022	076	022	S	EW	IN
112	N34W	57SW	085	020	046	020	S		IN
112	N34W	57SW	085	020	053	020	S		IN
112	N34W	57SW	085	020	085	020	S		IN
112	N34W	57SW	123	020	088	020	S		IN
112	N34W	57SW	123	020	164	020	S		IN
112	N84W	87SW	007	022	062	022	S	EW	IN
112	N84W	87SW	340	022	106	022	S	EW	IN
112	N84W	87SW	320	022	052	022	S	EW	IN
112	N84W	87SW	750	022	069	022	S	EW	IN
112	N84W	87SW	720	042	083	042	S	EW	IN
112	N84W	87SW	715	020	177	020	S	EW	IN
113	N50W	90SW	082	010	000	003	S	NW	IN
113	N45W	87SW	180	010	000	010	S	NW	IN
113	N50W	90SW	017	008	007	008	S	NW	IN
113	N50W	90SW	019	008	004	008	S	NW	IN
113	N50W	90SW	034	008	007	008	S	NW	IN
113	N50W	90SW	040	008	003	008	S	NW	IN
113	N50W	90SW	009	005	008	003	S	NW	IN
113	N50W	90SW	020	005	006	003	S	NW	IN
114	N87W	85SW	130	010	035	010	S	EW	IN
114	N87W	85SW	063	010	016	010	S	EW	IN
114	N87W	85SW	174	010	021	010	S	EW	IN
114	N87W	85SW	040	010	012	010	S	EW	IN
114	N87W	85SW	102	010	031	010	S	EW	IN
115	N83W	89SW	032	012	025	012	S	EW	IN
115	N83W	89SW	015	012	019	012	S	EW	IN
115	N83W	89SW	015	012	020	012	S	EW	IN
115	N83W	89SW	023	012	010	012	S	EW	IN
115	N83W	89SW	019	012	006	012	S	EW	IN
115	N83W	89SW	017	012	013	012	S	EW	IN
116	N44W	88SW	158	061	029	061	SC	NW	NT
116	N44W	88SW	132	030	058	030	SC	NW	NT
116	N44W	88SW	061	030	000	030	SC	NW	NT
116	N38W	85SW	049	031	018	031	SC	NW	NT
116	N38W	85SW	058	005	000	005	SC	NW	NT
116	N38W	85SW	057	026	044	026	SC	NW	NT
116	N38W	85SW	045	026	000	026	SC	NW	NT
117	N55W	87SW	025	040	010	040	R	NW	NT
117	N55W	87SW	024	040	009	040	R	NW	NT
117	N01W	86SW	020	009	000	009	R		NT
117	N01W	86SW	021	016	000	016	R		NT
117	N55W	87SW	015	012	010	012	R	NW	NT
117	N55W	87SW	019	012	009	012	R	NW	NT
117	N55W	87SW	017	012	008	012	R	NW	NT
117	N55W	87SW	023	012	007	012	R	NW	NT
117	N55W	87SW	015	012	010	012	R	NW	NT
117	N55W	87SW	007	014	017	012	R	NW	NT
117	N55W	87SW	015	042	015	025	R	NW	NT
117	N55W	87SW	012	025	019	025	R	NW	NT
118	N41W	77SW	020	006	016	006	SC	NW	NT
118	N41W	77SW	010	006	011	006	SC	NW	NT
118	N41W	77SW	021	006	008	006	SC	NW	NT
118	N41W	77SW	022	006	004	006	SC	NW	NT
118	N41W	77SW	023	006	003	006	SC	NW	NT
118	N41W	77SW	026	006	004	006	SC	NW	NT

STA	STRI	DIP	LNG	DPI	SPA	BED	EXP	SET	LOC
118	N41W	77SW	013	006	009	006	SC	NW	NT
118	N41W	77SW	022	006	007	006	SC	NW	NT
118	N41W	77SW	015	006	008	006	SC	NW	NT
118	N41W	77SW	027	006	004	006	SC	NW	NT
119	N80E	76NW	040	014	006	014	SC	EW	NT
119	N80E	76NW	084	014	018	014	SC	EW	NT
119	N80E	76NW	095	014	018	014	SC	EW	NT
119	N80E	76NW	067	014	024	014	SC	EW	NT
119	N80E	76NW	079	014	017	014	SC	EW	NT
119	N80E	76NW	069	014	030	014	SC	EW	NT
119	N80E	76NW	077	014	011	014	SC	EW	NT
119	N80E	76NW	075	014	021	014	SC	EW	NT
119	N44E	44NW	079	014	016	014	SC	NE	NT
119	N44E	44NW	091	014	009	014	SC	NE	NT
119	N44E	44NW	138	014	014	014	SC	NE	NT
119	N44E	44NW	179	014	003	014	SC	NE	NT
119	N44E	44NW	202	014	005	014	SC	NE	NT
119	N44E	44NW	203	014	030	014	SC	NE	NT
120	N83E	90NW	083	016	026	016	S	EW	NT
120	N83E	90NW	058	016	028	016	S	EW	NT
120	N83E	90NW	053	016	048	016	S	EW	NT
120	N83E	90NW	046	016	015	016	S	EW	NT
120	N83E	90NW	046	025	028	025	S	EW	NT
120	N83E	90NW	062	025	039	025	S	EW	NT
120	N83E	90NW	032	025	003	025	S	EW	NT
120	N83E	90NW	019	025	022	025	S	EW	NT
120	N83E	90NW	044	025	036	025	S	EW	NT
120	N32W	87SW	054	012	030	012	S		NT
120	N32W	87SW	058	012	013	012	S		NT
120	N32W	87SW	065	012	026	012	S		NT
120	N32W	87SW	057	012	018	012	S		NT
120	N32W	87SW	025	012	027	012	S		NT
120	N32W	87SW	030	012	015	012	S		NT
121	N85W	80SW	005	012	036	012	R	EW	NT
121	N85W	80SW	047	012	025	012	R	EW	NT
121	N85W	80SW	003	014	010	014	R	EW	NT
121	N85W	80SW	010	014	024	014	R	EW	NT
121	N85W	80SW	019	014	035	014	R	EW	NT
121	N35E	80NW	015	019	020	019	R	NE	NT
121	N35E	80NW	013	019	008	019	R	NE	NT
121	N35E	80NW	012	015	012	015	R	NE	NT
123	N80E	90NW	035	022	033	022	S	EW	NT
123	N80E	90NW	050	022	038	022	S	EW	NT
123	N80E	90NW	028	022	058	022	S	EW	NT
123	N03E	90NW	033	022	035	022	S		NT
123	N03E	90NW	038	022	050	022	S		NT
123	N03E	90NW	058	022	028	022	S		NT
123	N47W	90SW	070	012	038	012	S	NW	NT
123	N47W	90SW	034	012	041	012	S	NW	NT
123	N47W	90SW	057	012	008	012	S	NW	NT
123	N27E	90NW	021	012	038	012	S	NE	NT
123	N27E	90NW	016	012	017	012	S	NE	NT
123	N27E	90NW	018	012	027	012	S	NE	NT
124	N42W	87SW	115	014	025	014	S	NW	NT
124	N42W	87SW	106	014	036	014	S	NW	NT
124	N4E	90NW	190	020	025	007	S		NT
124	N42W	87SW	075	007	000	007	S	NW	NT
124	N42W	87SW	078	010	015	010	S	NW	NT
124	N42W	87SW	055	010	047	010	S	NW	NT
124	N42W	87SW	038	019	035	019	S	NW	NT

STA	STRI	DIP	LNG	DPT	SPA	BED	EXP	SET	LOC
124	N42W	87SW	042	019	031	019	S	NW	NT
124	N42W	87SW	065	019	042	019	S	NW	NT
124	N42W	87SW	069	019	028	019	S	NW	NT
124	N42W	87SW	070	019	025	019	S	NW	NT
124	N42W	87SW	350	035	018	020	S	NW	NT
125	N87E	90NW	196	007	036	007	S	EW	NT
125	N87E	90NW	134	007	024	007	S	EW	NT
125	N87E	90NW	158	007	020	007	S	EW	NT
125	N87E	90NW	152	007	022	007	S	EW	NT
125	N87E	90NW	152	007	021	007	S	EW	NT
125	N87E	90NW	127	073	047	025	S	EW	NT
125	N87E	90NW	097	077	042	025	S	EW	NT
125	N87E	90NW	180	074	032	025	S	EW	NT
126	N87W	85SW	546	270	030	020	SC	EW	NT
126	N87W	85SW	584	240	029	020	SC	EW	NT
126	N87W	85SW	042	020	023	020	SC	EW	NT
126	N35E	85NW	020	035	025	007	SC	NE	NT
126	N35E	85NW	005	007	027	007	SC	NE	NT
126	N35E	85NW	004	007	009	007	SC	NE	NT
126	N35E	85NW	003	007	016	007	SC	NE	NT
126	N35E	85NW	005	007	010	007	SC	NE	NT
127	N85W	90SW	063	007	033	007	S	EW	NT
127	N85W	90SW	030	007	040	007	S	EW	NT
127	N85W	90SW	033	007	020	007	S	EW	NT
127	N85W	90SW	028	007	026	007	S	EW	NT
128	N05E	90NW	074	024	012	024	SC		NT
128	N05E	90NW	055	024	010	024	SC		NT
128	N05E	90NW	012	024	038	024	SC		NT
128	N63W	90SW	035	024	001	024	SC		NT
128	N63W	90SW	014	024	075	024	SC		NT
128	N63W	90SW	023	024	018	024	SC		NT
128	N63W	90SW	022	024	072	024	SC		NT
128	N63W	90SW	015	011	023	007	SC		NT
128	N63W	90SW	013	011	030	007	SC		NT
128	N63W	90SW	021	011	027	007	SC		NT
128	N69W	90SW	106	033	059	033	SC		NT
128	N69W	90SW	074	033	071	033	SC		NT
128	N69W	90SW	150	036	058	033	SC		NT
128	N69W	90SW	135	036	081	033	SC		NT
128	N69W	90SW	150	033	069	033	SC		NT
128	N69W	90SW	083	033	043	033	SC		NT
128	N37W	85SW	030	035	009	019	SC	NW	NT
128	N37W	85SW	027	035	005	019	SC	NW	NT
128	N37W	85SW	007	016	026	016	SC	NW	NT
128	N37W	85SW	018	016	019	016	SC	NW	NT
128	N37W	85SW	027	020	030	020	SC	NW	NT
128	N37E	79NW	147	093	120	004	SC	NE	NT
128	N37E	79NW	180	112	072	004	SC	NE	NT
128	N37E	79NW	130	110	000	004	SC	NE	NT
128	N37E	79NW					SC	NE	NT
129	N73W	60SW	020	017	016	017	S		NT
129	N73W	60SW	010	017	016	017	S		NT
129	N73W	60SW	010	017	000	017	S		NT
129	N73W	60SW	010	029	005	029	S		NT
129	N73W	60SW	001	029	013	029	S		NT
129	N73W	60SW	006	029	018	029	S		NT
130	N35W	90SW	075	008	020	008	S	NW	NT
130	N35W	90SW	089	008	007	008	S	NW	NT
130	N35W	90SW	120	008	023	008	S	NW	NT
130	N35W	90SW	099	008	012	008	S	NW	NT

STA	STRI	DIP	LNG	DPT	SPA	BED	EXP	SET	LOC
130	N35W	90SW	039	008	016	008	S	NW	NT
130	N35W	90SW	104	008	018	008	S	NW	NT
130	N35W	90SW	109	008	008	008	S	NW	NT
130	N35W	90SW	121	008	023	008	S	NW	NT
130	N35W	90SW	083	008	028	008	S	NW	NT
130	N40E	88NW	182	008	033	008	S	NE	NT
130	N40E	88NW	197	008	034	008	S	NE	NT
130	N40E	88NW	184	008	031	008	S	NE	NT
130	N40E	88NW	098	008	000	008	S	NE	NT
131	N53W	90SW	118	055	032	001	SC	NW	NT
131	N53W	90SW	079	055	000	001	SC	NW	NT
131	N53W	90SW	101	012	024	012	SC	NW	NT
131	N53W	90SW	027	012	032	012	SC	NW	NT
131	N53W	90SW	043	012	016	012	SC	NW	NT
131	N53W	90SW	041	012	044	012	SC	NW	NT
131	N53W	90SW	050	012	029	012	SC	NW	NT
131	N53W	90SW	041	012	025	012	SC	NW	NT
131	N53W	90SW	037	012	036	012	SC	NW	NT
131	N53W	90SW	064	012	034	012	SC	NW	NT
131	N53W	90SW	081	012	032	012	SC	NW	NT
131	N53W	90SW	090	012	028	012	SC	NW	NT
131	N53W	90SW	210	156	021	012	SC	NW	NT
131	N53W	90SW	075	075	054	012	SC	NW	NT
131	N53W	90SW	052	063	019	012	SC	NW	NT
131	N53W	90SW	116	056	090	012	SC	NW	NT
131	N53W	90SW	210	124	019	012	SC	NW	NT
131	N53W	90SW	055	052	018	012	SC	NW	NT
131	N53W	90SW	035	061	008	012	SC	NW	NT
131	N53W	90SW	426	170	000	012	SC	NW	NT
132	N58W	83SW	035	027	073	027	SC		NT
132	N58W	83SW	023	027	070	027	SC		NT
132	N58W	83SW	036	027	060	027	SC		NT
132	N58W	83SW	056	027	014	027	SC		NT
132	N58W	83SW	020	027	065	027	SC		NT
132	N58W	83SW	029	027	020	027	SC		NT
132	N58W	83SW	036	027	062	027	SC		NT
132	N58W	83SW	009	040	033	027	SC		NT
132	N58W	83SW	001	027	024	027	SC		NT
132	N58W	83SW	007	027	026	027	SC		NT
132	N58W	83SW	001	027	021	027	SC		NT
132	N58W	83SW	001	027	032	027	SC		NT
132	N40E	79NW	027	016	017	016	SC	NE	NT
132	N40E	79NW	039	016	037	016	SC	NE	NT
132	N40E	79NW	018	016	016	016	SC	NE	NT
132	N40E	79NW	016	017	025	017	SC	NE	NT
132	N40E	79NW	054	017	027	017	SC	NE	NT
133	N84W	82SW	064	012	004	004	S	EW	NT
133	N84W	82SW	030	004	019	004	S	EW	NT
133	N61W	90SW	194	016	040	016	S		NT
133	N61W	90SW	182	016	007	016	S		NT
133	N61W	90SW	085	020	027	016	S		NT
133	N61W	90SW	084	020	029	016	S		NT
133	N61W	90SW	050	016	033	016	S		NT
133	N61W	90SW	174	016	053	016	S		NT
134	N48W	88SW	065	007	014	007	S	NW	NT
134	N48W	88SW	063	007	055	007	S	NW	NT
134	N48W	88SW	031	007	026	007	S	NW	NT
134	N48W	88SW	053	007	026	007	S	NW	NT
134	N48W	88SW	032	007	029	007	S	NW	NT
134	N48W	88SW	043	007	041	007	S	NW	NT

STA	STRI	DIP	LNG	DPI	SPA	BED	EXP	SET	LOC
135	N80E	86NW	054	109	019	005	SC	EW	NT
135	N80E	86NW	025	095	002	009	SC	EW	NT
135	N80E	86NW	077	234	013	009	SC	EW	NT
135	N80E	86NW	033	126	012	009	SC	EW	NT
135	N80E	86NW	035	049	011	006	SC	EW	NT
135	N80E	86NW	022	073	010	006	SC	EW	NT
135	N80E	86NW	042	104	021	008	SC	EW	NT
135	N80E	86NW	012	041	015	005	SC	EW	NT
135	N04W	79SW	067	010	005	001	SC		NT
135	N45W	88SW	059	016	036	016	SC	NW	NT
135	N45W	88SW	049	016	005	016	SC	NW	NT
135	N45W	88SW	040	015	031	015	SC	NW	NT
135	N45W	88SW	032	014	076	014	SC	NW	NT
135	N45W	88SW	050	011	006	011	SC	NW	NT
135	N45W	88SW	084	013	048	013	SC	NW	NT
135	N25W	87SW	068	006		001	SC		NT
135	N06E	75NW	155	012	020	012	SC		NT
135	N06E	75NW	071	015	023	015	SC		NT
135	N06E	75NW	065	017		017	SC		NT
135	N80E	86NW	110	030	038	001	SC	EW	NT
135	N80E	86NW	104	027	013	001	SC	EW	NT
135	N80E	86NW	057	018	023	001	SC	EW	NT
135	N80E	86NW	074	084	011	001	SC	EW	NT
135	N80E	86NW	213	096	015	001	SC	EW	NT
135	N80E	86NW	179	075	025	001	SC	EW	NT
136	N70W	75NE	146	020	022	009	S		NT
136	N70W	75NE	023	003	017	003	S		NT
136	N70W	75NE	176	013	035	003	S		NT
136	N70W	75NE	123	023	036	007	S		NT
136	N70W	75NE	079	006	029	006	S		NT
136	N70W	75NE	065	009	028	006	S		NT
137	N78W	90SW	103	014	007	014	S		NT
137	N78W	90SW	126	024	021	024	S		NT
137	N78W	90SW	043	032	014	012	S		NT
137	N78W	90SW	103	023	016	013	S		NT
137	N78W	90SW	001	015	016	016	S		NT
137	N78W	90SW	031	043	013	020	S		NT
138	N80E	82NW	087	111	057	111	S	EW	SO
138	N80E	82NW	079	062	012	062	S	EW	SO
138	N80E	82NW	030	025	021	062	S	EW	SO
138	N80E	82NW	128	083		083	S	EW	SO
138	N46W	86NE	052	060		060	S	NW	SO
138	N04W	67SW	056	064	038	112	S		SO
138	N15W	78SW	029	063	020	063	S		SO
138	N15W	78SW	072	053	032	053	S		SO
138	N80E	82NW	020	033	010	001	S	EW	SO
138	N80E	82NW	008	030	003	001	S	EW	SO
138	N80E	82NW	010	025	010	001	S	EW	SO
139	N55W	80SW	294	011	064	001	S	NW	SO
139	N55W	80SW	183	005	032	001	S	NW	SO
139	N55W	80SW	031	002	032	001	S	NW	SO
139	N55W	80SW	037	003	022	001	S	NW	SO
139	N55W	80SW	030	018	029	018	S	NW	SO
139	N55W	80SW	045	008	008	008	S	NW	SO
139	N55W	80SW	063	018	008	018	S	NW	SO
139	N55W	80SW	104	008	043	008	S	NW	SO
139	N55W	80SW	091	015	034	015	S	NW	SO
139	N72E	85SE	062	024	030	024	S		SO
139	N72E	85SE	062	021	019	018	S		SO
139	N72E	85SE	082	023	010	005	S		SO

STA	STRI	DIP	LNG	DPT	SPA	BED	EXP	SET	LOC
140	N87E	85NW	540	010	068	001	S	EW	SO
140	N87E	85NW	429	010	012	001	S	EW	SO
140	N87E	85NW	092	012	127	001	S	EW	SO
140	N87E	85NW	364	016	087	001	S	EW	SO
140	N87E	85NW	134	001	007	001	S	EW	SO
140	N87E	85NW	182	003	024	001	S	EW	SO
140	N87E	85NW	163	005		001	S	EW	SO
140	N03E	84SE	084	012	028	001	S		SO
140	N03E	84SE	070	007	050	001	S		SO
140	N03E	84SE	136	006	014	001	S		SO
140	N87E	85NW	268	025	003	001	S	EW	SO
140	N87E	85NW	182	019	008	001	S	EW	SO
140	N87E	85NW	204	022	027	001	S	EW	SO
140	N87E	85NW	255	027	095	001	S	EW	SO
140	N87E	85NW	246	025	083	001	S	EW	SO
140	N87E	85NW	217	024	008	001	S	EW	SO
140	N87E	85NW	229	025	010	001	S	EW	SO
140	N87E	85NW	242	025	114	001	S	EW	SO
141	N67W	90SW	180	009	027	009	S		SO
141	N67W	90SW	214	009	030	009	S		SO
141	N67W	90SW	131	009	043	009	S		SO
141	N67W	90SW	108	009	026	009	S		SO
141	N67W	90SW	224	009	015	009	S		SO
141	N67W	90SW	224	009	027	009	S		SO
141	N67W	90SW	182	009	017	009	S		SO
141	N67W	90SW	156	009	016	009	S		SO
141	N67W	90SW	130	009	014	009	S		SO
141	N67W	90SW	100	009	019	009	S		SO
141	N67W	90SW	077	009	009	009	S		SO
141	N67W	90SW	069	009	011	009	S		SO
141	N67W	90SW	065	009	013	009	S		SO
141	N30E	90NW	071	005	048	005	S	NE	SO
141	N30E	90NW	073	005	044	005	S	NE	SO
141	N30E	90NW	302	012	052	012	S	NE	SO
141	N30E	90NW	352	012	030	012	S	NE	SO
141	N30E	90NW	260	012	021	012	S	NE	SO
141	N30E	90NW	134	012	042	012	S	NE	SO
141	N30E	90NW	093	012		012	S	NE	SO
142	N83E	83SE	073	005	012	005	S	EW	SO
142	N83E	83SE	067	005	062	005	S	EW	SO
142	N83E	83SE	107		072		S	EW	SO
142	N83E	83SE	093		015		S	EW	SO
142	N83E	83SE	134		043		S	EW	SO
142	N83E	83SE	087		049		S	EW	SO
142	N83E	83SE	088		084		S	EW	SO
142	N83E	83SE	102		042		S	EW	SO
142	N83E	83SE	080		051		S	EW	SO
142	N83E	83SE	131		031		S	EW	SO
142	N83E	83SE	112		039		S	EW	SO
142	N83E	83SE	111		039		S	EW	SO
142	N83E	83SE	103		058		S	EW	SO
142	N83E	83SE	094		060		S	EW	SO
142	N83E	83SE	110		045		S	EW	SO
142	N83E	83SE	125		039		S	EW	SO
142	N13W	73SW	063		010		S		SO
142	N13W	73SW	029		013		S		SO
142	N13W	73SW	109		013		S		SO
142	N13W	73SW	141	012	026	012	S		SO
142	N13W	73SW	095		013		S		SO
142	N13W	73SW	064	007	003	007	S		SO

STA	STRI	DIP	LNG	DPT	SPA	BED	EXP	SET	LOC
142	N12E	70NW	072	014	019	014	S		SO
142	N12E	70NW	284	011	014	011	S		SO
142	N12E	70NW	141	012	031	012	S		SO
142	N75W	84NE	013	007	031	007	S		SO
142	N75W	84NE	010	010	072	010	S		SO
142	N75W	84NE	030	009	036	009	S		SO
142	N75W	84NE	017	009	029	009	S		SO
142	N75W	84NE	011	009	036	009	S		SO
143	N45W	64SW	030	007	012	007	S	NW	SO
143	N45W	64SW	027	007	011	007	S	NW	SO
143	N45W	64SW	041	007	016	007	S	NW	SO
143	N45W	64SW	029	007	006	007	S	NW	SO
143	N45W	64SW	057	011	037	011	S	NW	SO
143	N45W	64SW	023	011	013	011	S	NW	SO
143	N45W	64SW	025	011	027	011	S	NW	SO
143	N45W	64SW	056	020	042	020	S	NW	SO
143	N68E	75NW	042	007	028	007	S		SO
143	N68E	75NW	018	007	029	007	S		SO
143	N68E	75NW	052	007	023	007	S		SO
143	N68E	75NW	032	020	011	020	S		SO
143	N65W	84SW	034	011	026	011	S		SO
143	N65W	84SW	016	011	012	011	S		SO
143	N65W	84SW	042	007	017	007	S		SO
143	N65W	84SW	031	005	034	005	S		SO
143	N65W	84SW	057	007	025	007	S		SO
143	N65W	84SW	025	017	023	017	S		SO
143	N65W	84SW	038	017	010	017	S		SO
143	N65W	84SW	036	015	012	015	S		SO
144	N28E	90NW	120		018		S	NE	BR
144	N28E	90NW	134		019		S	NE	BR
144	N28E	90NW	172		024		S	NE	BR
144	N28E	90NW	234		023		S	NE	BR
144	N28E	90NW	186		023		S	NE	BR
144	N28E	90NW	100		016		S	NE	BR
144	N28E	90NW	089		014		S	NE	BR
144	N28E	90NW	115		012		S	NE	BR
144	N28E	90NW	140		013		S	NE	BR
144	N46W	90SW	045		082		S	NW	BR
144	N46W	90SW	130		017		S	NW	BR
144	N46W	90SW	090		017		S	NW	BR
144	N46W	90SW	090		024		S	NW	BR
145	N25E	65SE					S	NE	NT
145	N72W	87NE					S		NT
145	N10E	70SE					S		NT
145	N80E	90NW					S	EW	NT
145	N25E	65SE			070		S	NE	NT
145	N25E	65SE			092		S	NE	NT
145	N25E	65SE			060		S	NE	NT
145	N25E	65SE			035		S	NE	NT
145	N25E	65SE			024		S	NE	NT
145	N25E	65SE			031		S	NE	NT
145	N45W	88SW	058	022	128	022	S	NW	NT
145	N45W	88SW	088	022	103	022	S	NW	NT
145	N45W	88SW	020	020	032	020	S	NW	NT
145	N45W	88SW	030	020	090	020	S	NW	NT
145	N45W	88SW	012	020	071	020	S	NW	NT
146	N70W	86SW	070	048	027	012	S		NT
146	N70W	86SW	016	010	042	010	S		NT
146	N70W	86SW	089	010	010	010	S		NT
146	N70W	86SW	083	010		010	S		NT

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FIELD TECHNIQUES

FOR MEASURING JOINT INTENSITY

by

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INTRODUCTION

Hydrocarbon production from fractured reservoirs, increased water-well yields, coal mine roof falls, and some construction problems often have been cited as having been caused by an increase in fracture intensity. A relatively fast and easy method to measure fracture intensity and locating areas of intense fracturing would be generally useful, and in particular, in potential drilling areas where little or no subsurface data is available. As part of the Eastern Gas Shales Project, funded by the U. S. Department of Energy, such a method was developed (Wheeler and Dixon, in preparation). This paper reports the summary of methods used, a test of operator variability, and a "handbook" of suggested procedures.

METHODS

Joint intensity measurements of systematic joints have been taken in varying lithologies and bed thicknesses with varying amounts of deformation. Some methods remain constant throughout all studies, others vary somewhat according to exposure, amount of deformation, bed thickness, and lithology.

In the initial study, completed in Tucker County (Dixon, 1979a; 1979b), it was determined that joint strike, dip and spacing are the only necessary measurements. Spacing is the perpendicular distance to the adjacent joint in the same set (Stubbs and Wheeler, 1975; Wheeler and Stubbs, in press).

A measurement of joint intensity or joint surface area per unit volume of rock is made using inverses of average spacings, summed over

all sets in an exposure (Vialon and others, 1976; Dixon, 1979a; 1979b; Wheeler, 1979; Wheeler and Dixon, in preparation). If for example, three joint sets were exposed in an outcrop, then the following formula would be used to obtain an intensity (I) measure:

$$I = \frac{1}{\bar{S}_1} + \frac{1}{\bar{S}_2} + \frac{1}{\bar{S}_3} .$$

Regardless of the number of joints measured or the number of sets in an exposure, only one intensity measurement is calculated.

A question of reproducibility of data from operator variance is important in measuring joint intensity. To test this, four operators, with experience in measuring joint orientation but with extensive to no experience in measuring joint intensity, measured strike, dip, and spacing at three stations. No instructions or assistance were given. The operators worked independently, often taking measurements at different places on the outcrop and at different times. The outcrops varied in size, type, and complexity. Although the number of joints measured varied greatly among operators (Table 1), the intensities did not differ significantly (significance level of 0.05) as calculated by the Least-Squares Means and the Kruskal-Wallis tests (Davis, 1973; Gibbons, 1976). Thus, intensity measurements obtained in this or other studies can be considered generally valid and reproducible. One should note that even though variations might occur among operators, real and valid differences in intensities can well be detected by a single operator as long as he is consistent in his own methods. Operator consistency is an important factor.

TABLE I OPERATOR VARIANCE

Operator	Station 33		Station 87		Station 35	
	I	n	I	n	I	n
1	0.24	12	0.21	12	0.09	18
2	0.08	32	0.19	31	0.20	40
3	0.22	25	0.04	17	0.19	42
4	0.10	11	0.15	16	0.14	16

Table 1 Intensities (I) and number of observations (n) measured at data stations in Tucker County.

HANDBOOK TO MEASURING JOINT INTENSITY

This "handbook" is meant to assist people who are about to engage in a joint intensity study, perhaps for the first time. Certain procedures need to be strictly adhered to, regardless of the study; others will vary. Within a study, consistency is most important.

Ideally, the area to be studied should be previewed. Some rocks lend themselves to this type of study better than others. A preliminary investigation of rock type, number of exposures, and a few sample measurements could save time, trouble, and retracing of steps.

Joint strike, dip, and spacing are the only necessary measurements, however, bed thickness is a useful measurement. If the joints are very regular and consistent, only one strike and dip measurement may be necessary; two or three measurements may be useful where joints are less consistent.

Spacing is the perpendicular distance to the next adjacent joint in the same set. In an exposure, one should measure spacing consistently in one direction so as not to repeat a spacing measurement. If part of the exposure has been washed out, covered by vegetation, covered by talus, or in any way covered, spacing should not be measured across the area; a joint may be covered and the spacing measurement would be erroneous. Wherever possible, at least three spacings per set should be measured. The number of joint spacings one should measure at each exposure will vary according to the number of joint sets and the regularity or irregularity of the spacing. If joint spacing in a set is fairly consistent across the exposure, only three to five measurements are necessary; if spacing is

variable, 10-20 measurements may be necessary. The key to measuring spacings is to choose a representative sample. The exception to the rule is massive sandstone where joint spacing may be many meters. If the outcrop is large, and yet has only one or two joints or one or two spacings, then the intensity value may be considered equal to or less than the calculated value. For example, if an outcrop is 25 meters long and two joints at a high angle to the face of the outcrop are found at one end ten meters apart and the next joint spacing is greater than 15 meters, then no other joint from that set will be found in the remaining 15 meters of the outcrop. The average spacing of that set can be considered equal to or less than 10 meters. It is important to note when an outcrop has no joints, particularly if the outcrop is of fair size.

Field equipment is often a personal choice. However, two measuring instruments are found to be useful: a six-foot folding, metric/English carpenter's ruler and a 30m fiberglass tape. The carpenter's ruler is good when spacings are less than a few meters. It is invaluable when measuring high angle cuts where joints are a few feet above your reach. The ruler can be unfolded into an upside down "L" shape, using the long end for extension and the short end for measuring spacings. The 30m fiberglass tape, used when spacings are large, is flexible and will not rust when used in streams or wet areas.

One should beware of blasting fractures, weathering cracks, or other breaks which are not joints. As a general rule, when in doubt, don't. If you are unsure whether or not a fracture is a systematic joint, do not measure it for spacing. When you have completed the study, any differences in joint intensities will be detected from spacings you are sure are real.

Processing of the data will vary from study to study. In areas where a great number of intensity measurements were taken, a simple contour map may best illustrate areas of high or low intensities. When traverses are taken across an area, a line graph may well illustrate intensity variances. Using mean spacings of individual sets can be used to assist in analyzing causes of joint intensity. However, it is only the joint intensity measurement that estimates the total surface area of fractured rock per unit volume. An individual set may show close spacings in an area (i.e., increased intensity); but when added to all joints in the exposure, no increase may exist.

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OPERATOR VARIANCE DATA

OPR	STRI	SP	ST	STA
BRI	N74W	06	EW	33
BRI	N83W	08	EW	33
BRI	N87W	13	EW	33
BRI	N53W	07	NW	33
BRI	N18E	03	NE	33
BRI	N25E	10	NE	33
BRI	N83W	22	EW	33
BRI	N82W	26	EW	33
BRI	N86W	11	EW	33
BRI	N86E	28	EW	33
BRI	N10E	28	NN	33
BRI	N14E	29	NN	33
BRI	N75W	31	7W	87
BRI	N77W	32	7W	87
BRI	N73W	12	7W	87
BRI	N23E	27	NE	87
BRI	N83E	31	EW	87
BRI	N80E	20	EW	87
BRI	N15E	21	NN	87
BRI	N45W		NW	87
BRI	N85E	45	EW	87
BRI	N87W	15	EW	87
BRI	N82W	13	EW	87
BRI	N80E	05	EW	87
BRI	N18E	55	NN	87
BRI	N53W		NW	87
BRI	N58W	32	NW	35
BRI	N64W	13	6W	35
BRI	N60W	07	6W	35
BRI	N61W	06	6W	35
BRI	N57W	08	6W	35
BRI	N71W	10	6W	35
BRI	N26E	04	NE	35
BRI	N25E	03	NE	35
BRI	N12E	19	NE	35
BRI	N62W	12	6W	35
BRI	N63W	09	6W	35
BRI	N58W	39	6W	35
BRI	N60E	23	6E	35
BRI	N62E	28	6E	35
BRI	N89W	16	EW	35
BRI	N28E	45	NE	35
BRI	N32E	99	NE	35
TOM	N86W	29	EW	33
TOM	N87W	24	EW	33
TOM	N84W	35	EW	33
TOM	N86W	34	EW	33

OPR	STRI	SP	ST	STA
TOM	N87W	55	EW	33
TOM	N84W	66	EW	33
TOM	N86W	68	EW	33
TOM	N87W	12	EW	33
TOM	N84W	34	EW	33
TOM	N86W	40	EW	33
TOM	N19E	19	NE	33
TOM	N21E	02	NE	33
TOM	N42E	19	NE	33
TOM	N19E	23	NE	33
TOM	N21E	08	NE	33
TOM	N42E	16	NE	33
TOM	N19E	23	NE	33
TOM	N21E	10	NE	33
TOM	N42E	16	NE	33
TOM	N19E	17	NE	33
TOM	N21E	22	NE	33
TOM	N42E	32	NE	33
TOM	N19E	30	NE	33
TOM	N21E	03	NE	33
TOM	N42E	27	NE	33
TOM	N19E	34	NE	33
TOM	N21E	17	NE	33
TOM	N42E	C8	NE	33
TOM	N19E	13	NE	33
TOM	N21E	21	NE	33
TOM	N42E	23	NE	33
TOM	N19E	39	NE	33
TOM	N83E	30	EW	87
TOM	N85E	32	EW	87
TOM	N79W	37	EW	87
TOM	N83E	14	EW	87
TOM	N85E	11	EW	87
TOM	N79W	18	EW	87
TOM	N83E	25	EW	87
TOM	N85E	46	EW	87
TOM	N79W	13	EW	87
TOM	N83E	62	EW	87
TOM	N85E	18	EW	87
TOM	N79W	06	EW	87
TOM	N83E	15	EW	87
TOM	N85E	16	EW	87
TOM	N79W	03	EW	87
TOM	N83E	17	EW	87
TOM	N85E	10	EW	87
TOM	N79W	12	EW	87
TOM	N83E	09	EW	87

OPR	STRI	SP	ST	STA
TOM	N85E	06	EW	87
TOM	N79W	30	EW	87
TOM	N83E	10	EW	87
TOM	N85E	10	EW	87
TOM	N79W	16	EW	87
TOM	N83E	07	EW	87
TOM	N85E	17	EW	87
TOM	N40W		NW	87
TOM	N20E	15	NE	87
TOM	N26E	28	NE	87
TOM	N24E	13	NE	87
TOM	N20E	08	NE	87
TOM	N26E	06	NE	87
TOM	N44E	42	NE	35
TOM	N25E	35	NE	35
TOM	N29E	07	NE	35
TOM	N25E	46	NE	35
TOM	N61W	13	NW	35
TOM	N51W	23	NW	35
TOM	N51W	34	NW	35
TOM	N53W	35	NW	35
TOM	N53W	11	NW	35
TOM	N51W	32	NW	35
TOM	N53W	28	NW	35
TOM	N51W	15	NW	35
TOM	N53W	08	NW	35
TOM	N51W	39	NW	35
TOM	N53W	79	NW	35
TOM	N51W	39	NW	35
TOM	N73E	27	7E	35
TOM	N73E	23	7E	35
TOM	N52W	14	NW	35
TOM	N53W	15	NW	35
TOM	N51W	26	NW	35
TOM	N02E	12	NN	35
TOM	N02E	11	NN	35
TOM	N51W	32	NW	35
TOM	N53W	08	NW	35
TOM	N51W	07	NW	35
TOM	N53W	17	NW	35
TOM	N51W	24	NW	35
TOM	N25E	99	NE	35
TOM	N29E	37	NE	35
TOM	N25E	35	NE	35
TOM	N29E	14	NE	35
RUS	N87W	19	EW	33
RUS	N84W	12	EW	33

OPR	STRI	SP	ST	STA
RUS	N82W	10	EW	33
RUS	N84W	18	EW	33
RUS	N87W	31	EW	33
RUS	N84W	07	EW	33
RUS	N83W	12	EW	33
RUS	N39W	16	NW	33
RUS	N46W	18	NW	33
RUS	N47W	24	NW	33
RUS	N47W	27	NW	33
RUS	N39W	13	NW	33
RUS	N46W	18	NW	33
RUS	N47W	70	NW	33
RUS	N47W	36	NW	33
RUS	N39W	29	NW	33
RUS	N67W	17	6W	33
RUS	N63W	04	6W	33
RUS	N67W	08	6W	33
RUS	N21E	43	NE	33
RUS	N14E	26	NE	33
RUS	N14E	29	NE	33
RUS	N17E	53	NE	33
RUS	N21E	34	NE	33
RUS	N14E	33	NE	33
RUS	N14E	23	NE	33
RUS	N21E	59	NE	33
RUS	N14E	71	NE	33
RUS	N87E	70	EW	87
RUS	N85E	05	EW	87
RUS	N89E	99	EW	87
RUS	N85E	38	EW	87
RUS	N87E	06	EW	87
RUS	N85E	07	EW	87
RUS	N89E	03	EW	87
RUS	N85E	72	EW	87
RUS	N87E	70	EW	87
RUS	N85E	28	EW	87
RUS	N70W	30	7W	87
RUS	N72W	99	7W	87
RUS	N71W	32	7W	87
RUS	N72W	48	7W	87
RUS	N70W	43	7W	87
RUS	N72W	48	7W	87
RUS	N71W	47	7W	87
RUS	N58W	12	NW	35
RUS	N57W	11	NW	35
RUS	N57W	13	NW	35
RUS	N62W	09	NW	35

OPR	STRI	SP	ST	STA
RUS	N58W	24	NW	35
RUS	N57W	36	NW	35
RUS	N62W	38	NW	35
RUS	N74W	22	7W	35
RUS	N70W	12	7W	35
RUS	N70W	05	7W	35
RUS	N74W	08	7W	35
RUS	N70W	21	7W	35
RUS	N70W	16	7W	35
RUS	N70W	11	7W	35
RUS	N74W	02	7W	35
RUS	N70W	05	7W	35
RUS	N70W	24	7W	35
RUS	N70W	13	7W	35
RUS	N70W	13	7W	35
RUS	N70W	39	7W	35
RUS	N70W	32	7W	35
RUS	N70W	12	7W	35
RUS	N70W	16	7W	35
RUS	N70W	28	7W	35
RUS	N70W	30	7W	35
RUS	N57W	06	NW	35
RUS	N55W	09	NW	35
RUS	N57W	09	NW	35
RUS	N55W	08	NW	35
RUS	N57W	19	NW	35
RUS	N27E	28	NE	35
RUS	N17E	25	NE	35
RUS	N27E	32	NE	35
RUS	N17E	45	NE	35
RUS	N27E	03	NE	35
JAN	N80W	25	EW	33
JAN	N83W	20	EW	33
JAN	N80W	14	EW	33
JAN	N80W	11	EW	33
JAN	N83W	12	EW	33
JAN	N83W	08	EW	33
JAN	N80W	18	EW	33
JAN	N83W	24	EW	33
JAN	N80W	24	EW	33
JAN	N83W	32	EW	33
JAN	N50W	16	NW	33
JAN	N45W	20	NW	33
JAN	N48W	19	NW	33
JAN	N50W	12	NW	33
JAN	N87W	18	EW	87
JAN	N87W	08	EW	87

OPR	STRI	SP	ST	STA
JAN	N87W	12	EW	87
JAN	N87W	24	EW	87
JAN	N87W	38	EW	87
JAN	N87W	09	EW	87
JAN	N87W	17	EW	87
JAN	N87W	17	EW	87
JAN	N87W	34	EW	87
JAN	N51W	07	NW	87
JAN	N51W	26	NW	87
JAN	N84E	11	EW	87
JAN	N84E	11	EW	87
JAN	N73W	32	7W	87
JAN	N73W	31	7W	87
JAN	N24E	90	NE	35
JAN	N24E	59	NE	35
JAN	N24E	29	NE	35
JAN	N02E	21	NN	35
JAN	N02E	31	NN	35
JAN	N02E	11	NN	35
JAN	N55W	47	NW	35
JAN	N55W	09	NW	35
JAN	N55W	25	NW	35
JAN	N54W	35	NW	35
JAN	N85W	36	EW	35
JAN	N85W	29	EW	35
JAN	N85W	12	EW	35
JAN	N85W	16	EW	35
JAN	N85W	37	EW	35

STATION LOCATIONS IN TUCKER COUNTY

Appendix A - Station Locations in Tucker County

Appendix B - Tucker County Data

Appendix C - Station Locations at the Allegheny Front

Appendix D - Allegheny Front Data

Appendix E - Station Locations of the Westward Extensions Parsons and Petersburg Lineaments

Appendix F - Westward Extensions Data

Appendix G - Operator Variance Data

Appendix H - Coal Cleat Intensity Data

APPENDIX A

STATION LOCATIONS IN TUCKER COUNTY
(in UTM Grid Coordinates)

Key to Abbreviations:

STA - station number

STA	LATITUDE	LONGITUDE	STA	LATITUDE	LONGITUDE
001	4328.280	615.120	050	4333.900	617.470
002	4329.710	613.710	051	4333.790	618.170
003	4330.340	614.080	052	4334.940	614.420
004	4330.800	610.530	054	4333.600	613.450
005	4329.340	612.220	055	4338.430	623.520
006	4325.480	613.100	056	4338.780	622.980
007	4325.200	612.500	057	4338.280	620.510
008	4325.870	611.720	058	4339.400	620.080
009	4327.030	611.250	059	4340.170	619.370
010	4326.430	611.070	060	4341.340	618.560
011	4326.920	610.600	061	4341.940	617.730
012	4323.350	611.100	062	4339.500	622.920
013	4323.170	610.800	063	4339.920	623.300
014	4322.600	610.180	064	4340.420	623.310
015	4329.560	611.700	065	4343.180	623.170
016	4330.600	606.530	066	4342.680	624.210
017	4328.020	603.700	067	4341.220	623.180
018	4325.610	602.990	068	4341.650	624.310
019	4324.870	602.920	069	4337.770	621.360
020	4323.480	602.570	070	4337.480	620.910
021	4319.750	602.580	071	4335.990	619.440
022	4319.980	611.050	072	4337.620	614.910
023	4320.060	611.070	073	4339.380	616.180
024	4322.170	609.520	074	4336.200	611.610
025	4322.020	608.870	075	4336.270	612.530
026	4327.130	610.470	076	4336.540	613.300
027	4327.270	610.340	077	4337.210	613.890
028	4327.500	609.300	078	4333.230	616.750
029	4327.920	608.600	079	4333.020	616.460
030	4327.800	607.570	080	4332.420	615.920
031	4333.670	611.010	082	4326.500	616.700
032	4333.480	611.250	083	4332.900	612.910
033	4332.480	611.380	084	4334.700	612.430
035	4331.160	609.720	085	4335.520	611.590
036	4326.640	610.970	086	4335.390	610.920
037	4325.270	612.380	087	4334.810	610.980
038	4325.210	612.490	088	4333.730	609.500
040	4324.700	612.700	089	4330.370	609.760
041	4324.800	612.880	090	4329.880	609.590
042	4324.880	613.080	091	4330.320	608.650
043	4325.060	613.230	092	4329.730	608.640
044	4325.120	613.300	093	4329.950	606.990
045	4325.180	613.350	094	4329.450	606.720
046	4325.250	613.420	095	4331.600	605.670
047	4334.540	616.240	096	4332.160	605.300
048	4334.000	616.680	097	4332.870	604.300
049	4333.980	616.960	098	4332.960	603.770

STA	LATITUDE	LONGITUDE	STA	LATITUDE	LONGITUDE
099	4335.130	604.140	125	4335.620	620.390
100	4334.770	604.430	126	4335.480	620.620
101	4334.580	605.560	127	4335.230	621.170
102	4327.190	613.480	128	4335.380	613.380
103	4327.880	612.700	129	4335.680	615.170
104	4328.090	612.320	130	4335.770	614.900
105	4328.470	611.660	131	4335.920	614.580
106	4328.170	612.150	132	4336.110	614.550
107	4327.110	612.150	133	4336.510	615.130
108	4326.600	612.760	134	4337.230	615.220
109	4327.870	610.340	135	4323.160	610.330
110	4328.220	610.350	136	4323.690	609.170
111	4332.660	611.480	137	4323.900	609.100
112	4332.780	612.030	138	4320.770	607.490
113	4333.500	612.080	139	4323.120	608.840
114	4333.540	611.400	140	4322.550	609.540
115	4331.860	612.480	141	4322.370	608.360
116	4338.610	621.520	142	4323.480	607.630
117	4339.480	621.580	143	4322.870	607.460
118	4340.370	621.090	144	4323.010	604.680
119	4338.450	621.620	145	4338.960	617.630
120	4338.150	620.740	146	4338.430	617.360
121	4338.780	620.220	147	4338.110	617.150
123	4337.580	619.920	148	4337.660	616.910
124	4335.950	619.720	149	4337.900	616.690

APPENDIX B

TUCKER COUNTY DATA

Key to Abbreviations:

STA - station number

STRI- joint strike

DIP - joint dip

LNG - joint length (in cm)

DTH - joint depth (in cm)

SPA - joint spacing (in cm)

BED - bed thickness (in cm)

EX - type of exposure: R = roadcut, S = stream pavement, SC = streamcut

ST - indicates into which of three main joint sets the joint falls: NW = northwest, NE = northeast, EW = east-west

LO - location with respect to the Parsons lineament: IN = within, NO = north, SO = south

GR - group with respect to the Parsons lineament: IN = within, OT = outside

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
001	N45W	88SW	106	048	060	020	R	NW	IN	IN
001	N46E	90NW	004	022	013	015	R		IN	IN
001	N45W	88SW	148	020	002	015	R	NW	IN	IN
001	N46E	90NW	007	017	044	017	R		IN	IN
001	N46E	90NW	027	029	060	020	R		IN	IN
001	N45W	88SW	084	021	007	021	R	NW	IN	IN
001	N45W	88SW	074	022	002	022	R	NW	IN	IN
001	N45W	88SW	075	039	005	020	R	NW	IN	IN
001	N46E	90NW	007	015	014	015	R		IN	IN
001	N46E	90NW	009	008	014	008	R		IN	IN
001	N46E	90NW	012	008	022	008	R		IN	IN
002	N84W	81SW	013	002	007	002	R	EW	IN	IN
002	N30E	90NW	026	003	003	003	R	NE	IN	IN
002	N84W	81SW	005	002	005	002	R	EW	IN	IN
002	N45W	90SW	010	125		003	R	NW	IN	IN
002	N20E	90NW	110	070	010	004	R		IN	IN
002	N20E	90NW	087	065	003	004	R		IN	IN
002	N78W	90SW	007	005		005	R		IN	IN
002	N60W	90SW	023	010	007	010	R		IN	IN
002	N60W	90SW	063	011	015	011	R		IN	IN
002	N45W	90SW	027	007		007	R	NW	IN	IN
002	N45W	90SW	035	007	002	007	R	NW	IN	IN
002	N80E	80SE	040	012	045	012	R	EW	IN	IN
002	N30E	90NW	024	001	008	001	R	NE	IN	IN
002	N30E	90NW	020	001	005	001	R	NE	IN	IN
002	N30E	90NW	021	001	008	001	R	NE	IN	IN
002	N30E	90NW	018	001	004	001	R	NE	IN	IN
002	N45W	90SW	100	010	016	010	R	NW	IN	IN
002	N70W	90SW	027	005	016	005	R		IN	IN
002	N30E	90NW	016	001	008	001	R	NE	IN	IN
002	N30E	90NW	005	001	006	001	R	NE	IN	IN
002	N84W	81SW	022	003	016	003	R	EW	IN	IN
002	N84W	81SW	036	002	015	002	R	EW	IN	IN
002	N84W	81SW	020	004	010	004	R	EW	IN	IN
002	N84W	81SW	010	004	004	004	R	EW	IN	IN
002	N84W	81SW	023	004	010	004	R	EW	IN	IN
003	N34E	90NW	028	015	033	015	R	NE	IN	IN
003	N34E	90NW	035	015	017	015	R	NE	IN	IN
003	N34E	90NW	055	015	020	015	R	NE	IN	IN
003	N34E	90NW	045	015	008	015	R	NE	IN	IN
003	N34E	90NW	054	015	024	015	R	NE	IN	IN
003	N87E	80NW	153	015	030	015	R	EW	IN	IN
003	N87E	80NW	055	015	020	015	R	EW	IN	IN
003	N87E	80NW	036	015	022	015	R	EW	IN	IN
003	N87E	80NW	070	015	020	015	R	EW	IN	IN
003	N87E	80NW	033	015	016	015	R	EW	IN	IN
003	N87E	80NW	078	015	016	015	R	EW	IN	IN

STA	STRI	DIP	LNG	DTH	SPA	BED	FX	ST	LO	GR
003	N34E	90NW	012	003	007	003	R	NE	IN	IN
003	N34E	90NW	010	003	004	003	R	NE	IN	IN
003	N34E	90NW	007	006	008	006	R	NE	IN	IN
003	N87E	80NW	013	006	011	006	R	EW	IN	IN
003	N60W	85SW	105	044	030	006	R		IN	IN
004	N45W	88NE	135	048	050	010	R	NW	IN	IN
004	N45W	88NE	107	020	020	010	R	NW	IN	IN
004	N45W	88NE	175	015	005	010	R	NW	IN	IN
004	N50E	90NW	001	008	036	008	R		IN	IN
004	N50E	90NW	003	026	035	010	R		IN	IN
004	N50E	90NW	020	010	007	010	R		IN	IN
004	N50E	90NW	025	010	012	010	R		IN	IN
005	N55W	73NE	007	005	011	005	R	NW	IN	IN
005	N40E	15SE	007	007	007	007	R	NE	IN	IN
005	N55W	73NE	015	007	008	007	R	NW	IN	IN
005	N40E	15SE	005	007	003	007	R	NE	IN	IN
005	N40E	15SE	005	005	004	005	R	NE	IN	IN
005	N40E	15SE	001	005	002	005	R	NE	IN	IN
005	N55W	73NE	011	005	005	005	R	NW	IN	IN
005	N55W	73NE	020	006	007	006	R	NW	IN	IN
005	N84E	77SE	022	014	005	014	R	EW	IN	IN
005	N84E	77SE	042	003	005	003	R	EW	IN	IN
005	N84E	77SE	019	008	010	008	R	EW	IN	IN
005	N84E	77SE	024	010	002	010	R	EW	IN	IN
005	N50W	70NE	021	008	011	008	R	NW	IN	IN
005	N50W	70NE	026	015	007	010	R	NW	IN	IN
005	N50W	70NE	045	024	012	024	R	NW	IN	IN
005	N40E	15SE	025	024	033	024	R	NE	IN	IN
005	N40E	15SE	027	030	039	024	R	NE	IN	IN
005	N60W	70NE	032	016	003	010	R		IN	IN
005	N55W	73NE	022	010	008	010	R	NW	IN	IN
005	N40E	15SE	018	020	005	005	R	NE	IN	IN
006	N45W	82NE	007	012	015	012	R	NW	IN	IN
006	N45W	82NE	018	014	020	012	R	NW	IN	IN
006	N45W	82NE	009	020	015	010	R	NW	IN	IN
006	N45W	82NE	009	020	022	010	R	NW	IN	IN
006	N45W	82NE	007	017	012	010	R	NW	IN	IN
006	N45W	82NE	006	021	023	010	R	NW	IN	IN
006	N45W	82NE	035	021	016	011	R	NW	IN	IN
006	N45W	82NE	012	050	009	011	R	NW	IN	IN
006	N45W	82NE	005	020	007	011	R	NW	IN	IN
006	N45W	82NE	050	033	023	033	R	NW	IN	IN
006	N45W	82NE	022	006	010	006	R	NW	IN	IN
006	N45W	82NE	030	006	013	006	R	NW	IN	IN
006	N45W	82NE	031	006	012	006	R	NW	IN	IN
006	N45W	82NE	012	006	011	006	R	NW	IN	IN
006	N40E	56SE	010	006	010	006	R	NE	IN	IN

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
006	N40E	56SE	011	006	023	006	R	NE	IN	IN
006	N40E	56SE	010	010	011	010	R	NE	IN	IN
006	N40E	56SE	033	014	003	014	R	NE	IN	IN
007	N23W	90SW	104	019	023	019	R		IN	IN
007	N23W	90SW	033	019	022	019	R		IN	IN
007	N23W	90SW	016	019	017	019	R		IN	IN
007	N23W	90SW	001	019	010	019	R		IN	IN
007	N23W	90SW	018	019	011	019	R		IN	IN
007	N23W	90SW	012	019	022	019	R		IN	IN
007	N23W	90SW	022	019	017	019	R		IN	IN
007	N69E	90NW	260	090	048	025	R		IN	IN
007	N69E	90NW	250	048	017	017	R		IN	IN
007	N23W	90SW	010	005	012	005	R		IN	IN
007	N23W	90SW	008	005	014	003	R		IN	IN
007	N23W	90SW	001	008	002	003	R		IN	IN
007	N23W	90SW	001	020	005	005	R		IN	IN
007	N69E	90NW	043	021	011	021	R		IN	IN
007	N69E	90SE	001	034	015	034	R		IN	IN
007	N69E	90NW	015	007	040	007	R		IN	IN
007	N69E	90NW	007	007	041	007	R		IN	IN
007	N69E	90NW	002	007	060	007	R		IN	IN
007	N69E	90NW	002	007	065	007	R		IN	IN
007	N69E	90NW	032	010	010	010	R		IN	IN
007	N69E	90NW	010	010	009	010	R		IN	IN
008	N35E	90NW	010	011	010	011	R	NE	IN	IN
008	N75W	90SW	600	070	055	038	R		IN	IN
008	N35E	90NW	011	011	028	011	R	NE	IN	IN
008	N35E	90NW	011	011	015	011	R	NE	IN	IN
008	N35E	90NW	012	011	035	011	R	NE	IN	IN
008	N35E	90NW	009	011	021	011	R	NE	IN	IN
008	N85W	56NE	038	020	048	020	R	EW	IN	IN
008	N85W	56NE	165	011	050	011	R	EW	IN	IN
008	N35E	90NW	015	004	013	004	R	NE	IN	IN
008	N35E	90NW	001	004	013	004	R	NE	IN	IN
008	N35E	90NW	001	004	010	004	R	NE	IN	IN
008	N35E	90NW	017	007	014	007	R	NE	IN	IN
008	N35E	90NW	016	007	007	007	R	NE	IN	IN
008	N35E	90NW	014	015	020	015	R	NE	IN	IN
008	N53W	90SW	500	115		060	R	NW	IN	IN
008	N53W	90SW	500	233		085	R	NW	IN	IN
009	N74E	90NW	060	013	008	013	S		IN	IN
009	N74E	90NW	080	013	034	013	S		IN	IN
009	N74E	90NW	080	013	017	013	S		IN	IN
009	N74E	90NW	065	013	020	013	S		IN	IN
009	N74E	90NW	070	013	010	013	S		IN	IN
009	N74E	90NW	051	013	007	013	S		IN	IN
009	N74E	90NW	040	013	020	013	S		IN	IN

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
009	N74E	90NW	041	013	030	013	S		IN	IN
009	N74E	90NW	007	008	020	008	S		IN	IN
009	N35W	90SW	040	008	030	008	S	NW	IN	IN
009	N35W	90SW	063	013	037	013	S	NW	IN	IN
009	N35W	90SW	042	013	013	013	S	NW	IN	IN
009	N35W	90SW	043	013	021	013	S	NW	IN	IN
009	N35W	90SW	070	013	021	013	S	NW	IN	IN
010	N52W	90SW	105	007	010	007	R	NW	IN	IN
010	N52W	90SW	125	007	002	007	R	NW	IN	IN
010	N52W	90SW	029	007	009	007	R	NW	IN	IN
010	N52W	90SW	040	011	006	011	R	NW	IN	IN
010	N52W	90SW	022	011	010	011	R	NW	IN	IN
010	N52W	90SW	228	070	003	011	R	NW	IN	IN
010	N52E	90NW	001	007	043	007	R		IN	IN
010	N52E	90NW	001	007	011	007	R		IN	IN
010	N52E	90NW	001	007	023	007	R		IN	IN
010	N52E	90NW	010	007	026	007	R		IN	IN
010	N52E	90NW	001	007	043	007	R		IN	IN
010	N52E	90NW	005	007	024	007	R		IN	IN
010	N52E	90NW	009	007	046	007	R		IN	IN
010	N52E	90NW	001	007	038	007	R		IN	IN
010	N52E	90NW	001	007	031	007	R		IN	IN
010	N52E	90NW	001	007	030	007	R		IN	IN
010	N52E	90NW	001	010	021	010	R		IN	IN
010	N52E	90NW	001	010	020	010	R		IN	IN
010	N52E	90NW	001	010	024	010	R		IN	IN
011	N46W	87SW	057	018	030	018	R	NW	IN	IN
011	N46W	87SW	161	030	028	030	R	NW	IN	IN
011	N46W	87SW	022	009	028	009	R	NW	IN	IN
011	N46W	87SW	022	009	018	009	R	NW	IN	IN
011	N46W	87SW	105	030	025	030	R	NW	IN	IN
011	N46W	87SW	098	023	054	023	R	NW	IN	IN
011	N46W	87SW	050	023	020	023	R	NW	IN	IN
012	N48W	90SW	025	105	012	012	R	NW	IN	IN
012	N48W	90SW	020	057	012	012	R	NW	IN	IN
012	N48W	90SW	020	012	030	012	R	NW	IN	IN
012	N48W	90SW	120	130	080	012	R	NW	IN	IN
012	N65E	90NW	075	012	035	012	R		IN	IN
012	N65E	90NW	016	013	014	013	R		IN	IN
012	N21E	86SE	045	037		012	R		IN	IN
012	N46E	73NW	047	024	009	017	R		IN	IN
012	N46E	73NW	088	017	011	017	R		IN	IN
012	N48W	90SW	160	060	018	030	R	NW	IN	IN
012	N48W	90SW	015	028	022	011	R	NW	IN	IN
012	N48W	90SW	002	030		010	R	NW	IN	IN
012	N30E	90NW	057	020	004	008	R	NE	IN	IN
012	N28E	84NW	023	027	030	012	R	NE	IN	IN

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
012	N88W	90SW	030	002	005	002	R	EW	IN	IN
012	N88W	90SW	013	007	010	007	R	EW	IN	IN
012	N88W	90SW	014	007	025	007	R	EW	IN	IN
012	N55E	90NW	180	040		040	R		IN	IN
012	N55W	90SW	079	112		040	R	NW	IN	IN
012	N55W	90SW	150	040		040	R	NW	IN	IN
012	N55W	90SW	200	080	060	040	R	NW	IN	IN
013	N68W	90SW	039	058	023	047	R		IN	IN
013	N86W	90SW	038	038	043	038	R	EW	IN	IN
013	N68W	90SW	001	027	003	027	R		IN	IN
013	N68W	90SW	001	047	046	047	R		IN	IN
013	N68W	90SW	003	055	012	055	R		IN	IN
013	N68W	90SW	001	055	023	055	R		IN	IN
013	N68W	90SW	042	018	043	018	R		IN	IN
013	N68W	90SW	027	018	040	018	R		IN	IN
013	N68W	90SW	010	027	037	018	R		IN	IN
013	N68W	90SW	030	018	020	018	R		IN	IN
013	N68W	90SW	005	018	022	018	R		IN	IN
013	N78W	90SW	023	026	028	007	R		IN	IN
013	N78W	90SW	014	005	020	005	R		IN	IN
013	N78W	90SW	010	005	016	005	R		IN	IN
013	N20W	81SW	052	010		010	R		IN	IN
014	N75W	85NE					R		IN	IN
015	N73W	55NE	096	015	029	·003	R		IN	IN
015	N73W	55NE	040	006		003	R		IN	IN
015	N73W	55NE	020	007	012	003	R		IN	IN
015	N73W	55NE	012	007	013	003	R		IN	IN
015	N73W	55NE	020	007	022	003	R		IN	IN
015	N73W	55NE	045	007	011	003	R		IN	IN
015	N73W	55NE	045	010	028	003	R		IN	IN
015	N73W	55NE	045	010	038	003	R		IN	IN
015	N73W	55NE	037	010	040	003	R		IN	IN
015	N73W	55NE	035	010	033	003	R		IN	IN
015	N73W	55NE	029	010	025	003	R		IN	IN
016	N49W	76SW	060	050	074	050	R	NW	IN	IN
016	N46W	75SW	138	120	052	065	R	NW	IN	IN
016	N46W	75SW	092	055	049	055	R	NW	IN	IN
016	N46W	75SW	061	040	037	040	R	NW	IN	IN
016	N46W	74SW	064	065	024	060	R	NW	IN	IN
016	N46W	75SW	034	051	026	051	R	NW	IN	IN
016	N46W	75SW	071	035	033	035	R	NW	IN	IN
016	N46W	75SW	045	022	035	022	R	NW	IN	IN
016	N46W	75SW	070	054	078	054	R	NW	IN	IN
016	N46W	75SW	101	075	116	045	R	NW	IN	IN
016	N46W	75SW	083	052	077	052	R	NW	IN	IN
016	N46W	75SW	105	038	045	038	R	NW	IN	IN
016	N46W	75SW	095	038	029	038	R	NW	IN	IN

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	IO	GR
016	N46W	75SW	010	038	045	045	R	NW	IN	IN
016	N60E	78SE	014	008	021	008	R		IN	IN
016	N60E	72SE	003	008	028	008	R		IN	IN
017	N62E	78SE	006	008	041	008	R		BR	OT
017	N62E	78SE	018	008	057	008	R		BR	OT
017	N62E	78SE	018	012	039	010	R		BR	OT
017	N62E	78SE	001	012	026	010	R		BR	OT
017	N62E	78SE	014	010	046	010	R		BR	OT
017	N62E	78SE	008	010	030	010	R		BR	OT
017	N62E	78SE	014	006	038	003	R		BR	OT
017	N62E	78SE	014	006	035	006	R		BR	OT
017	N62E	78SE	002	006	040	006	R		BR	OT
017	N62E	78SE	001	006	035	006	R		BR	OT
018	N42W	75SW	061	004	055	004	R	NW	BR	OT
018	N42W	75SW	024	004	028	004	R	NW	BR	OT
018	N42W	75SW	034	012	045	012	R	NW	BR	OT
018	N42W	75SW	012	010	030	010	R	NW	BR	OT
018	N13E	90NW	043	004	018	004	R		BR	OT
018	N42W	75SW	020	014	014	004	R	NW	BR	OT
018	N42W	75SW	075	004	024	004	R	NW	BR	OT
018	N42W	75SW	028	008	028	008	R	NW	BR	OT
018	N42W	75SW	102	016	044	016	R	NW	BR	OT
018	N13E	90NW	058	016		016	R		BR	OT
018	N87E	90NW	015	001	007	001	R	EW	BR	OT
018	N87E	90NW	012	001		001	R	EW	BR	OT
018	N25E	90NW	087	005	052	005	R	NE	BR	OT
018	N45W	74SW	065	010	060	010	R	NW	BR	OT
018	N45W	75SW	059	049	040	005	R	NW	BR	OT
018	N45W	74SW	030	005	067	005	R	NW	BR	OT
018	N45W	74SW	050	005	059	005	R	NW	BR	OT
019	N33E	73NW	026	005	012	005	R	NE	BR	OT
019	N33E	73NW	013	005	010	005	R	NE	BR	OT
019	N33E	73NW	014	005	010	005	R	NE	BR	OT
019	N33E	73NW	026	005	013	005	R	NE	BR	OT
019	N33E	73NW	019	005	010	005	R	NE	BR	OT
019	N33E	73NW	015	004	005	004	R	NE	BR	OT
019	N33E	73NW	016	004	007	004	R	NE	BR	OT
019	N33E	73NW	016	004	010	004	R	NE	BR	OT
019	N33E	73NW	012	004	007	004	R	NE	BR	OT
019	N33E	73NW	012	003	008	003	R	NE	BR	OT
019	N33E	73NW	001	003	005	003	R	NE	BR	OT
019	N33E	73NW	015	005	012	005	R	NE	BR	OT
019	N33E	73NW	018	005	005	005	R	NE	BR	OT
019	N50W	88SW	005	004	023	004	R	NW	BR	OT
019	N50W	88SW	007	005	015	005	R	NW	BR	OT
019	N50W	88SW	001	005	015	005	R	NW	BR	OT
019	N50W	88SW	001	006	016	006	R	NW	BR	OT

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
019	N50W	88SW	001	006	014	006	R	NW	BR	OT
019	N50W	88SW	006	002	015	002	R	NW	BR	OT
019	N50W	88SW	007	002	011	002	R	NW	BR	OT
019	N50W	88SW	009	003	010	003	R	NW	BR	OT
019	N50W	88SW	006	003	007	003	R	NW	BR	OT
020	N24E	68SE	048	004	007	004	R		BR	OT
020	N35E	67SE	075	009		009	R	NE	BR	OT
020	N35E	66SE	010	007	003	007	R	NE	BR	OT
020	N49W	75SW	007	023	030	004	R	NW	BR	OT
020	N49W	75SW	017	011	065	004	R	NW	BR	OT
020	N49W	75SW	001	013	048	008	R	NW	BR	OT
020	N49W	75SW	001	013	050	008	R	NW	BR	OT
020	N24E	68SE	183	013	003	008	R		BR	OT
020	N24E	68SE	103	008		008	R		BR	OT
020	N05E	58NW	089	026		015	R		BR	OT
020	N05E	58NW	089	014	008	005	R		BR	OT
020	N05E	58NW	035	019	007	008	R		BR	OT
020	N05E	58NW	053	054	019	008	R		BR	OT
020	N05E	58NW	057	041		005	R		BR	OT
020	N05E	58NW	024	007	005	007	R		BR	OT
021	N37W	85SW	048	024	025	024	R	NW	BR	OT
021	N12E	67NW	066	026	023	026	R		BR	OT
021	N12E	67NW	064	023	004	023	R		BR	OT
021	N12E	67NW	119	023		023	R		BR	OT
021	N12E	67NW	078	023	030	023	R		BR	OT
021	N12E	67NW	045	023	004	023	R		BR	OT
021	N12E	67NW	078	023		023	R		BR	OT
021	N37W	85SW	035	010	024	010	R	NW	BR	OT
021	N37W	85SW	032	012	032	012	R	NW	BR	OT
021	N37W	85SW	006	011	016	001	R	NW	BR	OT
021	N37W	85SW	032	019	031	019	R	NW	BR	OT
021	N37W	85SW	070	023	030	023	R	NW	BR	OT
021	N37W	85SW	037	011	029	011	R	NW	BR	OT
021	N37W	85SW	037	022	026	022	R	NW	BR	OT
021	N37W	85SW	034	022	019	022	R	NW	BR	OT
021	N70W	90SW	007	021	006	021	R		BR	OT
021	N70W	90SW	001	024	004	024	R		BR	OT
021	N70W	90SW	001	024	003	024	R		BR	OT
021	N70W	90SW	001	024	007	024	R		BR	OT
021	N70W	90SW	001	024	008	024	R		BR	OT
021	N70W	90SW	001	024	009	024	R		BR	OT
021	N70W	90SW	001	024	008	024	R		BR	OT
021	N70W	90SW	001	024	026	024	R		BR	OT
022	N57E	78NW	062	039	029	039	R		SO	OT
022	N16E	77SE	040	039	084	039	R		SO	OT
022	N57E	78NW	050	039		039	R		SO	OT
022	N57E	78NW	125	028	025	028	R		SO	OT

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
022	N57E	78NW	012	037	044	037	R		SO	OT
022	N57E	78NW	027	037	057	037	R		SO	OT
022	N57E	78NW	038	037	018	037	R		SO	OT
022	N16E	77SE	003	007	029	007	R		SO	OT
022	N16E	77SE	030	007	018	007	R		SO	OT
022	N57E	78NW	055	025		025	R		SO	OT
022	N16E	77SE	045	025	075	025	R		SO	OT
022	N16E	77SE	080	025	052	025	R		SO	OT
023	N10E	90NW	025	005	018	005	R		SO	OT
023	N10E	90NW	014	005	028	005	R		SO	OT
023	N10E	90NW	012	005	028	005	R		SO	OT
023	N10E	90NW	009	005	014	005	R		SO	OT
023	N40E	90NW	017	005	023	005	R	NE	SO	OT
023	N40E	90NW	019	005	024	005	R	NE	SO	OT
023	N40E	90NW	014	005	030	005	R	NE	SO	OT
023	N45W	73SW	071	012		012	R	NW	SO	OT
023	N45W	73SW	087	009		009	R	NW	SO	OT
023	N13W	75SW	030	006	013	006	R		SO	OT
023	N13W	75SW	005	006	015	006	R		SO	OT
023	N40E	90NW	017	007	023	007	R	NE	SO	OT
023	N40E	90NW	007	007	005	007	R	NE	SO	OT
023	N40E	90NW	017	007	015	007	R	NE	SO	OT
023	N40E	90NW	010	007	015	007	R	NE	SO	OT
023	N45W	73SW	200	050	025	007	R	NW	SO	OT
024	N08W	70SW	020	007	022	007	R		SO	OT
024	N08W	70SW	021	007	022	007	R		SO	OT
024	N08W	70SW	020	010	022	010	R		SO	OT
024	N08W	70SW	020	002	020	002	R		SO	OT
024	N08W	72SW	044	009	043	009	R		SO	OT
024	N28E	90NW	015	003	025	003	R	NE	SO	OT
024	N28E	90NW	007	005	027	005	R	NE	SO	OT
024	N08W	72SW	010	006	014	006	R		SO	OT
024	N08W	72SW	017	008		008	R		SO	OT
024	N08W	72SW	049	014	022	014	R		SO	OT
024	N08W	72SW	026	014	018	004	R		SO	OT
024	N10E	65NW	014	005	023	005	R		SO	OT
024	N20E	77NW	007	007	002	007	R		SO	OT
024	N20E	77NW	010	008	008	008	R		SO	OT
025	N10W	69SW	012	017	008	017	R		SO	OT
025	N02E	69SE	006	017	005	017	R		SO	OT
025	N07W	69SW	002	017	008	017	R		SO	OT
025	N07W	69SW	010	017	013	017	R		SO	OT
025	N07W	69SW	010	010	023	010	R		SO	OT
025	N07W	69SW	017	010	014	010	R		SO	OT
025	N07W	69SW	040	025	052	025	R		SO	OT
025	N07W	69SW	057	025	018	025	R		SO	OT
025	N07W	69SW	047	110	026	025	R		SO	OT

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
025	N07W	69SW	023	004	008	004	R		SO	OT
025	N07W	69SW	009	004	018	004	R		SO	OT
025	N18E	61NW	027	006	006	006	R		SO	OT
025	N18E	61NW	010	006	004	006	R		SO	OT
025	N18E	61NW	017	006	007	006	R		SO	OT
025	N18E	61NW	010	006	004	006	R		SO	OT
025	N18E	61NW	020	008	004	008	R		SO	OT
025	N18E	61NW	007	008	005	008	R		SO	OT
025	N18E	61NW	001	008	008	008	R		SO	OT
025	N18E	61NW	001	008	009	008	R		SO	OT
025	N18E	61NW	001	008	009	008	R		SO	OT
026	N38W	90SW	413	018	010	018	R	NW	IN	IN
026	N80E	60SE	001	018	042	018	R	EW	IN	IN
026	N80E	60SE	001	018	057	018	R	EW	IN	IN
026	N80E	60SE	001	018	029	018	R	EW	IN	IN
026	N80E	60SE	001	018	059	018	R	EW	IN	IN
026	N35W	90SW	057	019	023	029	R	NW	IN	IN
026	N35W	90SW	048	019	013	019	R	NW	IN	IN
026	N35W	90SW	099	019	013	019	R	NW	IN	IN
026	N35W	90SW	099	019	012	019	R	NW	IN	IN
026	N35W	90SW	090	019	014	019	R	NW	IN	IN
026	N35W	90SW	057	019	010	019	R	NW	IN	IN
026	N35W	90SW	056	019	018	019	R	NW	IN	IN
026	N35W	90SW	120	019	024	019	R	NW	IN	IN
026	N80E	60SE	009	009	028	009	R	EW	IN	IN
026	N80E	60SE	003	009	026	009	R	EW	IN	IN
026	N80E	60SE	003	009	015	009	R	EW	IN	IN
026	N80E	60SE	001	009	012	009	R	EW	IN	IN
026	N80E	60SE	003	009	035	009	R	EW	IN	IN
026	N80E	60SE	016	009	013	009	R	EW	IN	IN
026	N80E	60SE	003	009	032	009	R	EW	IN	IN
026	N80E	60SE	003	009	035	009	R	EW	IN	IN
026	N38W	90SW	014	006	019	006	R	NW	IN	IN
026	N38W	90SW	008	103	015	006	R	NW	IN	IN
026	N38W	90SW	005	006	015	006	R	NW	IN	IN
027	N71W	90SW	114	012		012	R		IN	IN
027	N06W	90SW	127	010		010	R		IN	IN
027	N71W	90SW	022	007		007	R		IN	IN
027	N71W	90SW	032	011		011	R		IN	IN
027	N45E	90NW	038	013		013	R	NE	IN	IN
028	N50W	90SW	075	015	009	015	R	NW	IN	IN
028	N50W	90SW	078	017	014	017	R	NW	IN	IN
028	N50W	90SW	075	013		013	R	NW	IN	IN
028	N50W	90SW	091	008		008	R	NW	IN	IN
028	N50W	90SW	020	010	015	010	R	NW	IN	IN
028	N50W	90SW	025	008		008	R	NW	IN	IN
028	N50W	90SW	129	006		006	R	NW	IN	IN

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GP
028	N77W	74NE	050	013	027	013	R		IN	IN
028	N75W	75NE	072	014	011	014	R		IN	IN
028	N77W	78NE	025	009	011	009	R		IN	IN
028	N77W	78NE	001	009	005	009	R		IN	IN
028	N77W	78NE	030	009	003	009	R		IN	IN
028	N77W	78NE	022	004	011	004	R		IN	IN
028	N77W	78NE	048	004	016	004	R		IN	IN
028	N77W	78NE	020	004	008	004	R		IN	IN
028	N77W	78NE	015	004	006	004	R		IN	IN
028	N77W	78NE	015	003	009	003	R		IN	IN
028	N77W	78NE	028	015	022	004	R		IN	IN
029	N85E	85NW	139	021		021	R	EW	IN	IN
029	N45W	78SW	094	011		011	R	NW	IN	IN
029	N40W	80SW	083	032	008	032	R	NW	IN	IN
029	N40W	80SW	036	032	010	032	R	NW	IN	IN
029	N40W	80SW	042	032	031	032	R	NW	IN	IN
029	N40W	80SW	037	025	005	025	R	NW	IN	IN
029	N40W	80SW	154	025		025	R	NW	IN	IN
029	N40W	80SW	041	012	009	012	R	NW	IN	IN
029	N40W	80SW	047	012	013	012	R	NW	IN	IN
029	N40W	80SW	070	018	020	018	R	NW	IN	IN
029	N40W	80SW	015	012	008	012	R	NW	IN	IN
029	N40W	80SW	074	012		012	R	NW	IN	IN
029	N85E	85NW	052	019	011	007	R	EW	IN	IN
029	N85E	85NW	100	018	004	018	R	EW	IN	IN
029	N85E	85NW	195	030		030	R	EW	IN	IN
030	N59W	90SW	017	003	020	003	R		IN	IN
030	N59W	90SW	019	002	012	002	R		IN	IN
030	N59W	90SW	021	002	027	002	R		IN	IN
030	N59W	90SW	020	003	020	003	R		IN	IN
031	N42W	83SW	058	046	103	046	R	NW	IN	IN
031	N87W	85SW	045	069		033	R	EW	IN	IN
031	N65W	89NE	054	028	016	028	R		IN	IN
031	N65W	89NE	012	028		028	R		IN	IN
031	N87W	85SW	030	036	057	036	R	EW	IN	IN
031	N87W	85SW	010	050		050	R	EW	IN	IN
031	N87W	85SW	010	022	045	022	R	EW	IN	IN
031	N87W	85SW	017	024	022	024	R	EW	IN	IN
031	N87W	85SW	005	050		050	R	EW	IN	IN
031	N87W	85SW	017	101	044	050	R	EW	IN	IN
031	N38W	88SW	102	078	058	078	R	NW	IN	IN
031	N42W	83NE	120	078	076	078	R	NW	IN	IN
031	N42W	83NE	078	043	037	043	R	NW	IN	IN
031	N42W	83NE	045	042	044	042	R	NW	IN	IN
031	N42W	83NE	047	026	050	026	R	NW	IN	IN
032	N89E	83NW	024	020	028	020	R	EW	IN	IN
032	N89E	83NW	011	019		019	R	EW	IN	IN

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
032	N89E	83NW	011	008	017	008	R	EW	IN	IN
032	N89E	83NW	010	002	017	002	R	EW	IN	IN
032	N89E	83NW	005	005	013	005	R	EW	IN	IN
032	N89E	83NW	012	003	007	003	R	EW	IN	IN
032	N89E	83NW	022	013	034	013	R	EW	IN	IN
032	N89E	83NW	010	022	075	022	R	EW	IN	IN
032	N89E	83NW	015	022	048	022	R	EW	IN	IN
033	N83W	90SW	037	018	025	018	R	EW	IN	IN
033	N83W	90SW	012	018	020	018	R	EW	IN	IN
033	N83W	90SW	021	014	014	014	R	EW	IN	IN
033	N83W	90SW	007	006	011	006	R	EW	IN	IN
033	N83W	90SW	021	006	012	006	R	EW	IN	IN
033	N83W	90SW	006	010	008	010	R	EW	IN	IN
033	N83W	90SW	027	016	018	016	R	EW	IN	IN
033	N83W	90SW	087	019	024	019	R	EW	IN	IN
033	N83W	90SW	053	018	024	018	R	EW	IN	IN
033	N83W	90SW	056	025	032	025	R	EW	IN	IN
035	N47W	90SW	300				SC	NW	IN	IN
035	N24E	45SE	200		090		SC		IN	IN
035	N24E	45SE	200		059		SC		IN	IN
035	N24E	45SE	040		029		SC		IN	IN
035	N02E	45SE	040		021		SC		IN	IN
035	N02E	45SE	016		031		SC		IN	IN
035	N02E	45SE	023		011		SC		IN	IN
035	N55W	90SW	048	017	047	010	SC	NW	IN	IN
035	N55W	90SW	017	010	009	010	SC	NW	IN	IN
035	N55W	90SW	030	010	025	010	SC	NW	IN	IN
035	N55W	90SW	039	010	035	010	SC	NW	IN	IN
035	N85W	90SW	020	010	036	010	SC	EW	IN	IN
035	N85W	90SW	047	010	029	010	SC	EW	IN	IN
035	N85W	90SW	036	010	016	010	SC	EW	IN	IN
035	N85W	90SW	036	010	037	010	SC	EW	IN	IN
035	N68W		077				SC		IN	IN
036	N48W	84SW	029	018	010	007	R	NW	IN	IN
036	N81E	82SE	002	007	011	007	R	EW	IN	IN
036	N43E	57NW	012	007	017	007	R	NE	IN	IN
036	N48W	84SW	001	018	020	007	R	NW	IN	IN
036	N48W	84SW	029	018	016	007	R	NW	IN	IN
036	N48W	84SW	021	007		007	R	NW	IN	IN
036	N81E	82SE	012	007	010	007	R	EW	IN	IN
036	N81E	82SE	017	007	055	007	R	EW	IN	IN
036	N48W	84SW	086	019	022	007	R	NW	IN	IN
036	N48W	84SW	035	007	008	007	R	NW	IN	IN
036	N48W	84SW	001	007	008	007	R	NW	IN	IN
036	N48W	84SW	001	007	008	007	R	NW	IN	IN
036	N81E	82SE	010	007		007	R	EW	IN	IN
036	N43E	57NW	001	007	037	007	R	NE	IN	IN

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GB
036	N43E	57NW	001	007	005	007	R	NE	IN	IN
036	N43E	57NW	001	007	018	007	R	NE	IN	IN
036	N48W	84SW	015	003	009	003	R	NW	IN	IN
036	N48W	84SW	003	003	005	003	R	NW	IN	IN
036	N48W	84SW	001	003	010	003	R	NW	IN	IN
036	N48W	84SW	001	003	003	003	R	NW	IN	IN
036	N43E	57NW	019	005	013	005	R	NE	IN	IN
036	N43W	57NW	015	005	014	005	R	NW	IN	IN
036	N81E	82SE	014	005	021	005	R	EW	IN	IN
036	N81E	82SE	018	016	009	005	R	EW	IN	IN
037	N65W	90SW					R		IN	IN
037	N18E	90NW					R		IN	IN
038	N57W	90SW	500	019		019	R		IN	IN
038	N57W	90SW	043	006	012	006	R		IN	IN
038	N57W	90SW	014	006	015	006	R		IN	IN
038	N57W	90SW	007	006	012	006	R		IN	IN
038	N57W	90SW	019	006	010	006	R		IN	IN
038	N57W	90SW	052	006	006	006	R		IN	IN
038	N57W	90SW	250	008	023	008	R		IN	IN
038	N57W	90SW	117	016	020	016	R		IN	IN
039							R		IN	IN
040	N53W	90SW					R	NW	IN	IN
040	N46W	90SW					R	NW	IN	IN
040	N45W	90SW					R	NW	IN	IN
040	N72W	88NE		150			R		IN	IN
040	N51W	90SW					R	NW	IN	IN
040	N80W	90SW					R	EW	IN	IN
040	N73W	90SW					R		IN	IN
040	N74W	90SW					R		IN	IN
040	N80W	90SW		150	015		R	EW	IN	IN
041	N80W	88NE		150			R	EW	IN	IN
041	N25E	90NW					R	NE	IN	IN
041	N25E	90NW	180	090		090	R	NE	IN	IN
041	N25E	90NW		200			R	NE	IN	IN
042	N53W	90SW	035	006	020	006	R	NW	IN	IN
042	N55W	90SW	010	025	028	012	R	NW	IN	IN
042	N53W	90SW	020	150		012	R	NW	IN	IN
042	N53W	90SW	029	048		012	R	NW	IN	IN
042	N53W	90SW	015	012	020	012	R	NW	IN	IN
042	N53W	90SW	050	120	057	020	R	NW	IN	IN
042	N53W	90SW	020	110	040	020	R	NW	IN	IN
042	N53W	90SW	015	050	040	020	R	NW	IN	IN
043	N46W	90SW	005	064	020	020	R	NW	IN	IN
043	N46W	90SW	005	065	050	020	R	NW	IN	IN
043	N46W	90SW	012	063	027	020	R	NW	IN	IN
043	N46W	90SW	063	051		051	R	NW	IN	IN
043	N46W	90SW	012	006	016	006	R	NW	IN	IN

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GP
043	N46W	90SW	009	006	018	006	R	NW	IN	IN
043	N46W	90SW	004	058	029	058	R	NW	IN	IN
043	N46W	90SW	029	019	023	019	R	NW	IN	IN
044	N48W	90SW	210	185		025	R	NW	IN	IN
044	N48W	90SW	104	100		025	R	NW	IN	IN
044	N48W	90SW	200	101		050	R	NW	IN	IN
044	N48W	90SW	500	050		030	R	NW	IN	IN
044	N48W	90SW	001	062	005	026	R	NW	IN	IN
044	N48W	90SW	001	062	075	026	R	NW	IN	IN
045	N65W	90SW	125	092	030	015	R		IN	IN
045	N65W	90SW	025	149		015	R		IN	IN
045	N65W	90SW	003	010	006	003	R		IN	IN
045	N65W	90SW	003	010	005	003	R		IN	IN
045	N65W	90SW	001	010	007	003	R		IN	IN
045	N65W	90SW	001	010	010	003	R		IN	IN
045	N65W	90SW	001	010	006	003	R		IN	IN
046	N85W	90SW	012	182	052	020	R	EW	IN	IN
046	N85W	90SW	007	190	028	020	R	EW	IN	IN
046	N85W	90SW	015	146	007	020	R	EW	IN	IN
046	N85W	90SW	001	097	007	020	R	EW	IN	IN
046	N85W	90SW	002	097	002	020	R	EW	IN	IN
046	N85W	90SW	003	096	002	020	R	EW	IN	IN
046	N85W	90SW	002	092	003	020	R	EW	IN	IN
046	N85W	90SW	002	093	005	020	R	EW	IN	IN
047	N26E	83SE	083	057	065	001	R	NE	NO	OT
047	N26E	83SE	041	059	020	001	R	NE	NO	OT
047	N85W	86SW	014	007	020	007	R	EW	NO	OT
047	N85W	86SW	006	010	013	007	R	EW	NO	OT
047	N85W	86SW	007	006	006	006	R	EW	NO	OT
047	N85W	86SW	010	011	029	011	R	EW	NO	OT
047	N85W	86SW	014	015	017	009	R	EW	NO	OT
047	N85E	86SW	023	009	026	009	R	EW	NO	OT
047	N85E	86SE	009	010	014	010	R	EW	NO	OT
048	N33W	55SW	146	070		003	R		NO	OT
048	N83E	90NW	006	004	007	004	R	EW	NO	OT
048	N83E	90NW	006	004	005	004	R	EW	NO	OT
048	N83E	90NW	001	004	011	004	R	EW	NO	OT
048	N30W	62SW	012	004		004	R		NO	OT
048	N30W	62SW	009	004		004	R		NO	OT
048	N45W	62SW	010	004	005	004	R	NW	NO	OT
049	N46W	71SW	165	027		027	R	NW	NO	OT
049	N88W	76NE	121	028		028	R	EW	NO	OT
049	N88W	76NE	034	004	008	004	R	EW	NO	OT
049	N46W	71SW	066	016	028	016	R	NW	NO	OT
049	N46W	71SW	050	016	011	016	R	NW	NO	OT
049	N46W	71SW	035	010	011	010	R	NW	NO	OT
049	N88W	76NE	028	018	030	018	R	EW	NO	OT

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
049	N88W	76NE	036	013	015	013	R	EW	NO	OT
049	N46W	71SW	015	016	014	016	R	NW	NO	OT
049	N12W	28SW	010	022	019	022	R		NO	OT
049	N12W	28SW	012	017		017	R		NO	OT
049	N12W	28SW	005	007	005	007	R		NO	OT
049	N12W	28SW	001	006	006	006	R		NO	OT
049	N12W	28SW	012	027	040	027	R		NO	OT
049	N46W	71SW	028	027	021	027	R	NW	NO	OT
049	N46W	71SW	025	027	013	027	R	NW	NO	OT
049	N46W	71SW	065	027	014	027	R	NW	NO	OT
049	N12W	28SW	010	015	013	015	R		NO	OT
049	N12W	28SW	003	015	020	015	R		NO	OT
049	N88W	76NE	033	017	021	017	R	EW	NO	OT
049	N88W	76NE	023	025	012	025	R	EW	NO	OT
050	N21W	90SW	500		096	001	S		NO	OT
050	N21W	90SW	500				S		NO	OT
050	N05W	90SW	386		122	001	S		NO	OT
050	N05W	90SW	238			001	S		NO	OT
050	N05W	90SW	120		025	001	S		NO	OT
050	N05W	90SW	293		036	001	S		NO	OT
050	N05W	90SW	251		037	001	S		NO	OT
050	N03W	90SW	450		150		SC		NO	OT
050	N03W	90SW	223				SC		NO	OT
050	N45W	90SW	048	007	015	007	SC	NW	NO	OT
050	N45W	90SW	061	007	018	007	SC	NW	NO	OT
050	N45W	90SW	081	007	025	007	SC	NW	NO	OT
050	N45W	90SW	105	007	018	007	SC	NW	NO	OT
050	N45W	90SW	014	007	017	007	SC	NW	NO	OT
050	N45W	90SW	015	007	015	007	SC	NW	NO	OT
050	N45W	90SW	028	007	036	007	SC	NW	NO	OT
051	N48W	88SW	081	029	027	029	SC	NW	NO	OT
051	N48W	88SW	081	029	025	029	SC	NW	NO	OT
051	N48W	88SW	078	029	021	029	SC	NW	NO	OT
051	N48W	88SW	066	029	005	029	SC	NW	NO	OT
051	N48W	88SW	048	029	032	029	SC	NW	NO	OT
051	N48W	88SW	049	029	015	029	SC	NW	NO	OT
051	N83W	90SW	130	025	038	025	SC	EW	NO	OT
051	N43W	90SW	072	025	030	025	SC	NW	NO	OT
051	N43W	90SW	086	025	062	025	SC	NW	NO	OT
051	N43W	90SW	090	025	034	025	SC	NW	NO	OT
051	N48W	88SW	035	025		025	SC	NW	NO	OT
051	N48W	88SW	056	005	015	005	SC	NW	NO	OT
051	N48W	88SW	085	005	006	005	SC	NW	NO	OT
051	N48W	88SW	056	005	006	005	SC	NW	NO	OT
051	N48W	88SW	061	005	015	005	SC	NW	NO	OT
051	N48W	88SW	046	005	010	005	SC	NW	NO	OT
051	N48W	88SW	067	005	055	005	SC	NW	NO	OT

STA	STRI	DIP	LNG	DTH	SPA	BED	FX	ST	IO	GR
052	N58W	75SW	150	080			R		NO	OT
053							R		NO	OT
054	N66W	90SW			032	013	R		IN	IN
054	N66W	90SW			027	013	R		IN	IN
054	N66W	90SW			021	013	R		IN	IN
054	N66W	90SW			028	013	R		IN	IN
054	N66W	90SW			016	013	R		IN	IN
054	N66W	90SW			015	013	R		IN	IN
054	N66W	90SW			028	013	R		IN	IN
054	N66W	90SW			022	013	R		IN	IN
054	N42E	45NW			059		R	NE	IN	IN
054	N42E	45NW			053		R	NE	IN	IN
054	N42E	45NW			081		R	NE	IN	IN
054	N42E	45NW			068		R	NE	IN	IN
054	N42E	45NW			016		R	NE	IN	IN
054	N42E	45NW			027		R	NE	IN	IN
054	N42E	45NW			038		R	NE	IN	IN
054	N42E	45NW			021		R	NE	IN	IN
054	N88W	90SW			067		R	EW	IN	IN
054	N88W	90SW			030		R	EW	IN	IN
054	N88W	90SW			020		R	EW	IN	IN
054	N88W	90SW			071		R	EW	IN	IN
054	N88W	90SW			027		R	EW	IN	IN
054	N88W	90SW			026		R	EW	IN	IN
054	N88W	90SW			030		R	EW	IN	IN
054	N88W	90SW			009		R	EW	IN	IN
055	N46W	89SW	109	047	019	047	R	NW	NO	OT
055	N87W	89NE	075	034	038	047	R	EW	NO	OT
055	N87W	89NE	138	028	069	028	R	EW	NO	OT
055	N42E	85NW	010	056		001	R	NE	NO	OT
055	N36E	90NW	050	028	130	028	R	NE	NO	OT
055	N46W	89SW	013	019		028	R	NW	NO	OT
055	N25E	90NW	012	006	009	001	R	NE	NO	OT
055	N25E	90NW	001	006	019	001	R	NE	NO	OT
055	N25E	90NW	001	006	020	001	R	NE	NO	OT
055	N36E	90NW	050	027	092	027	R	NE	NO	OT
055	N46W	89SW	048	027		027	R	NW	NO	OT
055	N87W	89NE	030	008	015	008	R	EW	NO	OT
055	N87W	89NE	010	008		008	R	EW	NO	OT
056	N45W	90SW	034	043	036	043	R	NW	NO	OT
056	N45W	90SW	010	043	062	043	R	NW	NO	OT
056	N45W	90SW	120	134		100	R	NW	NO	OT
056	N45W	90SW	038	123	015	100	R	NW	NO	OT
056	N45W	90SW	146	200		200	R	NW	NO	OT
056	N45W	90SW	180	220		200	R	NW	NO	OT
057	N83W	83NE	073	026	018	026	R	EW	NO	OT
057	N83W	84NE	001	026	018	026	R	EW	NO	OT

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GE
057	N83W	83NE	020	026	054	026	R	EW	NO	OT
057	N36W	83SW	041	021	016	021	R	NW	NO	OT
057	N36W	83SW	028	021	025	021	R	NW	NO	OT
057	N36W	83SW	033	021	024	021	R	NW	NO	OT
057	N38E	33NW	016	021	046	021	R	NE	NO	OT
057	N38E	33NW	025	021	029	021	R	NE	NO	OT
057	N38E	33NW	024	021	029	021	R	NE	NO	OT
058	N83E	49SE	057	067	006	001	R	EW	NO	OT
058	N73W	75SW	173	049		058	R		NO	OT
058	N83E	49SE	007	075	006	010	R	EW	NO	OT
058	N83E	49SE	008	069	019	010	R	EW	NO	OT
058	N83E	49SE	020	180	063	010	R	EW	NO	OT
058	N83E	49SE	015	250		010	R	EW	NO	OT
058	N83E	49SE	012	053	009	010	R	EW	NO	OT
058	N83E	49SE	006	041	010	010	R	EW	NO	OT
059	N20E	90NW					R		NO	OT
059	N80W	90SW					R	EW	NO	OT
060	N49W	90SW	042	030	025	030	R	NW	NO	OT
060	N49W	90SW	031	030	036	030	R	NW	NO	OT
060	N49W	90SW	029	030	006	030	R	NW	NO	OT
061	N41W	77SW	019	061	051	061	R	NW	NO	OT
061	N41W	77SW	038	061	041	061	R	NW	NO	OT
061	N41W	77SW	049	061	058	061	R	NW	NO	OT
061	N41W	77SW	033	038	024	038	R	NW	NO	OT
061	N41W	77SW	028	038	023	038	R	NW	NO	OT
061	N41W	77SW	021	038	037	038	R	NW	NO	OT
062	N75W	90SW	300	104		083	R		NO	OT
062	N45E	48NW					R	NE	NO	OT
063	N47W	84NE	091	058	068	058	S	NW	NO	OT
063	N75W	72NE	027	058		058	S		NO	OT
063	N47W	84NE	050	058	064	058	S	NW	NO	OT
063	N47W	84NE	080	047	021	044	S	NW	NO	OT
063	N47W	84NE	087	047	060	044	S	NW	NO	OT
063	N47W	84NE	020	058	037	058	S	NW	NO	OT
063	N47W	84NE	008	058	035	058	S	NW	NO	OT
063	N75W	72NE	001	078	088	058	S		NO	OT
063	N75W	72NE	003	163	100	058	S		NO	OT
063	N75W	72NE	008	080	025	020	S		NO	OT
063	N47W	84NE	031	018	023	018	S	NW	NO	OT
063	N47W	84NE	037	018	019	018	S	NW	NO	OT
063	N75W	72NE	045	018	085	018	S		NO	OT
063	N75W	72NE	060	018	031	018	S		NO	OT
063	N75W	72NE	027	018	051	018	S		NO	OT
064	N75W	80NE	029	005	014	005	R		NO	OT
064	N45W	78SW	025	019	015	012	R	NW	NO	OT
064	N45W	78SW	052	010	012	010	R	NW	NO	OT
064	N75W	80NE	026	005	011	005	R		NO	OT

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
064	N45W	78SW	022	012	020	012	R	NW	NO	OT
064	N75W	80NE	046	010	007	010	R		NO	OT
064	N45W	78SW	035	019	028	019	R	NW	NO	OT
064	N45W	78SW	007	019	013	019	R	NW	NO	OT
064	N45W	78SW	018	019	014	019	R	NW	NO	OT
064	N45W	78SW	057	012	020	012	R	NW	NO	OT
064	N87E	76NW	021	017	014	017	R	EW	NO	OT
064	N87E	76NW	007	017	015	017	R	EW	NO	OT
064	N87E	76NW	015	017	014	017	R	EW	NO	OT
065	N44W	89SW	058	025	042	025	S	NW	NO	OT
065	N44W	89SW	043	025	010	025	S	NW	NO	OT
065	N44W	89SW	039	025	025	025	S	NW	NO	OT
065	N44W	89SW	037	025	036	025	S	NW	NO	OT
065	N44W	89SW	054	025	027	025	S	NW	NO	OT
065	N44W	89SW	032	012	010	025	S	NW	NO	OT
065	N44W	89SW	028	012	008	025	S	NW	NO	OT
065	N44W	89SW	027	012	013	025	S	NW	NO	OT
065	N44W	89SW	025	012	012	025	S	NW	NO	OT
065	N89W	90SW	053	025	018	025	S	EW	NO	OT
065	N89W	90SW	029	025	009	025	S	EW	NO	OT
066	N72W	66SW	031	007	032	007	R		NO	OT
066	N72W	66SW	011	012	026	012	R		NO	OT
066	N58W	63SW	010	009	011	009	R		NO	OT
066	N58W	63SW	025	009	014	009	R		NO	OT
066	N58W	63SW	029	009	015	009	R		NO	OT
066	N58W	63SW	020	009	012	009	R		NO	OT
066	N49W	76SW	014	010	066	024	R	NW	NO	OT
066	N49W	76SW	031	012	013	012	R	NW	NO	OT
066	N49W	76SW	026	012	017	012	R	NW	NO	OT
067	N78W	69SW	026	019			R		NO	OT
067	N78W	69SW	035	019			R		NO	OT
068	N40W	90NW	016		065		S	NW	NO	OT
068	N45W	90SW	067	017	020	007	S	NW	NO	OT
068	N45W	90SW	040	027	024	007	S	NW	NO	OT
068	N45W	90SW	058	009	011	009	S	NW	NO	OT
068	N45W	90SW	060	009	026	009	S	NW	NO	OT
068	N45W	90SW	055	009	022	009	S	NW	NO	OT
068	N45W	90SW	072	009	042	009	S	NW	NO	OT
068	N78W	69SW	250				S		NO	OT
068	N78W	69SW	005	006	023	006	S		NO	OT
068	N78W	69SW	008	007	009	006	S		NO	OT
068	N78W	69SW	003	007	020	006	S		NO	OT
068	N78W	69SW	002	009	010	006	S		NO	OT
069	N46W	90SW	121	050	035	050	R	NW	NO	OT
069	N46W	90SW	093	042		042	R	NW	NO	OT
069	N46W	90SW	105	017		020	R	NW	NO	OT
069	N46W	90SW	135	060	021	042	R	NW	NO	OT

STA	STRI	DIP	LNG	DTH	SPA	BED	FX	ST	LO	GR
069	N46W	90SW	098	043		043	R	NW	NO	OT
069	N46W	90SW	080	035		035	R	NW	NO	OT
069	N34E	90NW	080	035		035	R	NE	NO	OT
069	N64W	90SW	094	046		039	R		NO	OT
069	N46W	90SW	109	053		053	R	NW	NO	OT
069	N46W	90SW	068	025	034	025	R	NW	NO	OT
069	N46W	90SW	055	025		025	R	NW	NO	OT
069	N46W	90SW	025	012	005	012	R	NW	NO	OT
069	N46W	90SW	012	012	007	012	R	NW	NO	OT
069	N46W	90SW	013	012	009	012	R	NW	NO	OT
070	N32E	81NW	461	020	000	032	R	NE	NO	OT
070	N36E	82NW	479	012	000	032	R	NE	NO	OT
070	N41W	90SW	015	006	000	006	R	NW	NO	OT
070	N48E	65NW	025	006	000	006	R		NO	OT
070	N46W	90SW	016	008	009	008	R	NW	NO	OT
070	N41W	90SW	004	008	013	008	R	NW	NO	OT
070	N41W	90SW	022	010	018	010	R	NW	NO	OT
070	N41W	90SW	023	010	000	010	R	NW	NO	OT
070	N43W	90SW	006	013	006	013	R	NW	NO	OT
070	N41W	90SW	005	013	006	013	R	NW	NO	OT
070	N41W	90SW	015	013	009	013	R	NW	NO	OT
070	N41W	90SW	006	010	010	010	R	NW	NO	OT
070	N41W	90SW	007	010	011	010	R	NW	NO	OT
070	N41W	90SW	019	010	007	010	R	NW	NO	OT
070	N41W	90SW	011	017	060	017	R	NW	NO	OT
070	N41W	90SW	011	017	015	017	R	NW	NO	OT
071	N71W	84SW	005	008	011	008	R		NO	OT
071	N71W	84SW	008	008	016	008	R		NO	OT
071	N71W	84SW	001	008	010	008	R		NO	OT
071	N71W	84SW	019	008	013	008	R		NO	OT
071	N71W	84SW	022	008	010	008	R		NO	OT
071	N71W	84SW	004	009	001	009	R		NO	OT
071	N71W	84SW	001	009	012	009	R		NO	OT
071	N71W	84SW	008	009	015	009	R		NO	OT
071	N71W	84SW	003	009	014	009	R		NO	OT
071	N71W	84SW	003	009	002	009	R		NO	OT
071	N11E	59NW	033	010	006	010	R		NO	OT
071	N11E	59NW	028	010	000	010	R		NO	OT
071	N42W	77SW	033	023	017	017	R	NW	NO	OT
071	N42W	77SW	027	027	009	018	R	NW	NO	OT
071	N42W	77SW	010	017	000	022	R	NW	NO	OT
071	N78W	81SW	007	013	008	013	R		NO	OT
071	N78W	81SW	008	013	010	013	R		NO	OT
071	N78W	81SW	027	013	011	013	R		NO	OT
071	N42W	77SW	025	030	032	030	R	NW	NO	OT
071	N42W	77SW	039	055	032	030	R	NW	NO	OT
072	N60W	90SW	055	018	000	023	R		NO	OT

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	IO	GR
072	N25E	90NW	039	010	000	010	R	NE	NO	OT
072	N55W	90SW	020	028	000	021	R	NW	NO	OT
072	N60W	90SW	032	032	000	030	R		NO	OT
072	N60W	90SW	027	020	026	020	R		NO	OT
072	N85E	90NW	020	042	000	003	R	EW	NO	OT
072	N70W	83SW	020	083	000	007	R		NO	OT
072	N55W	90SW	038	080	000	015	R	NW	NO	OT
073	N85W	84SW	093	041	000	041	R	EW	NO	OT
073	N31W	79SW	045	036	099	036	R		NO	OT
073	N31W	79SW	039	036	099	036	R		NO	OT
073	N31W	79SW	010	036	000	036	R		NO	OT
073	N85W	84SW	044	020	000	020	R	EW	NO	OT
073	N41W	69SW	036	053	023	029	R	NW	NO	OT
073	N41W	69SW	043	060	000	020	R	NW	NO	OT
074	N87W	76SW	122	134	000	134	R	EW	NO	OT
074	N87W	76SW	070	027	000	023	R	EW	NO	OT
074	N87W	76SW	037	007	018	007	R	EW	NO	OT
074	N87W	76SW	031	007	010	007	R	EW	NO	OT
074	N87W	76SW	053	033	000	007	R	EW	NO	OT
074	N05E	79NW	046	007	000	007	R		NO	OT
075	N70E	60NW	165	010	000	005	R		NO	OT
075	N82E	90NW	135	015	035	015	R	EW	NO	OT
075	N82E	90NW	058	015	000	015	R	EW	NO	OT
076	N15E	90NW	076	012	076	012	S		NO	OT
076	N15E	90NW	050	012	037	012	S		NO	OT
076	N15E	90NW	086	012	047	012	S		NO	OT
076	N15E	90NW	094	012	049	012	S		NO	OT
076	N15E	90NW	080	012	000	012	S		NO	OT
076	N85E	90NW	157	012	000	012	S	EW	NO	OT
077	N22E	90NW	048	019	016	019	S		NO	OT
077	N45E	85NW	071	018	064	018	S	NE	NO	OT
077	N46W	90SW	051	025	019	019	S	NW	NO	OT
077	N87W	90SW	082	000	010	009	S	EW	NO	OT
077	N22E	90NW	037	019	016	019	S		NO	OT
077	N46W	90SW	053	019	014	019	S	NW	NO	OT
077	N45E	85NW	109	034	000	019	S	NE	NO	OT
077	N87W	90SW	110	009	011	009	S	EW	NO	OT
077	N87W	90SW	049	009	011	009	S	EW	NO	OT
078	N63W	90SW	206	034	065	034	R		NO	OT
078	N63W	90SW	101	015	080	015	R		NO	OT
078	N63W	90SW	080	015	000	015	R		NO	OT
078	N63W	90SW	278	034	000	034	R		NO	OT
078	N48W	90SW	050	008	017	008	R	NW	NO	OT
078	N55W	90SW	045	001	008	008	R	NW	NO	OT
078	N55W	90SW	086	001	008	008	R	NW	NO	OT
078	N55W	90SW	088	003	006	008	R	NW	NO	OT
078	N55W	90SW	098	002	005	008	R	NW	NO	OT

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
078	N55W	90SW	068	001	011	008	R	NW	NO	OT
078	N55W	90SW	062	004	013	008	R	NW	NO	OT
079	N47W	82SW	013	016	014	016	R	NW	NO	OT
079	N47W	82SW	039	019	000	019	R	NW	NO	OT
079	N47W	82SW	008	006	015	006	R	NW	NO	OT
079	N82W	87SW	020	016	038	016	R	EW	NO	OT
079	N82W	87SW	010	014	011	014	R	EW	NO	OT
079	N82W	87SW	015	014	003	014	R	EW	NO	OT
079	N82W	87SW	018	014	012	014	R	EW	NO	OT
079	N82W	87SW	017	014	024	014	R	EW	NO	OT
079	N47W	82SW	003	017	018	017	R	NW	NO	OT
079	N47W	82SW	018	018	013	018	R	NW	NO	OT
079	N47W	82SW	018	014	015	014	R	NW	NO	OT
079	N82W	87SW	009	014	017	014	R	EW	NO	OT
079	N82W	87SW	032	014	019	014	R	EW	NO	OT
079	N47W	82SW	017	018	012	018	R	NW	NO	OT
079	N47W	82SW	027	020	018	017	R	NW	NO	OT
079	N12W	70SW	043	013	000	013	R		NO	OT
079	N07E	59NW	018	018	001	018	R		NO	OT
079	N12E	48NW	033	013	014	013	R		NO	OT
080	N72W	84SW	033	008	008	008	R		NO	OT
080	N21E	84NW	017	008	018	008	R		NO	OT
080	N72W	84SW	007	008	013	008	R		NO	OT
080	N72W	84SW	024	008	018	008	R		NO	OT
080	N72W	84SW	044	009	015	009	R		NO	OT
080	N72W	84SW	018	009	009	009	R		NO	OT
080	N72W	84SW	018	009	018	009	R		NO	OT
080	N72W	84SW	018	009	011	009	R		NO	OT
080	N21E	84NW	017	008	029	008	R		NO	OT
080	N21E	84NW	001	009	013	009	R		NO	OT
080	N21E	84NW	015	009	012	009	R		NO	OT
080	N21E	84NW	024	009	025	009	R		NO	OT
080	N21E	84NW	010	009	018	009	R		NO	OT
080	N21E	84NW	019	010	017	010	R		NO	OT
082	N23E	74NW	049	026	080	026	R		IN	IN
082	N48W	88SW	064	027	065	027	R	NW	IN	IN
082	N48W	88SW	100	026	000	026	R	NW	IN	IN
082	N48W	88SW	020	036	039	036	R	NW	IN	IN
082	N48W	88SW	060	040	050	040	R	NW	IN	IN
082	N48W	88SW	062	046	067	046	R	NW	IN	IN
082	N84W	87SW	053	040	025	033	R	EW	IN	IN
082	N84W	87SW	005	040	020	033	R	EW	IN	IN
082	N84W	87SW	027	026	000	026	R	EW	IN	IN
082	N23E	74NW	058	030	063	030	R		IN	IN
082	N23E	74NW	072	033	000	033	R		IN	IN
083	N70W	87SW	020	015	000	013	R		IN	IN
083	N46W	88SW	012	004	010	008	R	NW	IN	IN

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GE
083	N46W	88SW	003	003	013	008	R	NW	IN	IN
083	N46W	88SW	005	004	010	008	R	NW	IN	IN
083	N70W	87SW	014	009	007	009	R		IN	IN
083	N21E	73NW	129	022	011	007	R		IN	IN
083	N21E	73NW	063	018	012	009	R		IN	IN
084	N85W	88SW	075	142	030	020	R	EW	IN	IN
084	N89W	90SW	034	034	044	034	R	EW	IN	IN
084	N89W	88SW	028	029	021	022	R	EW	IN	IN
084	N89W	88SW	035	056	041	022	R	EW	IN	IN
084	N89W	88SW	015	018	013	006	R	EW	IN	IN
084	N89W	88SW	012	026	014	006	R	EW	IN	IN
084	N89W	88SW	005	005	008	005	R	EW	IN	IN
084	N35E	84NW	015	019	006	019	R	NE	IN	IN
084	N35E	84NW	024	019	023	019	R	NE	IN	IN
084	N42W	71SW	024	014	000	014	R	NW	IN	IN
084	N89W	88SW	010	014	021	014	R	EW	IN	IN
084	N89W	88SW	010	014	022	014	R	EW	IN	IN
084	N89W	88SW	019	017	016	017	R	EW	IN	IN
084	N45W	84SW	146	018	015	018	R	NW	IN	IN
084	N42W	71SW	105	020	000	020	R	NW	IN	IN
084	N89W	88SW	216	020	015	012	R	EW	IN	IN
085	N54W	90SW	205	013	000	013	R	NW	IN	IN
085	N30E	51NW	005	036	030	036	R	NE	IN	IN
085	N30E	51NW	047	036	042	036	R	NE	IN	IN
085	N30E	51NW	012	036	023	036	R	NE	IN	IN
085	N30E	51NW	107	048	000	036	R	NE	IN	IN
085	N54W	90SW	102	013	000	013	R	NW	IN	IN
085	N54W	90SW	056	013	000	013	R	NW	IN	IN
086	N33E	90NW	046	005	000	005	S	NE	IN	IN
086	N47E	67NW	034	010	000	010	S		IN	IN
086	N47E	67NW	029	008	000	008	S		IN	IN
086	N33E	90NW	026	006	015	006	S	NE	IN	IN
086	N40W	90SW	030	007	000	007	S	NW	IN	IN
086	N40W	90SW	019	007	016	007	S	NW	IN	IN
086	N40W	90SW	013	007	000	007	S	NW	IN	IN
087	N87W	90SW	008	020	018	010	SC	EW	IN	IN
087	N51W	90SW	034	033	000	013	SC	NW	IN	IN
087	N87W	90SW	022	005	008	005	SC	EW	IN	IN
087	N87W	90SW	015	007	012	007	SC	EW	IN	IN
087	N87W	90SW	015	009	024	009	SC	EW	IN	IN
087	N87W	90SW	005	010	038	011	SC	EW	IN	IN
087	N87W	90SW	014	010	009	010	SC	EW	IN	IN
087	N87W	90SW	007	005	017	007	SC	EW	IN	IN
087	N87W	90SW	010	007	017	007	SC	EW	IN	IN
087	N87W	90SW	015	013	034	007	SC	EW	IN	IN
087	N87W	90SW	018	003	000	007	SC	EW	IN	IN
087	N51W	90SW	010	070	000	010	SC	NW	IN	IN

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	CP
087	N51W	90SW	010	056	000	010	SC	NW	IN	IN
087	N43W	90SW	070	061	000	010	SC	NW	IN	IN
087	N51W	90SW	197	050	007	015	SC	NW	IN	IN
087	N51W	90SW	040	012	026	012	SC	NW	IN	IN
087	N84E	90NW	182	057	011	007	SC	EW	IN	IN
087	N84E	90NW	085	043	011	007	SC	EW	IN	IN
087	N84E	90NW	063	038	000	007	SC	EW	IN	IN
087	N87W	90SW	047	067	006	007	SC	EW	IN	IN
087	N73W	90SW	124	073	032	006	SC		IN	IN
087	N73W	90SW	117	060	031	006	SC		IN	IN
088	N45W	90SW	050	019	030	019	S	NW	IN	IN
088	N45W	90SW	043	019	033	019	S	NW	IN	IN
088	N45W	90SW	047	019	000	019	S	NW	IN	IN
088	N86W	75SW	142	022	039	022	S	EW	IN	IN
088	N86W	75SW	062	022	031	022	S	EW	IN	IN
088	N86W	75SW	032	020	000	022	S	EW	IN	IN
089	N62W	72SW	060	039	038	039	SC		IN	IN
089	N62W	72SW	077	039	009	039	SC		IN	IN
089	N62W	72SW	045	039	005	039	SC		IN	IN
089	N62W	72SW	035	039	011	039	SC		IN	IN
089	N62W	72SW	064	039	007	039	SC		IN	IN
089	N03E	52NW	060	019	008	019	SC		IN	IN
089	N03E	52NW	043	014	004	007	SC		IN	IN
089	N28E	44NW	025	010	000	007	SC	NE	IN	IN
089	N62W	72SW	040	039	007	039	SC		IN	IN
089	N62W	72SW	038	039	006	039	SC		IN	IN
089	N28E	44NW	015	014	011	014	SC	NE	IN	IN
089	N28E	44NW	010	008	008	008	SC	NE	IN	IN
089	N28E	44NW	020	005	001	005	SC	NE	IN	IN
090	N43W	90SW	020	009	003	009	SC	NW	IN	IN
090	N43W	90SW	016	009	009	009	SC	NW	IN	IN
090	N43W	90SW	011	009	003	009	SC	NW	IN	IN
090	N43W	90SW	012	009	010	009	SC	NW	IN	IN
090	N43W	90SW	018	017	005	009	SC	NW	IN	IN
090	N43W	90SW	018	013	006	009	SC	NW	IN	IN
090	N43W	90SW	018	017	010	009	SC	NW	IN	IN
090	N43W	90SW	018	013	014	009	SC	NW	IN	IN
090	N43W	90SW	010	017	007	009	SC	NW	IN	IN
090	N43W	90SW	012	017	015	009	SC	NW	IN	IN
090	N43W	90SW	010	017	013	009	SC	NW	IN	IN
090	N43W	90SW	010	017	010	009	SC	NW	IN	IN
091	N36W	87SW	180	025	068	025	S	NW	IN	IN
091	N36W	87SW	130	025	025	025	S	NW	IN	IN
091	N36W	87SW	103	025	012	025	S	NW	IN	IN
091	N36W	87SW	090	025	039	025	S	NW	IN	IN
091	N36W	87SW	087	025	014	025	S	NW	IN	IN
091	N36W	87SW	085	025	040	025	S	NW	IN	IN

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
091	N36W	87SW	080	025	055	025	S	NW	IN	IN
092	N55W	74SW	017	007	016	007	SC	NW	IN	IN
092	N55W	74SW	020	007	000	007	SC	NW	IN	IN
092	N55W	74SW	005	002	022	002	SC	NW	IN	IN
092	N55W	74SW	005	002	000	002	SC	NW	IN	IN
092	N87E	90NW	051	030	004	004	SC	EW	IN	IN
093	N25E	90NW	206	005	029	005	SC	NE	IN	IN
093	N25E	90NW	174	005	043	005	SC	NE	IN	IN
093	N25E	90NW	355	012	000	005	SC	NE	IN	IN
093	N25E	90NW	089	015	020	010	SC	NE	IN	IN
093	N49W	88SW	039	013	000	013	SC	NW	IN	IN
093	N40W	72SW	043	012	000	012	SC	NW	IN	IN
093	N40W	72SW	031	012	005	012	SC	NW	IN	IN
093	N40W	72SW	011	012	013	012	SC	NW	IN	IN
093	N85W	84SW	021	006	000	006	SC	EW	IN	IN
093	N85W	84SW	043	015	023	015	SC	EW	IN	IN
093	N40W	72SW	010	005	017	005	SC	NW	IN	IN
093	N40W	72SW	014	007	015	008	SC	NW	IN	IN
093	N40W	72SW	011	007	010	008	SC	NW	IN	IN
093	N40W	72SW	008	007	008	009	SC	NW	IN	IN
093	N40W	72SW	004	007	016	010	SC	NW	IN	IN
094	N76W	80SW	020	010	043	010	S		IN	IN
094	N76W	80SW	015	010	050	010	S		IN	IN
094	N76W	80SW	020	010	055	010	S		IN	IN
094	N76W	80SW	022	009	017	009	S		IN	IN
094	N35E	78NW	050	010	015	010	S	NE	IN	IN
095	N36W	84SW	320	014	006	014	R	NW	IN	IN
095	N36W	84SW	340	015	000	015	R	NW	IN	IN
095	N36W	84SW	310	008	000	008	R	NW	IN	IN
095	N36W	84SW	010	010	040	010	R	NW	IN	IN
096	N43W	88SW	073	005	000	005	R	NW	IN	IN
096	N25E	90NW	015	008	026	008	R	NE	IN	IN
096	N25E	90NW	024	008	021	008	R	NE	IN	IN
096	N43W	88SW	050	007	000	007	R	NW	IN	IN
097	N76E	74NW	242	102	008	102	R		IN	IN
097	N76E	74NW	171	102	000	102	R		IN	IN
097	N76E	74NW	190	039	004	039	R		IN	IN
097	N76E	74NW	187	015	000	015	R		IN	IN
098	N84E	75NW	078	026	003	016	R	EW	IN	IN
098	N84E	75NW	196	021	000	011	R	EW	IN	IN
098	N84E	75NW	132	007	000	007	R	EW	IN	IN
098	N84E	75NW	106	007	000	007	R	EW	IN	IN
098	N40E	68NW	053	013	008	013	R	NE	IN	IN
098	N40E	68NW	045	013	007	013	R	NE	IN	IN
099	N10W	69SW	110	046	014	046	R		IN	IN
099	N10W	69SW	040	046	000	046	R		IN	IN
099	N45W	90SW	055	072	000	072	R	NW	IN	IN

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GP
099	N45W	90SW	016	046	048	046	R	NW	IN	IN
100	N72W	76SW	224	011	000	011	R		IN	IN
100	N72W	76SW	133	017	000	017	R		IN	IN
101	N33W	70SW	019	006	012	006	R		IN	IN
101	N33W	70SW	021	006	000	006	R		IN	IN
101	N42E	86NW	031	006	023	006	R	NE	IN	IN
101	N42E	86NW	041	010	000	010	R	NE	IN	IN
101	N77E	90NW	051	008	000	008	R		IN	IN
101	N65W	87SW	094	023	004	023	R		IN	IN
101	N65W	87SW	096	043	000	023	R		IN	IN
102	N41W	85SW	084	014	032	005	S	NW	IN	IN
102	N41W	85SW	109	013	052	005	S	NW	IN	IN
102	N41W	85SW	045	005	008	005	S	NW	IN	IN
102	N41W	85SW	109	005	013	007	S	NW	IN	IN
102	N41W	85SW	034	012	036	007	S	NW	IN	IN
102	N41W	85SW	108	015	000	015	S	NW	IN	IN
102	N87W	84SW	142	023	042	023	S	EW	IN	IN
102	N87W	84SW	035	012	012	012	S	EW	IN	IN
102	N87W	84SW	024	012	019	012	S	EW	IN	IN
102	N87W	84SW	048	014	054	014	S	EW	IN	IN
102	N87W	84SW	092	021	000	021	S	EW	IN	IN
102	N41W	85SW	174	011	025	006	S	NW	IN	IN
102	N41W	85SW	153	013	012	006	S	NW	IN	IN
102	N41W	85SW	085	009	032	006	S	NW	IN	IN
102	N41W	85SW	174	013	038	006	S	NW	IN	IN
102	N87W	84SW	092	010	051	010	S	EW	IN	IN
102	N87W	84SW	095	009	040	009	S	EW	IN	IN
102	N87W	84SW	057	005	034	009	S	EW	IN	IN
103	N38W	84SW	014	008	007	008	S	NW	IN	IN
103	N38W	84SW	013	008	012	008	S	NW	IN	IN
103	N38W	84SW	023	007	009	007	S	NW	IN	IN
103	N38W	84SW	017	007	011	007	S	NW	IN	IN
103	N38W	84SW	013	008	000	008	S	NW	IN	IN
103	N38W	84SW	010	010	009	010	S	NW	IN	IN
103	N38W	84SW	012	010	008	010	S	NW	IN	IN
103	N38W	84SW	016	010	010	010	S	NW	IN	IN
103	N85E	58NW	022	006	008	006	S	EW	IN	IN
103	N85E	58NW	015	014	006	006	S	EW	IN	IN
103	N85E	58NW	011	007	003	003	S	EW	IN	IN
103	N85E	58NW	005	004	009	006	S	EW	IN	IN
104	N42W	86SW	057	012	012	012	S	NW	IN	IN
104	N42W	86SW	030	012	014	012	S	NW	IN	IN
104	N42W	86SW	039	009	007	009	S	NW	IN	IN
104	N42W	86SW	053	009	010	009	S	NW	IN	IN
104	N42W	86SW	058	009	007	009	S	NW	IN	IN
104	N42W	86SW	115	007	032	007	S	NW	IN	IN
104	N42W	86SW	042	008	004	008	S	NW	IN	IN

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	IO	GR
104	N42W	86SW	021	008	006	008	S	NW	IN	IN
105	N77W	75SW	045	023	015	023	S		IN	IN
105	N77W	75SW	016	023	000	023	S		IN	IN
105	N44W	85SW	023	022	040	022	S	NW	IN	IN
105	N44W	85SW	020	022	040	022	S	NW	IN	IN
105	N44W	85SW	010	014	025	014	S	NW	IN	IN
105	N44W	85SW	023	012	016	012	S	NW	IN	IN
105	N44W	85SW	012	012	012	012	S	NW	IN	IN
105	N44W	85SW	015	022	029	022	S	NW	IN	IN
105	N44W	85SW	016	018	023	018	S	NW	IN	IN
105	N44W	85SW	030	016	009	016	S	NW	IN	IN
105	N44W	85SW	038	023	019	012	S	NW	IN	IN
105	N44W	85SW	035	023	016	012	S	NW	IN	IN
105	N44W	85SW	015	020	000	012	S	NW	IN	IN
106	N51W	82SW	050	025	011	025	S	NW	IN	IN
106	N51W	82SW	101	025	010	025	S	NW	IN	IN
106	N51W	82SW	240	025	019	025	S	NW	IN	IN
106	N51W	82SW	111	015	014	015	S	NW	IN	IN
106	N51W	82SW	099	007	005	007	S	NW	IN	IN
106	N51W	82SW	097	007	004	007	S	NW	IN	IN
106	N51W	82SW	089	007	015	007	S	NW	IN	IN
106	N51W	82SW	078	007	011	007	S	NW	IN	IN
106	N32E	58NW	130	025	000	025	S	NE	IN	IN
106	N32E	58NW	050	015	000	015	S	NE	IN	IN
106	N01E	58NW	026	007	000	007	S		IN	IN
106	N01E	58NW	019	015	000	015	S		IN	IN
107	N82E	70NW	053	004	006	004	S	EW	IN	IN
107	N82E	70NW	058	015	012	015	S	EW	IN	IN
107	N82E	70NW	030	015	020	015	S	EW	IN	IN
107	N46W	90SW	100	019	034	025	S	NW	IN	IN
107	N46W	90SW	101	007	000	025	S	NW	IN	IN
108	N88W	77SW	055	005	035	005	SC	EW	IN	IN
108	N88W	77SW	047	005	027	005	SC	EW	IN	IN
108	N88W	77SW	055	005	036	005	SC	EW	IN	IN
108	N18W	80SW	033	045	006	045	SC		IN	IN
108	N18W	80SW	073	045	030	045	SC		IN	IN
108	N18W	80SW	065	045	000	045	SC		IN	IN
108	N18W	80SW	075	007	006	007	SC		IN	IN
108	N18W	80SW	052	008	000	008	SC		IN	IN
108	N18W	80SW	062	045	037	045	SC		IN	IN
108	N35E	90NW	044	045	038	045	SC	NE	IN	IN
108	N35E	90NW	010	045	000	045	SC	NE	IN	IN
109	N43W	83SW	044	012	012	012	SC	NW	IN	IN
109	N43W	83SW	058	014	021	014	SC	NW	IN	IN
109	N43W	83SW	055	021	014	021	SC	NW	IN	IN
109	N43W	83SW	042	020	012	020	SC	NW	IN	IN
109	N43W	83SW	020	020	012	020	SC	NW	IN	IN

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GP
109	N43W	83SW	023	009	003	009	SC	NW	IN	IN
109	N43W	83SW	023	009	009	009	SC	NW	IN	IN
109	N43W	83SW	023	009	003	009	SC	NW	IN	IN
109	N43W	83SW	025	009	007	009	SC	NW	IN	IN
109	N43W	83SW	054	039	008	067	SC	NW	IN	IN
110	N48W	90SW	020	053	020	007	S	NW	IN	IN
110	N48W	90SW	021	054	029	007	S	NW	IN	IN
110	N48W	90SW	005	008	009	008	S	NW	IN	IN
110	N48W	90SW	006	008	004	008	S	NW	IN	IN
110	N48W	90SW	005	008	004	008	S	NW	IN	IN
110	N48W	90SW	005	008	010	008	S	NW	IN	IN
110	N48W	90SW	002	008	008	008	S	NW	IN	IN
110	N48W	90SW	002	008	007	008	S	NW	IN	IN
111	N87W	85SW	144	012	025	012	SC	EW	IN	IN
111	N87W	85SW	152	012	019	012	SC	EW	IN	IN
111	N87W	85SW	178	014	024	014	SC	EW	IN	IN
111	N87W	85SW	195	014	016	014	SC	EW	IN	IN
111	N87W	85SW	117	014	013	014	SC	EW	IN	IN
111	N87W	85SW	025	010	019	010	SC	EW	IN	IN
111	N87W	85SW	057	010	020	010	SC	EW	IN	IN
111	N87W	85SW	049	010	020	01	SC	EW	IN	IN
111	N87W	85SW	070	010	010	010	SC	EW	IN	IN
111	N08E	72NW	020	010	030	010	SC		IN	IN
111	N08E	72NW	020	010	047	010	SC		IN	IN
111	N08E	72NW	010	010	027	010	SC		IN	IN
111	N08E	72NW	022	015	047	015	SC		IN	IN
111	N08E	72NW	013	015	025	015	SC		IN	IN
112	N84W	87SW	728	020	085	020	S	EW	IN	IN
112	N84W	87SW	720	020	123	020	S	EW	IN	IN
112	N84W	87SW	320	022	076	022	S	EW	IN	IN
112	N34W	57SW	085	020	046	020	S		IN	IN
112	N34W	57SW	085	020	053	020	S		IN	IN
112	N34W	57SW	085	020	085	020	S		IN	IN
112	N34W	57SW	123	020	088	020	S		IN	IN
112	N34W	57SW	123	020	164	020	S		IN	IN
112	N84W	87SW	007	022	062	022	S	EW	IN	IN
112	N84W	87SW	340	022	106	022	S	EW	IN	IN
112	N84W	87SW	320	022	052	022	S	EW	IN	IN
112	N84W	87SW	750	022	069	022	S	EW	IN	IN
112	N84W	87SW	720	042	083	042	S	EW	IN	IN
112	N84W	87SW	715	020	177	020	S	EW	IN	IN
113	N50W	90SW	082	010	000	003	S	NW	IN	IN
113	N45W	87SW	180	010	000	010	S	NW	IN	IN
113	N50W	90SW	017	008	007	008	S	NW	IN	IN
113	N50W	90SW	019	008	004	008	S	NW	IN	IN
113	N50W	90SW	034	008	007	008	S	NW	IN	IN
113	N50W	90SW	040	008	003	008	S	NW	IN	IN

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	IO	GR
113	N50W	90SW	009	005	008	003	S	NW	IN	IN
113	N50W	90SW	020	005	006	003	S	NW	IN	IN
114	N87W	85SW	130	010	035	010	S	EW	IN	IN
114	N87W	85SW	063	010	016	010	S	EW	IN	IN
114	N87W	85SW	174	010	021	010	S	EW	IN	IN
114	N87W	85SW	040	010	012	010	S	EW	IN	IN
114	N87W	85SW	102	010	031	010	S	EW	IN	IN
115	N83W	89SW	032	012	025	012	S	EW	IN	IN
115	N83W	89SW	015	012	019	012	S	EW	IN	IN
115	N83W	89SW	015	012	020	012	S	EW	IN	IN
115	N83W	89SW	023	012	010	012	S	EW	IN	IN
115	N83W	89SW	019	012	006	012	S	EW	IN	IN
115	N83W	89SW	017	012	013	012	S	EW	IN	IN
116	N44W	88SW	158	061	029	061	SC	NW	NO	OT
116	N44W	88SW	132	030	058	030	SC	NW	NO	OT
116	N44W	88SW	061	030	000	030	SC	NW	NO	OT
116	N38W	85SW	049	031	018	031	SC	NW	NO	OT
116	N38W	85SW	058	005	000	005	SC	NW	NO	OT
116	N38W	85SW	057	026	044	026	SC	NW	NO	OT
116	N38W	85SW	045	026	000	026	SC	NW	NO	OT
117	N55W	87SW	025	040	010	040	R	NW	NO	OT
117	N55W	87SW	024	040	009	040	R	NW	NO	OT
117	N01W	86SW	020	009	000	009	R		NO	OT
117	N01W	86SW	021	016	000	016	R		NO	OT
117	N55W	87SW	015	012	010	012	R	NW	NO	OT
117	N55W	87SW	019	012	009	012	R	NW	NO	OT
117	N55W	87SW	017	012	008	012	R	NW	NO	OT
117	N55W	87SW	023	012	007	012	R	NW	NO	OT
117	N55W	87SW	015	012	010	012	R	NW	NO	OT
117	N55W	87SW	007	014	017	012	R	NW	NO	OT
117	N55W	87SW	015	042	015	025	R	NW	NO	OT
117	N55W	87SW	012	025	019	025	R	NW	NO	OT
118	N41W	77SW	020	006	016	006	SC	NW	NO	OT
118	N41W	77SW	010	006	011	006	SC	NW	NO	OT
118	N41W	77SW	021	006	008	006	SC	NW	NO	OT
118	N41W	77SW	022	006	004	006	SC	NW	NO	OT
118	N41W	77SW	023	006	003	006	SC	NW	NO	OT
118	N41W	77SW	026	006	004	006	SC	NW	NO	OT
118	N41W	77SW	013	006	009	006	SC	NW	NO	OT
118	N41W	77SW	022	006	007	006	SC	NW	NO	OT
118	N41W	77SW	015	006	008	006	SC	NW	NO	OT
118	N41W	77SW	027	006	004	006	SC	NW	NO	OT
119	N80E	76NW	040	014	006	014	SC	EW	NO	OT
119	N80E	76NW	084	014	018	014	SC	EW	NO	OT
119	N80E	76NW	095	014	018	014	SC	EW	NO	OT
119	N80E	76NW	067	014	024	014	SC	EW	NO	OT
119	N80E	76NW	079	014	017	014	SC	EW	NO	OT

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GP
119	N80E	76NW	069	014	030	014	SC	EW	NO	OT
119	N80E	76NW	077	014	011	014	SC	EW	NO	OT
119	N80E	76NW	075	014	021	014	SC	EW	NO	OT
119	N44E	44NW	079	014	016	014	SC	NE	NO	OT
119	N44E	44NW	091	014	009	014	SC	NE	NO	OT
119	N44E	44NW	138	014	014	014	SC	NE	NO	OT
119	N44E	44NW	179	014	008	014	SC	NE	NO	OT
119	N44E	44NW	202	014	005	014	SC	NE	NO	OT
119	N44E	44NW	203	014	030	014	SC	NE	NO	OT
120	N83E	90NW	083	016	026	016	S	EW	NO	OT
120	N83E	90NW	058	016	028	016	S	EW	NO	OT
120	N83E	90NW	053	016	048	016	S	EW	NO	OT
120	N83E	90NW	046	016	015	016	S	EW	NO	OT
120	N83E	90NW	046	025	028	025	S	EW	NO	OT
120	N83E	90NW	062	025	039	025	S	EW	NO	OT
120	N83E	90NW	032	025	003	025	S	EW	NO	OT
120	N83E	90NW	019	025	022	025	S	EW	NO	OT
120	N83E	90NW	044	025	036	025	S	EW	NO	OT
120	N32W	87SW	054	012	030	012	S		NO	OT
120	N32W	87SW	058	012	013	012	S		NO	OT
120	N32W	87SW	065	012	026	012	S		NO	OT
120	N32W	87SW	057	012	018	012	S		NO	OT
120	N32W	87SW	025	012	027	012	S		NO	OT
120	N32W	87SW	030	012	015	012	S		NO	OT
121	N85W	80SW	005	012	036	012	R	EW	NO	OT
121	N85W	80SW	047	012	025	012	R	EW	NO	OT
121	N85W	80SW	003	014	010	014	R	EW	NO	OT
121	N85W	80SW	010	014	024	014	R	EW	NO	OT
121	N85W	80SW	019	014	035	014	R	EW	NO	OT
121	N35E	80NW	015	019	020	019	R	NE	NO	OT
121	N35E	80NW	013	019	008	019	R	NE	NO	OT
121	N35E	80NW	012	015	012	015	R	NE	NO	OT
123	N80E	90NW	035	022	033	022	S	EW	NO	OT
123	N80E	90NW	050	022	038	022	S	EW	NO	OT
123	N80E	90NW	028	022	058	022	S	EW	NO	OT
123	N03E	90NW	033	022	035	022	S		NO	OT
123	N03E	90NW	038	022	050	022	S		NO	OT
123	N03E	90NW	058	022	028	022	S		NO	OT
123	N47W	90SW	070	012	038	012	S	NW	NO	OT
123	N47W	90SW	034	012	041	012	S	NW	NO	OT
123	N47W	90SW	057	012	008	012	S	NW	NO	OT
123	N27E	90NW	021	012	038	012	S	NE	NO	OT
123	N27E	90NW	016	012	017	012	S	NE	NO	OT
123	N27E	90NW	018	012	027	012	S	NE	NO	OT
124	N42W	87SW	115	014	025	014	S	NW	NO	OT
124	N42W	87SW	106	014	036	014	S	NW	NO	OT
124	N4E	90NW	190	020	025	007	S		NO	OT

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
124	N42W	87SW	075	007	000	007	S	NW	NO	OT
124	N42W	87SW	078	010	015	010	S	NW	NO	OT
124	N42W	87SW	055	010	047	010	S	NW	NO	OT
124	N42W	87SW	038	019	035	019	S	NW	NO	OT
124	N42W	87SW	042	019	031	019	S	NW	NO	OT
124	N42W	87SW	065	019	042	019	S	NW	NO	OT
124	N42W	87SW	069	019	028	019	S	NW	NO	OT
124	N42W	87SW	070	019	025	019	S	NW	NO	OT
124	N42W	87SW	350	035	018	020	S	NW	NO	OT
125	N87E	90NW	196	007	036	007	S	EW	NO	OT
125	N87E	90NW	134	007	024	007	S	EW	NO	OT
125	N87E	90NW	158	007	020	007	S	EW	NO	OT
125	N87E	90NW	152	007	022	007	S	EW	NO	OT
125	N87E	90NW	152	007	021	007	S	EW	NO	OT
125	N87E	90NW	127	073	047	025	S	EW	NO	OT
125	N87E	90NW	097	077	042	025	S	EW	NO	OT
125	N87E	90NW	180	074	032	025	S	EW	NO	OT
126	N87W	85SW	546	270	030	020	SC	EW	NO	OT
126	N87W	85SW	584	240	029	020	SC	EW	NO	OT
126	N87W	85SW	042	020	023	020	SC	EW	NO	OT
126	N35E	85NW	020	035	025	007	SC	NE	NO	OT
126	N35E	85NW	005	007	027	007	SC	NE	NO	OT
126	N35E	85NW	004	007	009	007	SC	NE	NO	OT
126	N35E	85NW	003	007	016	007	SC	NE	NO	OT
126	N35E	85NW	005	007	010	007	SC	NE	NO	OT
127	N85W	90SW	063	007	033	007	S	EW	NO	OT
127	N85W	90SW	030	007	040	007	S	EW	NO	OT
127	N85W	90SW	033	007	020	007	S	EW	NO	OT
127	N85W	90SW	028	007	026	007	S	EW	NO	OT
128	N05E	90NW	074	024	012	024	SC		NO	OT
128	N05E	90NW	055	024	010	024	SC		NO	OT
128	N05E	90NW	012	024	038	024	SC		NO	OT
128	N63W	90SW	035	024	001	024	SC		NO	OT
128	N63W	90SW	014	024	075	024	SC		NO	OT
128	N63W	90SW	023	024	018	024	SC		NO	OT
128	N63W	90SW	022	024	072	024	SC		NO	OT
128	N63W	90SW	015	011	023	007	SC		NO	OT
128	N63W	90SW	013	011	030	007	SC		NO	OT
128	N63W	90SW	021	011	027	007	SC		NO	OT
128	N69W	90SW	106	033	059	033	SC		NO	OT
128	N69W	90SW	074	033	071	033	SC		NO	OT
128	N69W	90SW	150	036	058	033	SC		NO	OT
128	N69W	90SW	135	036	081	033	SC		NO	OT
128	N69W	90SW	150	033	069	033	SC		NO	OT
128	N69W	90SW	083	033	043	033	SC		NO	OT
128	N37W	85SW	030	035	009	019	SC	NW	NO	OT
128	N37W	85SW	027	035	005	019	SC	NW	NO	OT

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
128	N37W	85SW	007	016	026	016	SC	NW	NO	OT
128	N37W	85SW	018	016	019	016	SC	NW	NO	OT
128	N37W	85SW	027	020	030	020	SC	NW	NO	OT
128	N37E	79NW	147	093	120	004	SC	NE	NO	OT
128	N37E	79NW	180	112	072	004	SC	NE	NO	OT
128	N37E	79NW	130	110	000	004	SC	NE	NO	OT
128	N37E	79NW					SC	NE	NO	OT
129	N73W	60SW	020	017	016	017	S		NO	OT
129	N73W	60SW	010	017	016	017	S		NO	OT
129	N73W	60SW	010	017	000	017	S		NO	OT
129	N73W	60SW	010	029	005	029	S		NO	OT
129	N73W	60SW	001	029	013	029	S		NO	OT
129	N73W	60SW	006	029	018	029	S		NO	OT
130	N35W	90SW	075	008	020	008	S	NW	NO	OT
130	N35W	90SW	089	008	007	008	S	NW	NO	OT
130	N35W	90SW	120	008	023	008	S	NW	NO	OT
130	N35W	90SW	099	008	012	008	S	NW	NO	OT
130	N35W	90SW	039	008	016	008	S	NW	NO	OT
130	N35W	90SW	104	008	018	008	S	NW	NO	OT
130	N35W	90SW	109	008	008	008	S	NW	NO	OT
130	N35W	90SW	121	008	023	008	S	NW	NO	OT
130	N35W	90SW	083	008	028	008	S	NW	NO	OT
130	N40E	88NW	182	008	033	008	S	NE	NO	OT
130	N40E	88NW	197	008	034	008	S	NE	NO	OT
130	N40E	88NW	184	008	031	008	S	NE	NO	OT
130	N40E	88NW	098	008	000	008	S	NE	NO	OT
131	N53W	90SW	118	055	032	001	SC	NW	NO	OT
131	N53W	90SW	079	055	000	001	SC	NW	NO	OT
131	N53W	90SW	101	012	024	012	SC	NW	NO	OT
131	N53W	90SW	027	012	032	012	SC	NW	NO	OT
131	N53W	90SW	043	012	016	012	SC	NW	NO	OT
131	N53W	90SW	041	012	044	012	SC	NW	NO	OT
131	N53W	90SW	050	012	029	012	SC	NW	NO	OT
131	N53W	90SW	041	012	025	012	SC	NW	NO	OT
131	N53W	90SW	037	012	036	012	SC	NW	NO	OT
131	N53W	90SW	064	012	034	012	SC	NW	NO	OT
131	N53W	90SW	081	012	032	012	SC	NW	NO	OT
131	N53W	90SW	090	012	028	012	SC	NW	NO	OT
131	N53W	90SW	210	156	021	012	SC	NW	NO	OT
131	N53W	90SW	075	075	054	012	SC	NW	NO	OT
131	N53W	90SW	052	063	019	012	SC	NW	NO	OT
131	N53W	90SW	116	056	090	012	SC	NW	NO	OT
131	N53W	90SW	210	124	019	012	SC	NW	NO	OT
131	N53W	90SW	055	052	018	012	SC	NW	NO	OT
131	N53W	90SW	035	061	008	012	SC	NW	NO	OT
131	N53W	90SW	426	170	000	012	SC	NW	NO	OT
132	N58W	83SW	035	027	073	027	SC		NO	OT

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
132	N58W	83SW	023	027	070	027	SC		NO	OT
132	N58W	83SW	036	027	060	027	SC		NO	OT
132	N58W	83SW	056	027	014	027	SC		NO	OT
132	N58W	83SW	020	027	065	027	SC		NO	OT
132	N58W	83SW	029	027	020	027	SC		NO	OT
132	N58W	83SW	036	027	062	027	SC		NO	OT
132	N58W	83SW	009	040	033	027	SC		NO	OT
132	N58W	83SW	001	027	024	027	SC		NO	OT
132	N58W	83SW	007	027	026	027	SC		NO	OT
132	N58W	83SW	001	027	021	027	SC		NO	OT
132	N58W	83SW	001	027	032	027	SC		NO	OT
132	N40E	79NW	027	016	017	016	SC	NE	NO	OT
132	N40E	79NW	039	016	037	016	SC	NE	NO	OT
132	N40E	79NW	018	016	016	016	SC	NE	NO	OT
132	N40E	79NW	016	017	025	017	SC	NE	NO	OT
132	N40E	79NW	054	017	027	017	SC	NE	NO	OT
133	N84W	82SW	064	012	004	004	S	EW	NO	OT
133	N84W	82SW	030	004	019	004	S	EW	NO	OT
133	N61W	90SW	194	016	040	016	S		NO	OT
133	N61W	90SW	182	016	007	016	S		NO	OT
133	N61W	90SW	085	020	027	016	S		NO	OT
133	N61W	90SW	084	020	029	016	S		NO	OT
133	N61W	90SW	050	016	033	016	S		NO	OT
133	N61W	90SW	174	016	053	016	S		NO	OT
134	N48W	88SW	065	007	014	007	S	NW	NO	OT
134	N48W	88SW	063	007	055	007	S	NW	NO	OT
134	N48W	88SW	031	007	026	007	S	NW	NO	OT
134	N48W	88SW	053	007	026	007	S	NW	NO	OT
134	N48W	88SW	032	007	029	007	S	NW	NO	OT
134	N48W	88SW	043	007	041	007	S	NW	NO	OT
135	N80E	86NW	054	109	019	005	SC	EW	NO	OT
135	N80E	86NW	025	095	002	009	SC	EW	NO	OT
135	N80E	86NW	077	234	013	009	SC	EW	NO	OT
135	N80E	86NW	033	126	012	009	SC	EW	NO	OT
135	N80E	86NW	035	049	011	006	SC	EW	NO	OT
135	N80E	86NW	022	073	010	006	SC	EW	NO	OT
135	N80E	86NW	042	104	021	008	SC	EW	NO	OT
135	N80E	86NW	012	041	015	005	SC	EW	NO	OT
135	N04W	79SW	067	010	005	001	SC		NO	OT
135	N45W	88SW	059	016	036	016	SC	NW	NO	OT
135	N45W	88SW	049	016	005	016	SC	NW	NO	OT
135	N45W	88SW	040	015	031	015	SC	NW	NO	OT
135	N45W	88SW	032	014	076	014	SC	NW	NO	OT
135	N45W	88SW	050	011	006	011	SC	NW	NO	OT
135	N45W	88SW	084	013	048	013	SC	NW	NO	OT
135	N25W	87SW	068	006		001	SC		NO	OT
135	N06E	75NW	155	012	020	012	SC		NO	OT

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
135	N06E	75NW	071	015	023	015	SC		NO	OT
135	N06E	75NW	065	017		017	SC		NO	OT
135	N80E	86NW	110	030	038	001	SC	EW	NO	OT
135	N80E	86NW	104	027	013	001	SC	EW	NO	OT
135	N80E	86NW	057	018	023	001	SC	EW	NO	OT
135	N80E	86NW	074	084	011	001	SC	EW	NO	OT
135	N80E	86NW	213	096	015	001	SC	EW	NO	OT
135	N80E	86NW	179	075	025	001	SC	EW	NO	OT
136	N70W	75NE	146	020	022	009	S		NO	OT
136	N70W	75NE	023	003	017	003	S		NO	OT
136	N70W	75NE	176	013	035	003	S		NO	OT
136	N70W	75NE	123	023	036	007	S		NO	OT
136	N70W	75NE	079	006	029	006	S		NO	OT
136	N70W	75NE	065	009	028	006	S		NO	OT
137	N78W	90SW	103	014	007	014	S		NO	OT
137	N78W	90SW	126	024	021	024	S		NO	OT
137	N78W	90SW	043	032	014	012	S		NO	OT
137	N78W	90SW	103	023	016	013	S		NO	OT
137	N78W	90SW	001	015	016	016	S		NO	OT
137	N78W	90SW	031	043	013	020	S		NO	OT
138	N80E	82NW	087	111	057	111	S	EW	SO	OT
138	N80E	82NW	079	062	012	062	S	EW	SO	OT
138	N80E	82NW	030	025	021	062	S	EW	SO	OT
138	N80E	82NW	128	083		083	S	EW	SO	OT
138	N46W	86NE	052	060		060	S	NW	SO	OT
138	N04W	67SW	056	064	038	112	S		SO	OT
138	N15W	78SW	029	063	020	063	S		SO	OT
138	N15W	78SW	072	053	032	053	S		SO	OT
138	N80E	82NW	020	033	010	001	S	EW	SO	OT
138	N80E	82NW	008	030	003	001	S	EW	SO	OT
138	N80E	82NW	010	025	010	001	S	EW	SO	OT
139	N55W	80SW	294	011	064	001	S	NW	SO	OT
139	N55W	80SW	183	005	032	001	S	NW	SO	OT
139	N55W	80SW	031	002	032	001	S	NW	SO	OT
139	N55W	80SW	037	003	022	001	S	NW	SO	OT
139	N55W	80SW	030	018	029	018	S	NW	SO	OT
139	N55W	80SW	045	008	008	008	S	NW	SO	OT
139	N55W	80SW	063	018	008	018	S	NW	SO	OT
139	N55W	80SW	104	008	043	008	S	NW	SO	OT
139	N55W	80SW	091	015	034	015	S	NW	SO	OT
139	N72E	85SE	062	024	030	024	S		SO	OT
139	N72E	85SE	062	021	019	018	S		SO	OT
139	N72E	85SE	082	023	010	005	S		SO	OT
140	N87E	85NW	540	010	068	001	S	EW	SO	OT
140	N87E	85NW	429	010	012	001	S	EW	SO	OT
140	N87E	85NW	092	012	127	001	S	EW	SO	OT
140	N87E	85NW	364	016	087	001	S	EW	SO	OT

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
140	N87E	85NW	134	001	007	001	S	EW	SO	OT
140	N87E	85NW	182	003	024	001	S	EW	SO	OT
140	N87E	85NW	163	005		001	S	EW	SO	OT
140	N03E	84SE	084	012	028	001	S		SO	OT
140	N03E	84SE	070	007	050	001	S		SO	OT
140	N03E	84SE	136	006	014	001	S		SO	OT
140	N87E	85NW	268	025	003	001	S	EW	SO	OT
140	N87E	85NW	182	019	008	001	S	EW	SO	OT
140	N87E	85NW	204	022	027	001	S	EW	SO	OT
140	N87E	85NW	255	027	095	001	S	EW	SO	OT
140	N87E	85NW	246	025	083	001	S	EW	SO	OT
140	N87E	85NW	217	024	008	001	S	EW	SO	OT
140	N87E	85NW	229	025	010	001	S	EW	SO	OT
140	N87E	85NW	242	025	114	001	S	EW	SO	OT
141	N67W	90SW	180	009	027	009	S		SO	OT
141	N67W	90SW	214	009	030	009	S		SO	OT
141	N67W	90SW	131	009	043	009	S		SO	OT
141	N67W	90SW	108	009	026	009	S		SO	OT
141	N67W	90SW	224	009	015	009	S		SO	OT
141	N67W	90SW	224	009	027	009	S		SO	OT
141	N67W	90SW	182	009	017	009	S		SO	OT
141	N67W	90SW	156	009	016	009	S		SO	OT
141	N67W	90SW	130	009	014	009	S		SO	OT
141	N67W	90SW	100	009	019	009	S		SO	OT
141	N67W	90SW	077	009	009	009	S		SO	OT
141	N67W	90SW	069	009	011	009	S		SO	OT
141	N67W	90SW	065	009	013	009	S		SO	OT
141	N30E	90NW	071	005	048	005	S	NE	SO	OT
141	N30E	90NW	073	005	044	005	S	NE	SO	OT
141	N30E	90NW	302	012	052	012	S	NE	SO	OT
141	N30E	90NW	352	012	030	012	S	NE	SO	OT
141	N30E	90NW	260	012	021	012	S	NE	SO	OT
141	N30E	90NW	134	012	042	012	S	NE	SO	OT
141	N30E	90NW	093	012		012	S	NE	SO	OT
142	N83E	83SE	073	005	012	005	S	EW	SO	OT
142	N83E	83SE	067	005	062	005	S	EW	SO	OT
142	N83E	83SE	107		072		S	EW	SO	OT
142	N83E	83SE	093		015		S	EW	SO	OT
142	N83E	83SE	134		043		S	EW	SO	OT
142	N83E	83SE	087		049		S	EW	SO	OT
142	N83E	83SE	088		084		S	EW	SO	OT
142	N83E	83SE	102		042		S	EW	SO	OT
142	N83E	83SE	080		051		S	EW	SO	OT
142	N83E	83SE	131		031		S	EW	SO	OT
142	N83E	83SE	112		039		S	EW	SO	OT
142	N83E	83SE	111		039		S	EW	SO	OT
142	N83E	83SE	103		058		S	EW	SO	OT

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
142	N83E	83SE	094		060		S	EW	SO	OT
142	N83E	83SE	110		045		S	EW	SO	OT
142	N83E	83SE	125		039		S	EW	SO	OT
142	N13W	73SW	063		010		S		SO	OT
142	N13W	73SW	029		013		S		SO	OT
142	N13W	73SW	109		013		S		SO	OT
142	N13W	73SW	141	012	026	012	S		SO	OT
142	N13W	73SW	095		013		S		SO	OT
142	N13W	73SW	064	007	003	007	S		SO	OT
142	N12E	70NW	072	014	019	014	S		SO	OT
142	N12E	70NW	284	011	014	011	S		SO	OT
142	N12E	70NW	141	012	031	012	S		SO	OT
142	N75W	84NE	013	007	031	007	S		SO	OT
142	N75W	84NE	010	010	072	010	S		SO	OT
142	N75W	84NE	030	009	036	009	S		SO	OT
142	N75W	84NE	017	009	029	009	S		SO	OT
142	N75W	84NE	011	009	036	009	S		SO	OT
143	N45W	64SW	030	007	012	007	S	NW	SO	OT
143	N45W	64SW	027	007	011	007	S	NW	SO	OT
143	N45W	64SW	041	007	016	007	S	NW	SO	OT
143	N45W	64SW	029	007	006	007	S	NW	SO	OT
143	N45W	64SW	057	011	037	011	S	NW	SO	OT
143	N45W	64SW	023	011	013	011	S	NW	SO	OT
143	N45W	64SW	025	011	027	011	S	NW	SO	OT
143	N45W	64SW	056	020	042	020	S	NW	SO	OT
143	N68E	75NW	042	007	028	007	S		SO	OT
143	N68E	75NW	018	007	029	007	S		SO	OT
143	N68E	75NW	052	007	023	007	S		SO	OT
143	N68E	75NW	032	020	011	020	S		SO	OT
143	N65W	84SW	034	011	026	011	S		SO	OT
143	N65W	84SW	016	011	012	011	S		SO	OT
143	N65W	84SW	042	007	017	007	S		SO	OT
143	N65W	84SW	031	005	034	005	S		SO	OT
143	N65W	84SW	057	007	025	007	S		SO	OT
143	N65W	84SW	025	017	023	017	S		SO	OT
143	N65W	84SW	038	017	010	017	S		SO	OT
143	N65W	84SW	036	015	012	015	S		SO	OT
144	N28E	90NW	120		018		S	NE	BR	OT
144	N28E	90NW	134		019		S	NE	BR	OT
144	N28E	90NW	172		024		S	NE	BR	OT
144	N28E	90NW	234		023		S	NE	BR	OT
144	N28E	90NW	186		023		S	NE	BR	OT
144	N28E	90NW	100		016		S	NE	BR	OT
144	N28E	90NW	089		014		S	NE	BR	OT
144	N28E	90NW	115		012		S	NE	BR	OT
144	N28E	90NW	140		013		S	NE	BR	OT
144	N46W	90SW	045		082		S	NW	BR	OT

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
144	N46W	90SW	130		017		S	NW	BR	OT
144	N46W	90SW	090		017		S	NW	BR	OT
144	N46W	90SW	090		024		S	NW	BR	OT
145	N25E	65SE					S	NE	NO	OT
145	N72W	87NE					S		NO	OT
145	N10E	70SE					S		NO	OT
145	N80E	90NW					S	EW	NO	OT
145	N25E	65SE			070		S	NE	NO	OT
145	N25E	65SE			092		S	NE	NO	OT
145	N25E	65SE			060		S	NE	NO	OT
145	N25E	65SE			035		S	NE	NO	OT
145	N25E	65SE			024		S	NE	NO	OT
145	N25E	65SE			031		S	NE	NO	OT
145	N45W	88SW	058	022	128	022	S	NW	NO	OT
145	N45W	88SW	088	022	103	022	S	NW	NO	OT
145	N45W	88SW	020	020	032	020	S	NW	NO	OT
145	N45W	88SW	030	020	090	020	S	NW	NO	OT
145	N45W	88SW	012	020	071	020	S	NW	NO	OT
146	N70W	86SW	070	048	027	012	S		NO	OT
146	N70W	86SW	016	010	042	010	S		NO	OT
146	N70W	86SW	089	010	010	010	S		NO	OT
146	N70W	86SW	083	010		010	S		NO	OT
146	N70W	86SW	045	020	015	005	S		NO	OT
146	N70W	86SW	040	016	067	003	S		NO	OT
146	N70W	86SW	059	014	036	003	S		NO	OT
146	N70W	86SW	065	012	038	003	S		NO	OT
146	N84W	80NE	052	020	068	020	S	EW	NO	OT
146	N84W	80NE	076	041	049	020	S	EW	NO	OT
146	N84W	80NE	063	015	019	015	S	EW	NO	OT
146	N70W	86SW	068	014	035	014	S		NO	OT
146	N70W	86SW	057	014	074	014	S		NO	OT
146	N84W	80NE	080	022	028	022	S	EW	NO	OT
146	N84W	86NE	070	012	014	012	S	EW	NO	OT
146	N84W	80NE	061	012	019	012	S	EW	NO	OT
146	N84W	86NE	073	006	021	006	S	EW	NO	OT
146	N84W	86NE	062	012	048	012	S	EW	NO	OT
146	N70W	86SW	098	022	089	022	S		NO	OT
147	N85W	78NE	070	030	037	030	S	EW	NO	OT
147	N85W	78NE	061	030	043	030	S	EW	NO	OT
147	N85W	78NE	052	030	038	030	S	EW	NO	OT
147	N85W	78NE	032	030	033	030	S	EW	NO	OT
147	N85W	78NE	028	030	031	030	S	EW	NO	OT
147	N85W	78NE	044	030	028	030	S	EW	NO	OT
147	N85W	78NE	056	030	032	030	S	EW	NO	OT
147	N85W	78NE	083	030	043	030	S	EW	NO	OT
147	N85W	78NE	079	030	055	030	S	EW	NO	OT
147	N85W	78NE	075	030	027	030	S	EW	NO	OT

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GP
147	N85W	78NE	082	030	027	030	S	EW	NO	OT
147	N65W	90SW	013	022	013	022	S		NO	OT
147	N65W	90SW	032	022	013	022	S		NO	OT
148	N80E	90NW	039	025	027	007	S	EW	NO	OT
148	N80E	90NW	079	045	021	009	S	EW	NO	OT
148	N80E	90NW	029	028	016	009	S	EW	NO	OT
148	N80E	90NW	025	015	007	009	S	EW	NO	OT
148	N80E	90NW	039	012	020	009	S	EW	NO	OT
148	N80E	90NW	007	007	020	007	S	EW	NO	OT
148	N80E	90NW	031	007	019	007	S	EW	NO	OT
148	N43W	87SW	024	006	006	006	S	NW	NO	OT
148	N43W	87SW	021	006	009	006	S	NW	NO	OT
148	N43W	87SW	030	006	015	006	S	NW	NO	OT
148	N43W	87SW	069	022	012	022	S	NW	NO	OT
148	N43W	87SW	061	012	013	012	S	NW	NO	OT
148	N43W	87SW	050	012	012	012	S	NW	NO	OT
149	N44W	85NE	025	012	009	012	S	NW	NO	OT
149	N44W	85NE	022	012	018	012	S	NW	NO	OT
149	N44W	85NE	016	012	014	012	S	NW	NO	OT
149	N44W	85NE	032	012	013	012	S	NW	NO	OT
149	N44W	85NE	033	012	011	012	S	NW	NO	OT
149	N44W	85NE	023	012	015	012	S	NW	NO	OT
149	N44W	85NE	029	012	016	012	S	NW	NO	OT
149	N44W	85NE	035	012	007	012	S	NW	NO	OT
149	N44W	85NE	028	012	013	012	S	NW	NO	OT
149	N44W	85NE	025	012		012	S	NW	NO	OT
149	N60W	41SW	027	020	016	007	S		NO	OT
149	N60W	41SW	024	020	010	020	S		NO	OT
149	N60W	41SW	018	007	017	007	S		NO	OT
149	N60W	41SW	035	027	036	007	S		NO	OT
149	N60W	41SW	016	037	017	012	S		NO	OT
149	N60W	41SW	021	040	032	012	S		NO	OT

APPENDIX C

STATION LOCATIONS AT THE ALLEGHENY FRONT
(in UTM Grid Coordinates)

Key to Abbreviations:

STA - station number

STA	LATITUDE	LONGITUDE
001	4317.020	646.880
002	4317.090	647.220
003	4316.590	647.850
004	4316.560	648.050
005	4324.310	648.460
006	4324.360	648.690
007	4324.870	649.130
008	4318.570	646.500
009	4318.720	647.550
010	4318.660	647.870
011	4318.510	648.280
012	4313.750	645.430
013	4313.470	646.070
014	4313.320	646.300
015	4313.120	646.420
016	4314.670	645.500
017	4314.740	645.640
018	4314.610	646.050
019	4314.460	646.420
020	4314.280	646.640
021	4309.770	644.080
022	4309.550	643.560
023	4309.130	644.310
024	4310.800	646.980
025	4307.000	642.710
026	4313.210	647.910
027	4313.760	648.230
028	4318.500	650.010
029	4314.090	645.800

APPENDIX D

ALLEGHENY FRONT DATA

Key to Abbreviations:

STA - station number

STRI- joint strike

DIP - joint dip

SPA - joint spacing (in cm)

LTH - unit: MPO = Pocono, DCK = Catskill, DCH = Chemung, DBS = black shales

LO - location with respect to the Petersburg lineament: IN = within, NO = north, SO = south

GR - group with respect to the Petersburg lineament: IN = within, OT = outside

STA	STRI	DIP	SPA	LTH	LO	GR
001	N70W	86SW	170	MPO	IN	IN
001	N65W	90SW	165	MPO	IN	IN
001	N71W	82SW	044	MPO	IN	IN
001	N70W	86SW	105	MPO	IN	IN
001	N69E	90SE	112	MPO	IN	IN
001	N75E	87SE	023	MPO	IN	IN
001	N75E	83SE	053	MPO	IN	IN
001	N69E	90SE	350	MPO	IN	IN
001	N12E	67SE		MPO	IN	IN
001	N30E	72SE	019	MPO	IN	IN
001	N25E	71SE	049	MPO	IN	IN
002	N78E	57SE	103	DCK	IN	IN
002	N68E	67SE	093	DCK	IN	IN
002	N78E	57SE	105	DCK	IN	IN
002	N68E	67SE	320	DCK	IN	IN
003	N63W	88NE	050	DCK	IN	IN
003	N69W	90SW	095	DCK	IN	IN
003	N73W	85SW	130	DCK	IN	IN
003	N63W	88NE	038	DCK	IN	IN
003	N69W	90SW	058	DCK	IN	IN
003	N73W	85SW	056	DCK	IN	IN
003	N88W	78SW	200	DCK	IN	IN
003	N86W	64SW	075	DCK	IN	IN
003	N88W	78SW	090	DCK	IN	IN
003	N27E	37SE	092	DCK	IN	IN
003	N37E	30SE	097	DCK	IN	IN
003	N28E	33SE	060	DCK	IN	IN
003	N27E	37SE	057	DCK	IN	IN
003	N37E	30SE	029	DCK	IN	IN
003	N28E	33SE	021	DCK	IN	IN
003	N27E	37SE	034	DCK	IN	IN
003	N37E	30SE	046	DCK	IN	IN
003	N28E	33SE	031	DCK	IN	IN
003	N27E	37SE	061	DCK	IN	IN
003	N37E	30SE	030	DCK	IN	IN
003	N28E	33SE	070	DCK	IN	IN
003	N27E	37SE	085	DCK	IN	IN
003	N37E	30SE	065	DCK	IN	IN
003	N28E	33SE	031	DCK	IN	IN
003	N27E	37SE	026	DCK	IN	IN
003	N28E	33SE	032	DCK	IN	IN
003	N27E	37SE	095	DCK	IN	IN
003	N37E	30SE	094	DCK	IN	IN
004	N86W	43SW	240	DCH	IN	IN
004	N86W	43SW	190	DCH	IN	IN
004	N86W	43SW	130	DCH	IN	IN
004	N86W	43SW	055	DCH	IN	IN

STA	STRI	DIP	SPA	LTH	LO	GR
004	N86W	43SW	030	DCH	IN	IN
004	N86W	43SW	238	DCH	IN	IN
004	N86W	43SW	157	DCH	IN	IN
004	N86W	43SW	100	DCH	IN	IN
004	N86W	43SW	050	DCH	IN	IN
004	N11W	39NE	028	DCH	IN	IN
004	N11W	39NE	033	DCH	IN	IN
004	N11W	39NE	035	DCH	IN	IN
004	N11W	39NE	056	DCH	IN	IN
004	N70W	69SW	024	DCH	IN	IN
004	N70W	71SW	026	DCH	IN	IN
004	N70W	69SW	015	DCH	IN	IN
004	N70W	71SW	083	DCH	IN	IN
004	N70W	69SW	055	DCH	IN	IN
004	N70W	71SW	067	DCH	IN	IN
004	N70W	69SW	044	DCH	IN	IN
004	N70W	71SW	036	DCH	IN	IN
004	N70W	69SW	045	DCH	IN	IN
004	N70W	71SW	047	DCH	IN	IN
004	N70W	69SW	075	DCH	IN	IN
004	N70W	71SW	066	DCH	IN	IN
005	N15E	87SW	132	MPO	NO	OT
005	N14E	83SE	370	MPO	NO	OT
005	N19E	76SE	022	MPO	NO	OT
005	N15E	87SE	230	MPO	NO	OT
005	N14E	83SE	050	MPO	NO	OT
005	N52W	89SW	066	MPO	NO	OT
005	N58W	89NE	045	MPO	NO	OT
005	N51W	90SW	042	MPO	NO	OT
005	N52W	89SW	113	MPO	NO	OT
005	N58W	89NE	310	MPO	NO	OT
005	N51W	90SW	195	MPO	NO	OT
005	N52W	89SW	110	MPO	NO	OT
005	N58W	89NE	054	MPO	NO	OT
005	N51W	90SW	020	MPO	NO	OT
005	N52W	89SW	092	MPO	NO	OT
005	N58W	89NE	078	MPO	NO	OT
005	N51W	90SW	030	MPO	NO	OT
005	N52W	89SW	115	MPO	NO	OT
005	N85W	84SW	048	MPO	NO	OT
005	N85W	84SW	035	MPO	NO	OT
005	N85W	84SW	030	MPO	NO	OT
005	N85W	84SW	070	MPO	NO	OT
005	N85W	84SW	050	MPO	NO	OT
005	N85W	84SW	085	MPO	NO	OT
006	N12E	58SE	086	DCK	NO	OT
006	N12E	61SE	300	DCK	NO	OT

STA	STRI	DIP	SPA	LTH	LO	GR
006	N19E	54SE	065	DCK	NO	OT
006	N12E	58AQ	380	DCK	NO	OT
006	N44W	90NE	250	DCK	NO	OT
006	N43W	90NE	084	DCK	NO	OT
006	N48W	88NE	068	DCK	NO	OT
006	N40W	90NE	089	DCK	NO	OT
006	N44W	90NE	086	DCK	NO	OT
006	N43W	90NE	178	DCK	NO	OT
006	N48W	88NE	361	DCK	NO	OT
006	N85E	75NW	030	DCK	NO	OT
006	N85W	80NE	028	DCK	NO	OT
006	N85E	75NW	250	DCK	NO	OT
006	N85W	80NE	125	DCK	NO	OT
006	N85E	75NW	222	DCK	NO	OT
006	N85W	80NE	180	DCK	NO	OT
006	N85E	75NW	030	DCK	NO	OT
006	N85W	80NE	221	DCK	NO	OT
007	N84E	87SE	120	DCK	NO	OT
007	N85E	82SE	043	DCK	NO	OT
007	N84E	87SE	148	DCK	NO	OT
007	N85E	82SE	050	DCK	NO	OT
007	N84E	87SE	100	DCK	NO	OT
007	N85E	82SE	150	DCK	NO	OT
007	N84E	82SE	110	DCK	NO	OT
007	N35W	80NE	134	DCK	NO	OT
007	N40W	85NE	110	DCK	NO	OT
007	N35W	80NE	115	DCK	NO	OT
007	N40W	85NE	180	DCK	NO	OT
007	N35W	80NE	114	DCK	NO	OT
007	N40W	85NE	128	DCK	NO	OT
007	N12E	50SE	092	DCK	NO	OT
007	N13E	50SE	150	DCK	NO	OT
007	N09E	60SE	180	DCK	NO	OT
007	N12E	50SE	212	DCK	NO	OT
007	N13E	50SE	250	DCK	NO	OT
008	N52W	90NE	053	MPO	NO	OT
008	N50W	90NE	080	MPO	NO	OT
008	N52W	90NE	075	MPO	NO	OT
008	N50W	90NE	200	MPO	NO	OT
008	N10E	70SE	105	MPO	NO	OT
008	N10E	70SE	180	MPO	NO	OT
008	N10E	70SE	085	MPO	NO	OT
008	N10E	70SE	075	MPO	NO	OT
008	N10E	70SE	040	MPO	NO	OT
008	N83E	90NW	150	MPO	NO	OT
008	N84E	90NW	055	MPO	NO	OT
008	N83E	90NW	064	MPO	NO	OT

STA	STRI	DIP	SPA	LTH	LO	GR
008	N84E	90NW	175	MPO	NO	OT
008	N83E	89NW	150	MPO	NO	OT
008	N35W	90NE	060	MPO	NO	OT
008	N41W	90NE	045	MPO	NO	OT
008	N36W	90NE	070	MPO	NO	OT
008	N41W	90NE	035	MPO	NO	OT
008	N36W	90NE	060	MPO	NO	OT
009	N82W	88NE		DCK	NO	OT
009	N88E	88NW	050	DCK	NO	OT
009	N88E	88NW	600	DCK	NO	OT
009	N88E	88NW	350	DCK	NO	OT
009	N88E	88NW	160	DCK	NO	OT
009	N88E	88NW	150	DCK	NO	OT
009	N05W	88SW	180	DCK	NO	OT
009	N00W	88SW	250	DCK	NO	OT
009	N05W	88SW	180	DCK	NO	OT
009	N00W	88SW	065	DCK	NO	OT
009	N05W	88SW	200	DCK	NO	OT
009	N00W	88SW	025	DCK	NO	OT
009	N05W	88SW	072	DCK	NO	OT
009	N00W	88SW	098	DCK	NO	OT
010	N40E	79SE	073	DCK	NO	OT
010	N32E	80SE	200	DCK	NO	OT
010	N40E	79SE	150	DCK	NO	OT
010	N28E	72NW	180	DCK	NO	OT
010	N25E	56SE	073	DCK	NO	OT
010	N25E	67SE	030	DCK	NO	OT
010	N28E	72NW	078	DCK	NO	OT
010	N25E	56SE	055	DCK	NO	OT
010	N25E	67SE	054	DCK	NO	OT
010	N28E	72NW	044	DCK	NO	OT
010	N78W	80NE	027	DCK	NO	OT
010	N83W	88SW	100	DCK	NO	OT
010	N78W	77NE	079	DCK	NO	OT
010	N80W	88NE	200	DCK	NO	OT
010	N78W	80NE	230	DCK	NO	OT
010	N83W	88SW	100	DCK	NO	OT
010	N78W	77NE	054	DCK	NO	OT
010	N80W	88NE	288	DCK	NO	OT
010	N78W	80NE	070	DCK	NO	OT
010	N50W	72NE	200	DCK	NO	OT
010	N50W	72NE	260	DCK	NO	OT
011	N32E	53SE	100	DCH	NO	OT
011	N32E	53SE	200	DCH	NO	OT
011	N32E	53SE	180	DCH	NO	OT
011	N32E	53SE	060	DCH	NO	OT
011	N32E	53SE	150	DCH	NO	OT

STA	STRI	DIP	SPA	LTH	LO	GP
011	N83W	90SW	050	DCH	NO	OT
011	N77W	90SW	070	DCH	NO	OT
011	N83W	90SW	050	DCH	NO	OT
011	N77W	90SW	095	DCH	NO	OT
011	N83W	90SW	040	DCH	NO	OT
011	N77W	90SW	110	DCH	NO	OT
011	N83W	90SW	150	DCH	NO	OT
011	N77W	90SW	110	DCH	NO	OT
011	N83W	90SW	080	DCH	NO	OT
011	N16E	70SE	170	DCH	NO	OT
011	N16E	70SE	120	DCH	NO	OT
012	N42W	89SW	062	MPO	IN	IN
012	N45W	88SW	055	MPO	IN	IN
012	N39W	90SW	088	MPO	IN	IN
012	N50W	85SW	043	MPO	IN	IN
012	N42W	89SW	110	MPO	IN	IN
012	N45W	88SW	085	MPO	IN	IN
012	N39W	90SW	120	MPO	IN	IN
012	N50W	85SW	075	MPO	IN	IN
012	N42W	89SW	130	MPO	IN	IN
012	N45W	88SW	068	MPO	IN	IN
012	N39W	90SW	049	MPO	IN	IN
012	N28E	90SE	080	MPO	IN	IN
012	N28E	80SE	060	MPO	IN	IN
012	N24E	85SE	110	MPO	IN	IN
012	N28E	90SE	074	MPO	IN	IN
012	N28E	80SE	096	MPO	IN	IN
012	N24E	85SE	060	MPO	IN	IN
012	N10E	75SE	042	MPO	IN	IN
012	N15E	90SE	055	MPO	IN	IN
012	N10E	75SE	040	MPO	IN	IN
012	N15E	90SE	027	MPO	IN	IN
012	N10E	75SE	080	MPO	IN	IN
012	N15E	90SE	060	MPO	IN	IN
013	N75W	86NE	058	DCK	IN	IN
013	N75W	86NE	095	DCK	IN	IN
013	N75W	86NE	105	DCK	IN	IN
013	N74W	86NE	047	DCK	IN	IN
013	N30E	53SE	057	DCK	IN	IN
013	N30E	53SE	052	DCK	IN	IN
013	N30E	53SE	045	DCK	IN	IN
013	N30E	53SE	049	DCK	IN	IN
013	N30E	53SE	059	DCK	IN	IN
013	N30E	53SE	083	DCK	IN	IN
013	N30E	53SE	048	DCK	IN	IN
013	N30E	53SE	045	DCK	IN	IN
014	N65W	86SW	150	DCK	IN	IN

STA	STRI	DIP	SPA	LTH	LO	GE
014	N65W	90SW	240	DCK	IN	IN
014	N65W	86SW	090	DCK	IN	IN
014	N64W	90SW	100	DCK	IN	IN
014	N65W	86SW	030	DCK.	IN	IN
014	N65W	86SW	030	DCK	IN	IN
014	N65W	90SW	080	DCK	IN	IN
014	N65W	86SW	120	DCK	IN	IN
014	N08E	78NW	040	DCK	IN	IN
014	N08E	78NW	040	DCK	IN	IN
014	N08E	78NW	100	DCK	IN	IN
014	N08E	78NW	100	DCK	IN	IN
014	N08E	78NW	090	DCK	IN	IN
014	N35E	55SE	039	DCK	IN	IN
014	N35E	55SW	045	DCK	IN	IN
014	N35E	55SW	030	DCK	IN	IN
014	N35E	55SW	050	DCK	IN	IN
014	N35E	55SW	040	DCK	IN	IN
014	N35E	55SW	050	DCK	IN	IN
014	N35E	55SW	063	DCK	IN	IN
014	N35E	55SW	049	DCK	IN	IN
014	N88W	60SW	039	DCK	IN	IN
014	N88W	60SW	022	DCK	IN	IN
014	N88W	60SW	030	DCK	IN	IN
015	N85W	88SW	026	DCH	IN	IN
015	N85W	88SW	034	DCH	IN	IN
015	N85W	88SW	026	DCH	IN	IN
015	N85W	88SW	033	DCH	IN	IN
015	N85W	88SW	080	DCH	IN	IN
015	N02E	27SE	020	DCH	IN	IN
015	N02E	27SE	030	DCH	IN	IN
015	N02E	27SE	038	DCH	IN	IN
015	N02E	27SE	055	DCH	IN	IN
015	N02E	27SE	038	DCH	IN	IN
015	N02E	27SE	024	DCH	IN	IN
015	N02E	27SE	025	DCH	IN	IN
015	N02E	27SE	050	DCH	IN	IN
016	N18E	78SE	081	DCK	IN	IN
016	N20E	70SE	008	DCK	IN	IN
016	N18E	78SE	016	DCK	IN	IN
016	N20E	70SE	040	DCK	IN	IN
016	N18E	78SE	045	DCK	IN	IN
016	N20E	70SE	040	DCK	IN	IN
016	N18E	78SE	035	DCK	IN	IN
016	N20E	70SE	080	DCK	IN	IN
016	N18E	70SE	045	DCK	IN	IN
016	N20E	70SE	110	DCK	IN	IN
016	N26W	74NE	068	DCK	IN	IN

STA	STRI	DIP	SPA	LTH	LO	GE
016	N26W	74NE	074	DCK	IN	IN
016	N26W	74NE	050	DCK	IN	IN
016	N26W	74NE	022	DCK	IN	IN
016	N85W	90SW	025	DCK	IN	IN
016	N85W	90SW	015	DCK	IN	IN
016	N85W	90SW	043	DCK	IN	IN
016	N85E	75SE	030	DCK	IN	IN
016	N85W	90SW	027	DCK	IN	IN
016	N85W	90SW	016	DCK	IN	IN
016	N85W	90SW	012	DCK	IN	IN
016	N85W	90SW	023	DCK	IN	IN
016	N85W	90SW	026	DCK	IN	IN
016	N85W	90SW	038	DCK	IN	IN
016	N85W	90SW	032	DCK	IN	IN
016	N85W	90SW	052	DCK	IN	IN
016	N85W	90SW	033	DCK	IN	IN
016	N85W	90SW	041	DCK	IN	IN
016	N85W	90SW	075	DCK	IN	IN
016	N85W	90SW	053	DCK	IN	IN
016	N85W	90SW	035	DCK	IN	IN
016	N85W	90SW	025	DCK	IN	IN
016	N85W	90SW	030	DCK	IN	IN
016	N85W	90SW	120	DCK	IN	IN
017	N82E	90SE		DCK	IN	IN
017	N10E	75SE	070	DCK	IN	IN
017	N10E	75SE	036	DCK	IN	IN
017	N10E	75SE	073	DCK	IN	IN
017	N10E	75SE	045	DCK	IN	IN
017	N10E	75SE	073	DCK	IN	IN
017	N45W	90SW	090	DCK	IN	IN
017	N45W	90SW	110	DCK	IN	IN
017	N45W	90SW	080	DCK	IN	IN
018	N80W	86NE	020	DCK	IN	IN
018	N80W	86NE	053	DCK	IN	IN
018	N80W	86NE	040	DCK	IN	IN
018	N80W	86NE	045	DCK	IN	IN
018	N80W	86NE	042	DCK	IN	IN
018	N80W	86NE	023	DCK	IN	IN
018	N80W	86NE	080	DCK	IN	IN
018	N50E	62SE	076	DCK	IN	IN
018	N50E	62SE	023	DCK	IN	IN
018	N50E	62SE	029	DCK	IN	IN
018	N50E	62SE	040	DCK	IN	IN
018	N50E	62SE	078	DCK	IN	IN
018	N50E	62SE	058	DCK	IN	IN
018	N50E	62SE	060	DCK	IN	IN
018	N50E	62SE	100	DCK	IN	IN

STA	STRI	DIP	SPA	LTH	LO	GR
019	N85W	83SW	060	DCK	IN	IN
019	N85W	83SW	082	DCK	IN	IN
019	N85W	83SW	060	DCK	IN	IN
019	N85W	83SW	040	DCK	IN	IN
019	N85W	83SW	023	DCK	IN	IN
019	N85W	83SW	040	DCK	IN	IN
019	N85W	83SW	150	DCK	IN	IN
019	N85W	83SW	150	DCK	IN	IN
019	N85W	83SW	040	DCK	IN	IN
019	N85W	83SW	018	DCK	IN	IN
019	N85W	83SW	028	DCK	IN	IN
019	N85W	83SW	032	DCK	IN	IN
020	N80W	90SW	070	DCH	IN	IN
020	N80W	90SW	050	DCH	IN	IN
020	N80W	90SW	040	DCH	IN	IN
020	N80W	90SW	020	DCH	IN	IN
020	N80W	90SW	050	DCH	IN	IN
020	N80W	90SW	040	DCH	IN	IN
020	N80W	90SW	080	DCH	IN	IN
020	N80W	90SW	020	DCH	IN	IN
020	N80W	90SW	040	DCH	IN	IN
020	N10E	50SE	020	DCH	IN	IN
020	N10E	50SE	020	DCH	IN	IN
020	N10E	50SE	020	DCH	IN	IN
020	N10E	50SE	040	DCH	IN	IN
021	N15E	66SE	110	MPO	SO	OT
021	N15E	66SE	175	MPO	SO	OT
021	N15E	66SE	080	MPO	SO	OT
021	N50W	80NE	150	MPO	SO	OT
021	N50W	80NE	120	MPO	SO	OT
021	N50W	80NE	120	MPO	SO	OT
021	N50W	80NE	070	MPO	SO	OT
021	N50W	80NE	050	MPO	SO	OT
021	N50W	80NE	070	MPO	SO	OT
021	N50W	80NE	200	MPO	SO	OT
021	N50W	80NE	175	MPO	SO	OT
021	N50W	80NE	075	MPO	SO	OT
021	N50W	80NE	250	MPO	SO	OT
022	N40E	70SE	300	DCK	SO	OT
022	N40E	70SE	175	DCK	SO	OT
022	N45W	88NE	070	DCK	SO	OT
022	N45W	88NE	300	DCK	SO	OT
022	N45W	88NE	250	DCK	SO	OT
022	N45W	88NE	150	DCK	SO	OT
023	N50E	21NW	070	DCK	SO	OT
023	N50E	21NW	075	DCK	SO	OT
023	N50E	21NW	090	DCK	SO	OT

STA	STRI	DIP	SPA	LTH	LC	GP
023	N50E	21NW	200	DCK	SO	OT
023	N50E	21NW	040	DCK	SO	OT
023	N50E	21NW	060	DCK	SO	OT
023	N51W	90SW	160	DCK	SO	OT
023	N51W	90SW	060	DCK	SO	OT
023	N51W	90SW	075	DCK	SO	OT
023	N51W	90SW	100	DCK	SO	OT
023	N51W	90SW	070	DCK	SO	OT
023	N51W	90SW	080	DCK	SO	OT
023	N51W	90SW	030	DCK	SO	OT
023	N51W	90SW	150	DCK	SO	OT
023	N51W	90SW	300	DCK	SO	OT
023	N34E	53NW		DCK	SO	OT
024	N81W	89NE	057	DCH	SO	OT
024	N81W	89NE	060	DCH	SO	OT
024	N81W	89NE	054	DCH	SO	OT
024	N81W	89NE	035	DCH	SO	OT
024	N81W	89NE	067	DCH	SO	OT
024	N81W	89NE	115	DCH	SO	OT
024	N81W	89NE	100	DCH	SO	OT
024	N81W	89NE	037	DCH	SO	OT
024	N81W	89NE	150	DCH	SO	OT
024	N81W	89NE	115	DCH	SO	OT
024	N81W	89NE	075	DCH	SO	OT
024	N81W	89NE	105	DCH	SO	OT
024	N16E	76NW	160	DCH	SO	OT
024	N16E	76NW	075	DCH	SO	OT
024	N16E	76NW	169	DCH	SO	OT
024	N16E	76NW	065	DCH	SO	OT
024	N16E	76NW	175	DCH	SO	OT
024	N16E	76NW	160	DCH	SO	OT
024	N16E	76NW	120	DCH	SO	OT
024	N16E	76NW	070	DCH	SO	OT
024	N16E	76NW	070	DCH	SO	OT
024	N16E	76NW	100	DCH	SO	OT
025	N50W	54SW	018	DBS	SO	OT
025	N50W	54SW	018	DBS	SO	OT
025	N50W	54SW	016	DBS	SO	OT
025	N50W	54SW	019	DBS	SO	OT
025	N50W	54SW	017	DBS	SO	OT
025	N50W	54SW	017	DBS	SO	OT
025	N50W	54SW	022	DBS	SO	OT
025	N50W	54SW	017	DBS	SO	OT
025	N50W	54SW	015	DBS	SO	OT
025	N50W	54SW	014	DBS	SO	OT
025	N50W	54SW	013	DBS	SO	OT
025	N50W	54SW	009	DBS	SO	OT

STA	STRI	DIP	SPA	LTH	LO	GE
025	N85W	30NE	030	DBS	SO	OT
025	N85W	30NE	017	DBS	SO	OT
025	N85W	30NE	025	DBS	SO	OT
025	N85W	30NE	040	DBS	SO	OT
025	N85W	30NE	030	DBS	SO	OT
025	N85W	30NE	040	DBS	SO	OT
025	N85W	30NE	020	DBS	SO	OT
025	N85W	30NE	052	DBS	SO	OT
025	N85W	30NE	016	DBS	SO	OT
025	N85W	30NE	050	DBS	SO	OT
026	N83E	71NW	045	DBS	IN	IN
026	N83E	71NW	007	DBS	IN	IN
026	N83E	71NW	007	DBS	IN	IN
026	N83E	71NW	013	DBS	IN	IN
026	N83E	71NW	015	DBS	IN	IN
026	N83E	71NW	008	DBS	IN	IN
026	N83E	71NW	009	DBS	IN	IN
026	N83E	71NW	015	DBS	IN	IN
026	N83E	71NW	010	DBS	IN	IN
026	N83E	71NW	028	DBS	IN	IN
026	N83E	71NW	013	DBS	IN	IN
026	N83E	71NW	015	DBS	IN	IN
026	N83E	71NW	018	DBS	IN	IN
026	N83E	71NW	025	DBS	IN	IN
026	N83E	71NW	007	DBS	IN	IN
026	N14E	34SE	028	DBS	IN	IN
026	N14E	34SE	028	DBS	IN	IN
026	N14E	34SE	019	DBS	IN	IN
026	N14E	34SE	011	DBS	IN	IN
027	N50E	45SE	016	DBS	IN	IN
027	N50E	45SE	010	DBS	IN	IN
027	N50E	45SE	020	DBS	IN	IN
027	N50E	45SE	020	DBS	IN	IN
027	N50E	45SE	020	DBS	IN	IN
027	N50E	45SE	009	DBS	IN	IN
027	N50E	45SE	010	DBS	IN	IN
027	N50E	45SE	030	DBS	IN	IN
027	N50E	45SE	019	DBS	IN	IN
027	N55W	86NE	013	DBS	IN	IN
027	N55W	86NE	012	DBS	IN	IN
027	N55W	86NE	007	DBS	IN	IN
027	N55W	86NE	007	DBS	IN	IN
027	N55W	86NE	012	DBS	IN	IN
027	N55W	86NE	030	DBS	IN	IN
028	N35E	55NW	020	DBS	NO	OT
028	N35E	55NW	016	DBS	NO	OT
028	N35E	55NW	009	DBS	NO	OT

STA	STRI	DIP	SPA	LTH	LO	GP
028	N35E	55NW	023	DBS	NO	OT
028	N35E	55NW	017	DBS	NO	OT
028	N35E	55NW	023	DBS	NO	OT
028	N35E	55NW	034	DBS	NO	OT
028	N35E	55NW	025	DBS	NO	OT
028	N50W	60SW	040	DBS	NO	OT
028	N50W	60SW	026	DBS	NO	OT
028	N50W	60SW	038	DBS	NO	OT
028	N50W	60SW	041	DBS	NO	OT
028	N50W	60SW	033	DBS	NO	OT
029			058	MPO	IN	IN
029			059	MPO	IN	IN
029			090	MPO	IN	IN
029			052	MPO	IN	IN
029			049	MPO	IN	IN
029			042	MPO	IN	IN
029			033	MPO	IN	IN
029			034	MPO	IN	IN
029			076	MPO	IN	IN
029			075	MPO	IN	IN
029			057	MPO	IN	IN
029			082	MPO	IN	IN

APPENDIX E

STATION LOCATIONS OF THE WESTWARD EXTENSIONS PARSONS AND PETERSBURG LINEAMENTS (in UTM Grid Coordinates)

Key to Abbreviations:

STA - station number

STA	LATITUDE	LONGITUDE	STA	LATITUDE	LONGITUDE
038	4340.470	592.200	81A	4311.470	580.210
042	4330.820	586.670	082	4313.780	578.540
043	4338.920	585.530	083	4314.000	578.020
044	4340.010	589.220	084	4308.180	576.310
045	4341.180	591.640	085	4307.770	576.620
046	4341.700	591.610	087	4304.660	586.050
047	4341.900	591.450	088	4304.510	586.690
048	4341.960	591.270	089	4305.600	588.780
049	4342.500	591.740	090	4313.450	589.900
050	4353.810	592.840	091	4311.540	589.900
051	4355.000	591.780	092	4306.030	585.600
052	4355.360	591.260	093	4305.130	583.910
053	4354.980	588.700	094	4321.510	581.100
054	4359.300	593.310	095	4303.280	588.650
055	4362.350	595.450	096	4300.260	588.170
056	4363.770	596.120	097	4299.210	587.180
057	4360.580	595.570	098	4296.560	582.920
058	4356.220	592.020	099	4296.800	582.100
059	4349.870	591.830	100	4294.590	578.900
060	4342.910	592.070	101	4302.330	575.710
061	4343.110	592.010	102	4344.770	584.380
062	4367.310	580.420	103	4322.850	589.800
063	4367.070	581.080	104	4331.470	586.340
064	4359.870	578.640	105	4326.170	578.380
065	4349.260	594.170	106	4326.480	578.480
066	4350.070	591.320	107	4302.250	570.990
068	4361.550	577.800	108	4302.720	571.330
069	4361.340	577.910	109	4303.100	571.520
070	4360.840	578.170	110	4332.110	587.660
071	4360.630	578.380	111	4334.280	589.070
072	4370.410	579.710	112	4334.550	590.570
078	4359.160	587.580	113	4337.390	588.710
079	4355.410	586.060	114	4339.020	588.090
080	4354.770	582.400	115	4339.940	587.960
081	4354.320	580.710			

APPENDIX F

WESTWARD EXTENSIONS DATA

Key to Abbreviations:

STA - station number

STRI- joint strike

DIP - joint dip

SPA - joint spacing (in cm)

LTH - unit: PAL = Allegheny, PPV = Pottsville

LOC - location with respect to lineaments. See Figure 14 for sub-area locations

GR - group with respect to lineaments: IN = within, OT = outside

STA	STRI	DIP	SPA	LTH	LOC	GE
038	N22E		0367	PPV	I-2	IN
038	N22E		0202	PPV	I-2	IN
038	N22E		0220	PPV	I-2	IN
038	N22E		0200	PPV	I-2	IN
038	N22E		0900	PPV	I-2	IN
038	N22E		0760	PPV	I-2	IN
038	N22E		0280	PPV	I-2	IN
038	N22E		0400	PPV	I-2	IN
038	N22E		0260	PPV	I-2	IN
038	N22E		0297	PPV	I-2	IN
038	N80E		0220	PPV	I-2	IN
038	N80E		0360	PPV	I-2	IN
038	N80E		0227	PPV	I-2	IN
042	N85E	77NE	0900	PAL	O-5	OT
042	N85E	77NE	1500	PAL	O-5	OT
042	N14E	82SE	0300	PAL	O-5	OT
042	N14E	82SE	0560	PAL	O-5	OT
042	N14E	82SE	0750	PAL	O-5	OT
042	N14E	82SE	0280	PAL	O-5	OT
042	N49W	86NE	0550	PAL	O-5	OT
042	N49W	86NE	1500	PAL	O-5	OT
042	N49W	86NE	1450	PAL	O-5	OT
043	N34E	85SE	0450	PAL	O-5	OT
043	N34E	85SE	0800	PAL	O-5	OT
043	N34E	85SE	0520	PAL	O-5	OT
043	N34E	85SE	1080	PAL	O-5	OT
043	N34E	85SE	0630	PAL	O-5	OT
043	N76E	88SE	0490	PAL	O-5	OT
043	N76E	88SE	0104	PAL	O-5	OT
043	N76E	88SE	0295	PAL	O-5	OT
043	N76E	88SE	0310	PAL	O-5	OT
043	N76E	88SE	0276	PAL	O-5	OT
043	N76E	88SE	0130	PPV	O-5	OT
043	N75E	88SE	0100	PPV	O-5	OT
044	N70W	90SW	0340	PPV	O-5	OT
044	N70W	90SW	0190	PPV	O-5	OT
044	N70W	90SW	0210	PPV	O-5	OT
044	N70W	90SW	0710	PPV	O-5	OT
044	N70W	90SW	0580	PPV	O-5	OT
044	N70W	90SW	0238	PPV	O-5	OT
044	N70W	90SW	0320	PPV	O-5	OT
044	N10E	90NW	1390	PPV	O-5	OT
044	N10E	90NW	0400	PPV	O-5	OT
044	N10E	90NW	1120	PPV	O-5	OT
044	N10E	90NW	0205	PPV	O-5	OT
044	N10E	90NW	0605	PPV	O-5	OT
044	N10E	90NW	0505	PPV	O-5	OT

STA	STRI	DIP	SPA	LTH	LOC	GE
045	N13E	81NW	0170	PPV	I-2	IN
045	N13E	81NW	0150	PPV	I-2	IN
045	N13E	81NW	0230	PPV	I-2	IN
045	N13E	81NW	0095	PPV	I-2	IN
045	N13E	81NW	0180	PPV	I-2	IN
045	N13E	81NW	0370	PPV	I-2	IN
045	N87E	75SE	0940	PPV	I-2	IN
045	N87E	75SE	0190	PPV	I-2	IN
045	N87E	75SE	0380	PPV	I-2	IN
045	N87E	75SE	0370	PPV	I-2	IN
046	N30W	77SW	0230	PPV	I-2	IN
046	N30W	77SW	0220	PPV	I-2	IN
046	N30W	77SW	0250	PPV	I-2	IN
047	N72E	87SE	0150	PAL	I-2	IN
047	N72E	87SE	0150	PAL	I-2	IN
047	N72E	87SE	0100	PAL	I-2	IN
047	N72E	87SE	0200	PAL	I-2	IN
047	N72E	87SE	0115	PAL	I-2	IN
047	N72E	87SE	0100	PAL	I-2	IN
047	N72E	87SE	0130	PAL	I-2	IN
047	N72E	87SE	0110	PAL	I-2	IN
047	N72E	87SE	0120	PAL	I-2	IN
047	N72E	87SE	0200	PAL	I-2	IN
047	N72E	87SE	0300	PAL	I-2	IN
047	N72E	87SE	0170	PAL	I-2	IN
048	N70E	90NW	0380	PAL	I-2	IN
048	N70E	90NW	0440	PAL	I-2	IN
048	N70E	90SW	0730	PAL	I-2	IN
048	N70E	90NW	0570	PAL	I-2	IN
048	N70E	90NW	0770	PAL	I-2	IN
048	N35E	90NW	0300	PAL	I-2	IN
048	N35E	90NW	0280	PAL	I-2	IN
048	N35E	90NW	0410	PAL	I-2	IN
048	N35E	90NW	0240	PAL	I-2	IN
048	N35E	90NW	0150	PAL	I-2	IN
048	N35E	90NW	0200	PAL	I-2	IN
049	N85W	70NE	0150	PAL	I-2	IN
049	N85W	70NE	0125	PAL	I-2	IN
049	N85W	70NE	0200	PAL	I-2	IN
049	N85W	70NE	0150	PAL	I-2	IN
049	N85W	70NE	0180	PAL	I-2	IN
049	N35E	90NW	0200	PAL	I-2	IN
049	N35E	90NW	0250	PAL	I-2	IN
050	N88E	88NW	0020	PST	I-1	IN
050	N88E	88NW	0055	PST	I-1	IN
050	N88E	88NW	0280	PST	I-1	IN
050	N88E	88NW	0200	PST	I-1	IN

STA	STRI	DIP	SPA	LTH	LOC	GE
050	N22E	90NW	0200	PST	I-1	IN
050	N22E	90NW	0220	PST	I-1	IN
051	N19E	72SE	0300	PAL	I-1	IN
051	N19E	72SE	0180	PAL	I-1	IN
051	N19E	72SE	0150	PAL	I-1	IN
051	N19E	72SE	0150	PAL	I-1	IN
051	N19E	72SE	0180	PAL	I-1	IN
051	N19E	72SE	0275	PAL	I-1	IN
051	N75E	90NW	0300	PAL	I-1	IN
051	N75E	90NW	0300	PAL	I-1	IN
051	N75E	90NW	0180	PAL	I-1	IN
051	N75E	90NW	0250	PAL	I-1	IN
051	N75E	90NW	0270	PAL	I-1	IN
051	N75E	90NW	0200	PAL	I-1	IN
051	N75E	90NW	0200	PAL	I-1	IN
051	N75E	90NW	0350	PAL	I-1	IN
052	N24E	90NW	0270	PAL	I-1	IN
052	N24E	90NW	0690	PAL	I-1	IN
052	N24E	90NW	1020	PAL	I-1	IN
052	N83E	75NW	0140	PAL	I-1	IN
052	N83E	75NW	0040	PAL	I-1	IN
052	N83E	75NW	0940	PAL	I-1	IN
052	N83E	75NW	0100	PAL	I-1	IN
052	N83E	75NW	0400	PAL	I-1	IN
052	N36W	75NW	0350	PAL	I-1	IN
052	N35W	75NW	0150	PAL	I-1	IN
053	N85W	90NE	0200	PAL	I-1	IN
053	N86W	90NE	0300	PAL	I-1	IN
053	N86W	90NE	0220	PAL	I-1	IN
053	N30W	89NE	0220	PAL	I-1	IN
053	N30W	89NE	0350	PAL	I-1	IN
053	N30W	89NE	0180	PAL	I-1	IN
054	N50W		0300	PAL	O-1	OT
054	N50W		0500	PAL	O-1	OT
054	N24E		0210	PAL	O-1	OT
054	N24E		0310	PAL	O-1	OT
054	N24E		0380	PAL	O-1	OT
054	N24E		0300	PAL	O-1	OT
054	N24E		0530	PAL	O-1	OT
055	N25E		0620	PAL	O-1	OT
055	N25E		0530	PAL	O-1	OT
055	N25E		0400	PAL	O-1	OT
055	N25E		0850	PAL	O-1	OT
055	N55W		0425	PAL	O-1	OT
055	N55W		0280	PAL	O-1	OT
055	N55W		0240	PAL	O-1	OT
055	N55W		0590	PAL	O-1	OT

STA	STRI	DIP	SPA	LTH	LOC	GP
055	N55W		0370	PAL	O-1	OT
055	N55W		0340	PAL	O-1	OT
056	N52W		0330	PAL	O-1	OT
056	N52W		1150	PAL	O-1	OT
056	N52W		0800	PAL	O-1	OT
056	N52W		0940	PAL	O-1	OT
057	N15E	88SE	1060	PAL	O-1	OT
057	N15E	88SE	0580	PAL	O-1	OT
057	N15E	88SE	0330	PAL	O-1	OT
057	N54W	80SW	0290	PAL	O-1	OT
057	N54W	80SW	0300	PAL	O-1	OT
057	N54W	80SW	0340	PAL	O-1	OT
057	N15E	88SE	0270	PAL	O-1	OT
058	N54W	90SW	0870	PAL	O-1	OT
058	N54W	90SW	0900	PAL	O-1	OT
058	N54W	90SW	0840	PAL	O-1	OT
058	N54W	90SW	0590	PAL	O-1	OT
058	N54W	90SW	0500	PAL	O-1	OT
058	N54W	90SW	0450	PAL	O-1	OT
058	N54W	90SW	0470	PAL	O-1	OT
058	N54W	90SW	0560	PAL	O-1	OT
058	N33E	75NW	0340	PAL	O-1	OT
058	N33E	75NW	0340	PAL	O-1	OT
058	N33E	75NW	0350	PAL	O-1	OT
058	N33E	75NW	0360	PAL	O-1	OT
059	N02W	75SW	0510	PAL	O-4	OT
059	N02W	75SW	2000	PAL	O-4	OT
059	N02W	75SW	0510	PAL	O-4	OT
059	N02W	75SW	1070	PAL	O-4	OT
059	N20E	75SW	0330	PAL	O-4	OT
060	N80W	80NE	0570	PPV	O-4	OT
060	N80W	80NE	0720	PPV	O-4	OT
060	N80W	80NE	1110	PPV	O-4	OT
060	N80W	80NE	0840	PPV	O-4	OT
060	N80W	80NE	0245	PPV	O-4	OT
060	N80W	80NE	0955	PPV	O-4	OT
060	N80W	80NE	0815	PPV	O-4	OT
060	N80W	80NE	0160	PPV	O-4	OT
060	N80W	80NE	0420	PPV	O-4	OT
060	N80W	80NE	0295	PPV	O-4	OT
060	N80W	80NE	0170	PPV	O-4	OT
060	N80W	80NE	0460	PPV	O-4	OT
060	N80W	80NE	0210	PPV	O-4	OT
060	N80W	80NE	0170	PPV	O-4	OT
060	N80W	80NE	0270	PPV	O-4	OT
061	N25E			PPV	O-4	OT
061	N04W	80SW	0480	PPV	O-4	OT

STA	STRI	DIP	SPA	LTH	LOC	GE
061	N04W	90SW	0400	PPV	O-4	OT
061	N85E		0500	PPV	O-4	OT
061	N85E		0500	PPV	O-4	OT
061	N85E		0800	PPV	O-4	OT
061	N85E		0740	PPV	O-4	OT
062	N11E		0350	PPV	O-2	OT
062	N11E		0200	PPV	O-2	OT
063	N56W	90SW	0380	PAL	O-2	OT
063	N56W	90SW	0360	PAL	O-2	OT
064	N75W	90SW	0184	PAL	O-3	OT
064	N75W	90SW	0227	PAL	O-3	OT
064	N75W	90SW	0250	PAL	O-3	OT
064	N75W	90SW	0530	PAL	O-3	OT
064	N75W	90SW	0445	PAL	O-3	OT
064	N75W	90SW	0320	PAL	O-3	OT
064	N75W	90SW	0100	PAL	O-3	OT
064	N75W	90SW	0180	PAL	O-3	OT
064	N75W	90SW	0100	PAL	O-3	OT
064	N75W	90SW	0200	PAL	O-3	OT
064	N75W	90SW	0210	PAL	O-3	OT
064	N75W	90SW	0240	PAL	O-3	OT
064	N75W	90SW	0310	PAL	O-3	OT
064	N75W		0440	PAL	O-3	OT
064	N75W		0610	PAL	O-3	OT
065	N45E		0250	PAL	I-1	IN
065	N45E		0325	PAL	I-1	IN
065	N45E		0200	PAL	I-1	IN
065	N45E		0225	PAL	I-1	IN
065	N45E		0325	PAL	I-1	IN
065	N38W		0280	PAL	I-1	IN
065	N38W		0350	PAL	I-1	IN
065	N38W		0350	PAL	I-1	IN
065	N38W		0300	PAL	I-1	IN
065	N38W		0150	PAL	I-1	IN
065	N38W		0175	PAL	I-1	IN
065	N38W		0275	PAL	I-1	IN
065	N38W		0275	PAL	I-1	IN
066	N15W		1117	PAL	O-4	OT
066	N15W		0420	PAL	O-4	OT
066	N15W		0640	PAL	O-4	OT
066	N37W		0260	PAL	O-4	OT
066	N37W		0330	PAL	O-4	OT
066	N37W		0220	PAL	O-4	OT
066	N37W		0240	PAL	O-4	OT
066	N37W		0140	PAL	O-4	OT
066	N37W		0310	PAL	O-4	OT

STA	STRI	DIP	SPA	LTH	LOC	GP
068	N75W		0200	PAL	O-3	OT
068	N75W		0190	PAL	O-3	OT
068	N75W		0460	PAL	O-3	OT
068	N75W		0350	PAL	O-3	OT
068	N75W		0260	PAL	O-3	OT
069	N70W		0560	PAL	O-3	OT
069	N70W		0560	PAL	O-3	OT
069	N70W		0700	PAL	O-3	OT
070	N18E	88NW	0675	PAL	O-3	OT
070	N18E	88NW	0475	PAL	O-3	OT
070	N75W	86NE	0775	PAL	O-3	OT
070	N75W	86NE	0690	PAL	O-3	OT
070	N75W	86NE	1090	PAL	O-3	OT
070	N75W	86NE	1030	PAL	O-3	OT
070	N75W	86NE	0530	PAL	O-3	OT
071	N69W	89NE	0330	PAL	O-3	OT
071	N69W	89NE	0520	PAL	O-3	OT
071	N69W	89NE	0230	PAL	O-3	OT
071	N69W	89NE	0450	PAL	O-3	OT
072	N07E		0530	PAL	O-2	OT
072	N07E		0340	PAL	O-2	OT
072	N07E		0280	PAL	O-2	OT
072	N80E		0790	PAL	O-2	OT
078	N01E	89NW		PAL	I-1	IN
078	N45W	79SW	0490	PAL	I-1	IN
078	N45W	79SW	0410	PAL	I-1	IN
078	N80W	85SW	0220	PAL	I-1	IN
079	N87W	90SW	0350	PAL	O-4	OT
080	N25E	90NW	0540	PAL	O-3	OT
080	N25E	90NW	0190	PAL	O-3	OT
080	N25W	90SW	0430	PAL	O-3	OT
081	N15E	90NW	0570	PAL	O-3	OT
081	N15E	90NW	0480	PAL	O-3	OT
081	N15E	90NW	0840	PAL	O-3	OT
081	N15E	90NW	0430	PAL	O-3	OT
081	N85W	74SW	1200	PAL	O-3	OT
81A	N20E	90NW	1810	PPV	O-6	OT
81A	N20E	90NW	1270	PPV	O-6	OT
81A	N20E	90NW	1950	PPV	O-6	OT
81A	N20E	90NW	1410	PPV	O-6	OT
81A	N45W	80NE	0230	PPV	O-6	OT
81A	N45W	80NE	0760	PPV	O-6	OT
81A	N45W	80NE	1730	PPV	O-6	OT
81A	N45W	80NE	1200	PPV	O-6	OT
082	N40E	90NW	1030	PAL	O-6	OT
082	N40E	90NW	0830	PAL	O-6	OT
082	N40E	90NW	0670	PAL	O-6	OT

STA	STRI	DIP	SPA	LTH	LOC	GP
082	N80E	75SE	0070	PAL	O-6	OT
082	N80E	75SE	0220	PAL	O-6	OT
082	N80E	75SE	0400	PAL	O-6	OT
083				PAL	O-6	OT
084	N80W	88SW	1220	PAL	O-6	OT
084	N03E	87SE			O-6	OT
086	N75E	89SE	0130	PPV	O-6	OT
086	N75E	89SE	0110	PPV	O-6	OT
086	N75E	89SE	0230	PPV	O-6	OT
087	N73E	87SE	1000	PAL	I-3	IN
087	N73E	87SE	0460	PAL	I-3	IN
087	N01E	77NW	0740	PAL	I-3	IN
088	N81E	90NW	0330	PPV	I-3	IN
088	N81E	90NW	0330	PPV	I-3	IN
088	N81E	90NW	0340	PPV	I-3	IN
088	N81E	90NW	0380	PPV	I-3	IN
088	N81E	90NW	0440	PPV	I-3	IN
088	N81E	90NW	0490	PPV	I-3	IN
088	N81E	90NW	0240	PPV	I-3	IN
088	N81E	90NW	0190	PPV	I-3	IN
088	N60W	90SW	0270	PPV	I-3	IN
088	N60W	90SW	0260	PPV	I-3	IN
089	N25E	83SE	0450	PPV	I-3	IN
089	N65W	90SW	0275	PPV	I-3	IN
090	N55E	78NW	0620	PAL	O-6	OT
090	N55E	78NW	0710	PAL	O-6	OT
090	N85E	85NW	0800	PAL	O-6	OT
091	N75E	78SE	0810	PAL	O-6	OT
091	N75E	78SE	1900	PAL	O-6	OT
091	N75E	78SE	0650	PAL	O-6	OT
091	N75E	78SE	0250	PAL	O-6	OT
091	N75E	78SE	1130	PAL	O-6	OT
091	N75E	78SE	0520	PAL	O-6	OT
092	N10E	90NW	0160	PAL	I-3	IN
092	N10E	90NW	0110	PAL	I-3	IN
092	N10E	90NW	1320	PAL	I-3	IN
092	N10E	90NW	0840	PAL	I-3	IN
092	N85E	90NW	1140	PAL	I-3	IN
092	N27E	75NW	0160	PAL	I-3	IN
093	N22W	82SW	0120	PPV	I-3	IN
093	N22W	82SW	0100	PPV	I-3	IN
093	N22W	82SW	0080	PPV	I-3	IN
093	N45W	90SW		PPV	I-3	IN
094	N35E	90NW		PAL	O-6	OT
095	N65W	90SW	0150	PPV	I-3	IN
095	N89W	90SW	0480	PPV	I-3	IN
096	N75E	78NW	0180	PPV	I-3	IN

STA	STRI	DIP	SPA	LTH	LOC	GP
096	N75E	78NW	0300	PPV	I-3	IN
096	N75E	78NW	0190	PPV	I-3	IN
096	N75E	78NW	0080	PPV	I-3	IN
096	N75E	78NW	0210	PPV	I-3	IN
096	N75E	78NW	0210	PPV	I-3	IN
096	N75E	78NW	0140	PPV	I-3	IN
096	N75E	78NW	0140	PPV	I-3	IN
096	N75E	78NW	0510	PPV	I-3	IN
096	N75E	78NW	0490	PPV	I-3	IN
096	N05W	77NE	0190	PPV	I-3	IN
096	N05W	77NE	0780	PPV	I-3	IN
096	N05W	77NE	0250	PPV	I-3	IN
096	N05W	77NE	0340	PPV	I-3	IN
097	N72E	83SE	0440	PAL	O-7	OT
097	N72E	83SE	1070	PAL	O-7	OT
097	N10W	90SW	1500	PAL	O-7	OT
097	N10W	90SW	0580	PAL	O-7	OT
097	N10W	90SW	0450	PAL	O-7	OT
098	N75E	78NW	0870	PPV	O-7	OT
098	N75E	78NW	1230	PPV	O-7	OT
098	N75E	78NW	1430	PPV	O-7	OT
099	N55E	90NW		PPV	O-7	OT
100				PPV	O-7	OT
101	N52E	80SE		PAL	O-8	OT
102	N53W	65SW	0950	PAL	O-5	OT
102	N55W	65SW	1910	PAL	O-5	OT
102	N34E	80SE	0510	PAL	O-5	OT
103	N12E	80SE		PAL	O-6	OT
104	N30W	85SW	0640	PAL	O-5	OT
104	N30W	85SW	0700	PAL	O-5	OT
104	N70W	90SW	0850	PAL	O-5	OT
105				PAL	O-5	OT
106	N05W	78NE	1000	PAL	O-5	OT
106	N67E	90NW	1060	PAL	O-5	OT
106	N67E	90NW	0850	PAL	O-5	OT
107	N37E	85SE	0850	PAL	O-8	OT
107	N37E	85SE	0480	PAL	O-8	OT
107	N85W	90SW	0750	PAL	O-8	OT
108	N20W	80SW	0700	PAL	O-8	OT
108	N20W	80SW	0600	PAL	O-8	OT
108	N20W	80SW	0800	PAL	O-8	OT
108	N20W	80SW	0600	PAL	O-8	OT
108	N20W	80SW	0900	PAL	O-8	OT
108	N75E	90NW	0700	PAL	O-8	OT
109	N70W	90SW		PAL	O-8	OT
110	N56E	87NW		PAL	O-5	OT
110	N25W	77NE	0410	PAL	O-5	OT
111	N81E	89NW	0670	PAL	O-5	OT
111	N81E	89NW	2100	PAL	O-5	OT
112	N22E	80SE		PAL	O-5	OT
113	N10W	79NE	0970	PPV	O-5	OT

STA	STRI	DIP	SPA	LTH	LOC	GR
113	N62E	90NW	1700	PPV	0-5	OT
114	N21E	88SE	0400	PPV	0-5	OT
115	N87W	90SW	0800	PPV	0-5	OT
115	N87W	90SW	0600	PPV	0-5	OT
115	N87W	90SW	1000	PPV	0-5	OT
115	N87W	90SW	1000	PPV	0-5	OT

APPENDIX G

OPERATOR VARIANCE DATA

Key to Abbreviations:

OPR - operator

STRI- joint strike

SP - joint spacing (in cm)

ST - joint set: EW = east-west, 7W = N 70-79°W, 6W = N 60-69°W, NE = northeast, NN = N 05°W to N 05°E, NW = northwest

STA - station number. See Appendix A, Station Locations in Tucker County

OPR	STRI	SP	ST	STA
BRI	N74W	06	EW	33
BRI	N83W	08	EW	33
BRI	N87W	13	EW	33
BRI	N53W	07	NW	33
BRI	N18E	03	NE	33
BRI	N25E	10	NE	33
BRI	N83W	22	EW	33
BRI	N82W	26	EW	33
BRI	N86W	11	EW	33
BRI	N86E	29	EW	33
BRI	N10E	28	NN	33
BRI	N14E	29	NN	33
BRI	N75W	31	7W	87
BRI	N77W	32	7W	87
BRI	N73W	12	7W	87
BRI	N23E	27	NE	87
BRI	N83E	31	EW	87
BRI	N80E	20	EW	87
BRI	N15E	21	NN	87
BRI	N45W		NW	87
BRI	N85E	45	EW	87
BRI	N87W	15	EW	87
BRI	N82W	13	EW	87
BRI	N80E	05	EW	87
BRI	N18E	55	NN	87
BRI	N53W		NW	87
BRI	N58W	32	NW	35
BRI	N64W	13	6W	35
BRI	N60W	07	6W	35
BRI	N61W	06	6W	35
BRI	N57W	08	6W	35
BRI	N71W	10	6W	35
BRI	N26E	04	NE	35
BRI	N25E	03	NE	35
BRI	N12E	19	NE	35
BRI	N62W	12	6W	35
BRI	N63W	09	6W	35
BRI	N58W	39	6W	35
BRI	N60E	23	6E	35
BRI	N62E	28	6E	35
BRI	N89W	16	EW	35
BRI	N28E	45	NE	35
BRI	N32E	99	NE	35
TOM	N86W	29	EW	33
TOM	N87W	24	EW	33
TOM	N84W	35	EW	33
TOM	N86W	34	EW	33

OBR	STRI	SP	ST	STA
TOM	N87W	55	EW	33
TOM	N84W	66	EW	33
TOM	N86W	68	EW	33
TOM	N87W	12	EW	33
TOM	N84W	34	EW	33
TOM	N86W	40	EW	33
TOM	N19E	19	NE	33
TOM	N21E	02	NE	33
TOM	N42E	19	NE	33
TOM	N19E	23	NE	33
TOM	N21E	08	NE	33
TOM	N42E	16	NE	33
TOM	N19E	23	NE	33
TOM	N21E	10	NE	33
TOM	N42E	16	NE	33
TOM	N19E	17	NE	33
TOM	N21E	22	NE	33
TOM	N42E	32	NE	33
TOM	N19E	30	NE	33
TOM	N21E	03	NE	33
TOM	N42E	27	NE	33
TOM	N19E	34	NE	33
TOM	N21E	17	NE	33
TOM	N42E	08	NE	33
TOM	N19E	13	NE	33
TOM	N21E	21	NE	33
TOM	N42E	23	NE	33
TOM	N19E	39	NE	33
TOM	N83E	30	EW	87
TOM	N85E	32	EW	87
TOM	N79W	37	EW	87
TOM	N83E	14	EW	87
TOM	N85E	11	EW	87
TOM	N79W	18	EW	87
TOM	N83E	25	EW	87
TOM	N85E	46	EW	87
TOM	N79W	13	EW	87
TOM	N83E	62	EW	87
TOM	N85E	18	EW	87
TOM	N79W	06	EW	87
TOM	N83E	15	EW	87
TOM	N85E	16	EW	87
TOM	N79W	03	EW	87
TOM	N83E	17	EW	87
TOM	N85E	10	EW	87
TOM	N79W	12	EW	87
TOM	N83E	09	EW	87

OPR	STRI	SP	ST	STA
TOM	N85E	06	EW	87
TOM	N79W	30	EW	87
TOM	N83E	10	EW	87
TOM	N85E	10	EW	87
TOM	N79W	16	EW	87
TOM	N83E	07	EW	87
TOM	N85E	17	EW	87
TOM	N40W		NW	87
TOM	N20E	15	NE	87
TOM	N26E	28	NE	87
TOM	N24E	13	NE	87
TOM	N20E	08	NE	87
TOM	N26E	06	NE	87
TOM	N44E	42	NE	35
TOM	N25E	35	NE	35
TOM	N29E	07	NE	35
TOM	N25E	46	NE	35
TOM	N61W	13	NW	35
TOM	N51W	23	NW	35
TOM	N51W	34	NW	35
TOM	N53W	35	NW	35
TOM	N53W	11	NW	35
TOM	N51W	32	NW	35
TOM	N53W	28	NW	35
TOM	N51W	15	NW	35
TOM	N53W	08	NW	35
TOM	N51W	39	NW	35
TOM	N53W	79	NW	35
TOM	N51W	39	NW	35
TOM	N73E	27	7E	35
TOM	N73E	23	7E	35
TOM	N52W	14	NW	35
TOM	N53W	15	NW	35
TOM	N51W	26	NW	35
TOM	N02E	12	NN	35
TOM	N02E	11	NN	35
TOM	N51W	32	NW	35
TOM	N53W	08	NW	35
TOM	N51W	07	NW	35
TOM	N53W	17	NW	35
TOM	N51W	24	NW	35
TOM	N25E	99	NE	35
TOM	N29E	37	NE	35
TOM	N25E	35	NE	35
TOM	N29E	14	NE	35
RUS	N87W	19	EW	33
RUS	N84W	12	EW	33

OPR	STRI	SP	ST	STA
BUS	N82W	10	EW	33
BUS	N84W	18	EW	33
BUS	N87W	31	EW	33
BUS	N84W	07	EW	33
BUS	N83W	12	EW	33
BUS	N39W	16	NW	33
BUS	N46W	18	NW	33
BUS	N47W	24	NW	33
BUS	N47W	27	NW	33
BUS	N39W	13	NW	33
BUS	N46W	13	NW	33
BUS	N47W	70	NW	33
BUS	N47W	36	NW	33
BUS	N39W	29	NW	33
BUS	N67W	17	6W	33
BUS	N63W	04	6W	33
BUS	N67W	08	6W	33
BUS	N21E	43	NE	33
BUS	N14E	26	NE	33
BUS	N14E	29	NE	33
BUS	N17E	53	NE	33
BUS	N21E	34	NE	33
BUS	N14E	33	NE	33
BUS	N14E	23	NE	33
BUS	N21E	59	NE	33
BUS	N14E	71	NE	33
BUS	N87E	70	EW	87
BUS	N85E	05	EW	87
BUS	N89E	99	EW	87
BUS	N85E	38	EW	87
BUS	N87E	06	EW	87
BUS	N85E	07	EW	87
BUS	N89E	03	EW	87
BUS	N85E	72	EW	87
BUS	N87E	70	EW	87
BUS	N85E	28	EW	87
BUS	N70W	30	7W	87
BUS	N72W	99	7W	87
BUS	N71W	32	7W	87
BUS	N72W	48	7W	87
BUS	N70W	43	7W	87
BUS	N72W	48	7W	87
BUS	N71W	47	7W	87
BUS	N58W	12	NW	35
BUS	N57W	11	NW	35
BUS	N57W	13	NW	35
BUS	N62W	09	NW	35

OPR	STRI	SP	ST	STA
BUS	N58W	24	NW	35
BUS	N57W	36	NW	35
BUS	N62W	38	NW	35
BUS	N74W	22	7W	35
BUS	N70W	12	7W	35
BUS	N70W	05	7W	35
BUS	N74W	08	7W	35
BUS	N70W	21	7W	35
BUS	N70W	16	7W	35
BUS	N70W	11	7W	35
BUS	N74W	02	7W	35
BUS	N70W	05	7W	35
BUS	N70W	24	7W	35
BUS	N70W	13	7W	35
BUS	N70W	13	7W	35
BUS	N70W	39	7W	35
BUS	N70W	32	7W	35
BUS	N70W	12	7W	35
BUS	N70W	16	7W	35
BUS	N70W	28	7W	35
BUS	N70W	30	7W	35
BUS	N57W	06	NW	35
BUS	N55W	09	NW	35
BUS	N57W	09	NW	35
BUS	N55W	08	NW	35
BUS	N57W	19	NW	35
BUS	N27E	29	NE	35
BUS	N17E	25	NE	35
BUS	N27E	32	NE	35
BUS	N17E	45	NE	35
BUS	N27E	03	NE	35
JAN	N80W	25	EW	33
JAN	N83W	20	EW	33
JAN	N80W	14	EW	33
JAN	N80W	11	EW	33
JAN	N83W	12	EW	33
JAN	N83W	08	EW	33
JAN	N80W	18	EW	33
JAN	N83W	24	EW	33
JAN	N80W	24	EW	33
JAN	N83W	32	EW	33
JAN	N50W	16	NW	33
JAN	N45W	20	NW	33
JAN	N48W	19	NW	33
JAN	N50W	12	NW	33
JAN	N87W	18	EW	87
JAN	N87W	09	EW	87

OPR	STRI	SP	ST	STA
JAN	N87W	12	EW	87
JAN	N87W	24	EW	87
JAN	N87W	38	EW	87
JAN	N87W	09	EW	87
JAN	N87W	17	EW	87
JAN	N87W	17	EW	87
JAN	N87W	34	EW	87
JAN	N51W	07	NW	87
JAN	N51W	26	NW	87
JAN	N84E	11	EW	87
JAN	N84E	11	EW	87
JAN	N73W	32	7W	87
JAN	N73W	31	7W	87
JAN	N24E	90	NE	35
JAN	N24E	59	NE	35
JAN	N24E	29	NE	35
JAN	N02E	21	NN	35
JAN	N02E	31	NN	35
JAN	N02E	11	NN	35
JAN	N55W	47	NW	35
JAN	N55W	09	NW	35
JAN	N55W	25	NW	35
JAN	N54W	35	NW	35
JAN	N85W	36	EW	35
JAN	N85W	29	EW	35
JAN	N85W	12	EW	35
JAN	N85W	16	EW	35
JAN	N85W	37	EW	35

APPENDIX H

COAL CLEAT INTENSITY DATA

Key to Abbreviations:

STA - station number

STRI - joint strike

DIP - joint dip

CLEAT- type of cleat: FACE, BUTT

SPA - cleat spacing (in cm)

BT - bed thickness (in cm)

STA	STRI	DIP	CLEAT	SPA	BT
001	N75W	90SW	FACE	02.5	40
001	N75W	90SW	FACE	02.0	40
001	N75W	90SW	FACE	04.5	40
001	N75W	90SW	FACE	03.0	40
001	N75W	90SW	FACE	01.0	40
001	N75W	90SW	FACE	02.5	40
001	N75W	90SW	FACE	03.0	40
001	N75W	90SW	FACE	01.0	40
001	N75W	90SW	FACE	02.5	40
001	N75W	90SW	FACE	02.0	40
001	N11E	75SE	BUTT	03.5	40
001	N11E	75SE	BUTT	05.0	40
001	N11E	75SE	BUTT	03.0	40
001	N11E	75SE	BUTT	07.0	40
001	N11E	75SE	BUTT	04.0	40
001	N11E	75SE	BUTT	08.0	40
001	N11E	75SE	BUTT	04.0	40
001	N11E	75SE	BUTT	10.0	40
001	N11E	75SE	BUTT	04.0	40
001	N11E	75SE	BUTT	05.5	40
002	N70W	90SW	FACE	03.0	38
002	N70W	90SW	FACE	04.0	38
002	N70W	90SW	FACE	06.0	38
002	N70W	90SW	FACE	02.5	38
002	N70W	90SW	FACE	02.5	38
002	N70W	90SW	FACE	03.0	38
002	N70W	90SW	FACE	03.0	38
002	N70W	90SW	FACE	03.0	38
002	N70W	90SW	FACE	03.0	38
002	N70W	90SW	FACE	02.5	38
002	N05E	70SE	BUTT	02.5	38
002	N05E	70SE	BUTT	02.0	38
002	N05E	70SE	BUTT	03.0	38
002	N05E	70SE	BUTT	02.0	38
002	N05E	70SE	BUTT	04.0	38
002	N05E	70SE	BUTT	01.5	38
002	N05E	70SE	BUTT	02.0	38
002	N05E	70SE	BUTT	03.5	38
002	N05E	70SE	BUTT	04.0	38
002	N05E	70SE	BUTT	01.5	38
004	N74W	90SW	FACE	02.0	35
004	N74W	90SW	FACE	02.0	35
004	N74W	90SW	FACE	02.5	35
004	N74W	90SW	FACE	01.0	35
004	N74W	90SW	FACE	02.5	35
004	N74W	90SW	FACE	02.5	35
004	N74W	90SW	FACE	02.0	35

STA	STRI	DIP	CLEAT	SPA	BT
004	N74W	90SW	FACE	01.5	35
004	N74W	90SW	FACE	02.5	35
004	N74W	90SW	FACE	03.0	35
004	N15E	83SE	BUTT	09.0	35
004	N15E	83SE	BUTT	05.0	35
004	N15E	83SE	BUTT	04.0	35
004	N15E	83SE	BUTT	05.0	35
004	N15E	83SE	BUTT	05.0	35
004	N15E	83SE	BUTT	04.0	35
004	N15E	83SE	BUTT	04.0	35
004	N15E	83SE	BUTT	06.0	35
004	N15E	83SE	BUTT	05.0	35
004	N15E	83SE	BUTT	08.5	35
006	N78W	90SW	FACE	03.5	20
006	N78W	90SW	FACE	03.0	20
006	N78W	90SW	FACE	03.0	20
006	N78W	90SW	FACE	02.0	20
006	N78W	90SW	FACE	02.0	20
006	N78W	90SW	FACE	01.5	20
006	N78W	90SW	FACE	02.0	20
006	N78W	90SW	FACE	04.0	20
006	N78W	90SW	FACE	04.0	20
006	N78W	90SW	FACE	02.5	20
006	N22E	87NW	BUTT	03.0	20
006	N22E	87NW	BUTT	02.0	20
006	N22E	87NW	BUTT	03.5	20
006	N22E	87NW	BUTT	02.5	20
006	N22E	87NW	BUTT	04.0	20
006	N22E	87NW	BUTT	04.0	20
006	N22E	87NW	BUTT	07.0	20
006	N22E	87NW	BUTT	03.0	20
006	N22E	87NW	BUTT	03.0	20
006	N22E	87NW	BUTT	03.5	20
007	N75W	90SW	FACE	07.0	35
007	N75W	90SW	FACE	08.5	35
007	N75W	90SW	FACE	07.0	35
007	N75W	90SW	FACE	08.0	35
007	N75W	90SW	FACE	09.5	35
007	N75W	90SW	FACE	06.5	35
007	N75W	90SW	FACE	07.5	35
007	N75W	90SW	FACE	06.5	35
007	N75W	90SW	FACE	09.0	35
007	N75W	90SW	FACE	07.5	35
007	N15E	80NW	BUTT	08.5	35
007	N15E	80NW	BUTT	09.0	35
007	N15E	80NW	BUTT	10.5	35
007	N15E	80NW	BUTT	12.0	35

STA	STRI	DIP	CLEAT	SPA	BT
007	N15E	80NW	BUTT	10.5	35
007	N15E	80NW	BUTT	08.0	35
007	N15E	80NW	BUTT	08.0	35
007	N15E	80NW	BUTT	09.5	35
007	N15E	80NW	BUTT	08.0	35
007	N15E	80NW	BUTT	10.0	35
008	N75W	89SW	FACE	02.0	40
008	N75W	89SW	FACE	03.0	40
008	N75W	89SW	FACE	03.5	40
008	N75W	89SW	FACE	03.0	40
008	N75W	89SW	FACE	05.5	40
008	N75W	89SW	FACE	03.5	40
008	N75W	89SW	FACE	02.5	40
008	N75W	89SW	FACE	02.5	40
008	N75W	89SW	FACE	02.5	40
008	N75W	89SW	FACE	02.0	40
008	N11E	73SE	BUTT	08.0	40
008	N11E	73SE	BUTT	10.0	40
008	N11E	73SE	BUTT	06.0	40
008	N11E	73SE	BUTT	05.0	40
008	N11E	73SE	BUTT	11.0	40
008	N11E	73SE	BUTT	13.0	40
008	N11E	73SE	BUTT	06.0	40
008	N11E	73SE	BUTT	06.5	40
008	N11E	73SE	BUTT	13.0	40
008	N11E	73SE	BUTT	05.0	40
011	N77W	89NE	FACE	02.0	40
011	N77W	89NE	FACE	02.0	40
011	N77W	89NE	FACE	02.0	40
011	N77W	89NE	FACE	03.0	40
011	N77W	89NE	FACE	02.0	40
011	N77W	89NE	FACE	02.0	40
011	N77W	89NE	FACE	02.0	40
011	N77W	89NE	FACE	01.0	40
011	N77W	89NE	FACE	03.0	40
011	N77W	89NE	FACE	01.0	40
011	N15E	77SE	BUTT	06.0	40
011	N15E	77SE	BUTT	09.0	40
011	N15E	77SE	BUTT	07.0	40
011	N15E	77SE	BUTT	05.0	40
011	N15E	77SE	BUTT	07.0	40
011	N15E	77SE	BUTT	05.0	40
011	N15E	77SE	BUTT	07.0	40
011	N15E	77SE	BUTT	12.0	40
011	N15E	77SE	BUTT	10.0	40
011	N15E	77SE	BUTT	10.0	40
012	N73W	86SW	FACE	04.0	40

STA	STRI	DIP	CLEAT	SPA	BT
012	N73W	86SW	FACE	02.5	40
012	N73W	86SW	FACE	06.0	40
012	N73W	86SW	FACE	04.0	40
012	N73W	86SW	FACE	05.0	40
012	N73W	86SW	FACE	03.0	40
012	N73W	86SW	FACE	06.0	40
012	N73W	86SW	FACE	05.0	40
012	N73W	86SW	FACE	03.0	40
012	N73W	86SW	FACE	02.0	40
012	N18E	90NW	BUTT	08.0	40
012	N18E	90NW	BUTT	04.0	40
012	N18E	90NW	BUTT	04.5	40
012	N18E	90NW	BUTT	03.0	40
012	N18E	90NW	BUTT	04.0	40
012	N18E	90NW	BUTT	05.0	40
012	N18E	90NW	BUTT	06.0	40
012	N18E	90NW	BUTT	06.0	40
012	N18E	90NW	BUTT	07.0	40
012	N18E	90NW	BUTT	06.0	40
013	N76W	90SW	FACE	03.0	40
013	N76W	90SW	FACE	03.0	40
013	N76W	90SW	FACE	03.0	40
013	N76W	90SW	FACE	03.5	40
013	N76W	90SW	FACE	02.5	40
013	N76W	90SW	FACE	03.0	40
013	N76W	90SW	FACE	03.0	40
013	N76W	90SW	FACE	04.0	40
013	N76W	90SW	FACE	03.0	40
013	N76W	90SW	FACE	02.5	40
013	N25E	75SE	BUTT	11.0	40
013	N25E	75SE	BUTT	09.0	40
013	N25E	75SE	BUTT	04.0	40
013	N25E	75SE	BUTT	14.0	40
013	N25E	75SE	BUTT	09.0	40
013	N25E	75SE	BUTT	10.0	40
013	N25E	75SE	BUTT	11.0	40
013	N25E	75SE	BUTT	12.0	40
013	N25E	75SE	BUTT	08.0	40
013	N25E	75SE	BUTT	11.0	40
014	N74W	85SW	FACE	05.0	35
014	N74W	85SW	FACE	03.5	35
014	N74W	85SW	FACE	06.0	35
014	N74W	85SW	FACE	05.0	35
014	N74W	85SW	FACE	05.5	35
014	N74W	85SW	FACE	06.5	35
014	N74W	85SW	FACE	06.0	35
014	N74W	85SW	FACE	05.0	35

STA	STRI	DIP	CLEAT	SPA	BT
014	N74W	85SW	FACE	04.0	35
014	N74W	85SW	FACE	06.0	35
014	N10E	83SE	BUTT	07.5	35
014	N10E	83SE	BUTT	12.0	35
014	N10E	83SE	BUTT	12.5	35
014	N10E	83SE	BUTT	13.0	35
014	N10E	83SE	BUTT	13.0	35
014	N10E	83SE	BUTT	13.0	35
014	N10E	83SE	BUTT	17.0	35
014	N10E	83SE	BUTT	16.0	35
014	N10E	83SE	BUTT	10.0	35
014	N10E	83SE	BUTT	09.0	35
015	N72W	90SW	FACE	08.0	35
015	N72W	90SW	FACE	07.0	35
015	N72W	90SW	FACE	04.0	35
015	N72W	90SW	FACE	05.0	35
015	N72W	90SW	FACE	10.0	35
015	N72W	90SW	FACE	07.0	35
015	N72W	90SW	FACE	10.0	35
015	N72W	90SW	FACE	11.0	35
015	N72W	90SW	FACE	11.0	35
015	N72W	90SW	FACE	11.0	35
015	N12E	80NW	BUTT	14.0	35
015	N12E	80NW	BUTT	18.0	35
015	N12E	80NW	BUTT	16.0	35
015	N12E	80NW	BUTT	05.0	35
015	N12E	80NW	BUTT	07.0	35
015	N12E	80NW	BUTT	18.0	35
015	N12E	80NW	BUTT	11.0	35
015	N12E	80NW	BUTT	17.0	35
015	N12E	80NW	BUTT	14.0	35
015	N12E	80NW	BUTT	13.0	35

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STYLE ELEMENTS, INTENSITY, AND RELATIVE AGES OF JOINTS ON A DETACHED ANTICLINE

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ABSTRACT

Previous work showed that sets of systematic joints can differ significantly in values of joint style elements - aspects of orientation, size, spacing, shape, and rock character. As part of a project funded by the Department of Energy to improve exploration for fractured Appalachian gas reservoirs from New York State to Virginia, we studied effects on joint types of structural position on an anticline in Upper Devonian siltstones and mudstones in the eastern Plateau province of northern West Virginia. In one road cut exposing the anticline, Holland measured as many as feasible of 32 style elements on each of 100 planar, mostly filled joints in beds of relatively constant thickness and lithology. Partial repetition by four others showed operator variability to be insignificant. Joint spacing and size vary significantly between sets but insignificantly between limbs. On limbs, nonsystematic longitudinal cross joints are bigger and more abundant than are systematic diagonals. Joint surface area per unit volume varies little between and within limbs. Joint intersections and delicate structures on joint faces show that rare systematic transverse joints formed first, then the diagonals, and lastly the longitudinals. In 149 nearby exposures of the same lithologies, transverse joints form the most abundant set but the sets formed in the same order. In the single road cut, relative ages of folding and jointing are indeterminate. From fillings and Secor's model, we infer that the joints formed under increasing effective stresses and stress difference.

* Presented by Ms. Dixon at 14th Annual Meeting NE Section GSA, March 1979.

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APPENDIX C

Surface Fracture Data

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FRACTURE DENSITY AND ORIENTATION STUDY OF THE MERC #1 CORE FROM MONONGALIA COUNTY, WEST VIRGINIA

by

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ABSTRACT

Fracture data based on the description of the MERC #1 Core shows the relationships of natural fractures in the Devonian shales of West Virginia to depth and stratigraphy. Core induced fractures, mineralized and unmineralized natural fractures (joints), slickensided surfaces, and slickenlines were differentiated in the MERC #1 oriented Devonian shale core.

Two major subvertical to vertical fracture (joint) sets were found, N80°E and N70°W. Inclined slickensided surfaces (>10° dip) show one major set, N0°-30°E. The major trend of the slickenlines (striations) on the slickensides is N70°W. This is the direction of regional tectonic transport. The highest densities of slickensides occur near the base of the Mahantango Formation and near the base of the Marcellus Shale. These two intervals may represent decollement horizons. Many of the fractures are mineralized, some with fibrous mineral growth which is indicative of high fluid pressure within the shale.

Eventually the results of this study will be combined with those of other cored wells to present an integrated regional analysis of Devonian shale fractures.

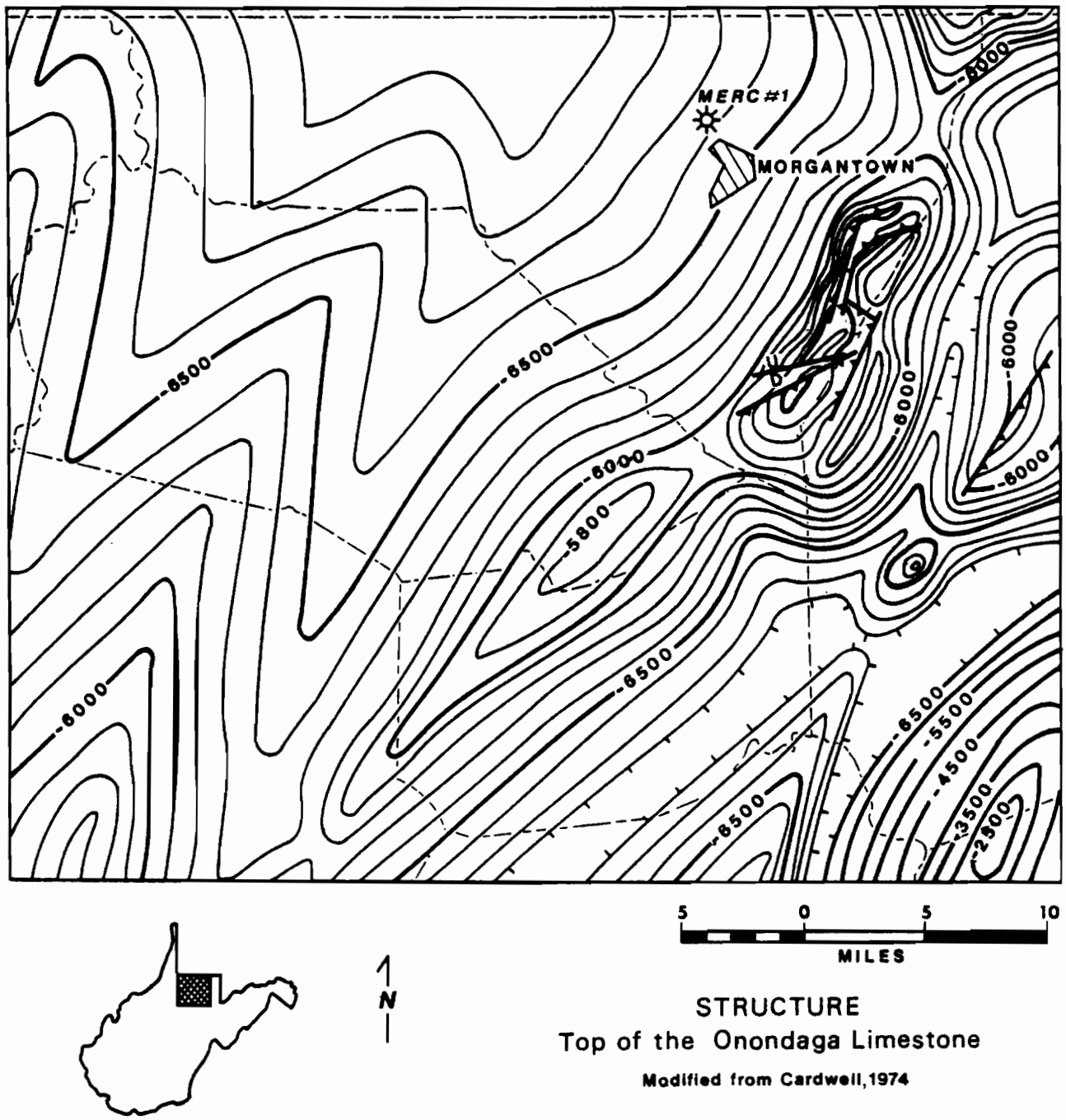
PURPOSE

The study of the MERC #1 Core is conducted under DOE Contract number DE-AC21-76MC05194 with West Virginia University. This is the second in a series of reports planned to document the results of our analysis of fractures found in oriented cores taken from several Devonian shale wells. These wells were drilled by private industry in cooperation with ERDA-DOE under the Eastern Gas Shales Program. Each report will serve as a record of all fractures logged from the oriented shale core taken in that particular well. Some preliminary interpretations will be made. However, it is the author's intent to record, summarize, and present a visual comparison of fracture data from each core. Then, in a separate report, written at the end of the investigation, he will integrate and compare the data from the several reports written by the author and other investigators. The final report will interpret the significance of fractures found in all oriented cores, and it will attempt to relate the findings to shale production and to the regional tectonics of the study area.

LOCATION AND DRILLING DATA

The MERC #1 Well is located in Monongalia County, West Virginia, approximately two miles north of the city of Morgantown in the Morgantown North quadrangle at latitude 39°40'14" N and longitude 79°58'44" W (Figure 1). Ground level elevation at the well site is 959' above sea level. The borehole diameter at corepoint was 8-23/32 inches. A plastic sleeve was used inside the inner core barrel, and a 3-1/2 inch core was retrieved.

The core was oriented by the author at the Morgantown Energy Technology Center's Core Lab according to guidelines set forth by Byrer and Komar (1977). Interval '7232'-'7290' of the core could not be oriented because of a malfunction of the camera taking orientation photographs of the core. The interval was not used in this study to obtain fracture orientation data; however, fracture frequency data from this interval was recorded.



5 0 5 10
MILES

STRUCTURE
Top of the Onondaga Limestone

Modified from Cardwell, 1974

CI=100 ft, 500 ft in eastern folded areas

M. EVANS 1979

Figure 1

STRATIGRAPHIC INTERVAL CORED

A total of 341 feet of the Devonian sediment was cored, from 7168' to 7509', plus 11 feet of the Onondaga Limestone to 7520' (Figures 2 and 3). The top of the core includes the Tully(?) Limestone (7168'-6192'), the Mahantango Formation (7192'-7395'), and the highly radioactive Marcellus Shale (7395'-7509'). The bottom of the core includes the top portion of the underlying Onondaga Limestone (7509'-7520') (Schwietering, personal communication).

GENERALIZED GEOLOGIC COLUMN

SERIES	GROUP OR FORMATION	IMPORTANT ROCK UNITS	DRILLERS TERMS
PERMIAN	DUNKARD	Gilmore SS	Gilmore Coal
		Rockport LS	
		Nineveh Coal	Nineveh Sand
		Dunkard Coal	
		Jollytown Coal	Jollytown Sand
			Hundred Sand
		Upper Marietta SS	
			Washingtown Coal
PENNSYLVANIAN	MONONGAHELA	Waynesburg Coal	Uniontown Coal
		Sewickley Coal	Redstone Coal
		Pittsburgh Coal	
	CONEMAUGH	Connellsville SS	Morgantown Sand
		Bakerstown Coal	Saltsburg Sand
		Mahoning SS	
	ALLEGHENGY		Burning Springs Sand
		Lower Freeport SS	Gas Sand
	POTTSVILLE	Salt Sands	1st Salt Sand
			2nd Salt Sand
			3rd Salt Sand
MISSISSIPPIAN	MAUCH CHUNK	Maxton SS	Ravencliff Sand
			Lower Maxon
			Little Lime
	GREENBRIER	Greenbrier Limestone	Big Lime
		Big Injun SS	Keener Sand
	POCONO	Squaw SS	
		Weir Sand	
		Berea SS	Sunbury Shale
DEVONIAN	HAMPSHIRE	Fifty-foot SS	
		Gordon SS	
	CHEMUNG	Fifth Sand	
	BRALLIER		BROWN SHALE
	HARRELL	Burkett Mbr	
	TULLY (?)		
	MAHANTANGO		
	MARCELLUS		
	ONONDAGA	Onondaga LS	Corniferous LS
	HELDERBERG		Oriskany Sand
		Helderberg LS	

Figure 2

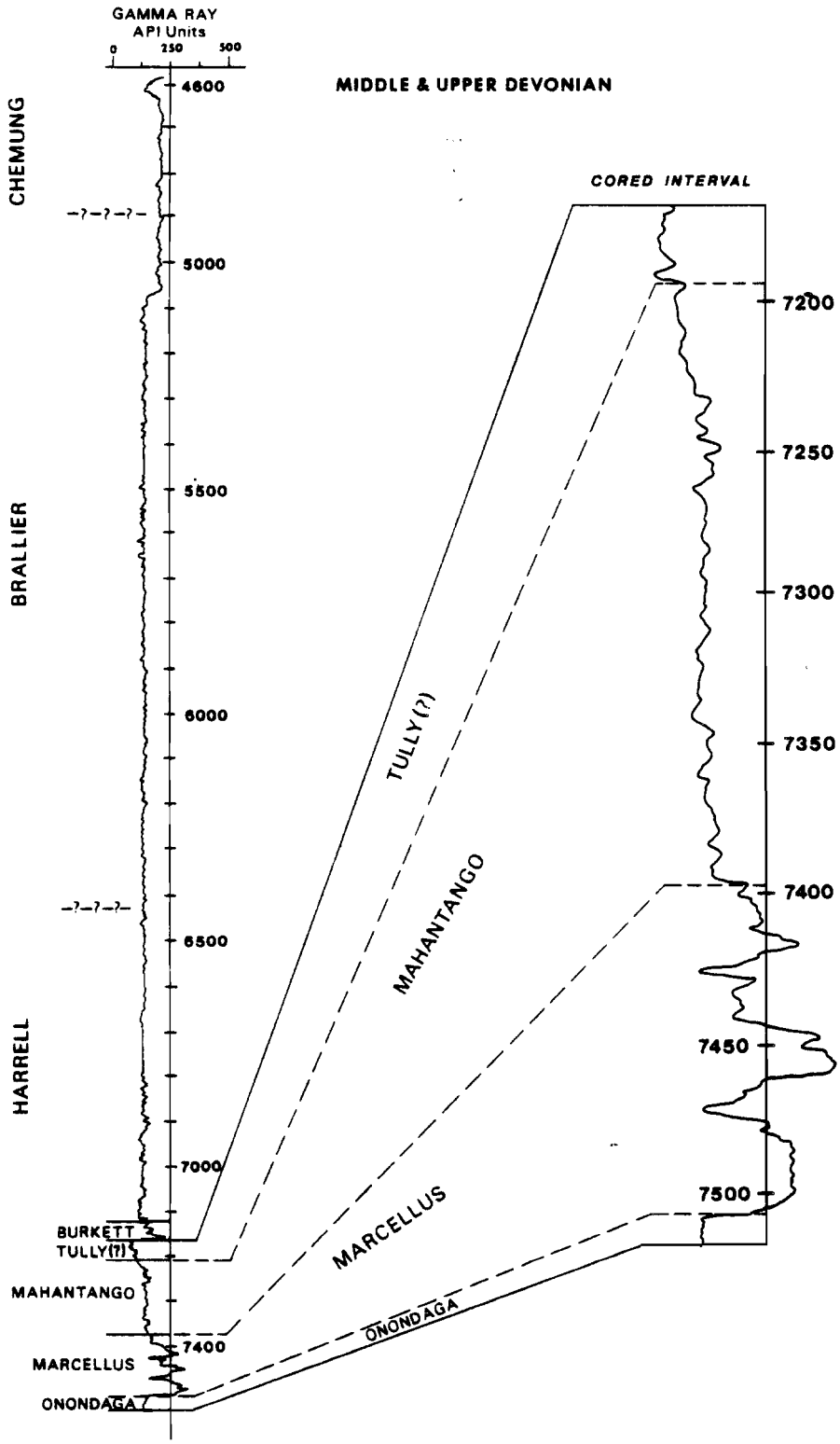

GAMMA RAY
API Units
0
250
500
MIDDLE & UPPER DEVONIAN
CORED INTERVAL
CHEMUNG
BRALLIER
HARRELL
4600
5000
5500
6000
6500
7000
7400
7200
7250
7300
7350
7400
7450
7500
TULLY(?)
MAHANTANGO
MARCELLUS
ONONDAGA
BURKETT
TULLY(?)
MAHANTANGO
MARCELLUS
ONONDAGA

Figure 3

REGIONAL GEOLOGY

Structure

The MERC #1 Well is located on the western flank of the Fayette anticline, which is just west of the large N30°E trending Chestnut Ridge anticline. Regional structure of the Devonian shales shows a monoclinal dip of less than 1° (Figure 1) to the northwest.

Stratigraphy

The surface rocks of the area are Permian, Pennsylvanian, Mississippian, and Devonian in age (Figure 2). The Permian Dunkard Group covers the western portion on Monongalia County and includes the Washington Coal. Rocks of Pennsylvanian age exposed in the area of the well includes the Monongahela and Conemaugh Groups, Allegheny Formation and the Pottsville Group. Rocks of Mississippian age are exposed in the eastern portion of the county on the crest of the Chestnut Ridge anticline and in stream valleys. These rocks include the Mauch Chunk Group, the Greenbrier Group, containing the Productive Big Lime of West Virginia, and the lowest group of the Mississippian, the Pocono, which includes the Big Injun Sandstone and Berea Sandstone at its base. The uppermost portion of the Devonian Catskill Formation is exposed in the channel of the Cheat River which cuts through the Chestnut Ridge anticline. In the subsurface the Devonian is divided into the Catskill Formation, the Chemung Formation, the Brallier Formation, Harrell Formation, Tully(?) Limestone, Mahantango Formation and Marcellus Shale. Lower Devonian sediments include the Onondaga Limestone, Oriskany Sandstone, and Helderberg Formation.

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HYDROCARBON PRODUCTION

There is very little current hydrocarbon production from the general area around the MERC #1 Well. The nearest fields in West Virginia include the Cassville-Bowlby Field, which produced gas from the Mississippian Big Injun Sand, and the Westover Field, which produced gas from the Big Injun Sand and the Pennsylvanian Cow Run Sand. Both fields are now inactive. The nearest active field is the South Burns Chapel Field on the crest of the Chestnut Ridge anticline southeast of MERC #1. Production is mainly from the Devonian Huntersville and Oriskany (Cardwell 1977).

The MERC #1 Well had shows of gas from the Big Injun, Squaw, Gordon, 4th, 5th, Baynard, and Riley Sands, all of which are well above the cored interval. The only significant production from the Devonian shales was from the Burkett Member of the Harrell Formation, which produced 25 MCF per day after fracing. This is immediately above the cored interval.

FRACTOGRAPHIC LOGGING

The fracture data was collected by the author at the Morgantown Energy Technology Center's Core Lab. During the study certain structural and surface features were used to interpret the type or origin of the fractures. The terminology used to describe these fractures may be unfamiliar to most readers, so before proceeding with a discussion of the fracture analysis it is necessary to discuss this terminology.

Surface Features Observed on Rock Fractures

Most features on the surface of fractures are called transient features. According to Kulander, Dean, and Barton (1977), transient features are short range perturbations of a fracture surface which can be attributed to:

1) material inhomogeneties (fossils, pyrite nodules, pore space, etc.)
2) sonic wave interference
3) local changes in stress directions and stress gradients in the dominant stress field
4) fracture velocity variations

Among the more common transient features are arrest lines or rib marks (Figure 4a) which are generated through temporary fracture hesitation resulting from a momentarily decreased stress field or a sudden change in principle stress direction. Essentially, they record an instantaneous picture of the fracture front configuration at a particular point in time during fracture propagation (Kulander, Dean and Barton, 1977).

Inclusion hackle (Figure 4a) is most likely generated when a fracture front advances into the vicinity of an inclusion (pore space, weakly cemented area, grain of different composition or size, etc.). The fracture plane may be locally warped by the interference of local stress gradients associated with the inclusion boundary. This planar warping, occurring as the main fracture plan passes around the inclusion, often results in the fracture being at different levels by the time it reaches the far side of the inclusion (side opposite that first encountered by the fracture). This divergence results in a fracture plane that is not interconnected. Therefore, after passing the inclusion, the fracture advances on two closely spaced subparallel levels which soon rejoin to advance as a single front with the trailing fracture stepping (hooking up or down) into the other. This step forms on the far side of the inclusions that points in the direction of fracture propagation.

Twist hackle (Figure 4a) is generated at the fracture fronts when the direction of principle tension rotates in the plane containing the fracture front. The entire fracture front cannot instantaneously rotate to a new planar direction perpendicular to the new principle stress. Therefore, the fracture at the fracture front breaks up into individual en echelon elongate tongues. Each tongue is inclined to the original fracture plant and each tongue is perpendicular to the local resultant principle tension. These tongues continue to spread laterally and eventually curve into one another to complete the fracture, thereby producing the steps seen as hackle markings.

Another common transient feature is hackle plume or "feather feature" (Figure 4a). Hackle plumes are made up of twist hackle and inclusion hackle.

They consist of a central axis that originates at the initial point of fracture propagation and faint ridges which diverge outward from the axis in a plumose fashion toward the edge of the fracture plane. The presence of plumose markings on a fracture surface indicate that there has been no significant lateral movement along the fracture surface (Roberts, 1961).

Besides transient fracture features there are also tendential fracture features. These features arise from long range changes in the stress field and are recorded as undulations in the fracture profile or trace line formed by the intersection of the fracture plane and a previously existing free surface. The bifurcation (forking) or directional change in the fracture trace generally reflects long-range stress alterations rather than the local stress perturbations responsible for transient features.

One tendential feature, hooking (Figure 4b), results when a fracture plane curves due to interaction with a neutral surface of a flexed object, or when a fracture plane curves in an attempt to meet a free surface orthogonally. Another tendential feature, forking (Figure 4b), is applied to fracture bifurcation into two or more diverging fracture planes. Forking is generated when a fracture reaches a limiting velocity in an increasing stress field (Kulander, Dean and Barton, 1977).

Types of Fractures

There are two types of fractures found in cores, core-induced fractures and natural fractures (pre-core fractures of Kulander, *et al*, 1977). Core induced fractures occur in response to stresses produced by the drilling and/or core extraction process. Pre-core or natural fractures are formed as a result of the failure of the rock under natural tensile and

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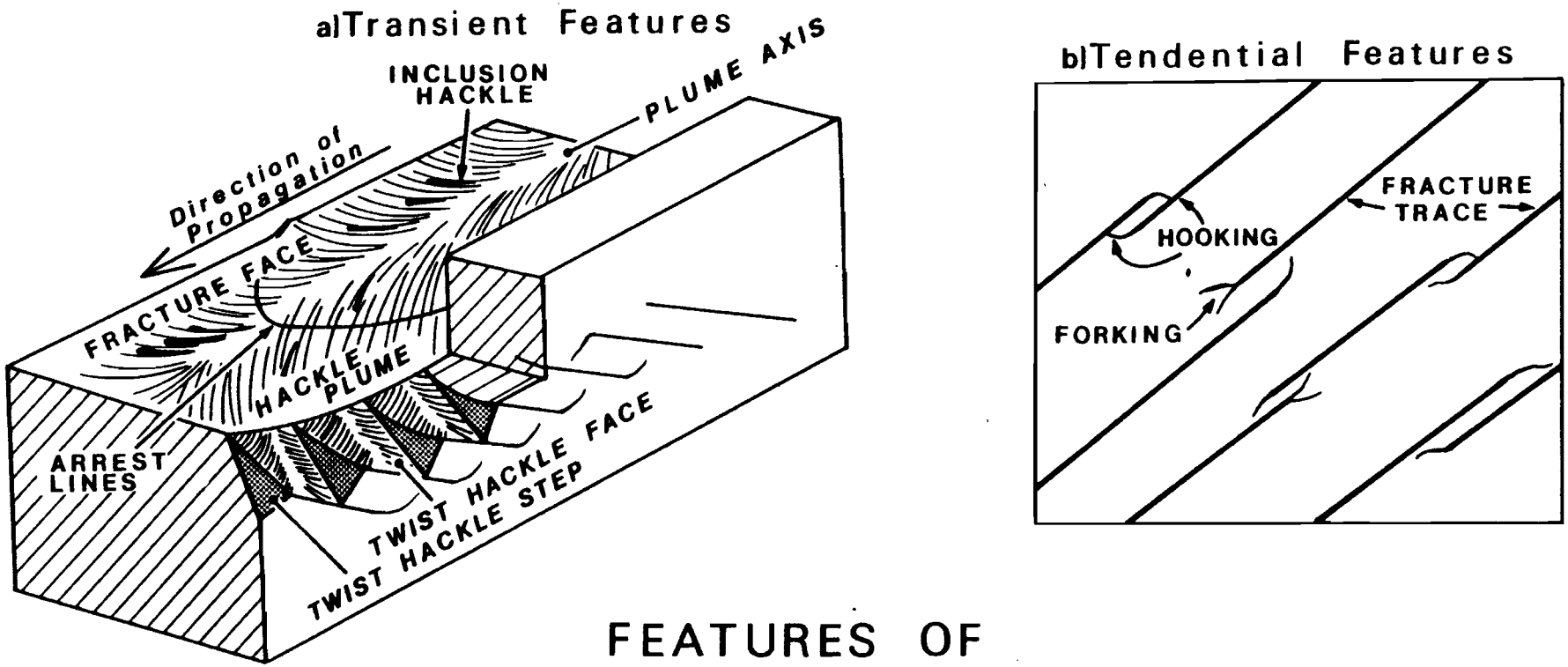
shear stresses. Natural fractures may be subdivided into mineralized surfaces, unmineralized surfaces, and slickenlined surfaces (slickensides). In this study, slickensides are small faults which are discussed separately. Natural fractures, exclusive of slickensides, are referred to simply as "natural fractures," and they are the joints of surface rocks.

The orientations of the striations or slickenlines on the slickensides are considered separately. These striations appear only when the surfaces of the fracture are forced past one another during slippage. The criteria used by the West Virginia Geological Survey personnel and by the author to distinguish pre-core from core-induced fractures were set forth by Kulander, Dean, and Barton, (1977) and are presented below.

Core induced fractures have the following characteristics:

1) A fracture origin at the core boundary or within the core itself.
2) Hackle marks diverging and attempting to meet the core boundary or pre-existing fracture surface orthogonally.
3) Hackle marks becoming more coarse, the hackle steps increasing in relief in the immediate vicinity of the core boundary or pre-existing fracture surface.
4) Twist hackle originating near the core boundary or pre-existing fracture surface.
5) Hackle plumes on sub-horizontal fractures that diverge from the central core area in a spiral pattern indicating a torque stress.
6) Closely spaced arrest lines on vertical and inclined fractures; arrest lines are convex downcore and symmetrical about the imaginary line down the fracture surface center.



FEATURES OF NATURAL FRACTURES

Figure 4

7) Hackle marks on vertical or inclined fractures that diverge downcore symmetrically about an imaginary line down the fracture surface center.

8) Fractures that hook abruptly towards the core boundary or a precore fracture surface.

Natural fractures have the following characteristics:

1) Polished and slickensided fracture faces (almost always smooth and planar).

2) Fractures filled by fibrous or non-fibrous mineralization.

3) Smooth fractures extending entirely across the core and against which later fractures usually terminate.

4) Inclined-vertical fracture faces displaying small, often conchoidal chips at the fracture-drilled core boundary intersection. The chips hook to meet the inclined fracture orthogonally.

DISCUSSION OF CORE INDUCED FRACTURES

There were very few well defined core-induced fractures in the MERC #1 Core. Of the four basic types of core-induced fractures - petal, scallop, torsion, and bedding plane fractures - only the last two were identified in this core. This lack of core-induced fractures may be the result of the physical characteristics of the rock and/or stress conditions present in the rock. The lack of petal and scallop fractures also restricts our ability to infer in situ stress directions in the Devonian sediments of this area.

The orientations of horizontal to subhorizontal bedding plane fractures and torsion fractures were not measured; these fractures will not be treated further.

DISCUSSION OF NATURAL FRACTURES

A total of 103 subvertical to vertical natural fractures were measured in the 283 feet of core studied. Certain fractures are up to four feet in length, and in many cases, the fractures cut diagonally across the core. Figure 5 shows an unmineralized fracture from the upper portion of the Mahantango Formation. Some unmineralized fracture faces exhibit the common hackle plume as well as twist hackle and arrest lines. The ends of two calcite mineralized fractures occur in the Upper Mahantango (Figure 6). The Tully (?) Limestone and Marcellus Shales have the greatest proportion of natural fractures, while, the Mahantango Formation has relatively few natural fractures.

Nearly all of the natural fractures are mineralized with either calcite, dolomite (rare), anhydrite, pyrite, barite, or some combination of these. A natural fracture mineralized with calcite and pyrite is shown in Figure 7. A fracture mineralized with calcite, pyrite, and anhydrite is shown in Figure 8. The mineralization is usually crystalline but also occurs as thin massive or fibrous coatings covering the fracture faces. Mineral growth fibers, perpendicular to the fracture, may imply fracture development where mineralization has occurred parallel to the principle tension as the fracture opened (Durney and Ramsay 1973). This situation is most likely to occur under very high fluid pressure conditions. Mineralization may also take place long after fracture development and merely fill void space created by the fracture. Most of the mineralized fractures are found in the Marcellus Shale, many are also found in the Tully (?) Limestone. The Mahantango Formation has few mineralized fractures. The type of mineralization filling a fracture shows no preference for fracture orientation, lithology, or depth (Plate 1).

An equal area net projection of poles to natural fracture surfaces plotted and contoured by the Mellis method and a rose diagram, were plotted for all natural fractures measured (Figures 9A and 9B). Unless otherwise stated, all rose diagrams presented in this paper have a five-degree class interval. Overall, two major fracture sets, having strikes of N80°E and N70°W, are predominant. Since most of the natural fractures are subvertical to vertical, the equal area net projection shows four clusters corresponding to the strike of two main fracture groups.

Equal area net projections and rose diagrams were plotted for 30 feet intervals wherever orientation data could be obtained. These plots are presented next to a gamma-ray log in order that the reader can compare changes in fracture patterns with depth and stratigraphy (Figure 10).

The natural fracture orientations in the core show a great amount of scatter with depth. This may be due to variations in stress conditions with depth and lithology. The low number of fractures present in some of the intervals studied may not be representative of the number and orientation of all fractures in those intervals as the sample area of a core for a particular lithology is very small. Subvertical to vertical fractures are less likely to be sampled than low dipping fractures.

One of the most interesting natural fractures found in the core is illustrated in Figure 11. One end of the vertical calcite mineralized fracture shows twist hackle which died out into the surrounding rock.

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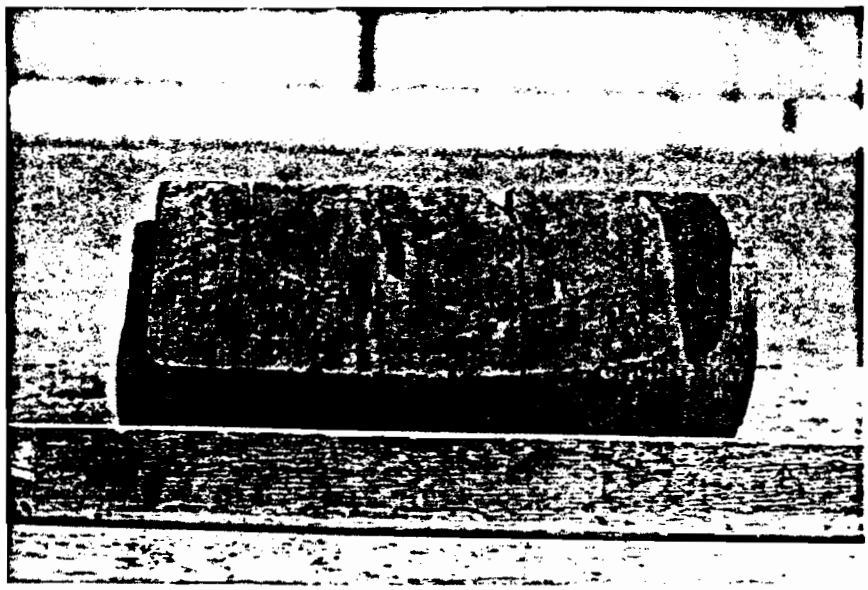

Figure 5

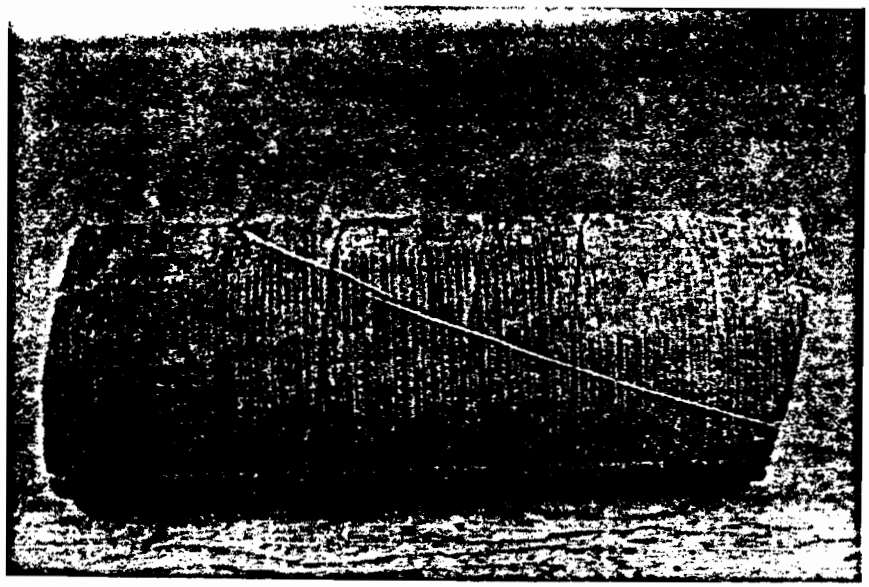

Figure 6

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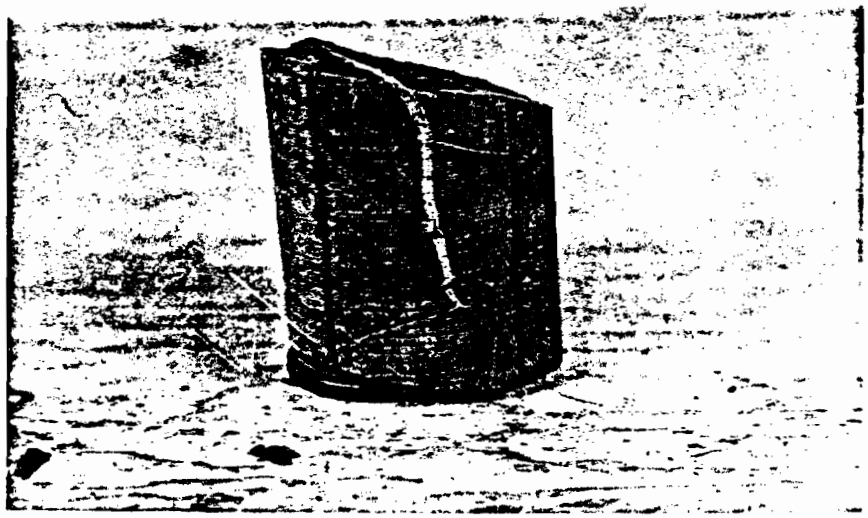

Figure 7

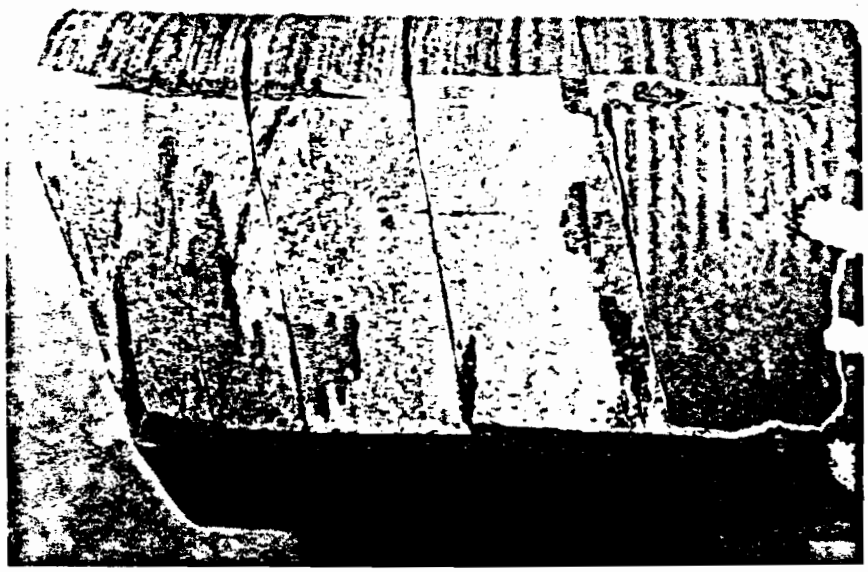

Figure 8

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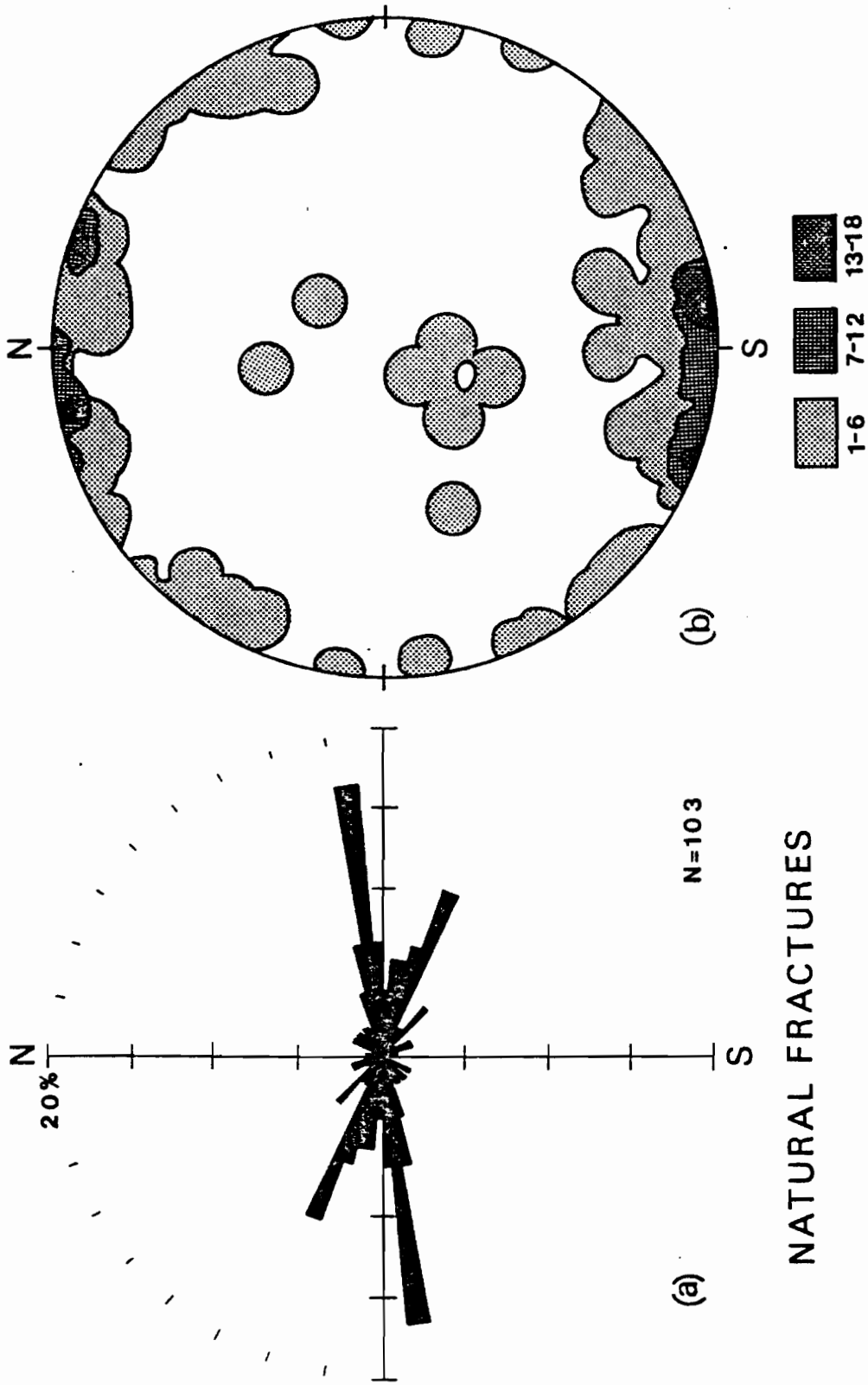

NATURAL FRACTURES

Figure 9

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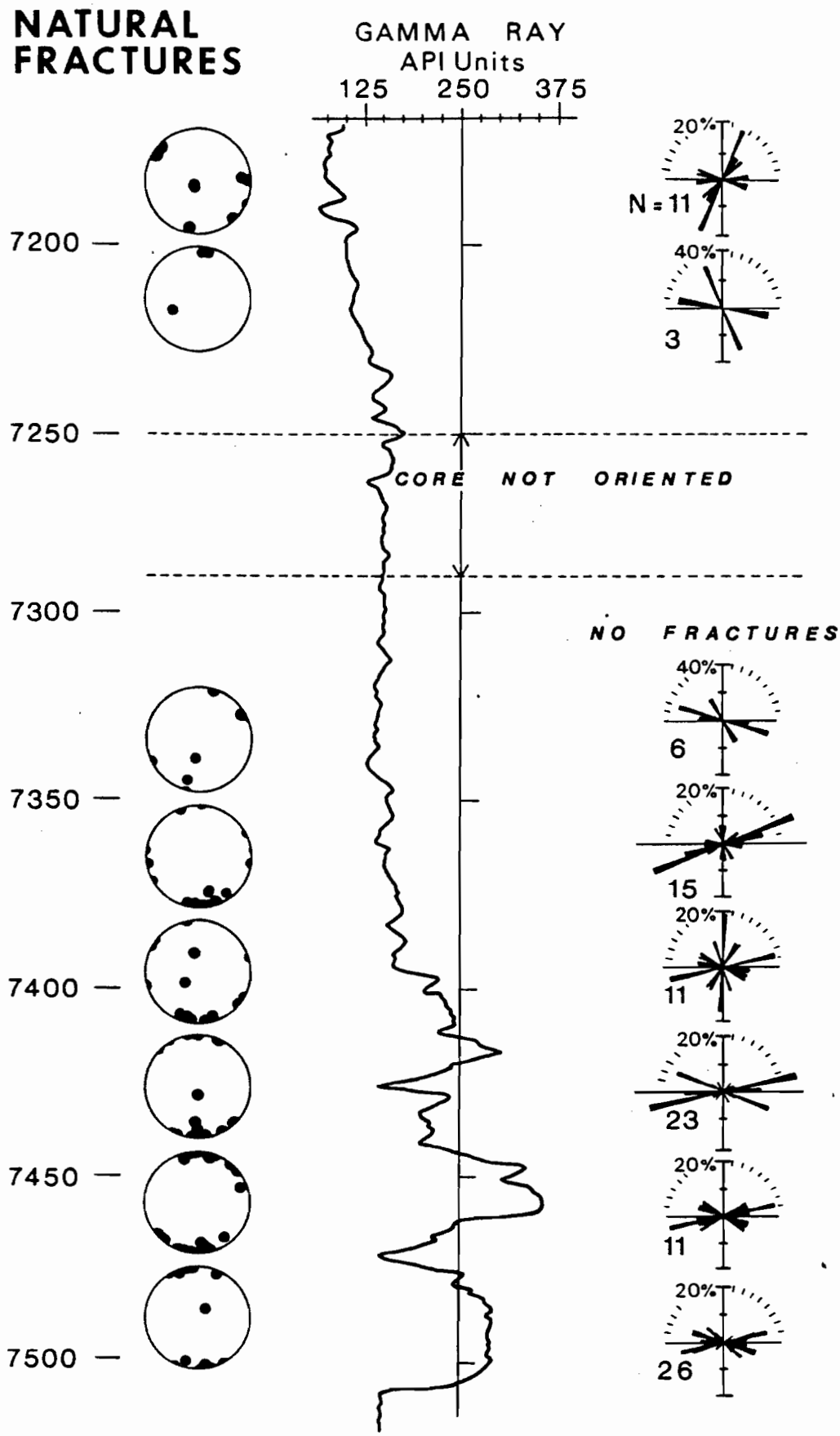
NATURAL FRACTURES
GAMMA RAY
API Units
125
250
375
7200
7250
7300
7350
7400
7450
7500
20%
N = 11
40%
3
CORE NOT ORIENTED
NO FRACTURES
40%
6
20%
15
20%
11
20%
23
20%
11
20%
26

Figure 10

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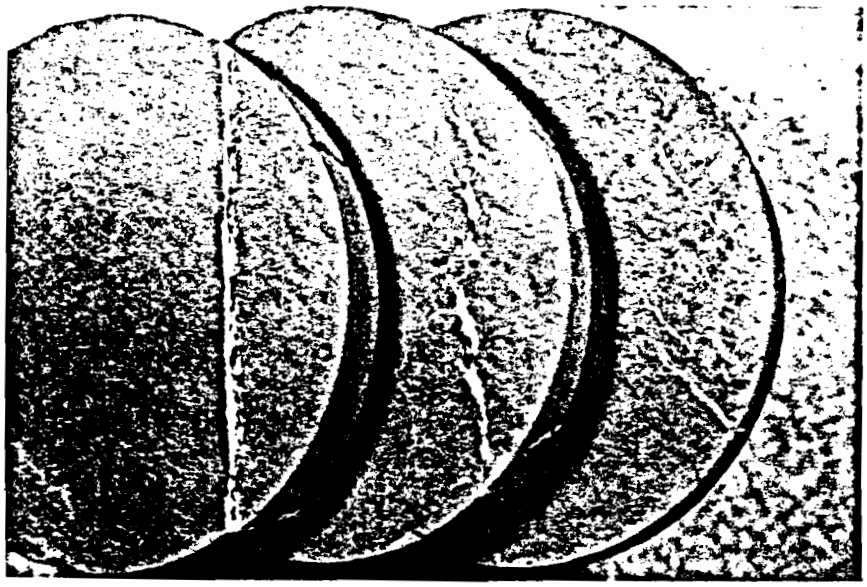

Figure 11

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SLICKENSIDES AND SLICKENLINES

Slickensides are created by the movement of one fracture face past the other. The orientation of the slickensides reveals information about the movement subsequent to or synchronous with fracture formation. In this particular case the strong preference of lines to an orientation perpendicular to fold trends suggest that they are tectonic in origin.

Slickensides in the MERC #1 Core were divided into two classes, subhorizontal to horizontal (dip <10°) and inclined (dip >10°). Due to the irregularity of the fracture surfaces the orientations of the subhorizontal to horizontal slickensides were not measured; however, the trends of the slickenlines (striations) on these surfaces were recorded. Figure 12 illustrates an inclined slickenside; Figure 13, a horizontal slickenside; and Figure 14, an inclined slickenside exhibiting twist hackle. Slickensides are most abundant in the Tully (?) Limestone, and in the lower portions of both the Mahantango Formation and Marcellus Shale.

An equal area net projection of poles to inclined slickensided fracture faces and a rose diagram were plotted for all 106 inclined slickensides measured in the MERC #1 Core (Figures 15A and 15B). There is one major inclined slickensided fracture set in the core, N0°-30°E. Dips for the inclined slickensides are generally unimodal to the west and southwest and most are low angle (10°-30°).

Equal area net projections and rose diagrams of inclined slickensides were plotted for each 30' interval of the core. They are presented next to a gamma-ray log of the cored interval (Figure 16) in order that the reader can easily compare changes in both dip and orientation of the inclined slickensides with depth and stratigraphy.

Throughout the core the strikes of inclined slickensides are quite variable. There is no apparent relationship between depth and stratigraphy. The orientations of the strikes of several of the slickensides may not be reliable due to their low dips.

Slickenlines (striations) on a slickenside show the relative movement trend of one fracture face past another. The trends and plunges for 194 slickenlines on both horizontal and inclined slickensides were measured. An equal area net projection of lines and a rose diagram were plotted for all slickenlines (Figures 17A and 17B). One major slickenline trend which averages N70°W is present. This trend transects the maxima of poles to surfaces, and thus it is really at right angles to the general strike of the low dipping slickensides. The equal area net plot illustrates the low dips of the northwest-southeast trending slickenlines. There is very little scatter in trends of the slickenlines.

Equal area net projections and rose diagrams were plotted for each 30' interval of the core. They are presented next to a gamma-ray log of the cored interval (Figure 18) in order that the reader can compare changes in trend and plunge of the slickenlines with depth and stratigraphy.

There is very little variation in the trend (N45°-80°W) or plunge (0°-30°) of the slickenlines throughout the core. The greatest amount of scatter occurs in interval 7351'-7380' which is near the base of the Mahantango Formation.

Many of the slickensides in the core are mineralized with calcite (most common), dolomite, barite, or anhydrite, or some combination of these. The mineralization is usually found on the horizontal (dip <10°) slickensides and is in the form of vertical to curved fibers (Figure 19).

These horizontal fiber-filled fractures are indicative of a very high fluid pressure in bedding planes of the shales, and of the fact that the shales acted as a decollement horizon.

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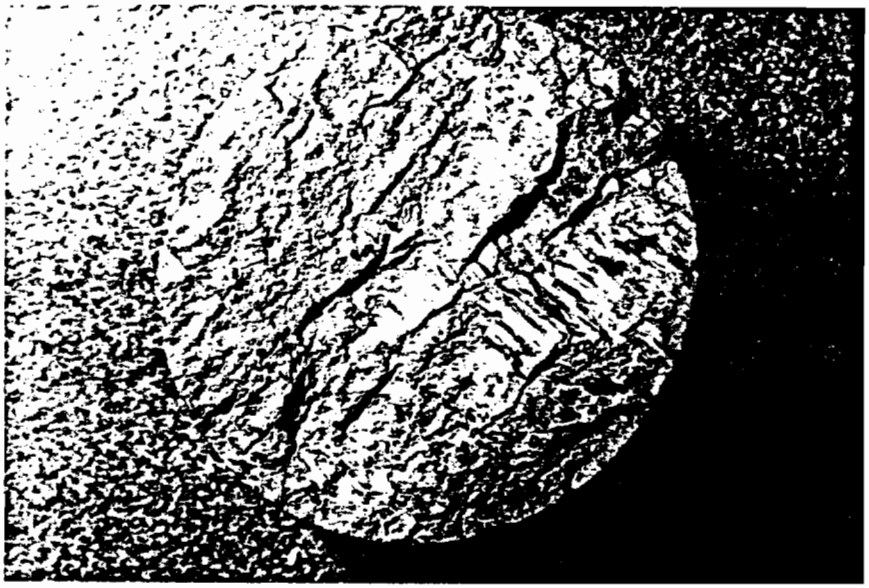

Figure 12

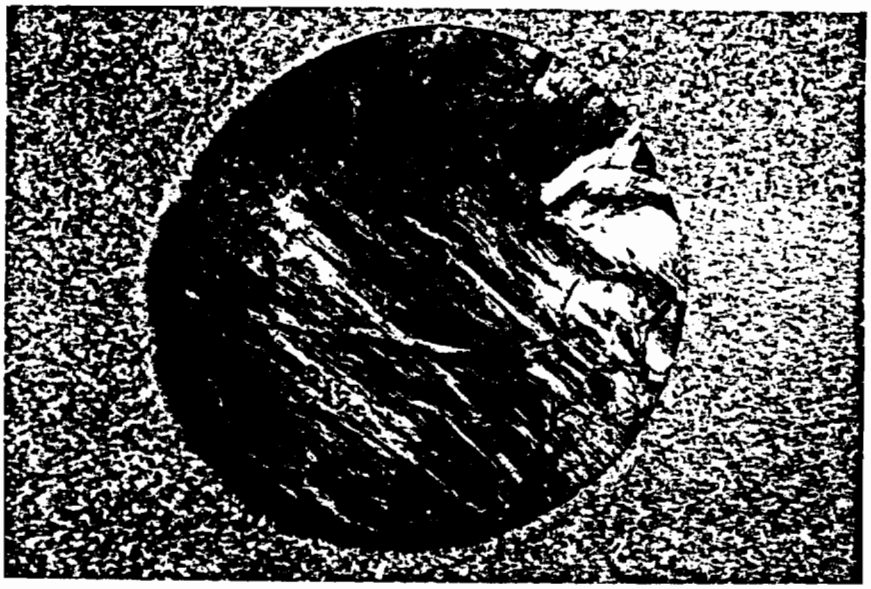

Figure 13

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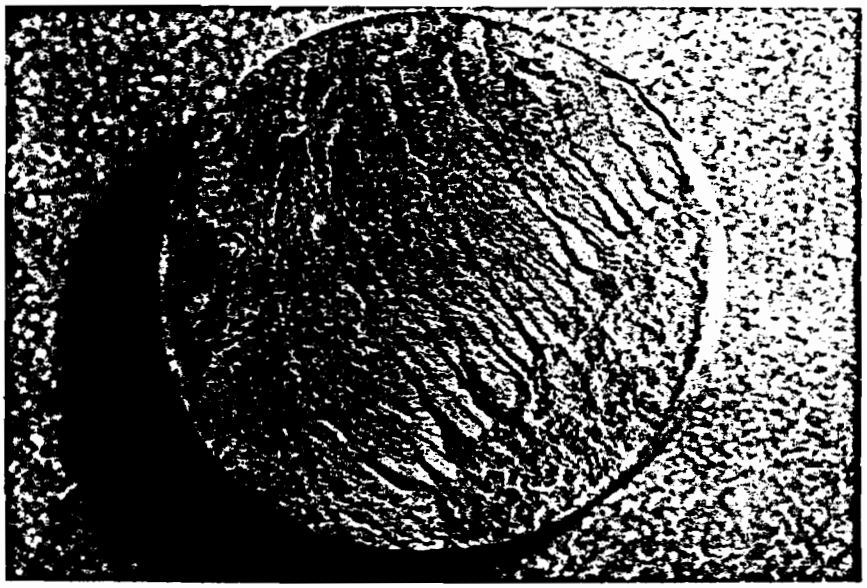

Figure 14

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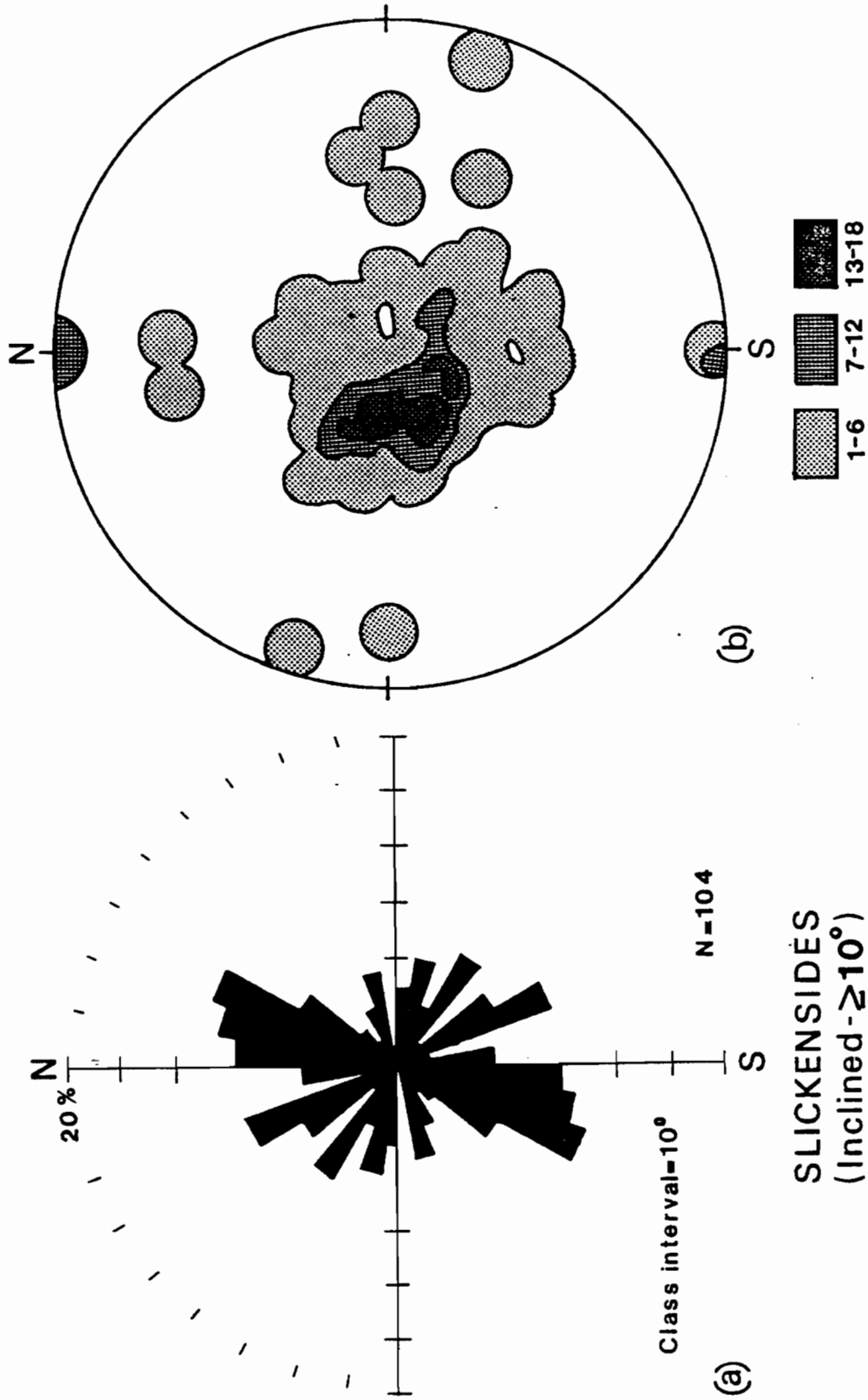

SLICKENSIDES
(Inclined-≥10°)

Figure 15

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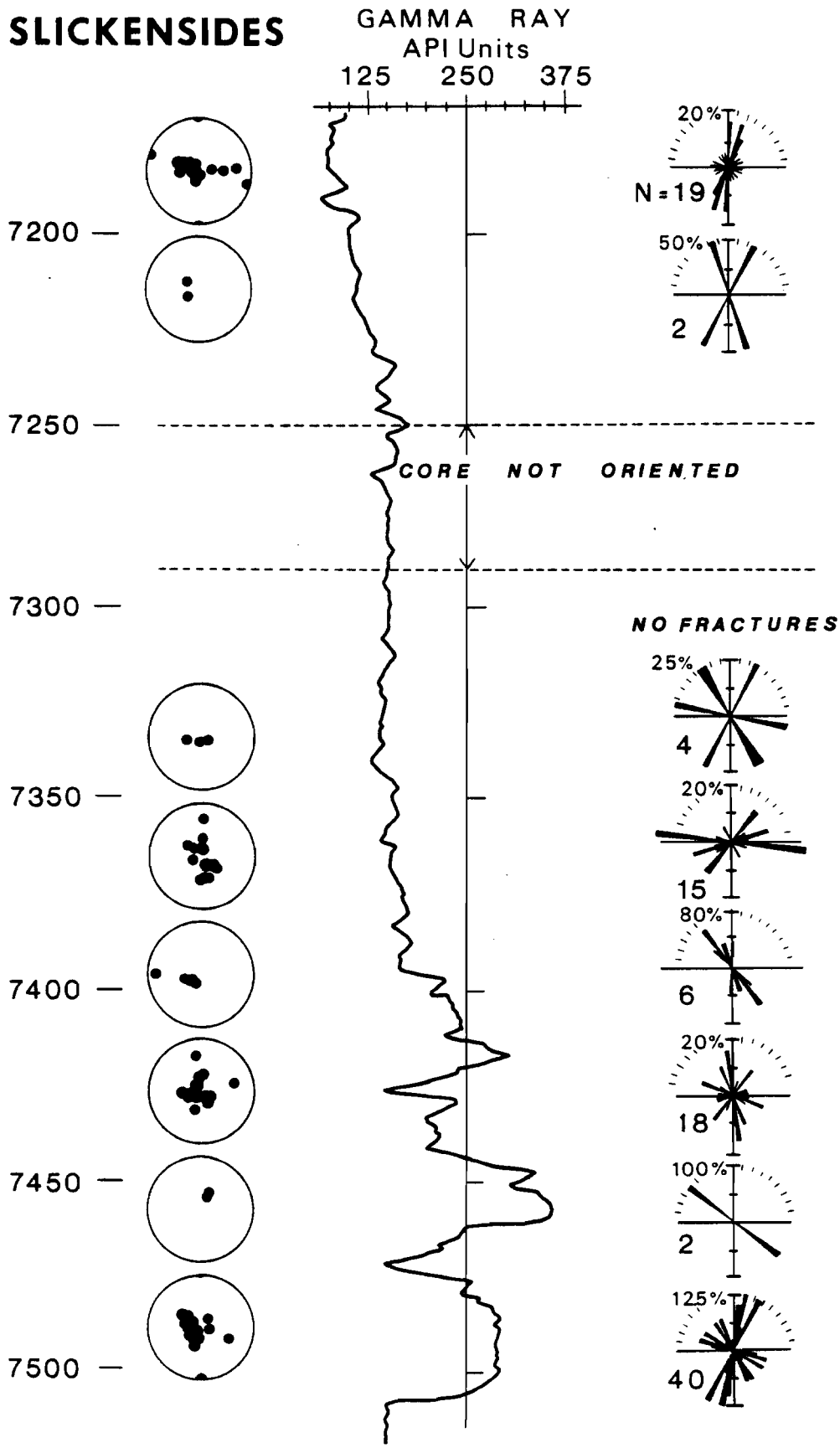
SLICKENSIDES
GAMMA RAY
API Units
125
250
375
7200
7250
7300
7350
7400
7450
7500
CORE NOT ORIENTED
NO FRACTURES
20%
N=19
50%
2
25%
4
20%
15
80%
6
20%
18
100%
2
125%
40

Figure 16

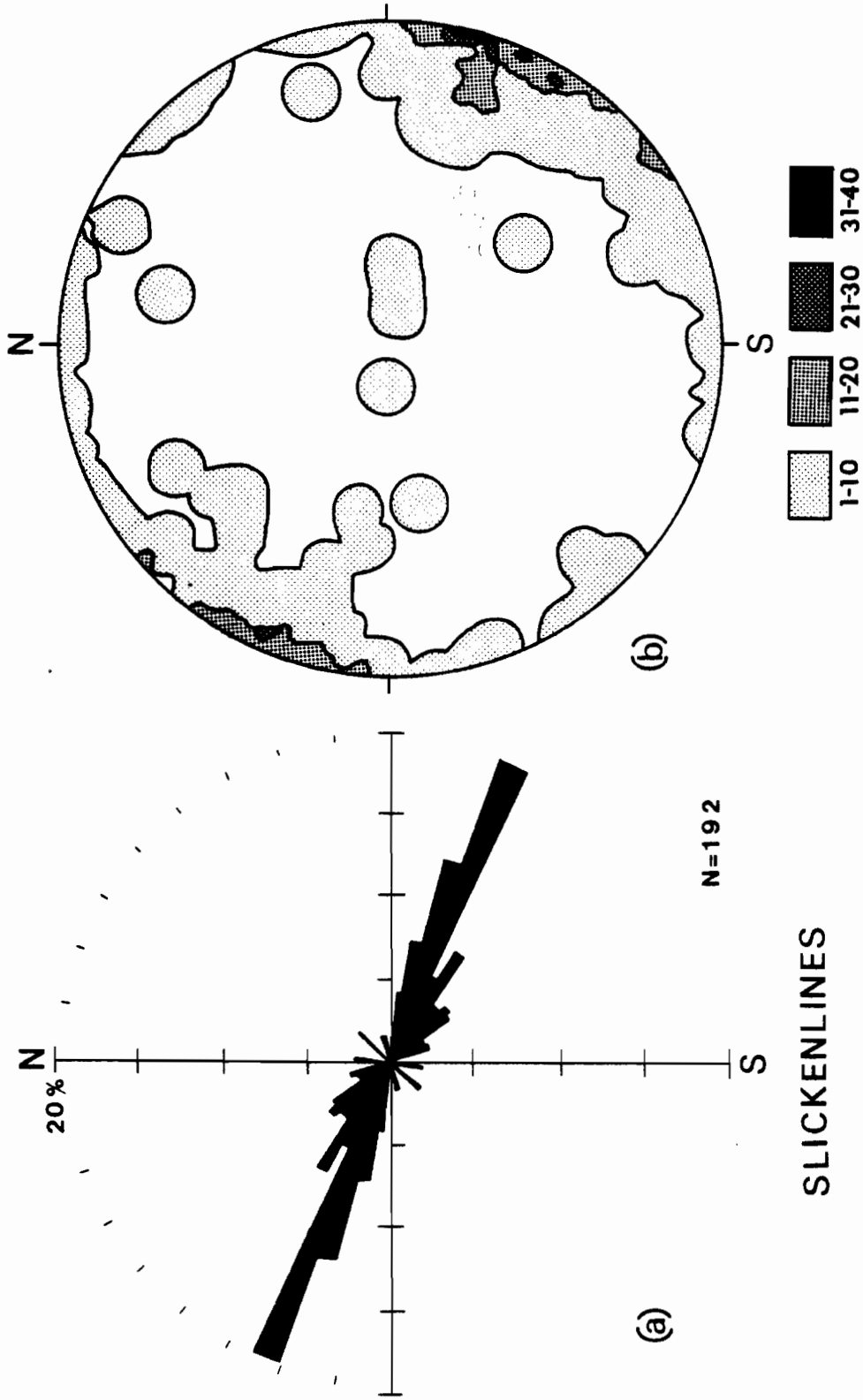

Figure 17

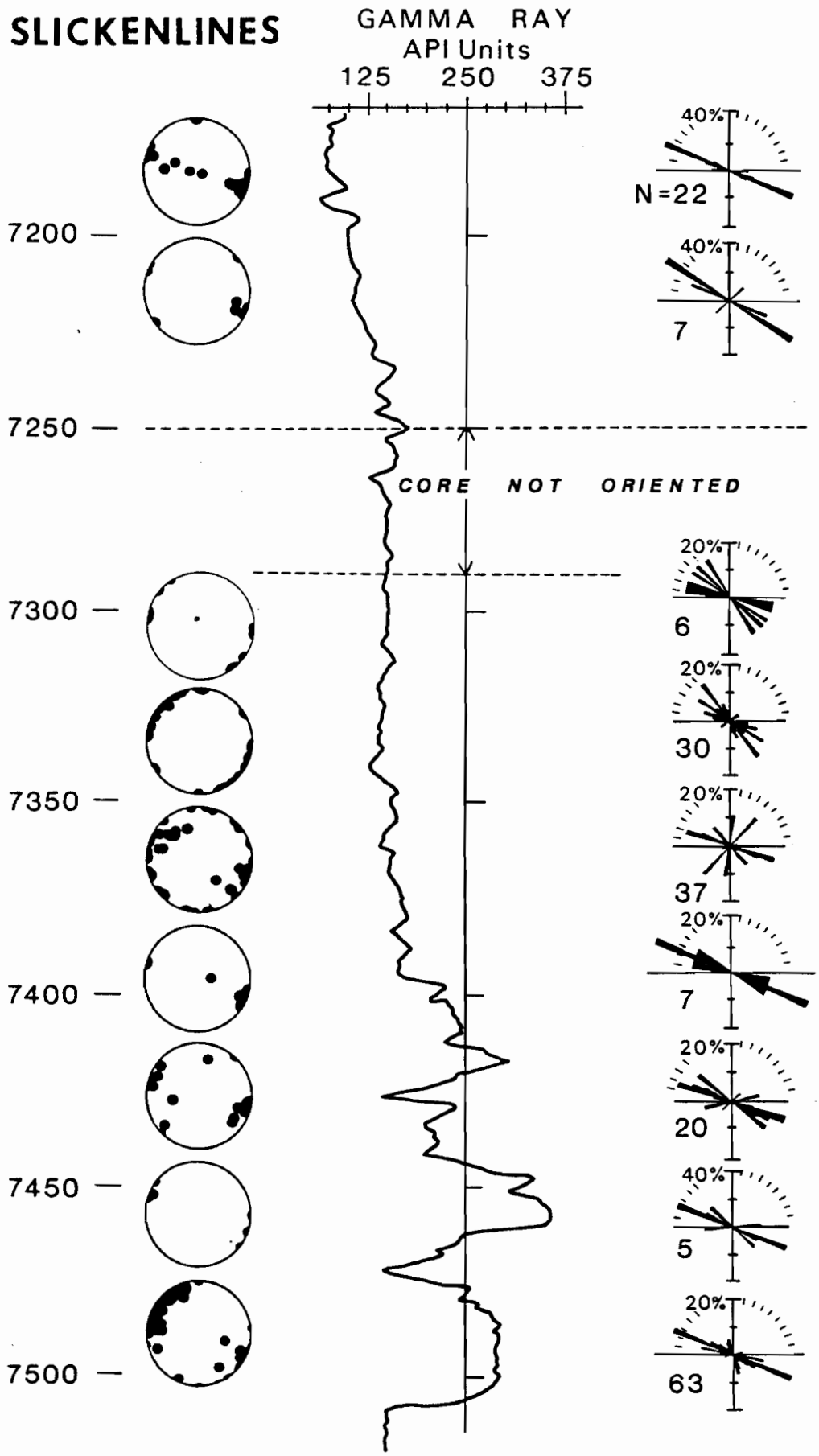
SLICKENLINES
GAMMA RAY
API Units
125
250
375
7200
7250
7300
7350
7400
7450
7500
CORE NOT ORIENTED
40%
N=22
40%
7
20%
6
20%
30
20%
37
20%
7
20%
20
40%
5
20%
63

Figure 18

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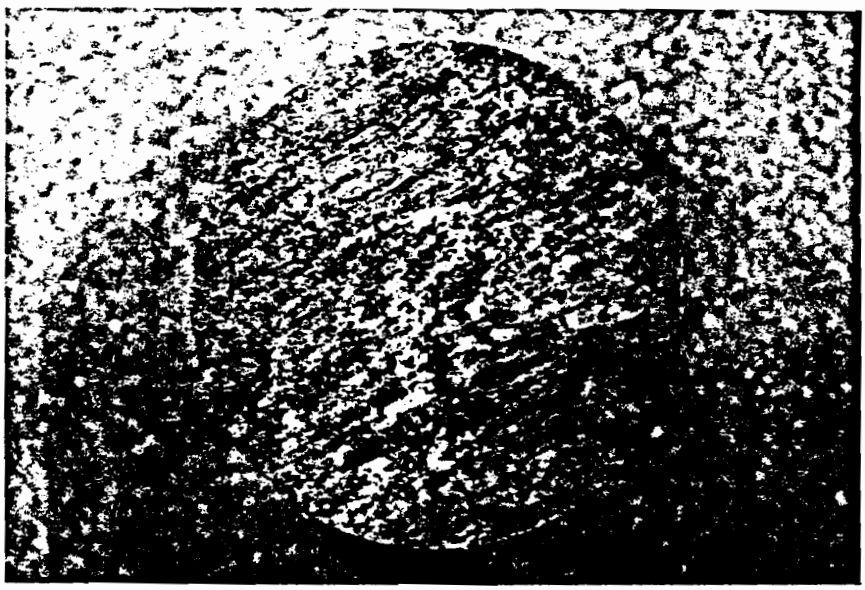

Figure 19

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SUMMARY

All fractures found in the MERC #1 Core could be subdivided into four types, core-induced fractures, unmineralized natural fractures, mineralized natural fractures, and slickensided fractures. A visual summary of fracture density and orientations is presented in Plate 1.

Core-induced fractures were the least common and only bedding plane and torsion fractures were identified. The lack in petal and scallop fractures restricts the ability to determine the in situ stress of the area.

The subvertical to vertical natural fractures (joints) can be subdivided by strike into two fracture sets, N70°W and N80°E. The Tully (?) Limestone and Marcellus Shale have the greatest proportion of natural fractures. Most of these fractures are mineralized with calcite, dolomite, anhydrite, pyrite, barite, or some combination of these.

The slickensided fractures in the core are most abundant in the Tully (?) Limestone, and in the lower portion of both the Mahantango Formation and Marcellus Shale. These lower intervals may represent decollement horizons. The strike of the surfaces of these slickensides is quite variable, however, one major set, N0°-30°E, can be distinguished.

Trends of the slickenlines (striations) are generally N70°W and most vary between N45°W to N80°W. Many of the horizontal slickensides are filled with fibrous mineral growth which is indicative of very high fluid pressure in the bedding planes of the shales, and which suggests that the shales acted as a decollement horizon.

From the orientations of the natural fractures and the trends of the slickenlines it can be concluded that the major tectonic stress was directed in a northwest-southeast direction. This is the same stress direction as that forming the Alleghenian folds. It is presumed that the fractures relate to Alleghenian deformation.

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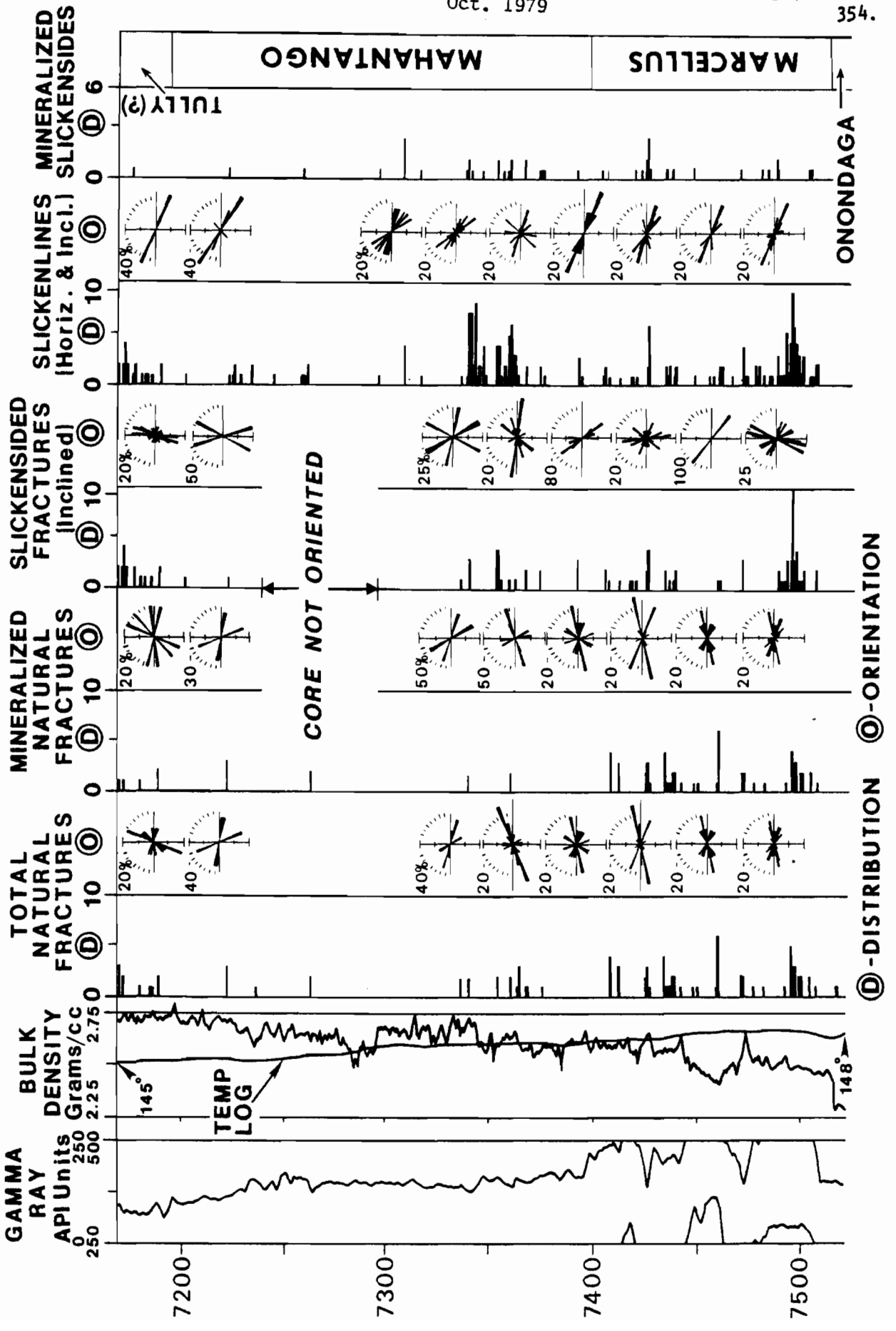
GAMMA RAY
API Units
250
500
0
250
BULK DENSITY
Grams/cc
2.25
2.75
145°
148°
TEMP LOG
TOTAL NATURAL FRACTURES
Ⓓ 0 10 Ⓞ
MINERALIZED NATURAL FRACTURES
Ⓓ 0 10 Ⓞ
SLICKENSIDED FRACTURES (Inclined)
Ⓓ 0 10 Ⓞ
SLICKENLINES (Horiz. & Incl.)
Ⓓ 0 10 Ⓞ
MINERALIZED SLICKENSIDES
Ⓓ 0 6
CORE NOT ORIENTED
TULLY (?)
MAHANTANGO
MARCELLUS
ONONDAGA
7200
7300
7400
7500
Ⓓ-DISTRIBUTION
Ⓞ-ORIENTATION

Plate 1

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REGIONAL SURVEY OF SURFACE JOINTS IN EASTERN KENTUCKY

by

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ABSTRACT

A regional survey of eastern Kentucky surface joints was completed. Maps of joint strikes plotted a. rose diagrams show coal has the most consistent regional orientation of joints of all lithologies studied. Coal face cleats and coal structure form lines swing in the foreland of the Pine Mountain thrust fault. The face cleat swing could be due to the thrust, but may instead be a separate system related to basement shape or an edge effect created by the Russell Fork tear fault. The apparent independence of coal cleat strikes from the Pine Mountain thrust may be a result of isolation of coal from fault stress by movement along the fault plane or by the coal having too low a rank for fracturing when faulting occurred.

Outcropping Devonian shales show consistent joint strikes of N25E, N45E and N65W. First-formed and second-formed joints strike northeast and northwest, respectively. The N45E joint strikes occur predominantly along the eastern flanks of the Cincinnati Arch and Nashville Dome. The N25E joint strikes are concentrated in the Cumberland saddle between the Cincinnati Arch and Nashville Dome.

INTRODUCTION-LOCATION

It is generally believed that fractures in the Devonian shale provide the permeability needed for significant commercial gas production. It follows that if the nature, orientation and intensity of jointing in the Devonian shale can be determined, then the extent and location of potentially productive permeable zones can be predicted and better estimates of ultimate gas production realized. Jointing of the Devonian shales in gas producing areas may be reflected in surface joints through regional joint strike, size and spacing trends. A survey of surface joints was completed in order to establish these trends within the largest Devonian shale gas field in the world, the Big Sandy Field.

The study area is located in the unglaciated Appalachian Plateau of eastern Kentucky (Figure 1). Joints from 130 quadrangles east of a north-south line drawn between Maysville and Middlesboro, Kentucky and from quadrangles in the Devonian shale outcrop belt on the east side of the Cincinnati Arch were documented.

Rocks of Pennsylvania, Mississippian and Devonian age are exposed in the study area. Pennsylvanian strata are composed of deltaic sequences of sandstone, shale and coal. The Mississippian contains sandstones with some shales and older massive limestone formations. The Devonian comprises black shales underlain in some areas by a thin limestone.

METHOD

A random sampling system was used by considering the boundaries of 7½ minute quadrangles as a grid and obtaining one or more stations within each quadrangle. At each sampling station the strike and dip of joints, lithology (shales separated by color only), bed thickness, horizontal and vertical joint extent and joint spacing were noted.

The sequence of jointing was determined through abutting relationships. Kulander and others (1977) have shown that tension joints which form first provide a free surface which, unless cemented closed, cannot be crossed by later formed tension joints. Therefore, first-formed joints are abutted by second-formed joints, usually at or near a 90 degree angle. The first- and second-formed joint sets are generally the best formed joints at any given outcrop.

RESULTS

In addition to dewatering and devolatilization, tectonic stress plays an important part in coal cleat formation (Ting, 1977). Cleats generally have a directional relationship relative to coal form line structure and basement structure trends in West Virginia (Kulander and Dean, 1979) and eastern Kentucky. In eastern Kentucky, coal face cleat strikes rotate in the foreland of the Pine Mountain thrust (Figure 2). The thrust appears to have caused the cleat rotation; however, with the limited data available several alternative possibilities are feasible.

If coal fracturing occurred at the same time and as a direct result of the Pine Mountain thrust movement, then the coal cleats should have extension and release orientations relative to thrust movement. The thrust movement is presumed to be northwestward, so the tensional joint trend should be northwestward. These extension-release orientations would be expected to form a second cleat set

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with any previously formed sets. These trends are not present. The coals do show one simple face-butt cleat set but it has a regional rotation.

Assuming coal cleats formed prior to the Pine Mountain thrust, a second fracture system related to the thrust should be present on the foreland, but it is not. The simplicity of cleat sets and their rotation in the foreland suggest that the cleat formation may be post thrust in response to basement deformation shape. Basement shape is poorly defined in the Pine Mountain foreland, however, the coal form line map (Figure 3) shows a general contour swing in this area. Coal face cleats show a consistent orthogonal relationship to coal form lines through West Virginia and rotate with them in front of Pine Mountain.

A second explanation for the absence of a fracture system related to the Pine Mountain thrust is linked to the time of coal lithification. Coal lithification may not have progressed far enough by the time of the thrust movement to allow significant fracturing. Lignite will fracture with wide spacing compared to normal coal fracturing; these fractures may have formed, but could have been obscured by later fractures operating under a different stress field.

A third explanation for coal cleat rotation in the foreland may relate to the Russell Fork fault. The junction of the Russell Fork and Pine Mountain faults (Figure 1) appears to be the hub around which coal face cleats rotate (Figure 2). This junction was probably an area of considerable stress between the Pine Mountain thrust sheet and sheets adjacent to it. Coal cleat rotation may be the foreland effect of two sheets moving at different speeds and having a definite point of stress at their extreme edges.

Plotting of joint strikes as rose diagrams by station and lithology on the map reveal consistent coal face cleat orientations over relatively large areas (Figure 2). Shale and sandstone joints are not consistently oriented and their first- and second- formed joint strikes were plotted separately to determine their degree of correlation with coal cleat strikes. Plotting of the angles formed between coal cleats and first- and second-formed joints as histograms found several relationships. Black shales show 46 percent of the angles are within 10 degrees of coal cleats and 37 percent lie between 20-30 degrees of coal cleats. This fairly good correlation may reflect the close proximity of coal and black shale often seen in the stratigraphic sequence. Gray shales show 41 percent of the angles are within 15 degrees of coal cleats and 44 percent are between 25-40 degress. The lack of close proximity of gray shales to coal and their increased silt content (with resulting change in strength characteristics) may account for these angular relationships. Sandstone showed no significant angular relationship to coal cleats. This indicates sandstone jointing in the deltaic Pennsylvanian sequence is too complex for regional interpretation.

DEVONIAN SHALE

Devonian shales along the eastern flank of the Cincinnati Arch and Nashville Dome (Figure 1) show consistent joint strikes of N25E, N45E and N65W. First-formed and second-formed joints strike northeast and northwest, respectively. The N45E joint strikes occur predominantly along the eastern flanks of the Cincinnati Arch and Nashville Dome. This strike set is roughly parallel to the N40E striking outcrop belt and may have formed as a tension feature related to the regional dip of the Cincinnati Arch and Nashville Dome. The N25E joint strike set is concentrated in the Cumberland saddle area (Figure 1) and is clearly a rotation from the previously discussed strike set. The Cumberland saddle is an area of Cambrian age basement faulting which probably rotated the regional stress fields of the Cincinnati Arch and Nashville Dome.

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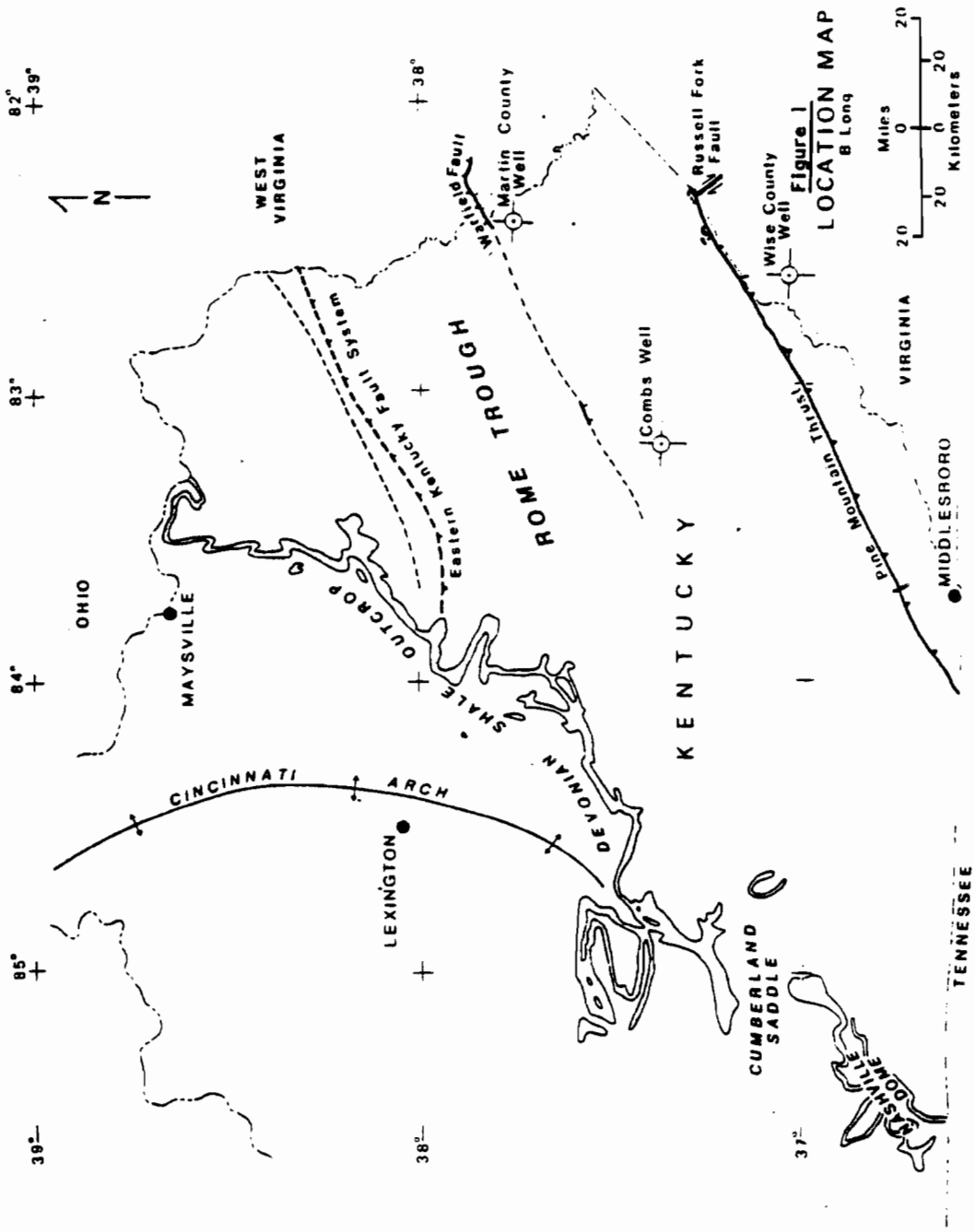

Figure 1
LOCATION MAP
B Long

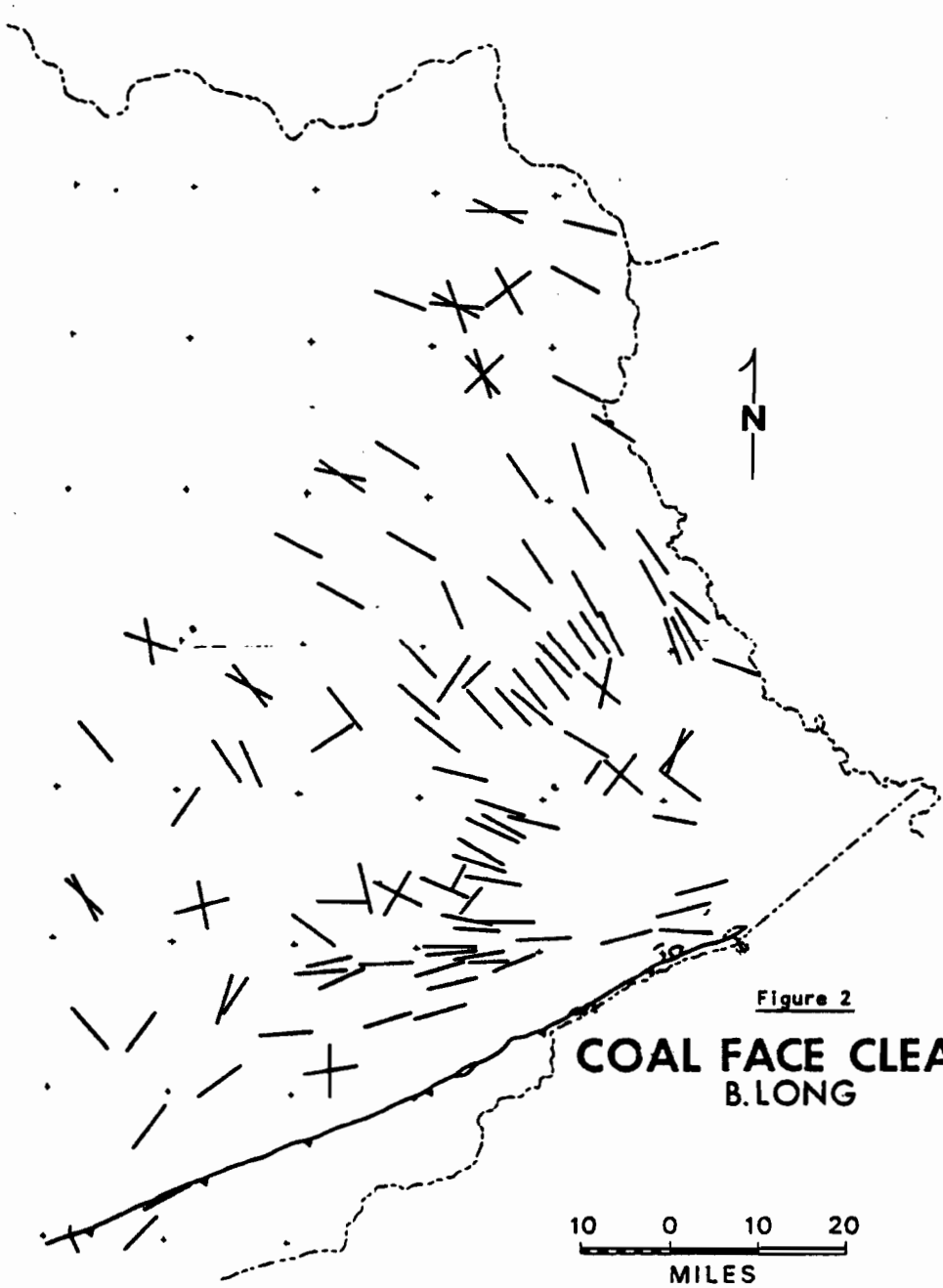

Figure 2

COAL FACE CLEATS

B. LONG

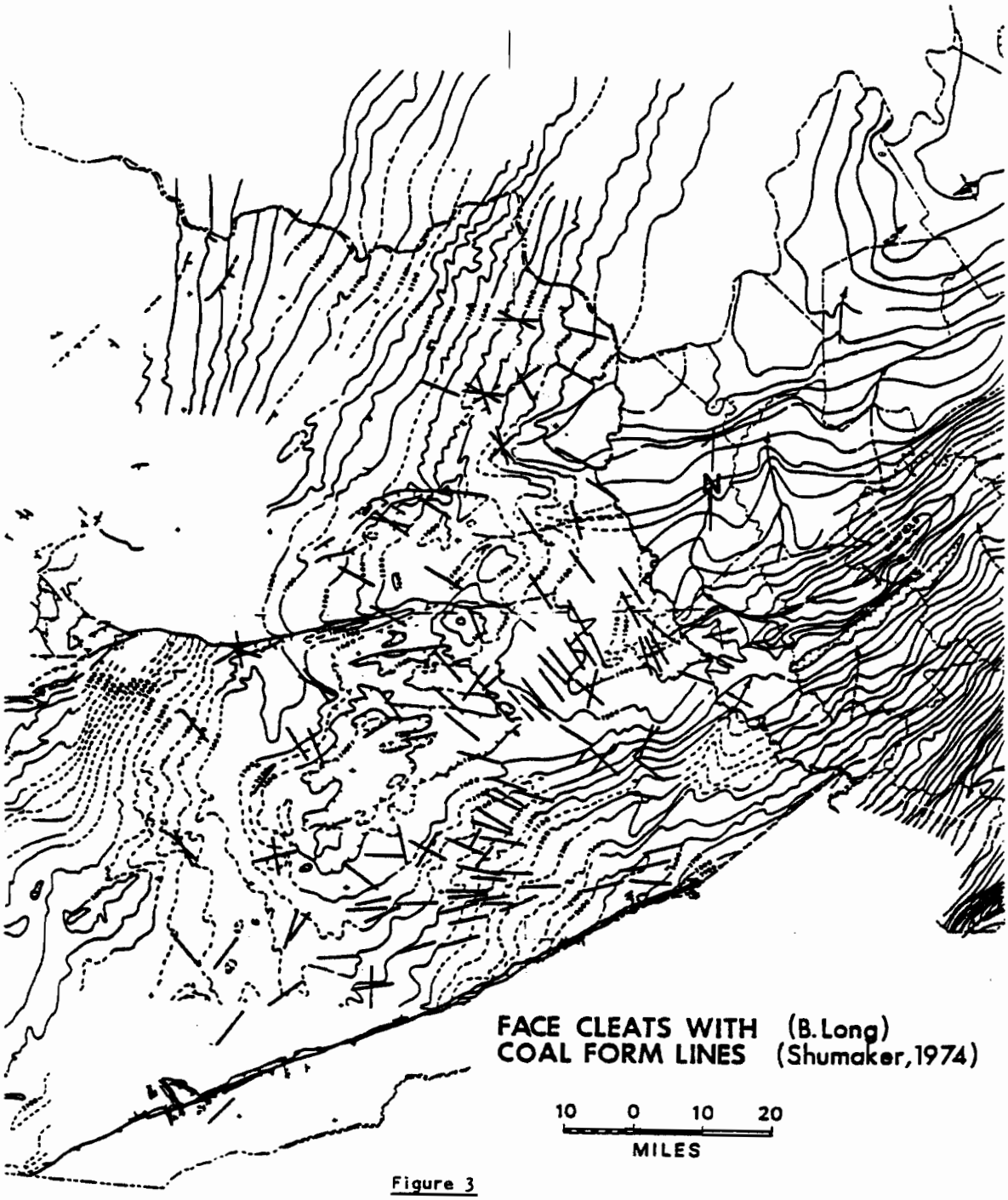
FACE CLEATS WITH (B.Long)
COAL FORM LINES (Shumaker,1974)
10 0 10 20
MILES

Figure 3

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FRACTURES FROM DEVONIAN SHALE OUTCROPS ALONG THE PINE MOUNTAIN THRUST

by

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United States Department of Energy
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Abstract

Fracture patterns in the Devonian shale exposed along the Pine Mountain Thrust show much greater complexity than the overlying units. However, the trends of fractures in the upper part of the Devonian shale are nearly those of the overlying units. The amount and complexity of fracturing reflects the degree of, and distance from, the basal detachment fault plain.

Two zones of movement were found within the shales. The major fault occurs at the base of the shale, and the shales adjacent to the thrust plain show the most deformation. However, a zone of lesser movement occurred in the upper part of the shale. The two zones of deformation may match the reported productive zones found in the Big Sandy shale gas field to the west.

Joints in the Grainger shales and Berea sandstone have trends similar to that of the upper part of the underlying shale, but they are less variable.

Jointing in the overlying Newman limestone along Pine Mountain is similar but slightly rotated from the underlying Grainger shales. The joint trends consist of a dominant set parallel to the Pine Mountain Fault; and a less dominant set, perpendicular to the thrust front.

Eventually the results of this study will be combined with those of cored wells and other surface studies to present an integrated regional analysis of Devonian shale farctures.

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Purpose

Natural gas in the Big Sandy field of eastern Kentucky produces from fractures within the Devonian shale. There are only two areas where one can study these shale fractures at the surface near this field. The Devonian shales crop out in central Kentucky along the Cincinnati Arch, and in eastern Kentucky, they crop out just above the Pine Mountain Thrust. A separate study will report on fractures in the shales along the eastern flank of the Arch (Long, in progress). This study reports on the nature and origin of fractures in the Devonian shale that crop out along the Pine Mountain Thrust.

We hope that thru the documentation of fracture patterns in adjacent outcrops, meaningful comparisons can eventually be made with the production of natural gas from the Big Sandy gas field.

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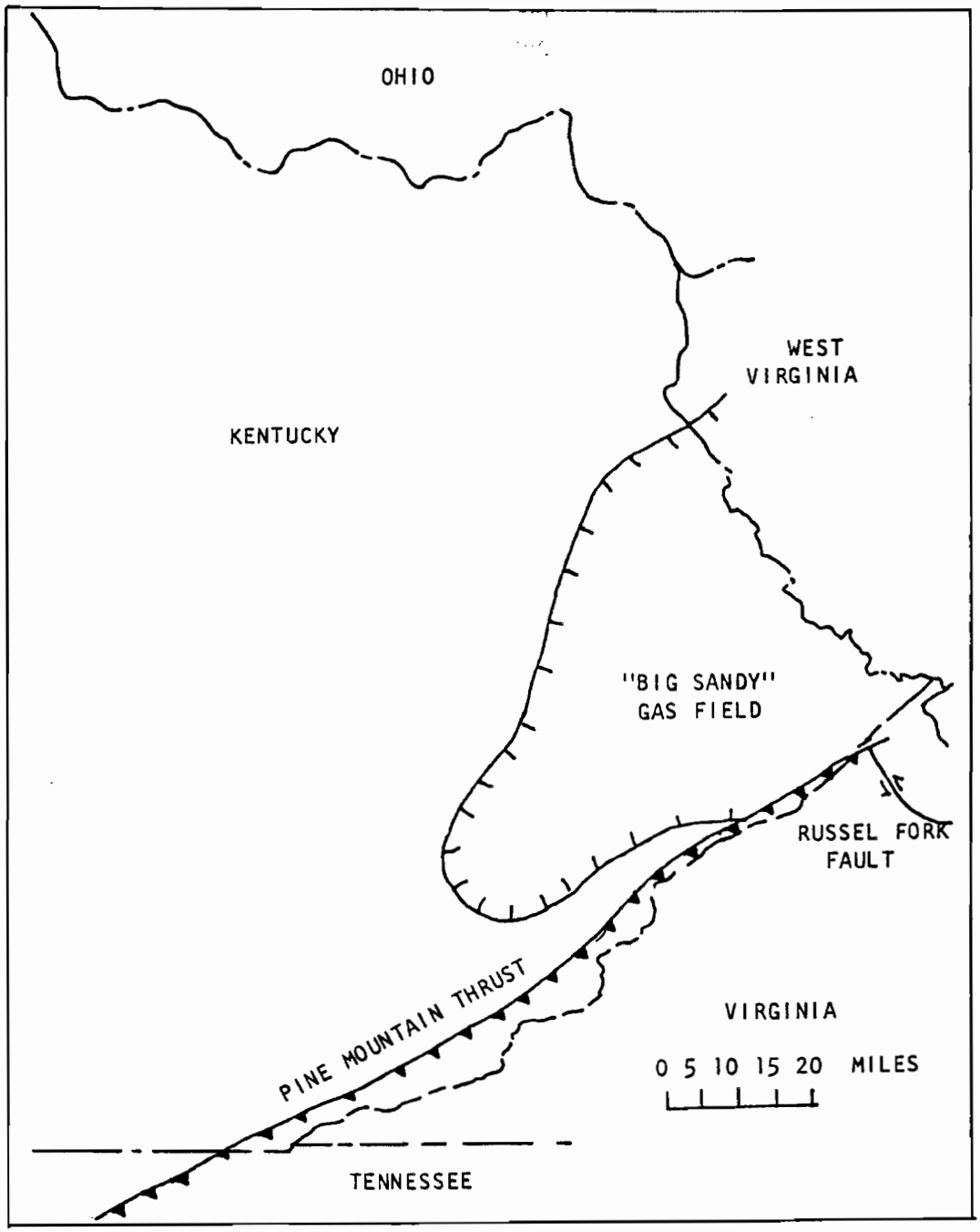
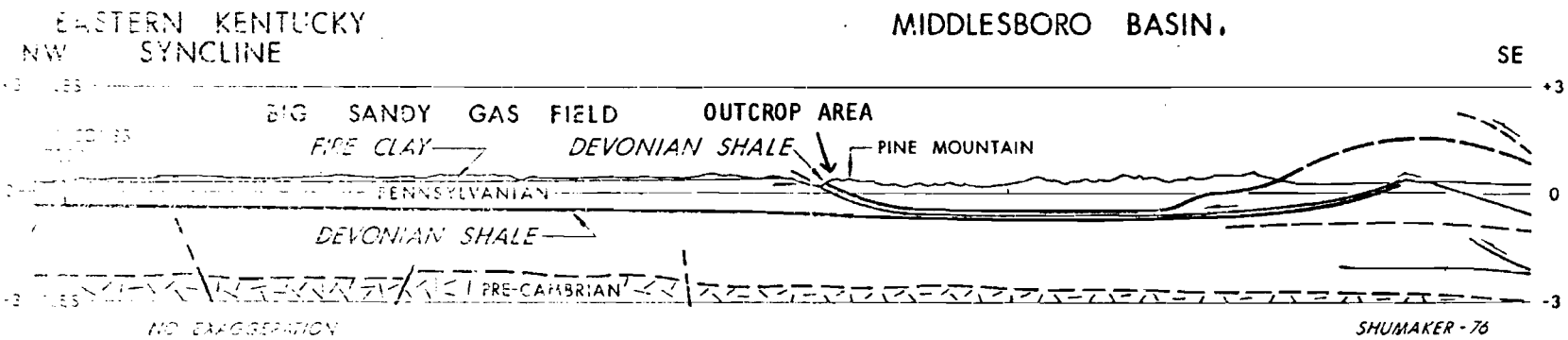
FIGURE 1

LOCATION MAP



Modified from Ray, 1976



PINE MOUNTAIN THRUST AREA
COMBS-7239 WELL

FIGURE 2
CROSS-SECTION-BIG SANDY GAS FIELD-
PINE MOUNTAIN THRUST

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Location and Geologic Setting

Pine Mountain is a linear feature about 125 miles long extending from just northeast of Elkhorn City, Kentucky, where it abuts against the Russel Fork fault, southwestward to near Jacksboro, Tennessee, where it abuts against the Jacksboro fault (see Figure 1). It was interpreted by Rich, 1934, and many others since as the surface expression of a major ramp of a detachment thrust in the Devonian shale, across more competent units, either to extend the surface or to an incompetent horizon in the Pennsylvanian clastics. The upper part of the ramp has since been eroded. The movement of the upper plate along the ramp has brought sediments of Devonian and Mississippian age to the surface. Presumably the stress that created the thrust also extended into the foreland in the area of the Big Sandy shale gas field. However, major movement was diverted by the ramp of the thrust at Pine Mountain so that extensive transpost did not occur under the Big Sandy shale gas field. However, if the stress and some minor movement did extend into the shales under the Big Sandy field, as suggested by Shumaker (1978), then the documentation of joints on the Pine Mountain may lead to insights concerning the fracture patterns and production in the Big Sandy shale gas field. For a more complete analysis and discussion of the geology of the area, readers are referred expecially to Harris (1970) and Harris and Milici (1977).

PENNSYLVANIAN
and MISSIPPIAN
SANDSTONE and
SHALE

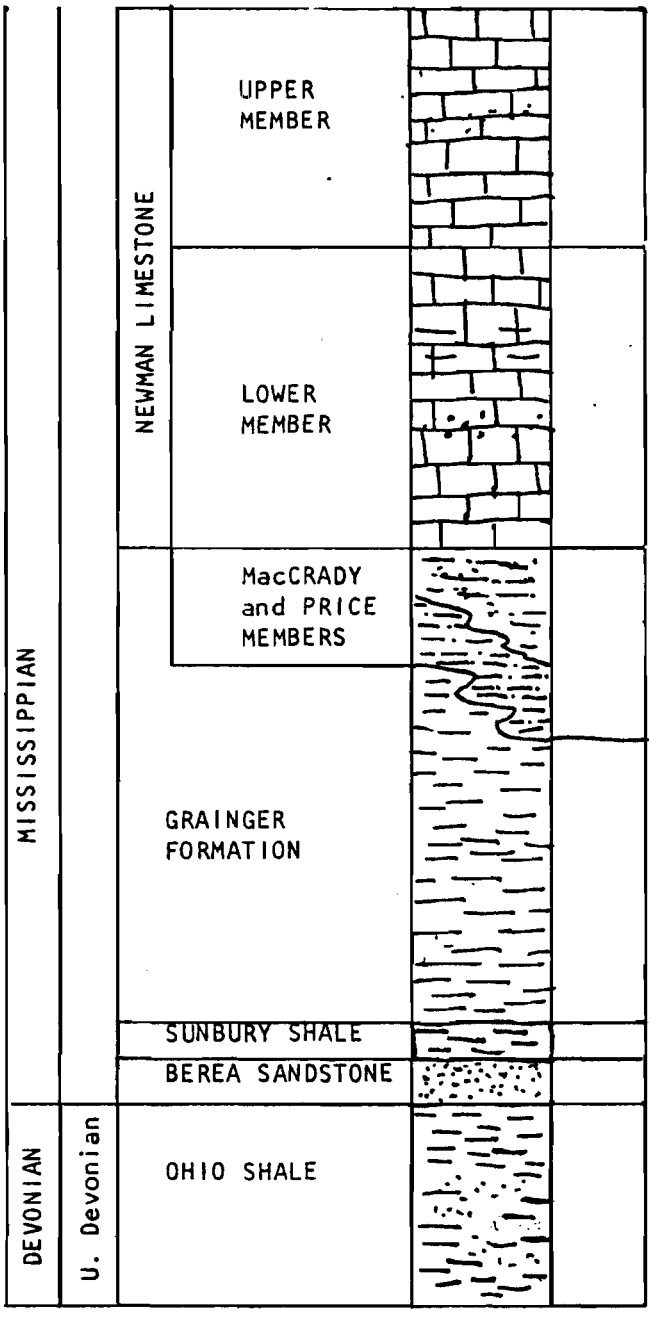

FIGURE 3
GENERAL STRATIGRAPHIC COLUMN

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Method of Investigation

Field work was undertaken during July and August, 1978, to study fractures in the Devonian shales exposed along the base of Pine Mountain. Usually the shales are poorly exposed except in a few areas. The most complete exposures of the shale are along roads which cross the mountain or along quarry access roads to limestone which overlies the Devonian shale. Six exposures were found that were adequate to provide sufficient data for analyses of joints and outcrop-scale structures (Figures 4).

Except for the shale outcrop KL6 in the Bledsoe Quad, all exposures were moderately to intensely weathered.

Only joint sets that were consistant and repetitious throughout the outcrop were measured. Those joints judged to be random or unrepresentative of the dominant directions in the outcrop were noted, but not measured.

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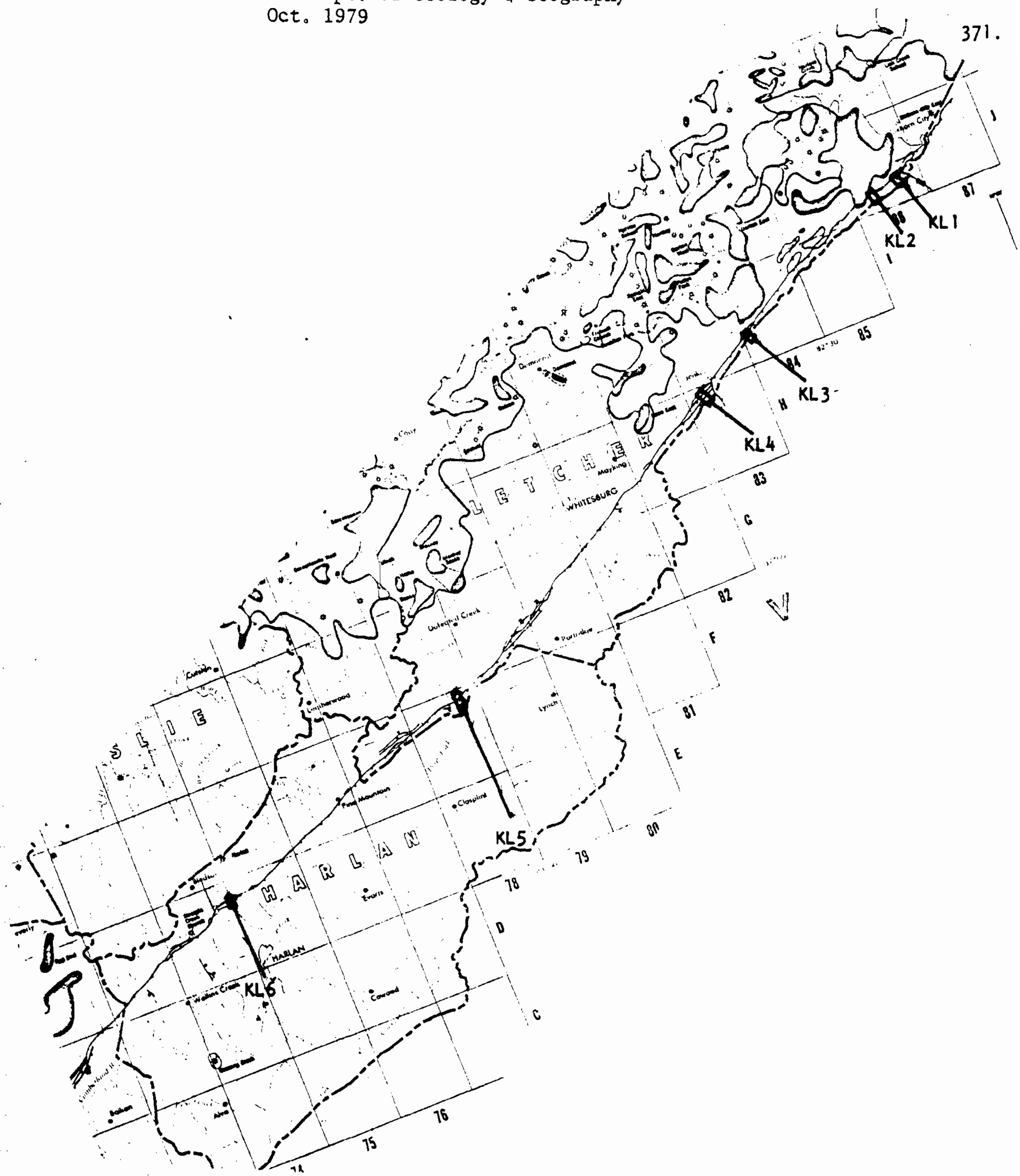


FIGURE 4.
OUTCROP LOCATIONS

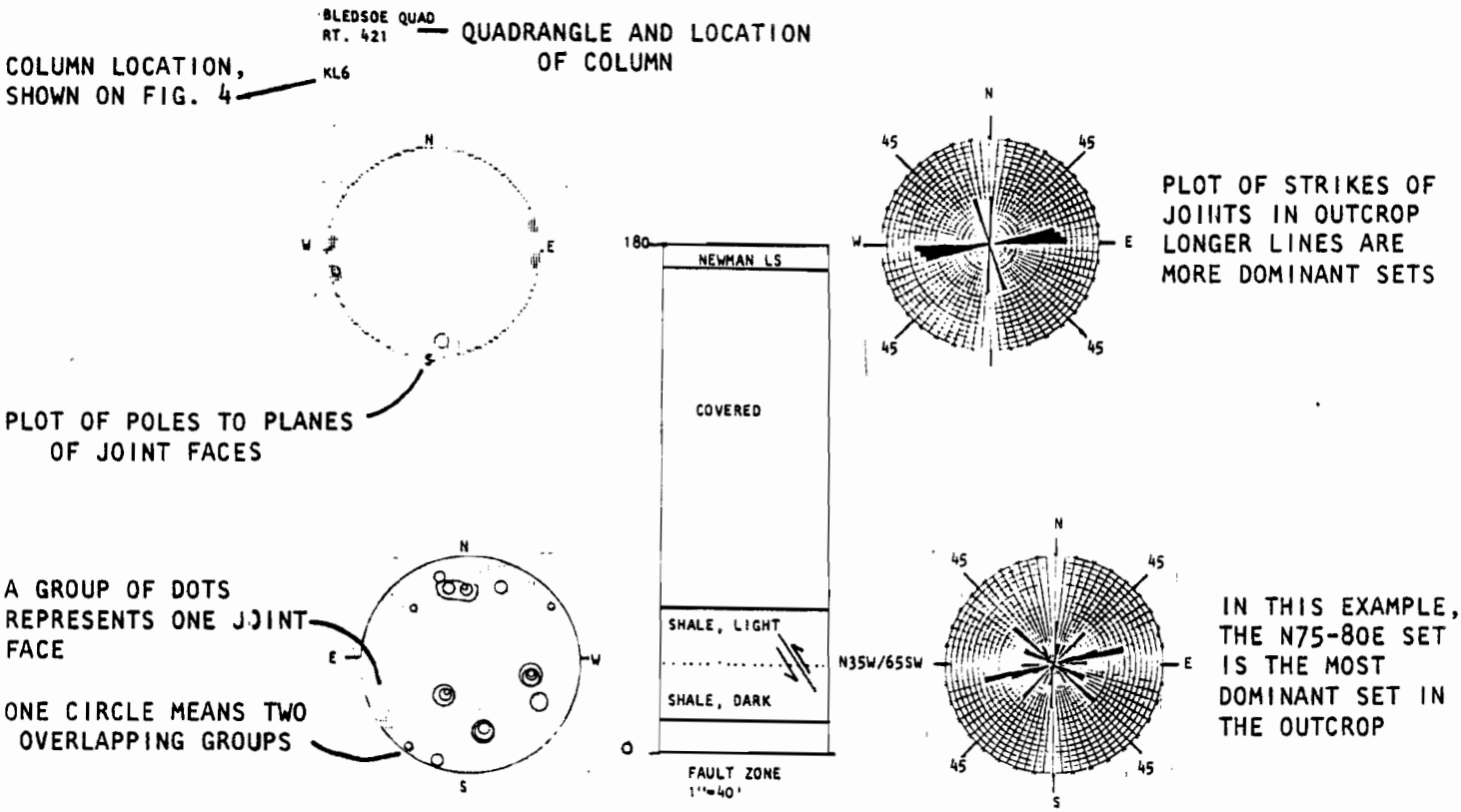


FIGURE 5
KEY TO COLUMNAR SECTIONS -
GUIDE TO INTERPRETATION

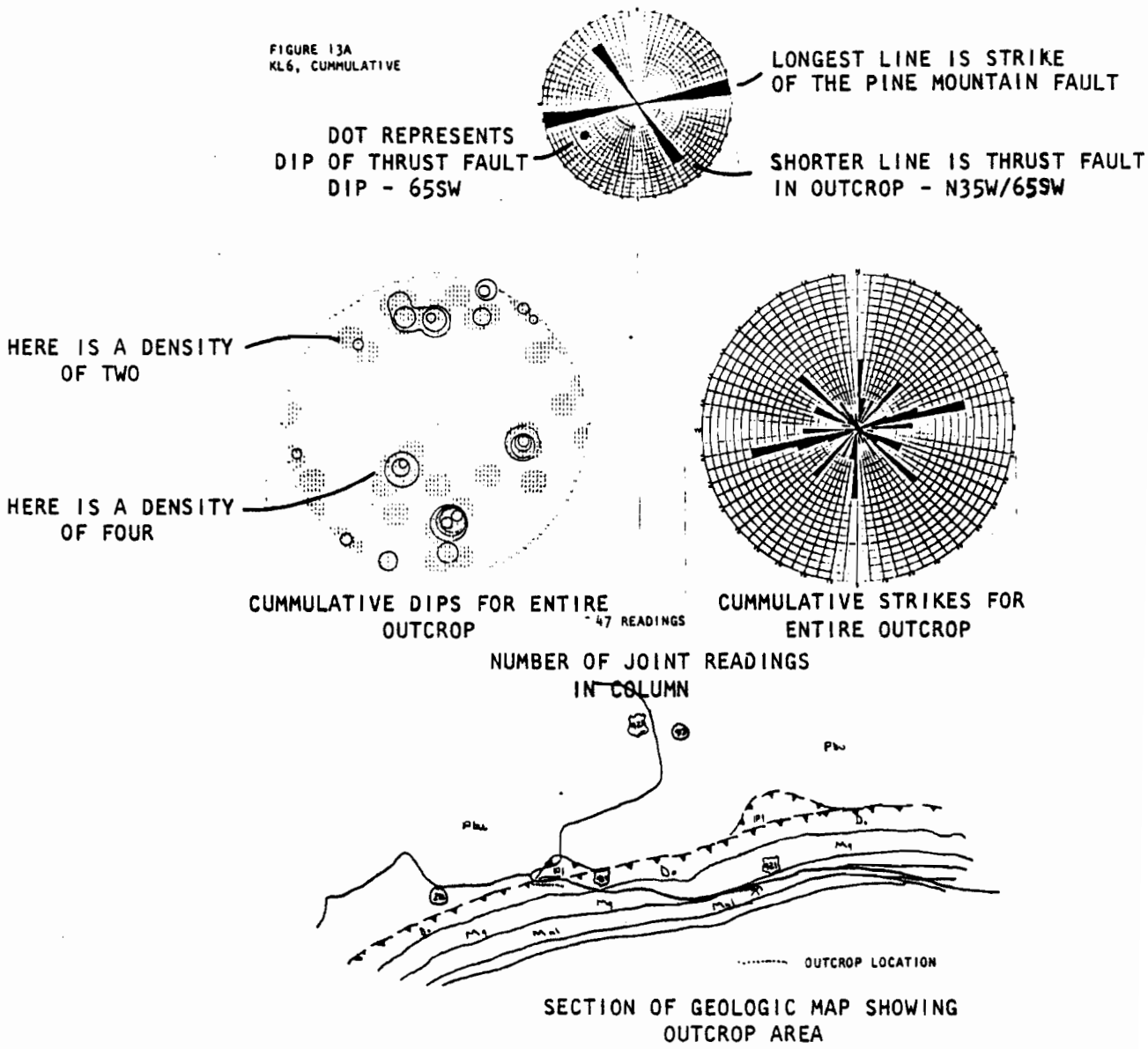


FIGURE 6
KEY TO COLUMN CUMULATIVE DATA -
GUIDE TO INTERPRETATION

ELKHORN CITY QUAD
ACCESS ROAD TO ELKHORN
CITY GRAVEL CO.

KL1

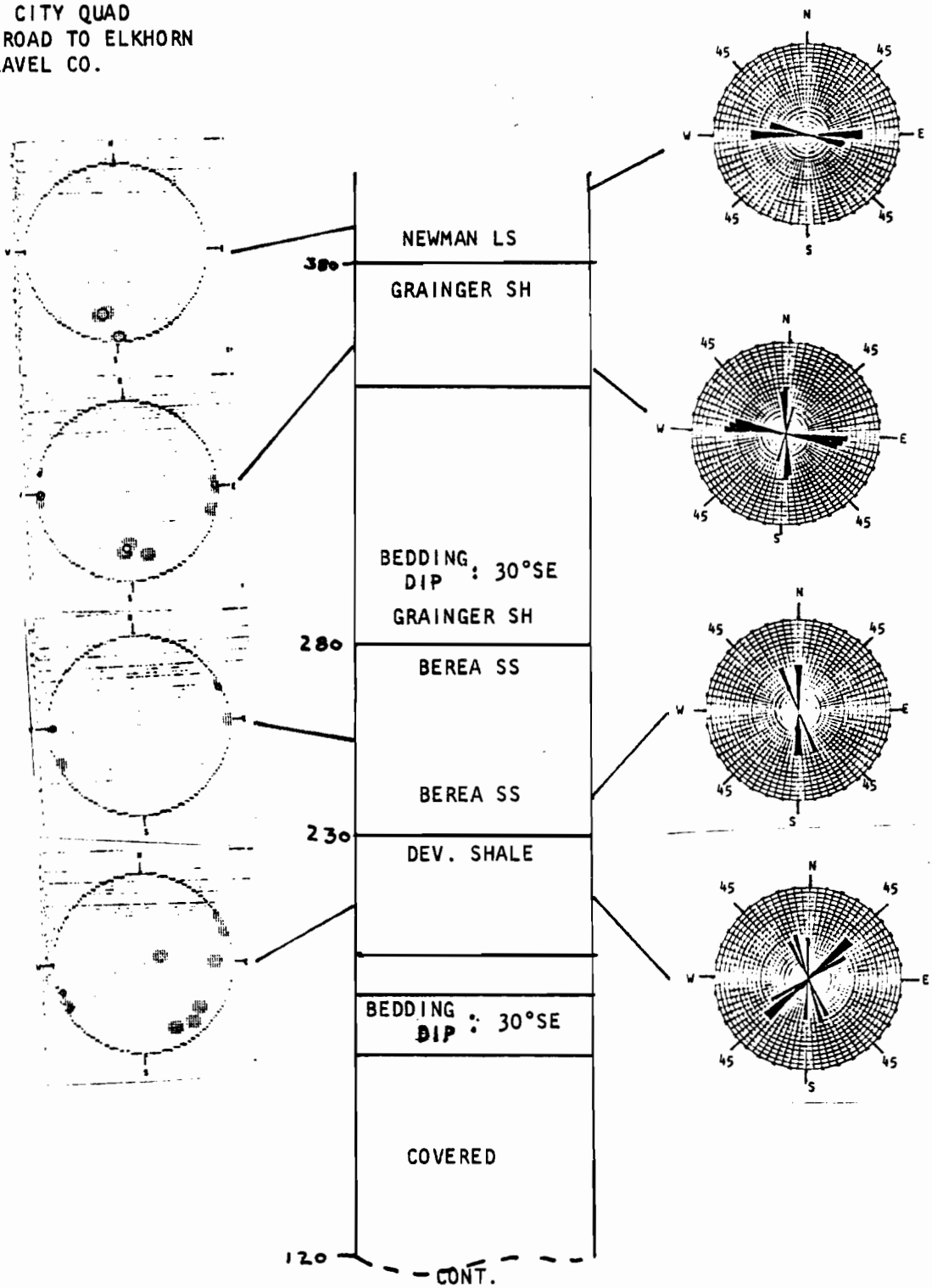
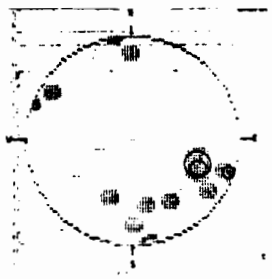


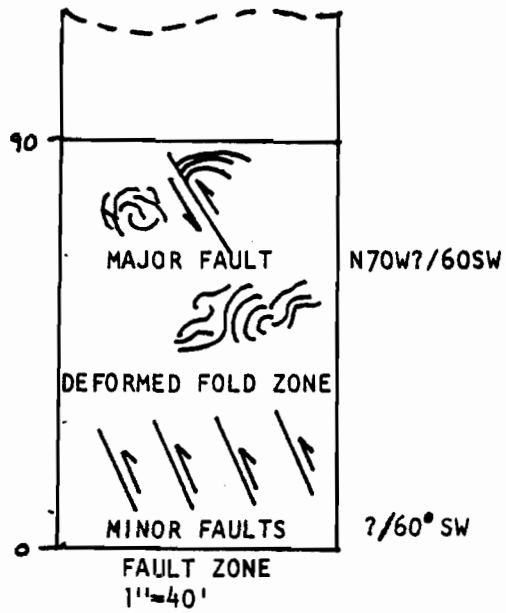
FIGURE 7

ELKHORN CITY QUAD
CONT.

KL1

CONT.





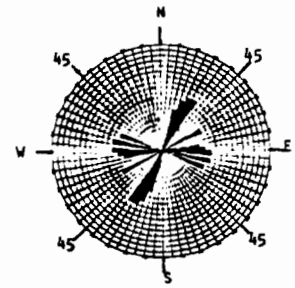
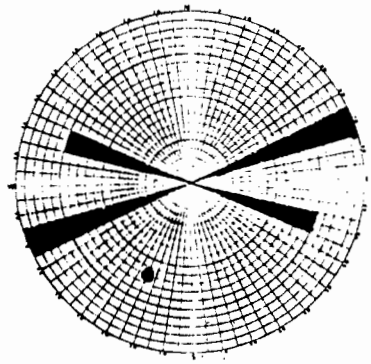
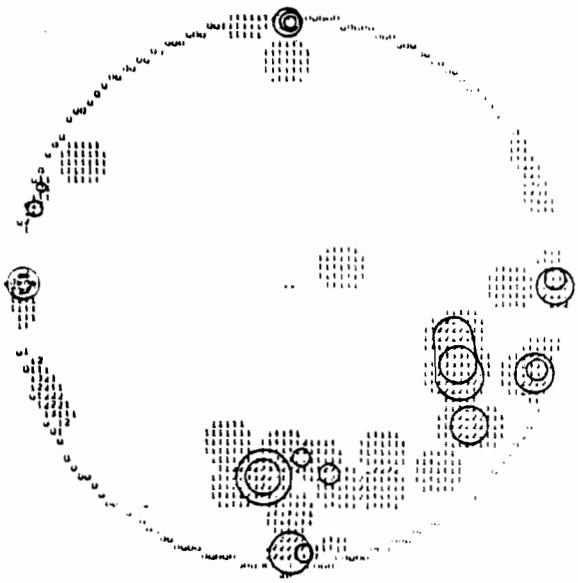
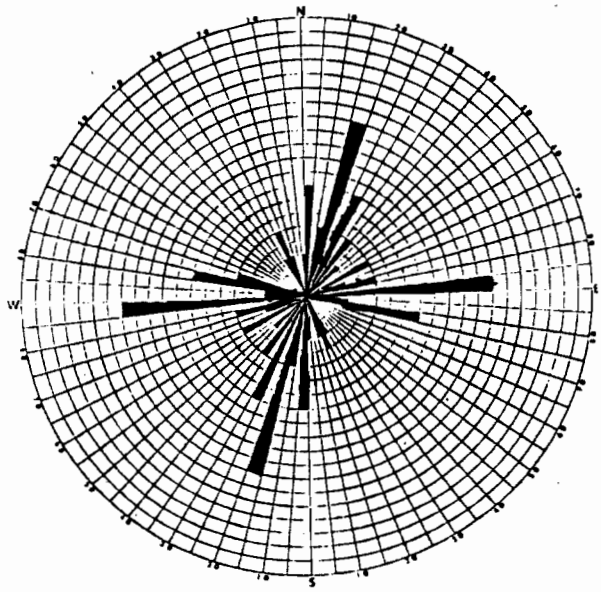


FIGURE 7A

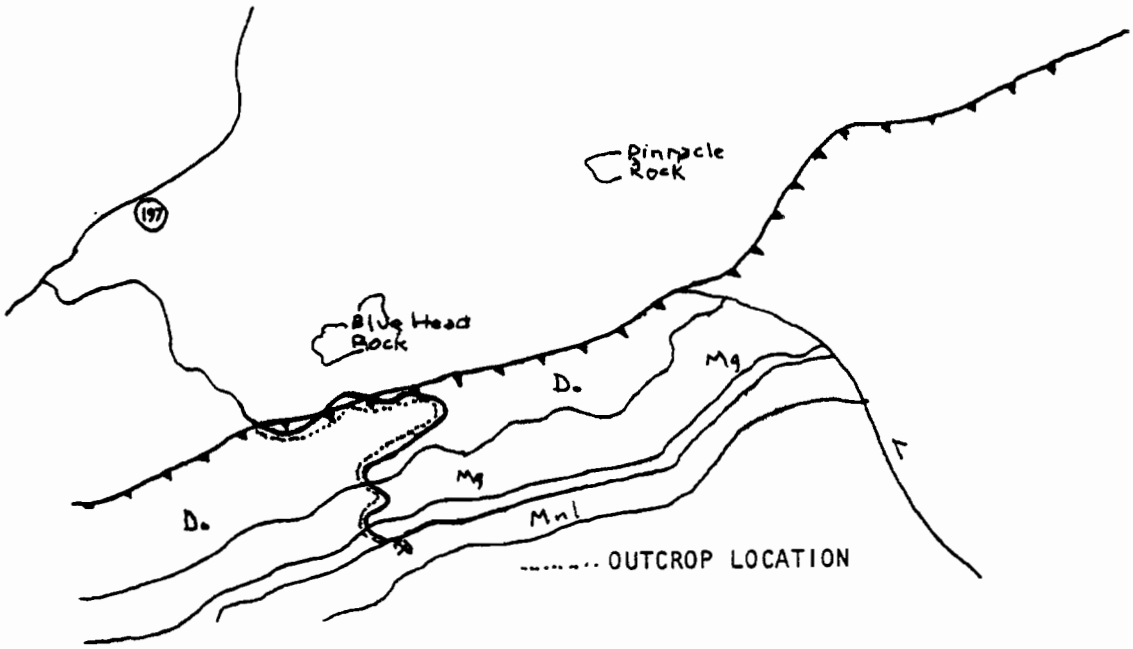
FIGURE 78
KL1, CUMMULATIVE







34READINGS



HELLIER QUAD
ACCESS ROAD TO JOHNSON
BROS. LS QUARRY
SECTION 10 IN THREE
LICK BED: GUIDE BOOK

KL2

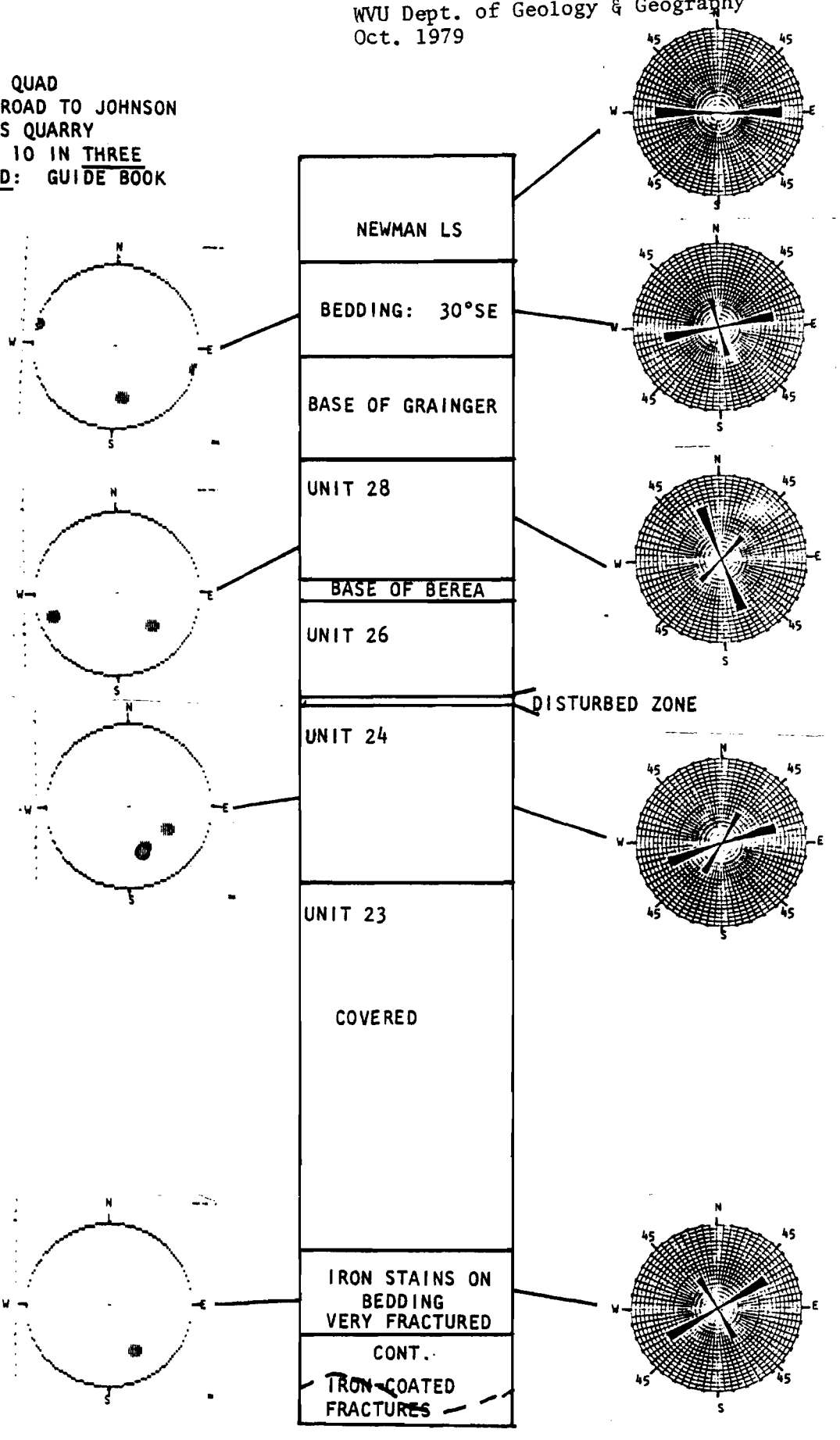
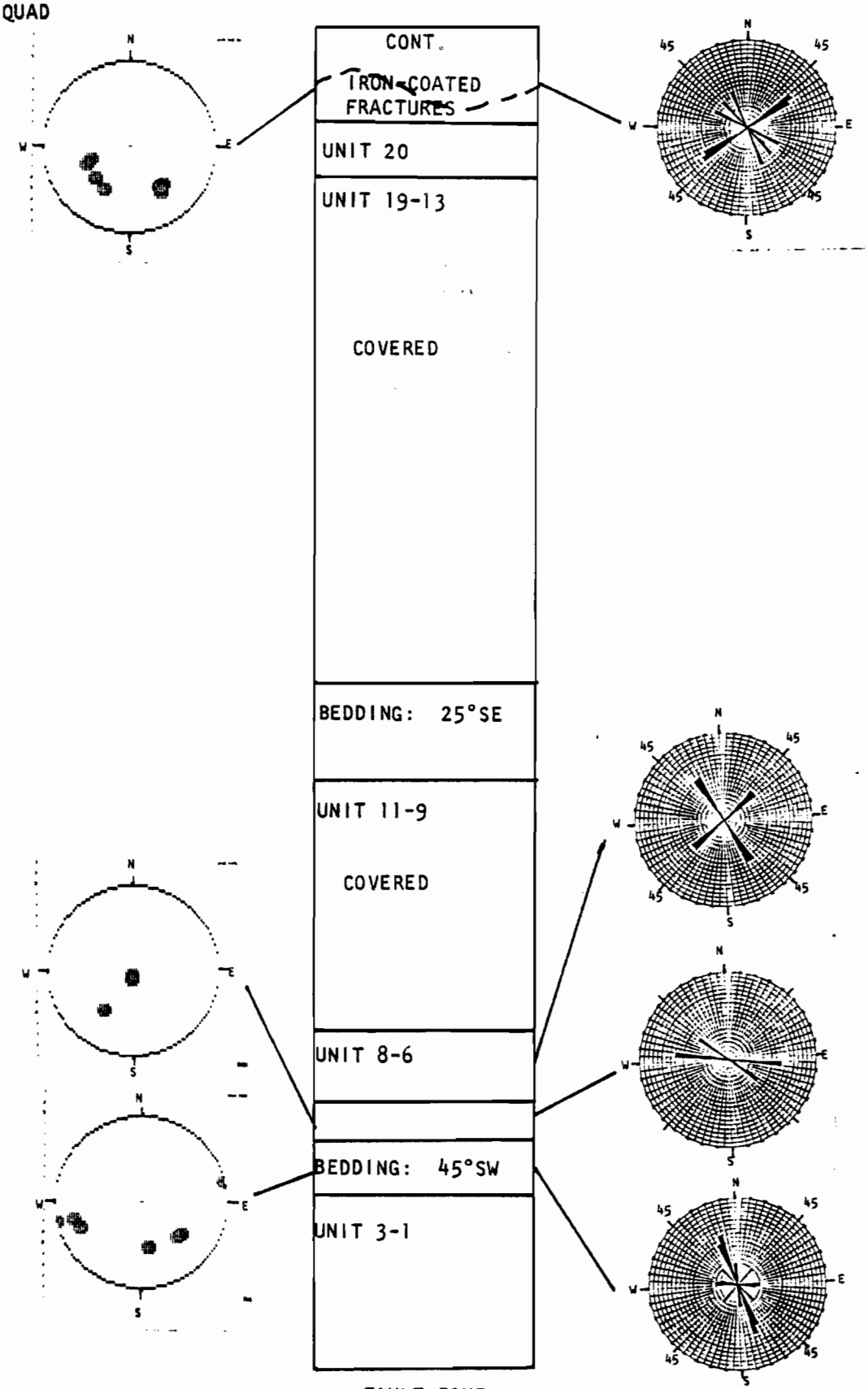


FIGURE 8

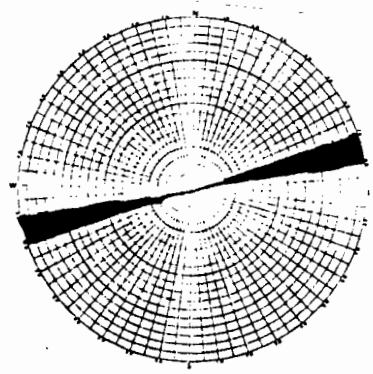
HELLIER QUAD
CONT.

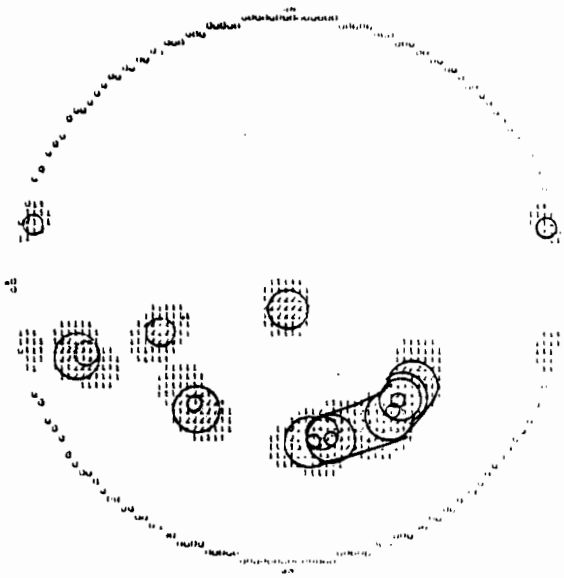
KL2

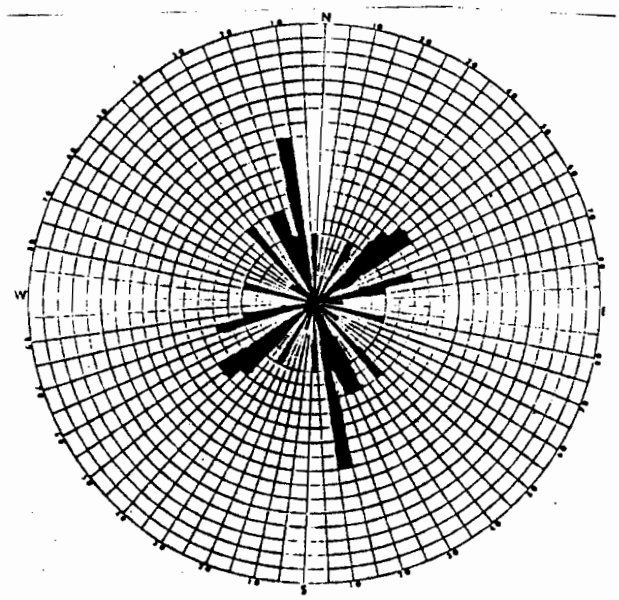


FAULT ZONE
1" = 40'

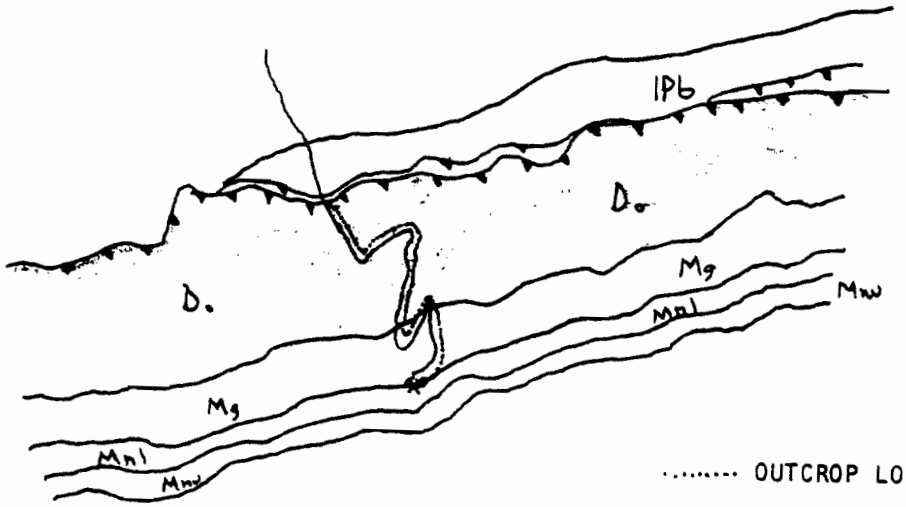
FIGURE 8A







26 READINGS



..... OUTCROP LOCATION

FIGURE 8B
KL2, CUMMULATIVE

JENKINS EAST QUAD
ACCESS ROAD TO ADAMS STONE
CORP. LS QUARRY

KL3

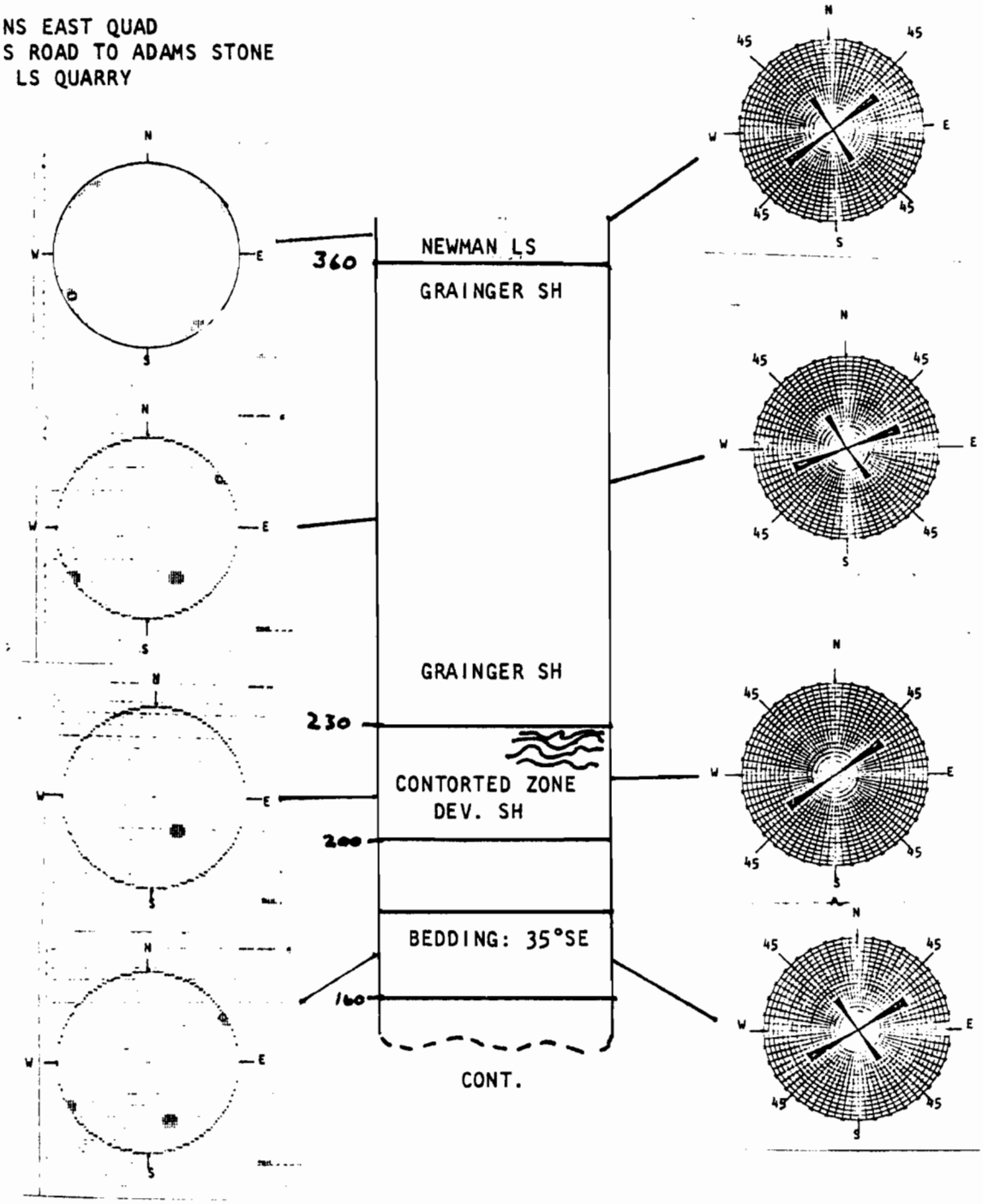


FIGURE 9

JENKINS EAST QUAD
CONT.

KL3

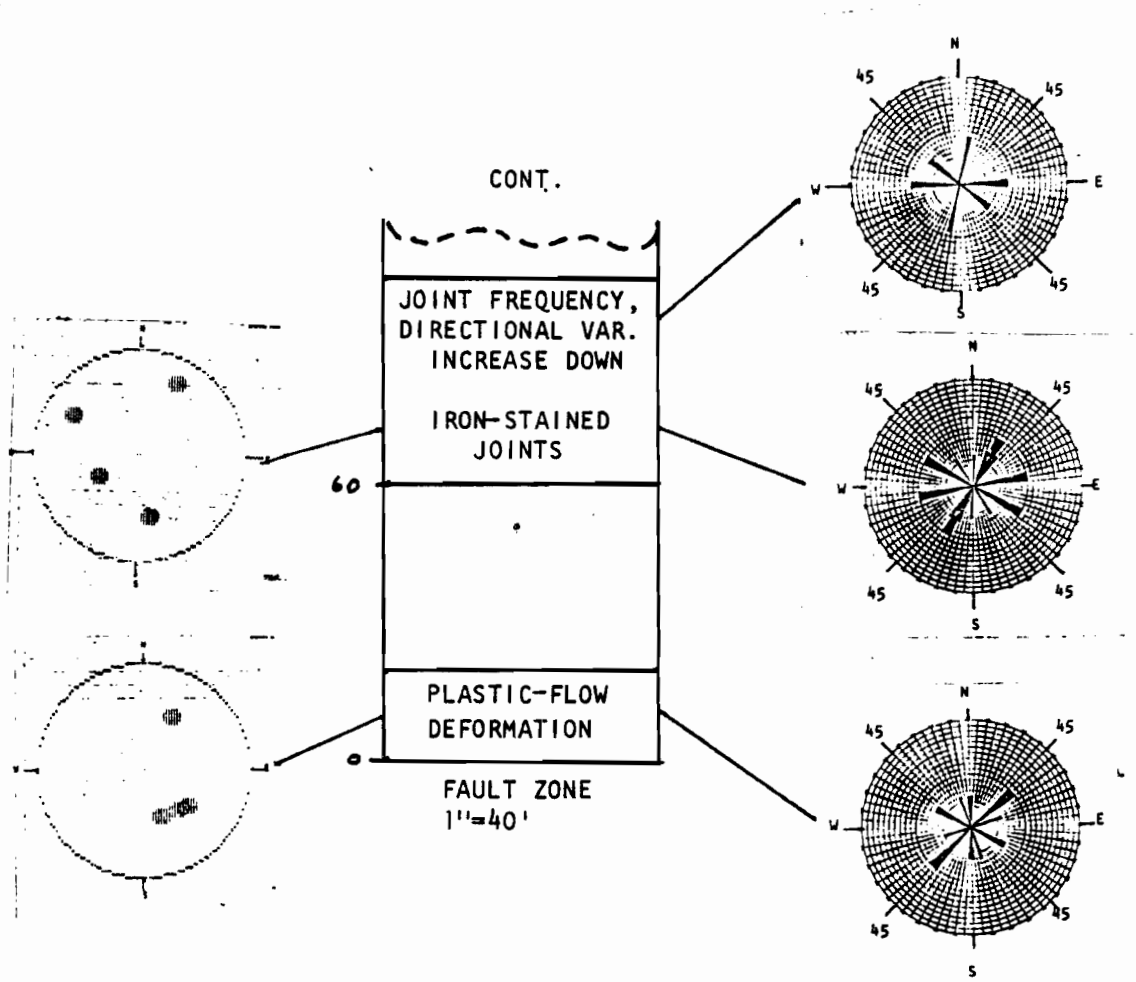
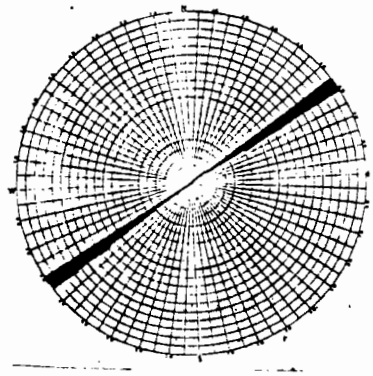
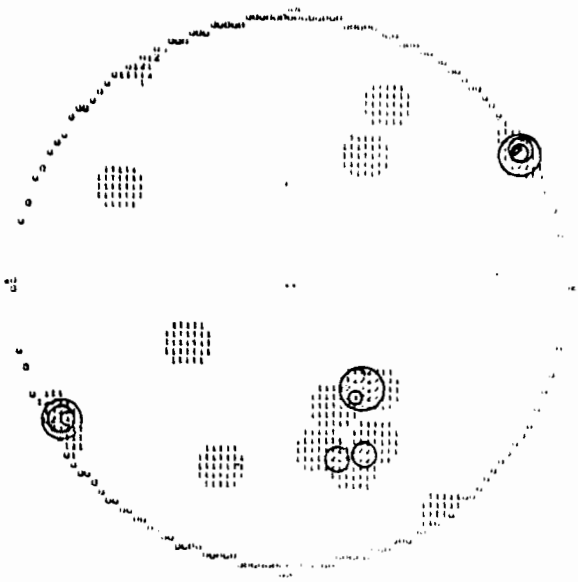
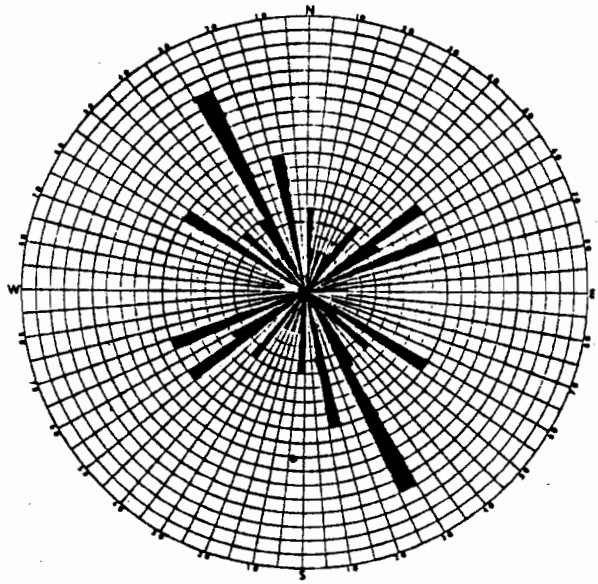


FIGURE 9A

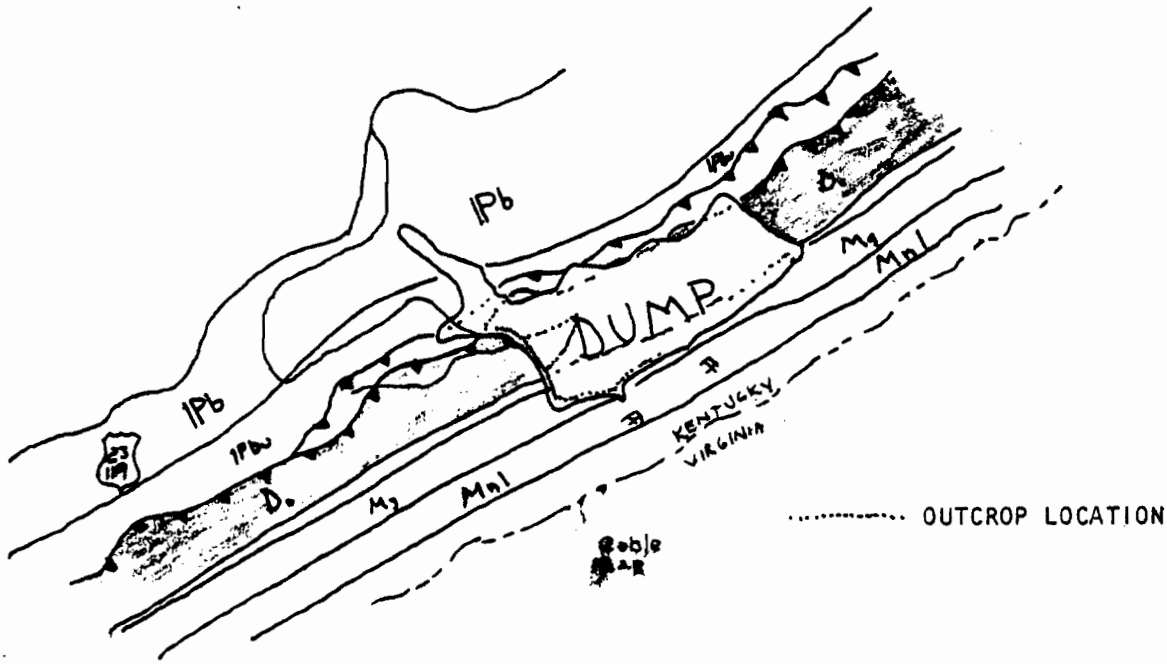
FIGURE 9B.
KL3, CUMMULATIVE







25 READINGS



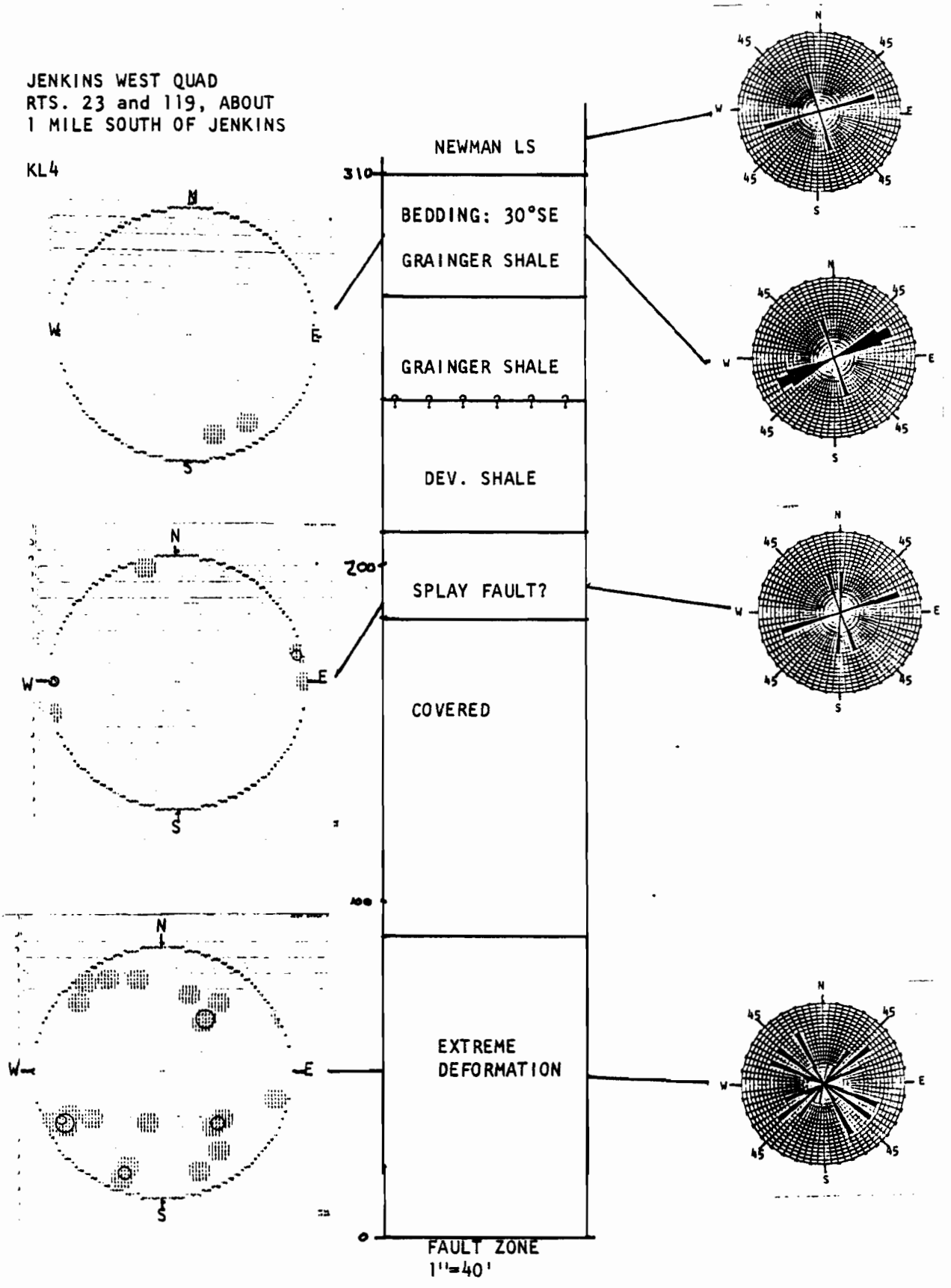
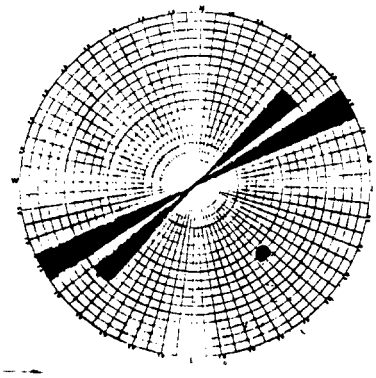
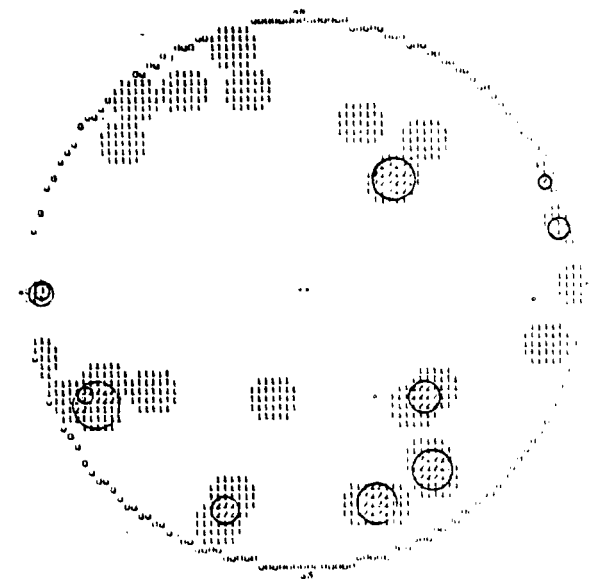
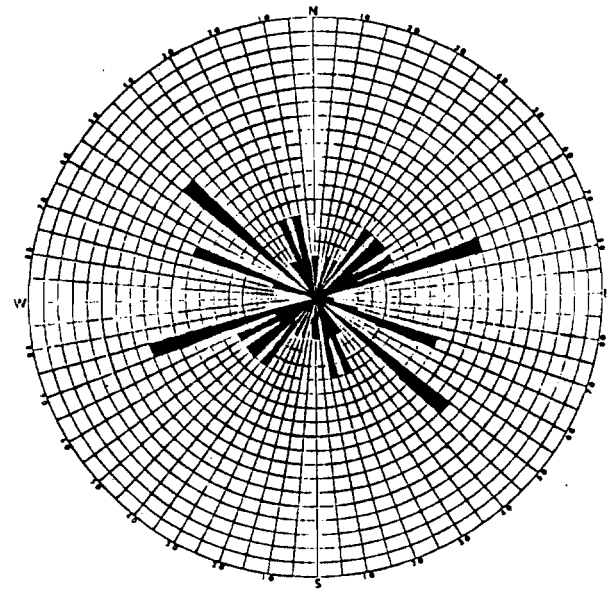

JENKINS WEST QUAD
RTS. 23 and 119, ABOUT
1 MILE SOUTH OF JENKINS
KL4
NEWMAN LS
310
BEDDING: 30°SE
GRAINGER SHALE
GRAINGER SHALE
DEV. SHALE
200
SPLAY FAULT?
COVERED
100
EXTREME
DEFORMATION
0
FAULT ZONE
1"=40'
N
S
E
W
45

FIGURE 10







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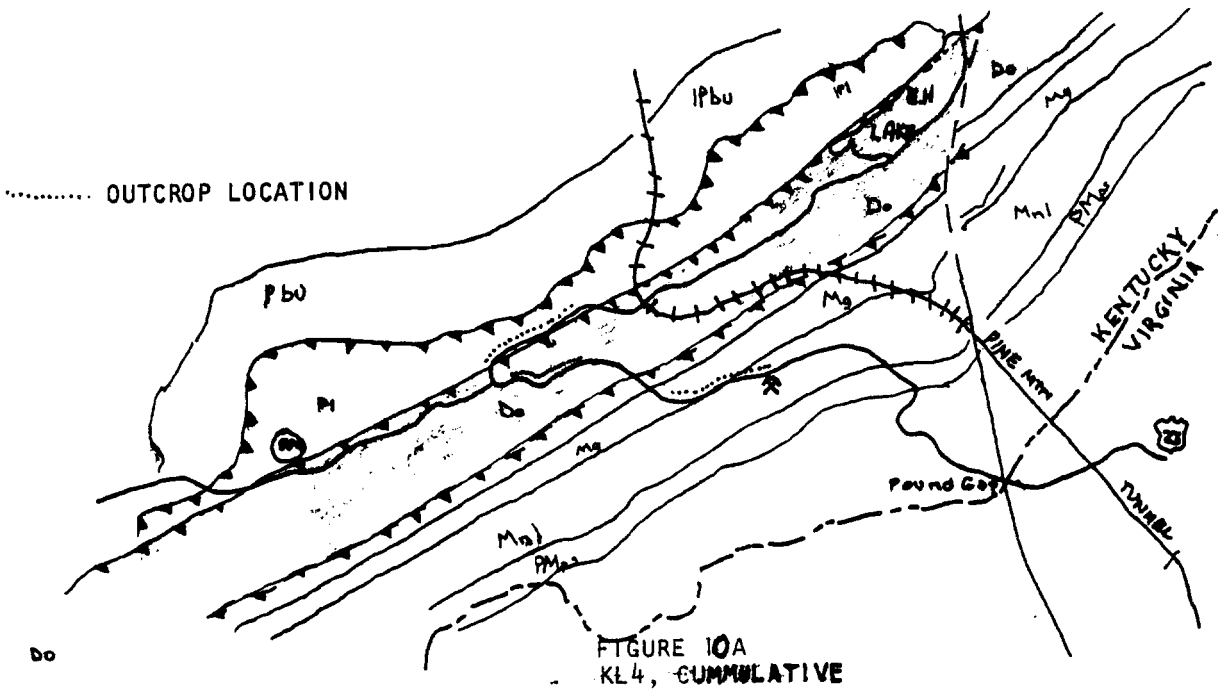


FIGURE 10A
KL4, CUMMULATIVE

LOUELLEN QUAD
RT. 160, BELOW
HURRICANE PASS

KL5

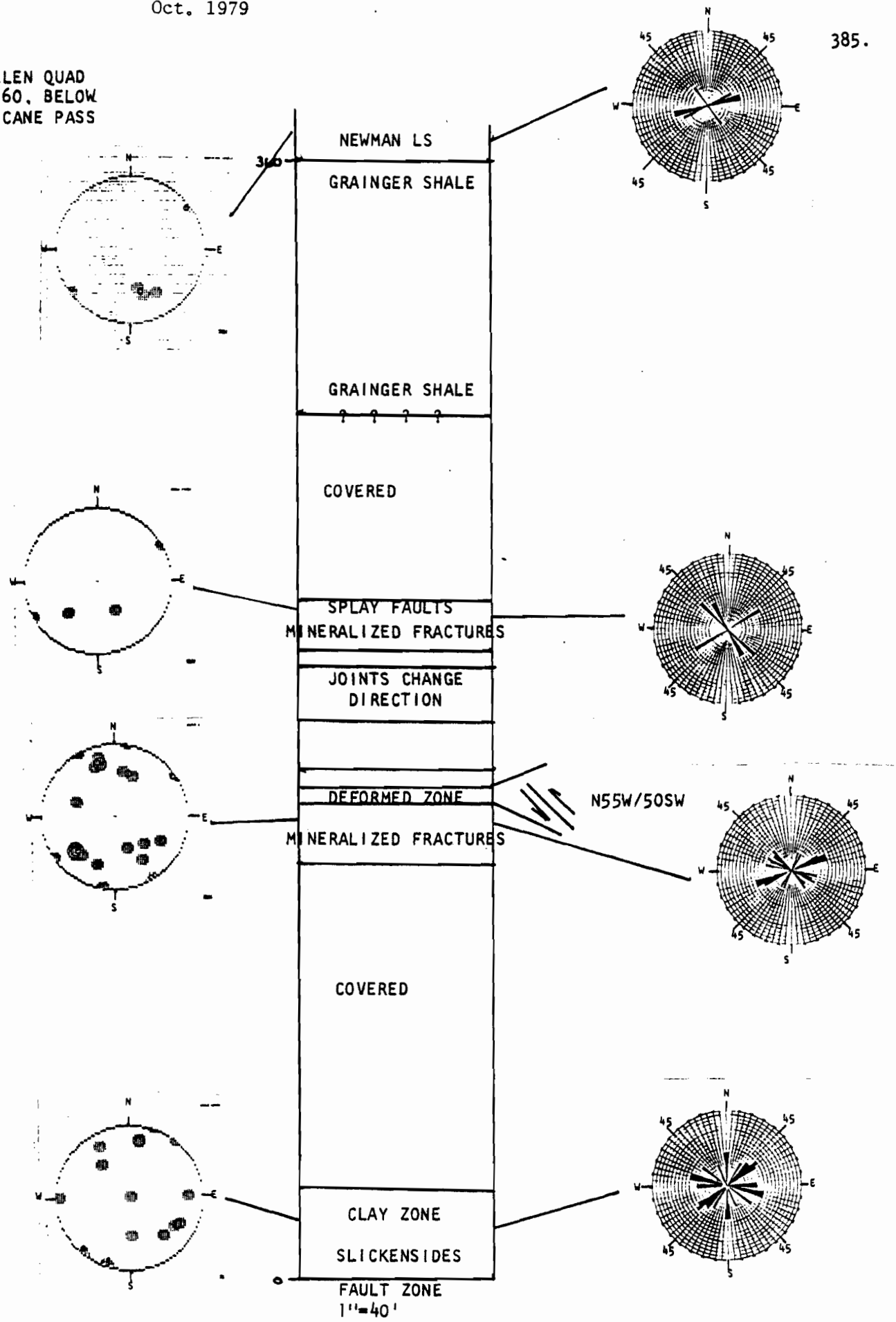
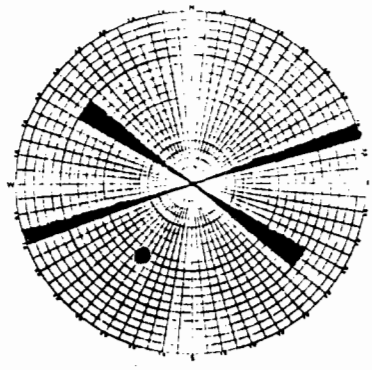
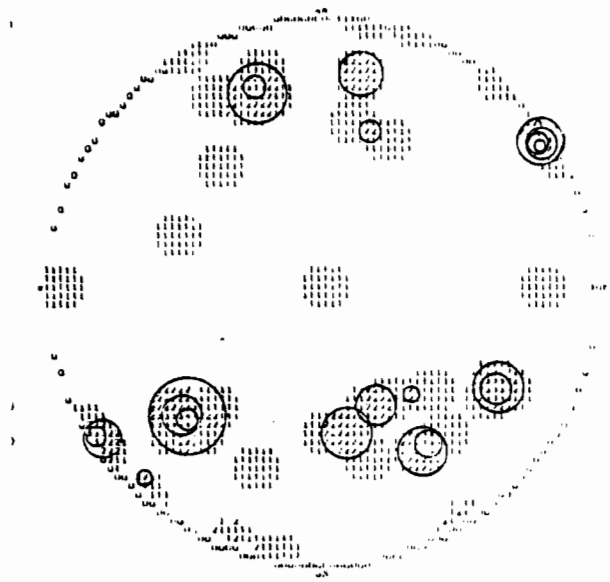
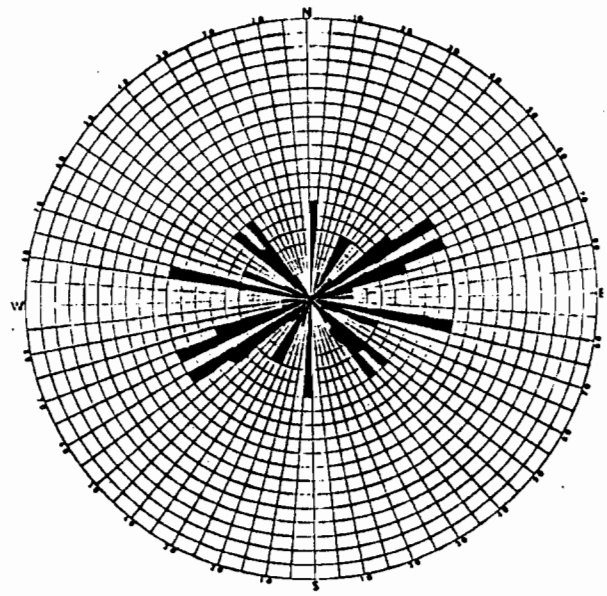


FIGURE 11







38 READINGS

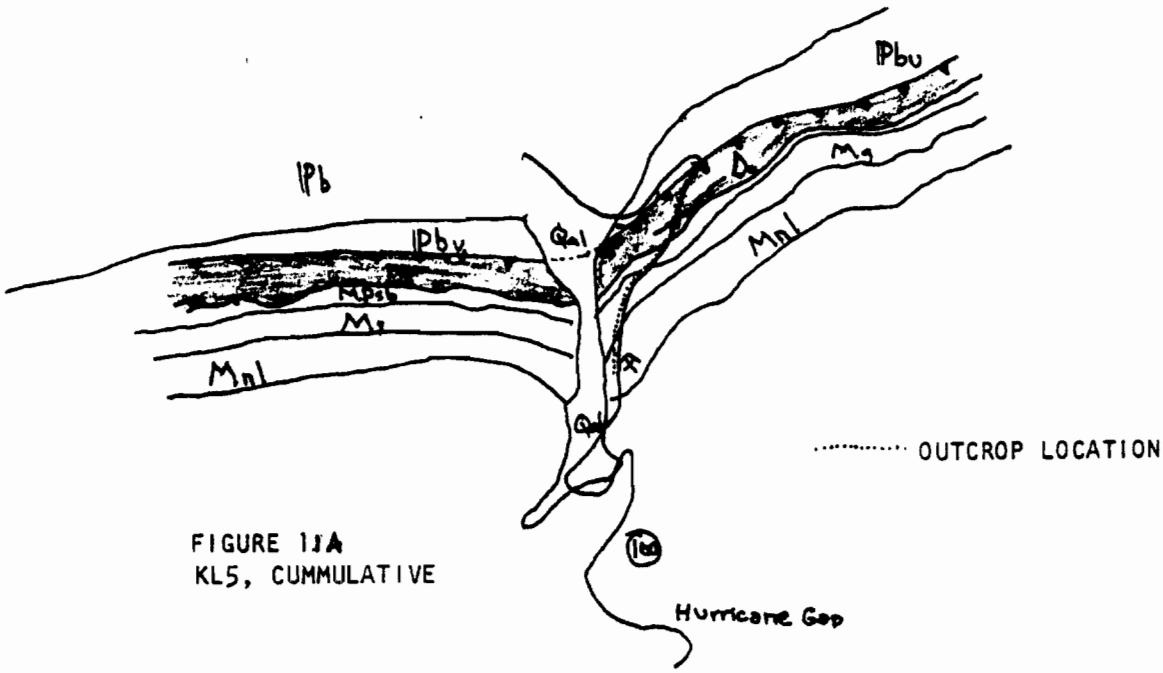


FIGURE 11A
KL5, CUMMULATIVE

BLEDSOE QUAD
RT. 421

KL6

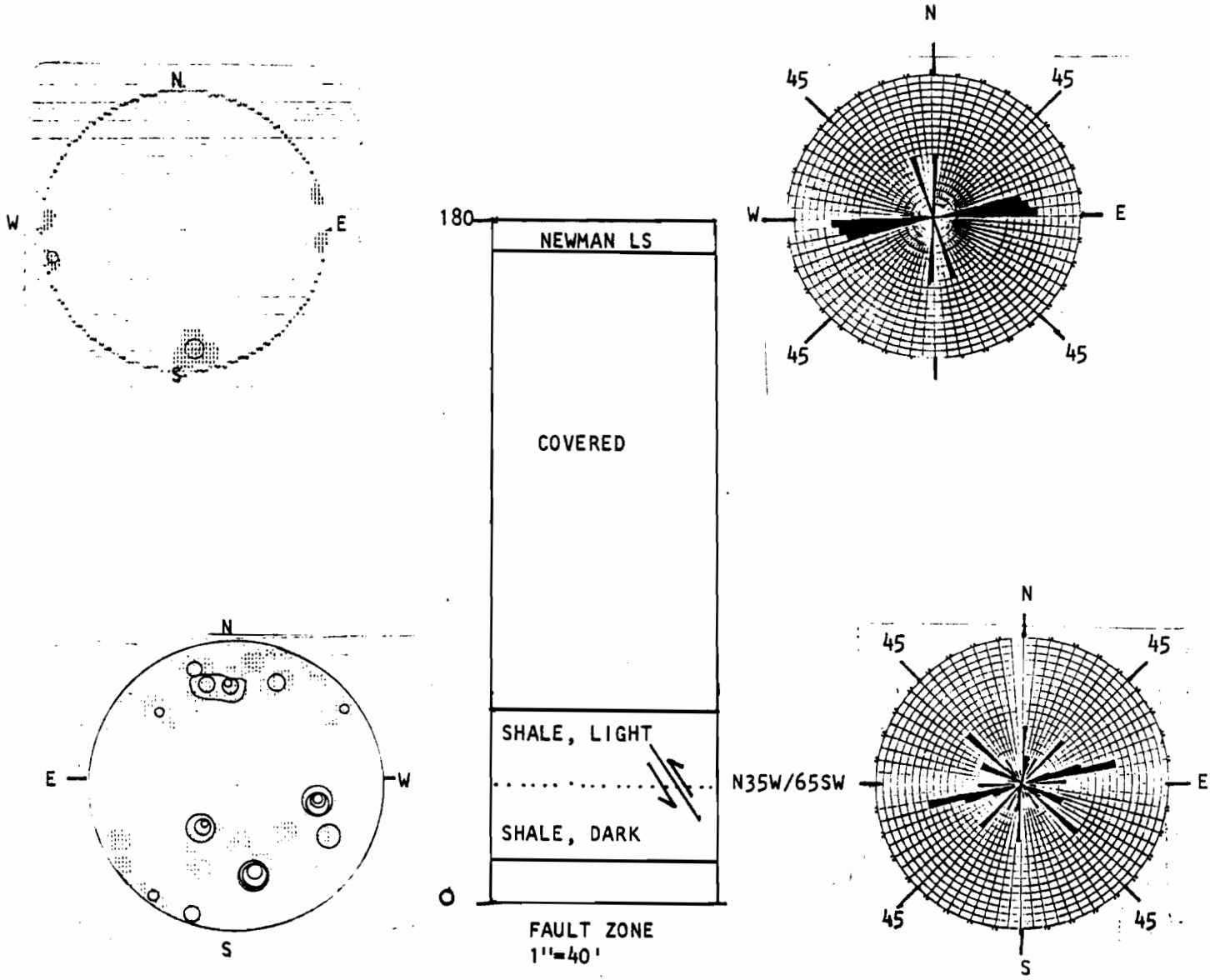
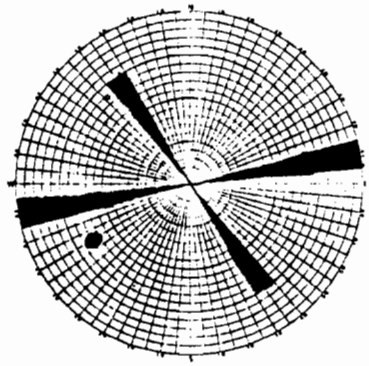
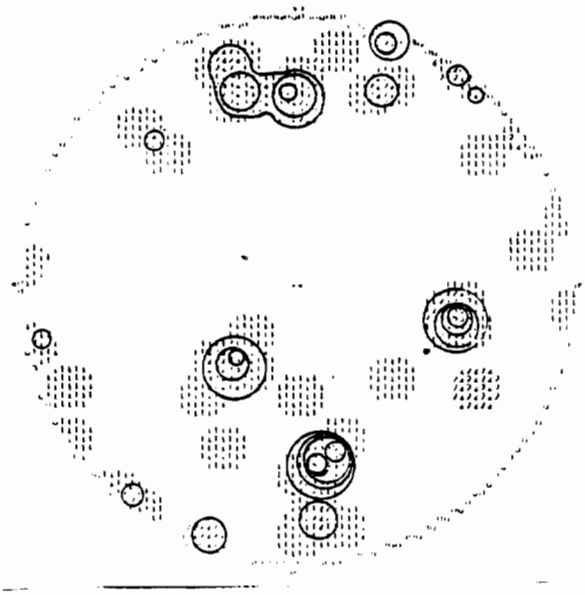
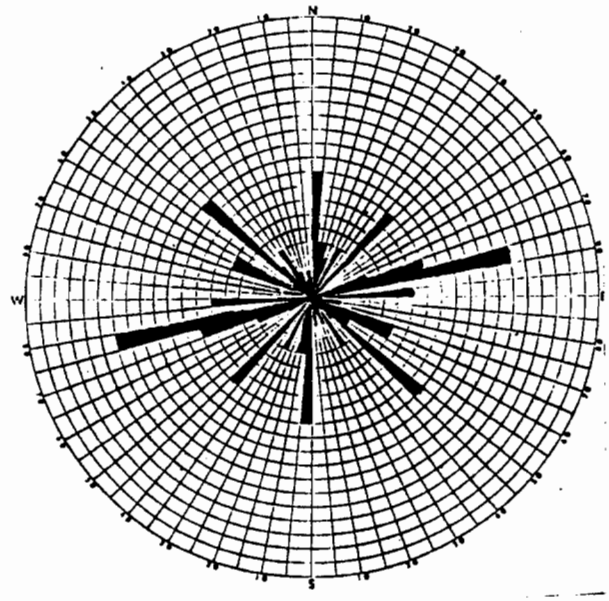


FIGURE 12

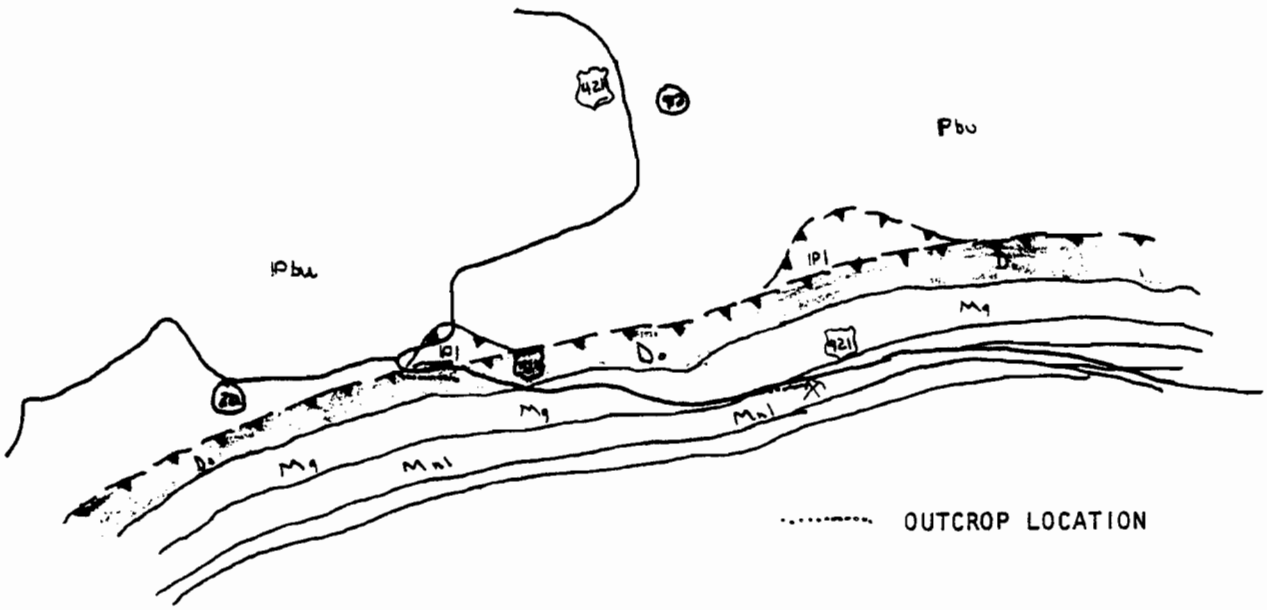
FIGURE 12A
KL6, CUMMULATIVE







47 READINGS



	CLOSE TO PINCHOUT OF SHALE ALONG STRIKE	SPLAY FAULTS ON OUTCROP SCALE	THRUST FAULTS ON OUTCROP SCALE	RANDOM FRACTURES	FLOW CHARACTERISTICS		JOINT DENSITY INCREASES DOWN	JOINTS CHANGE DIRECTION DOWN
					AT TOP OF SHALE	AT BOTTOM OF SHALE		
JOHNSON BROS. QUARRY **KL 2** ROAD	NO	NO	NO	YES	YES	NO	?	YES
JENKINS EAST QUARRY **KL 3** ROAD	NO	?	?	YES	YES	YES	YES	YES
JENKINS WEST **KL 4** ROADCUT	YES	YES	YES	YES	?	YES	?	?
HURRICANE PASS **KL 5**	NO	YES	YES	YES	?	YES	?	YES
BLEDSOE CHURCH **KL 6**	NO	?	YES	YES	?	?	?	?
ELKHORN QUARRY ROAD **KL 7**	YES	NO	YES	YES	NO	YES	YES	YES

FIGURE 13
CHART OF STRUCTURAL FEATURES

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Conclusions

1) Jointing in the Newman Limestone consists of a dominate strike set parallel to the Pine Mountain thrust, and a dip set perpendicular to the thrust front.

2) Jointing in the underlying Grainger shales and Berea sandstone are similar to jointing in the limestone, but can show slight rotation of joint strike, and greater variability in the strike of joint directions, especially in the second, or dip set.

3) A Narrow zone of deformation may be present near the top of the Devonian shales. This zone may reflect flexurial flow as the stiffer units above glided over the weaker shales during formation of the main Pine Mountain thrust, found at the base of the shale.

4) The number of joint sets throughout an outcrop increase with depth, or, the closer to the fault zone, the greater the trend and number of joint sets. Shumaker (1976) noted anamolous dip readings in the dip meters of the No. 1 Combs well in the Big Sandy field (perhaps reflecting mineralized fractures) in organic zones near the base of the shale and near the top of the shale. The two zones also contain slickensides indicative of movement (Shumaker, 1976). In addition Ray (1967) reports two main zones of production from these same organic layers. (See Figure 14) It seems possible that the two deformed zones at Pine Mountain correlate with those discussed by Shumaker (1978) and Ray (1967).

5) The strikes of joint sets at the top of the Devonian shales do not match the strikes of joint sets at the bottom of the Devonian shales. Somewhere between the top and bottom of the Devonian shales is a zone, sometimes narrow, where the joints change strike. This is graphically illustrated on KL3 between elev. 80 and 160, and was seen on one outcrop

FRACTURED DEVONIAN SHALE WELLS
PERRY COUNTY, KY.

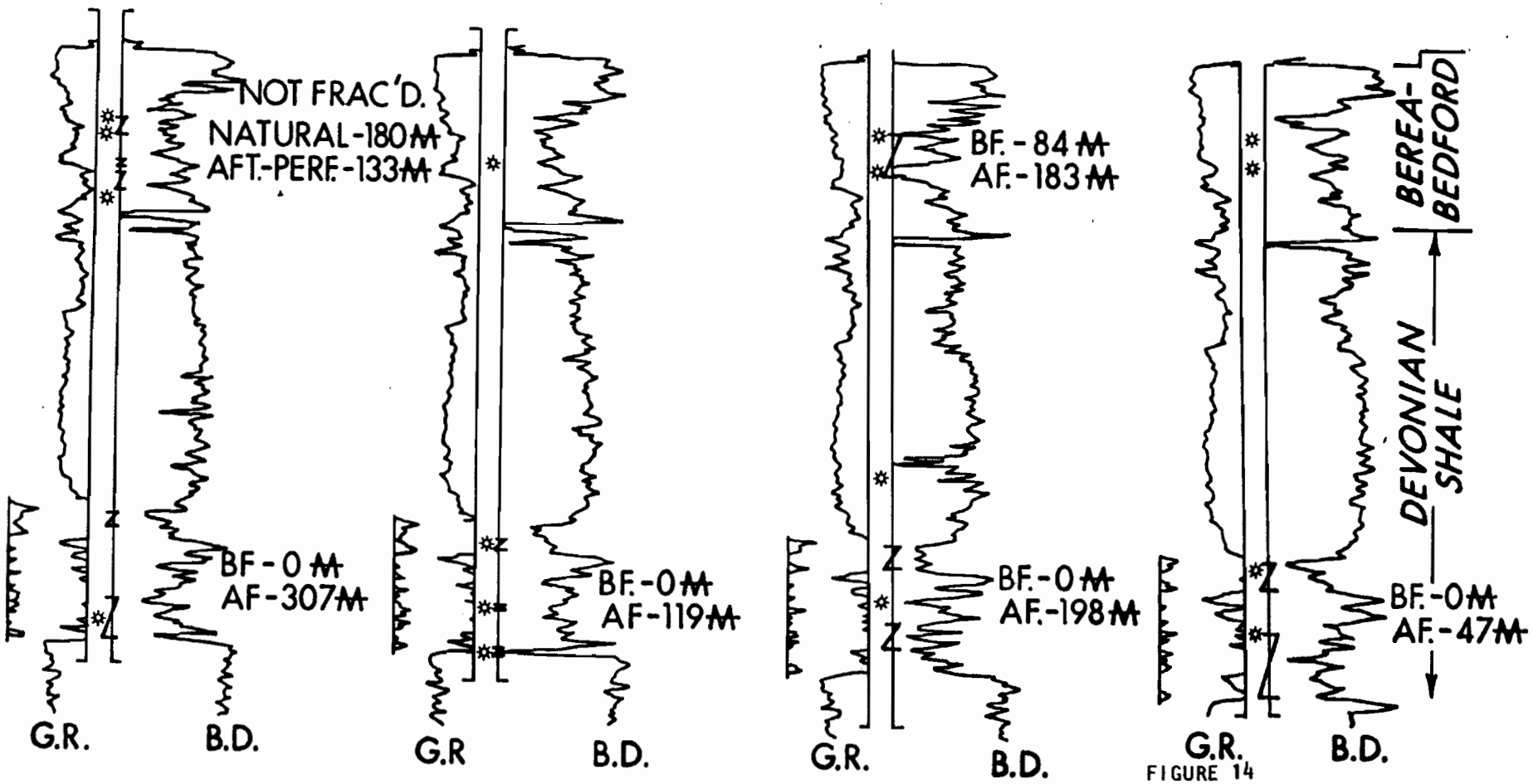

FIGURE 14
PRODUCTIVE ZONES IN DEVONIAN SHALE

RAY-1967

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on KL5.

6) The most deformed zones occur in the lower part of the Devonian shales near to the disappearance of the shales along strike of the Pine Mountain thrust, and conversely as the shale thickens above the thrust there is a greater section of undeformed shale.

7) Thrust faults in the Devonian shale, as seen in outcrop, are not parallel to the main Pine Mountain fault. Thrust faults in the shale that are parallel to the main thrust may be obscured on bedding planes. A clay rich zone at the bottom of KL5 may be one such fault.

8) Random fractures, or non-systematic fractures throughout entire outcrops, were noted in some exposures at every column studied. These could be related to blasting, weathering, or tectonic deformation.

9) Each column usually has joint sets sub-parallel and sub-perpendicular to the Pine Mountain thrust.

10) Where thrust faults are detectable in outcrop, the strikes consistantly correspond to strikes of a joint pattern. However, the dips of the thrust faults do not consistantly correspond to dips of a joint pattern.

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APPENDIX D

Production Data

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E. B. Nuckols III

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RELATIONSHIPS OF GAS OCCURRENCE TO GEOLOGICAL PARAMETERS IN THE EASTERN KENTUCKY GAS FIELD(S)

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ABSTRACT

A study of initial open flow gas data from 4750 wells in the Eastern Kentucky Gas Field(s) relates gas occurrence to geological parameters including structural/stratigraphic sections, lithology, and geochemistry.

Approximately 300 formation density logs are used for stratigraphic correlation, reinforced by data from two cored wells and cuttings from 11 wells in this 3,000 square mile, 10 county study area known historically as the Big Sandy Field. This field has produced for over 50 years.

Trend traces of initial open flow data are interpreted as zones of more intense fracturing and show four preferential directional trends.

The gentle anticlinal structure in the northern part of the field, which may be an extension of the Paint Creek Uplift, broadens to the south and bifurcates. Small faults are identified to the southwest of the main field and the Rome Trough occurs across the northern portion of the field.

The 100' per mile dip to the southeast of the basement rocks is subdued to 30-50' per mile dip in the producing Devonian shale sequence which thickens by an order of magnitude into the basin to the northeast.

Relationships of these parameters and geochemistry from well cuttings are presented.

* Ms. Negus-de Wys presented this talk at the AAPG Annual Meeting, 1979. The AAPG Bulletin has asked Ms. Negus-de Wys to prepare a paper for publication.

EASTERN KENTUCKY GAS FIELD:
STRUCTURAL-STRATIGRAPHIC CROSS SECTIONS AND POTENTIAL PRODUCTION PATTERNS

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In August of 1977, Mrs. de Wys joined the staff on the Devonian Shale Program as Research Associate in the Geology Department at West Virginia University. Her Ph.D. dissertation is STUDY OF THE EASTERN KENTUCKY GAS FIELD(S): GEOLOGICAL PARAMETERS AND POSSIBLE RELATIONSHIPS TO GAS OCCURRENCE AND PRODUCTION.

Dr. Shumaker received his A.B. degree in Geology from Brown University and his M.S. and Ph.D. degrees in Geology from Cornell University.

He was employed with Exxon Corporation at their research lab in Houston for six years and in their operations exploration department in Midland, Texas, and New Orleans, Louisiana, for seven years. For the past six years he has been teaching petroleum geology, photo geology, and basin structure courses within the Department of Geology and Geography at West Virginia University.

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ABSTRACT

Preliminary results on a projected three-year study of about 3000 square miles of Eastern Kentucky Gas Field(s) are presented. Initial open flow data are compared with basement structure, dip and strike, and thicknesses of producing units in Devonian Ohio shales.

A series of seven preliminary cross sections are presented for comparison of log signature changes and correlation, stratigraphy and structure. A three-dimensional plexiglas model is presented for spatial relationships of the geological parameters to the initial open flow values and gas occurrence shown on temperature logs.

On-going studies on this field include lithology study of samples from each county, and geochemical analysis of samples for vertical and horizontal variation.

A preliminary computer-produced map of contours on the initial open flow data has been run using the Fortran SYMAP program. Additional refinements are being made prior to running a final map. A hand contoured map is also being prepared.

Comparison of the initial open flow map will then be made with the geological parameters.

INTRODUCTION

Ed Ray of Kentucky-West Virginia Gas has described the historical development of this area which has undergone exploratory drilling for over 150 years, first for brine, then oil and eventually for gas. "The commercial production of gas commenced in the 1920's and now comprises 85% of the gas produced in Kentucky. The most important producing horizon in the Eastern Kentucky Field is the Upper Devonian Ohio 'Brown Shale' which includes the Cleveland Shales, Three Lick of Chagrin, and the Huron Shales. These highly organic units are 200-900 feet thick in this area and have a southeast monoclinal dip of 30-50 feet per mile. Only 5% of completed wells have natural commercial open flows. Shooting with explosives was shown to bring 40% of nonproducers into commercial production. Presently hydrofracturing is the standard procedure, which results in only 43% of drilled wells falling within 0-100Mcf range as against 54% of total completions with shot wells in that range.

These procedures reflect the fact that the Devonian Brown Shale of Eastern Kentucky is a relatively small volume producer in individual wells but the productive life far exceeds any other producing formation in the area. An explanation for this slow but long well life may lie in the concept of production from "fracture facies" of the shales, possibly related to deep basement structural features, coupled with the extremely low average matrix porosity and permeability. This field is the largest gas field in the Appalachian Basin, having produced over 1.7 trillion cubic feet of gas."

PURPOSE OF STUDY

The purpose of this investigation is to identify and describe geological parameters and relate these to gas occurrence and potential production. Geological parameters in this study include stratigraphy, structure, lithology, and geochemistry. Identification of Protosalvinia (also described as Foerstia) in well cuttings and cores is included as a possible time line or restricted habitat zone.

Gas occurrence data is derived from temperature logs. Initial open flow data is used as an indicator of gas occurrence and potential production.

Data

The data to be included in this study consists of:

1) Approximately 300 formation density logs,
2) approximately 75 temperature logs,
3) initial open flow data on approximately 4750 wells,
4) well cuttings from ten counties,
5) core data on two wells and one tunnel,
6) fracture study data from 2 cores and field surface studies,
7) outcrop data to the west,
8) West Virginia University and Geological Survey studies to the east,
9) literature including especially work by the Kentucky Geological Survey, the U. S. Geological Survey, the University of Kentucky, the University of Cincinnati, Ohio, State University, and

especially the dissertations of Linda Provo and J. Schwietering.

Status of investigation

The work presented in this paper includes seven preliminary stratigraphic-structural cross sections and preliminary initial open flow data patterns. Some gas occurrence from temperature logs is included on cross-sections, although this work has not yet been completed.

Structural maps, isopach maps, lithology, geochemistry, and final analysis are yet to be accomplished.

Stratigraphic-structural maps

The seven cross sections presented in this report are oriented as follows:

1) three in a SW - NE direction, and
2) four in NNW - SSE directions.

See Figure 1.

These sections are shown in a 1/163 ratio of the horizontal to vertical scale in order to emphasize the gentle structure and permit the display of the fine intertonguing gray and black shales in the Cleveland section.

The cross sections show a more sharply defined anticline in the northernmost SW - NE cross section, broadening in the central part of the field and gently bifurcating to the south. The NW - SE cross sections show the regional dip to the SE at about 30-60 feet per mile, with some suggestion of slight interruptions of this dip in the form of small steps. In the central SW - NE cross section two small normal faults are apparent in the extreme SW. These are not apparent in the other two near parallel sections. A fault is suggested in the vicinity of the Warfield fault and possibly to the NE.

The stratigraphic sections thicken by as much as an order of magnitude to the east.

The intertonguing of the gray and black shales in the Cleveland sequence is reflected in the natural radioactivity in the gamma-gamma readings on the formation density logs. Core samples bear out the color changes. However, a simple gray/black designation is actually not truly representative of this section. A more detailed study should show a gradation in grays from very light to extremely dark or black. This study is only showing relative changes and thus the cross sections show only two relative gradations.

Gas occurrence from temperature logs is shown on the cross sections. This work has not yet been completed; the lack of gas occurrence shown on some logs may be due to lack of data at this time.

Initial open flow data from 4750 wells is used to develop pattern maps and run a Fortran SYMAP program. The pattern maps shown show the results in terms of four levels as 1) a color representation with red as highest, orange as second highest, yellow as third, and dots as fourth; and 2) as a black pattern. See Figures 2 and 3. Points were connected where not contra-indicated. In the black pattern in Figure 3 several linear band-like trends may be noted, within which there appear suggestions of arcuate or almost meandering patterns. Sample checks across these bands are planned to investigate lithology changes.

The first completely run SYMAP on twice the scale of the original map is presented. This will be contoured from the printout and reduced for comparison with other parameters.

A three-dimensional plexiglas model of the field with cross sections discussed here and an areal histogram of initial open flow data is presented in the poster session area.

Protosalvinia has been identified and photographed in both cores and has been found in the well samples studied to date. The existence of this brown algae may represent a time line, or, more possibly represent a restricted unique set of environmental habit conditions in which this form could flourish.

This paper represents essentially a status report on the first year of an on-going three-year study. As such, conclusions are not drawn at this time. However, inferences at this point in the investigation suggest both structural and stratigraphic influences on gas occurrence in this field.

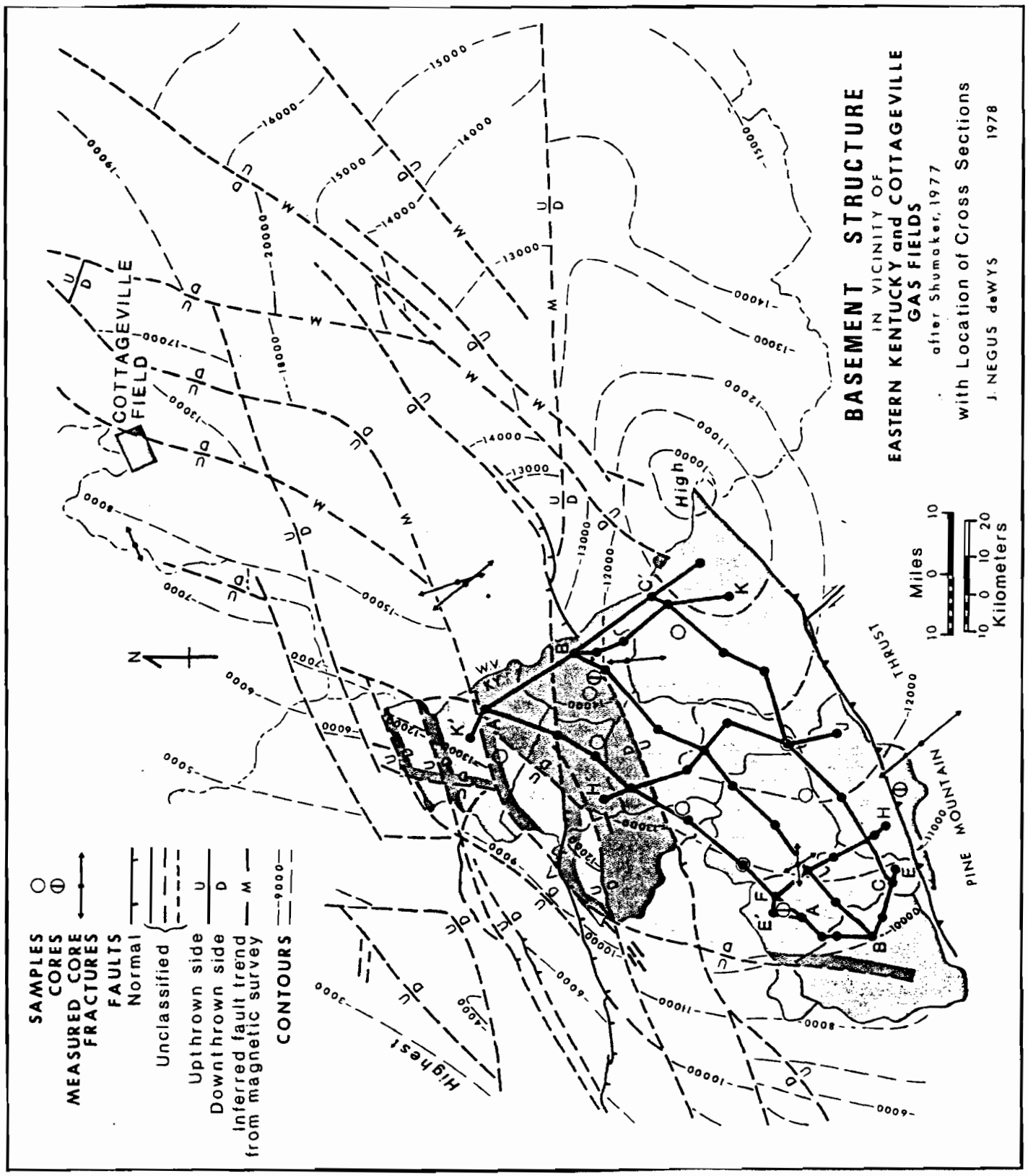

Figure 1: Location of study area showing cross sections under study and structural setting.

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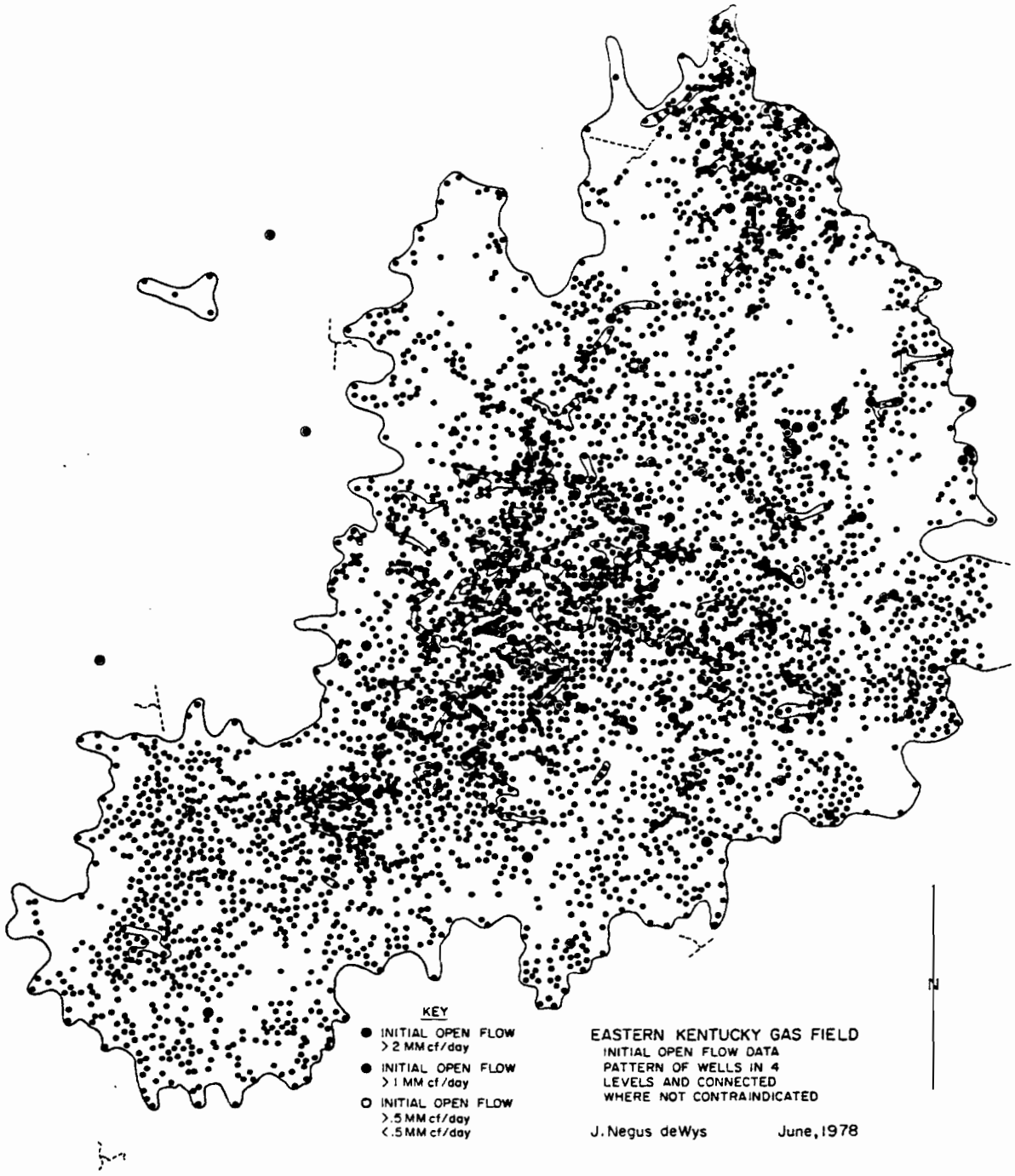

Figure 2. Location of open flow data points (from Griffiths 1976).

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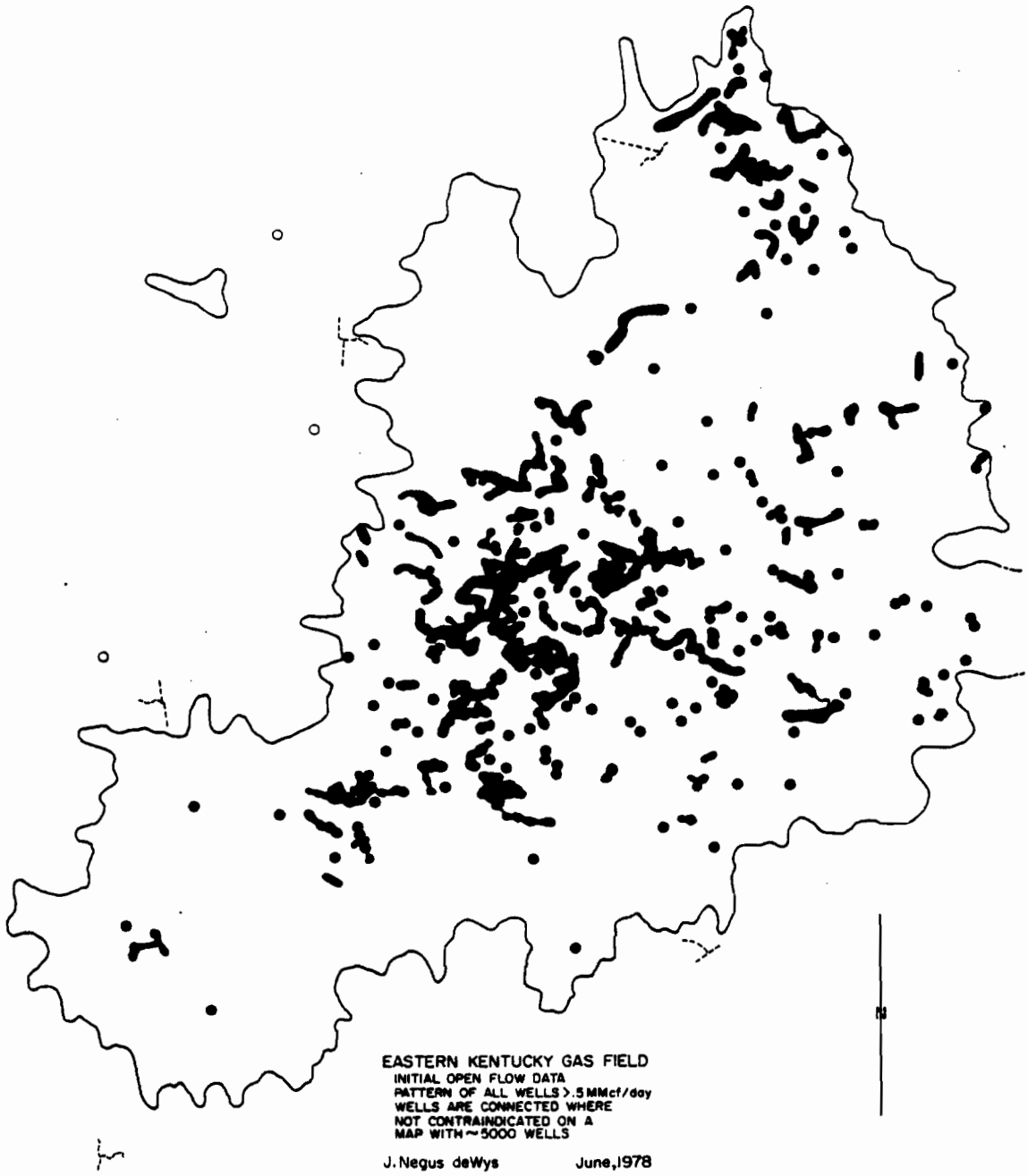

Figure 3. Pattern resulting from connection of all wells with open flow ≥ 0.5. No wells with lower flow occur within the pattern.

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TREND ANALYSIS OF GAS PRODUCTION IN THE COTTAGEVILLE FIELD

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ABSTRACT

Results of a trend analysis study of the Cottageville Gas Field are presented. A series of maps are developed from geological factors, gas production data, and production decline calculations. Trends are plotted on each map and then compared on a compass rose.

Relationships of geological trends to production and production decline are shown through a stacked block diagram sequence.

Suggestion of a fault or faults is made by production and production decline map trends which do not relate to other geological factors.

This method of analysis is presently being applied to the Eastern Kentucky Field(s).

INTRODUCTION

The purpose of this study is to apply various methods of gas production data analysis to gas field data in order to objectively evaluate and explore relationships in the production history of the Cottageville gas field in the Devonian shale. An understanding of such relationships may contribute to estimation of recoverable reserves and to conclusions or hypotheses in the study area which may be applied to other potential gas producing shale areas.

The scope of the study is the gas production from 63 wells from Devonian shales in the southwestern Jackson County and eastern Mason County. This paper represents a step further in analysis and conclusions from a paper by the authors in 1977 (de Wys and Shumaker, 1977).

Devonian shales underlie approximately 100,000 square miles in Kentucky, Ohio, West Virginia, Pennsylvania, and New York. It has been estimated that this area contains about 460 trillion tons of shale readily accessible to drilling, and most of this at about 10,000 feet in depth (Columbia Gas System).

The horizon of "brown shales" from which most gas has been produced is a 400' section with finer grain size, darker colors with spores and brown algae (Protosalvinia) reported. Above this zone is 1,200 feet of gray to greenish-gray shales with sandy and silty zones and a dark gray to black interval. Grain size coarsens upward from the producing horizon. Below the producing horizon is 300-400 feet of greenish-gray shale with no silt and below that 200-400 feet of lower black shale, calcareous in the bottom portion (Tully Ls.). Gas has been produced from the Brown Shale horizon for nearly 50 years from low-volume shallow wells in the western one-third of West Virginia.

Up to 4.4% by weight organic content is found in the brown shales.

Porosity in Devonian shales is very low. In two Jackson County wells in West Virginia, porosity ranged from .1 - 4.6% with overburden of 1650 PSI and 3700 PSI (obtained by oil method). By comparison, highly productive sandstone reservoirs show 10-20% of total rock volume. Most pore space found in shales is between the mineral crystals or grains and in micro and macrofractures (Science Applications, Inc., 1977).

Permeability values for the same two Jackson County wells range from .0001 - .001 Md with overburden pressures of 1650 and 3700 PSI. This is very low permeability which limits the rate of gas production by the rate at which gas can diffuse through the matrix and reach a free surface such as a bore hole or a fracture. Compared with sandstones this results in low production rates, but extended production life. Clastic silt-size quartz and feldspar are commonly segregated into lenses parallel to bedding in the very dark, organic-rich shale specimens. Higher permeability in such lenses may permit migration through such silt zones to accumulation fracture facies areas.

Mineral lined vertical fractures were commonly noted in the pay zones of two wells in western and southwestern West Virginia. In one core from western West Virginia filled and unfilled natural fractures resemble parts of nearly vertical systematic joints (Wheeler, et al., 1976). The fractures strike N 40° - 50° E above the pay zone, and show four dominant orientations within the pay zone. As noted earlier a higher percentage of total production appears to be the result of absorbed (matrix) and adsorbed (on fracture surfaces) than from free gas. Wheeler, et al. suggest that fracture density on a larger scale may be influenced by old or reactivated suballochthon faults, by allochthony itself, by erosional release, or by two or more of these factors interacting. They further suggest slickensides can seal fractures and thus decrease permeability.

Rogers (1971) concludes from stratigraphic evidence that after a period of extensional tectonics accompanying the main subsidence, a period of true compression ensued in late Mississippian to early Permian time during which the final group of clastic sediments were deposited and the whole section deformed.

The outline of Brown shale production in West Virginia coincides strikingly with the trend of the Rome Trough. Martin and Nuckols (1976) postulated that fractures in the Devonian shales in the gas-producing areas result from reactivated movement of the basement fault blocks comprising the Rome Trough. Weaver, 1972, noted the relationship of the structure to Devonian gas production. The basement structure and magnetic intensity values in the Cottageville area (Shumaker, 1978) show the magnetic intensity contours are closely correlated with the edge of the Rome Trough which comprises a valley rift system on the Precambrian basement level. It is reasonable to assume that fracture facies developed over fault movements associated with the Rome Trough structure.

The term fracture facies is proposed for use in certain Devonian shales with the following definitio of the term: rock facies containing fractures that occur over a wide area within a distinct stratigraphic interval. As applied to Cottageville field, the image conveyed is similar to a stratigraphic trap - but one where the porosity is caused by laterally limited fracture porosity with a distinct stratigraphic interval.

Data

Production data has been used as given. No standardization or altering of the data has been attempted. The complete data analysis includes mapping of production data in various relationships and decline curve analysis by computer programs and historical relationships. The comparison of production data map trends to trends of geological factors is presented here. This study includes trends from the following maps: (Figures and complete study available in MERC Technical Series Publication MERC/CR/78/6 July, 1978.)

Drilling Completion Dates,
Isocontours of Highest Annual Production (1st or 2nd year production),
Isocontours of First Five Years Accumulated Gas Production,
Isocontours of Total Accumulated Production,
Isocontours of Mean Annual Gas Production,
Loss Ratio Isocontours for First Year of Gas Production Decline,
Loss Ratio Isocontours for Second Year of Gas Production Decline,
Loss Ratio Isocontours for Third Year of Gas Production Decline,
Loss Ratio Isocontours for Gas Production Decline from 1st to 5th Year of Production,
Structure Contours on Top of the Onondaga,
Structure Contours on the Bottom of the Huron Shales,
Isopressure Contours of Initial Well Pressures,
Fracture Facies Orientation, and Devonian Shale Dip and Strike.

Gas production data was tabulated by year. From this tabulation the highest annual production, accumulated total production, first five years accumulated production, and mean production are computed. Most of these computations are fairly standard procedure, however, loss ratios may be unfamiliar. Loss ratios (Arps, 1944; Campbell, 1973) are computed in this study as follows:

$$d = \frac{q_1 - q_2}{q_1}$$

where: d = fraction or percent production lost

$q_1 - q_2$ = The gas production for the first year considered less the gas production for the second year considered.

q_1 = The gas production for the first year considered.

The resultant value represents the slant of the gas production decline curve for the period under consideration. Loss ratio values are computed for 1-2 years, 2-3 years, 3-4 years, and 1-5 years.

Structure contour maps are shown for the top of the Onondaga below the Devonian shales and for the structure at the bottom of the Huron shales which overlie the producing Devonian shales. The trend strike of the Devonian shale isopachs (N 6° E) is also used in the map comparison.

Isopressure contours are drawn on the initial pressure data obtained following well completion. No adjustment of pressure data to standardize these data has been attempted.

DISCUSSION AND CONCLUSIONS

Erwin, et al. (1976) described the problem of the Devonian shales as the nature, cause, timing of fractures, relation to regional stress and structural patterns below, within, and above the Devonian shales. This pilot study of gas production analysis methods applied to a portion of the Cottageville Field is an attempt to look at these relationships in terms of axial trends to examine what correlations may exist. Highest annual production could be indicative of porosity, fractures (permeability), gas entrapment, migration, and possibly connection with other wells (when compared with chronology of drilling). First five years total accumulation may represent aspects of permeability, total gas reserves, and gas pressures. Total accumulation should reflect all the factors related to first five year production plus a stronger indication of permeability, and reserves. Mean of Total Accumulation may show a field porosity trend and permeability interrelationship of wells. This may be one of the better indicators of reserves. Loss Ratio maps are related to permeability, pressure, and supply.

The production data, calculated production decline, and geological data computed for each well is contoured on a series of maps. The trends of the contour axes on each map are traced onto a common overlay and these trends are tabled according to correlation of trend angle with other sections of the study area. For a comparison of major map trends of the geologic, production, and production decline, the trends are plotted on a compass rose in Figure 12. It can be observed that the angular relationship is very restricted and not a broad interval. The strike of the basement magnetic survey trends relate to the first five years cumulative production and initial pressure. The dip again relates to initial pressure as well as production decline the 1-2 years. These relationships suggest the basement affects collection and availability of free gas as compared with adsorbed or absorbed gas.

The strike of structure on the top of the Onondaga limestone relates to highest annual production, first five years cumulative production, total production and the fracture facies direction (40-50° NE) of 80% of fractures in the Baler well above the gas zone and 21% in the production zone. The dip of the Onondaga relates to total production, mean annual production, and initial gas pressure. The top of this more brittle rock, as compared with shale, may represent the lower control, which reflects the basement, on the formation of fracture facies. Differential compaction of the shales over basement structures and faults may be the causal agent in fracture facies formation.

The strike on the bottom of the Huron shales relates to production decline trends both for the 3-4 years and 1-5 years. The dip relates to total production, mean annual production and initial pressure. The production decline trend for 2-3 years is also very close. The difference is possibly due to structure anomalies. Thus, the structure on the bottom of the Huron appears to affect permeability, as reflected in the slope of production decline curves.

The fracture facies orientations taken from the CGSC #11940 well in Jackson County (Larese and Heald, 1977) show three predominant directions. The main direction is 40-50° NE and relates to five production maps: highest annual production, first five years production, total production, mean annual production, and initial pressure. This strike direction is also related to strike of the top of the Onondaga limestone and to the production decline map 1-2 years. Thus, the major fracture facies direction is strongly correlated with free gas accumulation and availability, and this trend is similar in its lower limits to the top of the Onondaga. This fact as mentioned above may relate to the genesis of the fractures.

Initial gas pressure it may be noted is related to all the geologic maps, suggesting that these different geological parameters may each play a role in accumulation and availability.

The highest degree of production relationships is seen with the top of the Onondaga limestone. Second is the fracture facies main trend, which in turn relates to the Onondaga.

The highest degree of production decline correlation is seen with the bottom of the Huron and close to it, which suggests that the structure at the base of the producing Devonian shales is somehow

influencing permeability. Differential compaction, and variations in silt and organic content could be related factors in paleoenvironment. Also the fact that the permeability, as reflected in decline curves, is related to strike on the bottom of the Huron, suggests that permeability differences may occur along strike onlap of beds onto the craton during the time of deposition. These various suggested relationships point to the importance of studying paleoenvironments of these stratigraphic units in projecting gas resources.

Application of this type of analysis and suggested relationships will be tested on the Eastern Kentucky Gas Field, which is presently under study.

ACKNOWLEDGEMENT

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EXPLORATION PARAMETERS DERIVED FROM HISTORICAL DEVONIAN SHALE PRODUCTION IN WESTERN WEST VIRGINIA

by

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Oct. 1979

ABSTRACT

Successful application of exploration parameters to "tight" Devonian organic shales can be formulated from prior development of Devonian shale gas fields. One such field, the Cottageville Gas Field in western West Virginia, has been producing for almost 50 years. A random exploration rationale implemented in this field has produced less than optimal results in maximizing gas production. However, from a detailed analysis of development history and geologic variables, a Devonian shale exploration rationale using critical exploration parameters can be derived. These parameters are as follows:

Stratigraphic Parameters

- To maximize the potential for gas production, the existence of several organic shale zones is required.
- Regional shale gas producing horizons should be evaluated with the goal of obtaining maximum producing shale thickness.
- Geochemical composition and thermal maturity are important factors which must be considered in exploration.

Structural Parameters

- Fracturing resulting from basement movement.
- Folding or faulting causing structural disruption (i.e. fracturing) of rock units.
- Surface fracturing, principal stress directions and subsurface fracturing are direct indicators of potential Devonian shale gas production.

INTRODUCTION

The Cottageville Devonian Shale Gas Field lies in the western portion of the Appalachian Basin near the West Virginia - Ohio border in the West Virginia counties of Jackson and Mason (Figure 1). Hydracarbon production (mostly natural gas) from this field originates from organic shale zones found within the Middle Devonian Lower Huron Shale Member of the Ohio Shale Formation. Drilling activity within this gas field since the late 1920's has seen the completion of 110 shale wells with production of more than 10 Billion cubic feet of natural gas (Figure 2). Deliniation of production parameters that have controlled the accumulation and production of these hydracarbon.follows.

Stratigraphic Parameters

The Devonian age formations that underlie the Cottageville Gas Field are approximately 2,300 feet thick. The middle and upper Devonian shales comprise the upper 2,100 feet of the total section. The upper contact of the Devonian shales is placed at the base of the Mississippian Age Berea Sandstone, and the lower contact is with the Onondaga Limestone. Within this predominantly shale section, are found light grey to brown-black shales, light to medium grey siltstones and very rarely white to light grey sandstones. Of these different lithologies, the dark organic rich shale zones occupy approximately 500 feet or 23 percent of the entire shale section. These highly organic shale zones occur in three stratigraphically distinct portions of the shale section, and they are easily recognizable on gamma-ray and density logs (Figure 3). The upper two organic zones (Zones II and III) are found within the Lower Huron Shale Member of the Ohio Shale Formation. These two zones are mainly composed of dark brown-black organic rich shales, but occasionally they have light to medium grey shale and siltstone interbeds. Separating the lower and upper organic rich shale zones of the Huron are lithologies of shale and siltstone with an occassional thin organic shale bed. Within the Cottageville Gas Field, these two zones have an average combined thickness of 250 feet, and they the main reservoirs of Devonian shale gas production. Below these two organic zones found in the Huron is a third organic zone found in the Westfalls Formation. Like the younger shales found in the Huron Shale, this organic rich shale has interbeds of light to medium grey shale and siltstones. This organic rich shale has an average thickness of 100 feet, but has rarely produced any gas within the Cottageville area.

Regional east-west correlations of the Devonian shale sequence (Figure 4) indicate the absence of deposition of the Huron organic rich shale zones just to the east of the Cottageville field. The gradual facies change of the organic shales to the east seems to coincide with the western edge of

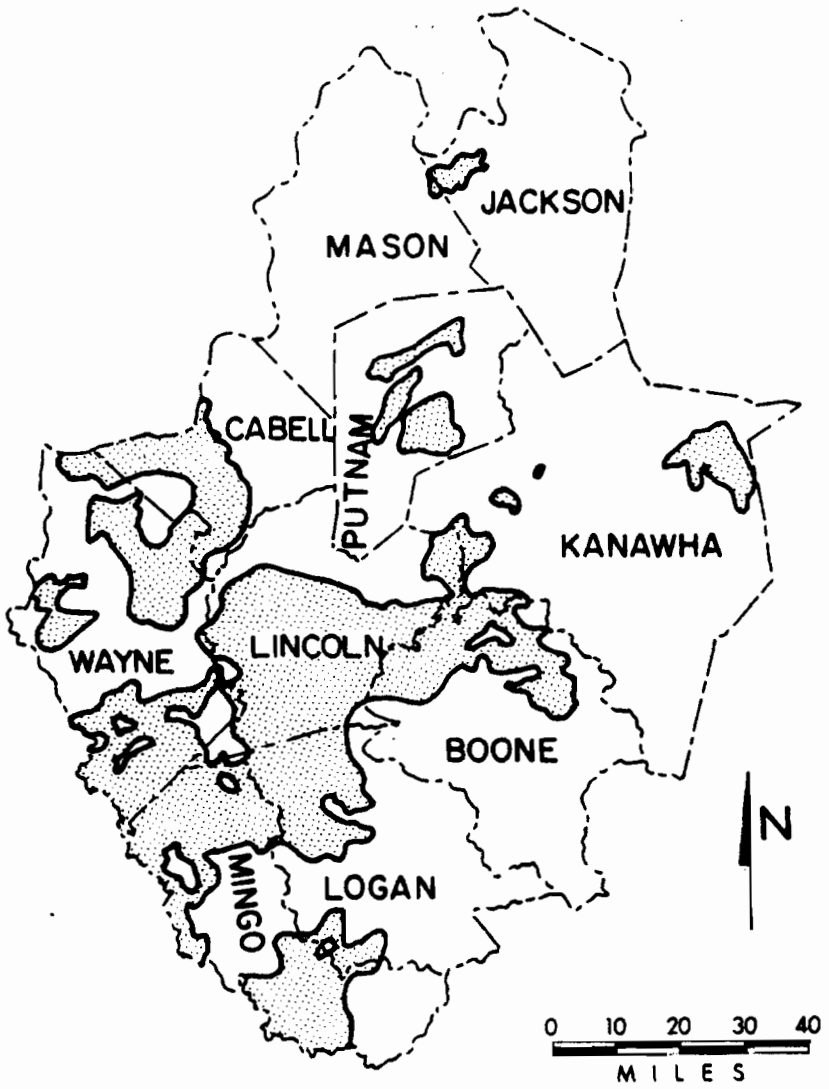

Figure 1 Gas fields with production from the Brown shale in southwestern West Virginia. Production extends northward from Cabell County into Ohio, and southwestward from Wayne and Mingo Counties into the Big Sandy Field, eastern Kentucky (after Patchen, 1977).

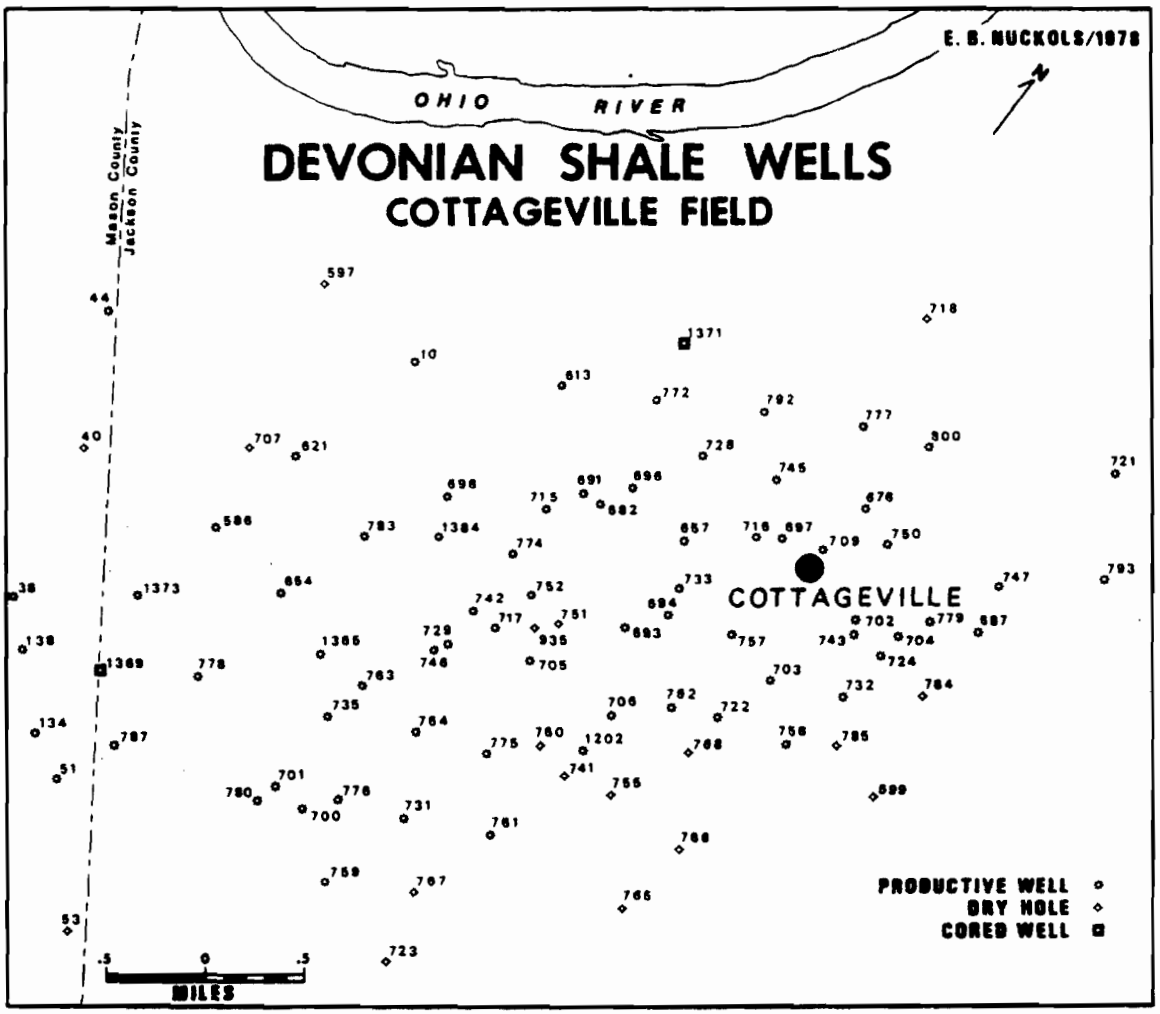
E. B. NUCKOLS/1978
OHIO RIVER
DEVONIAN SHALE WELLS
COTTAGEVILLE FIELD
Mason County
Jackson County
COTTAGEVILLE
PRODUCTIVE WELL
DRY HOLE
CORED WELL
.5 0 .5
MILES

FIGURE 2

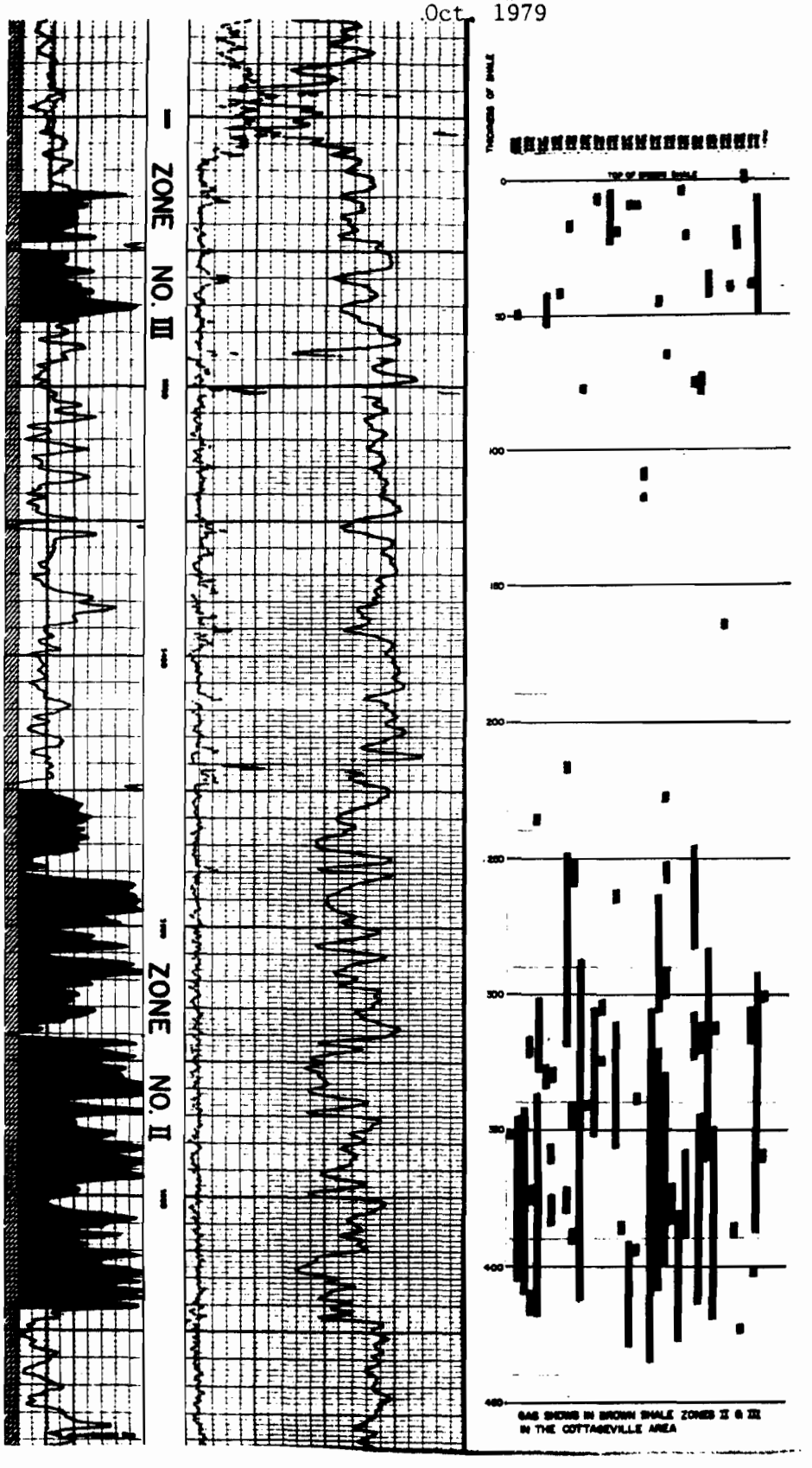

Figure 3 - Gamma ray log portraying organic rich shale zones of the Lower Huron Shale Member of the Ohio Shale with gas shows from 37 wells drilled within the Cottageville Field (after Martin and Nuckols, 1976).

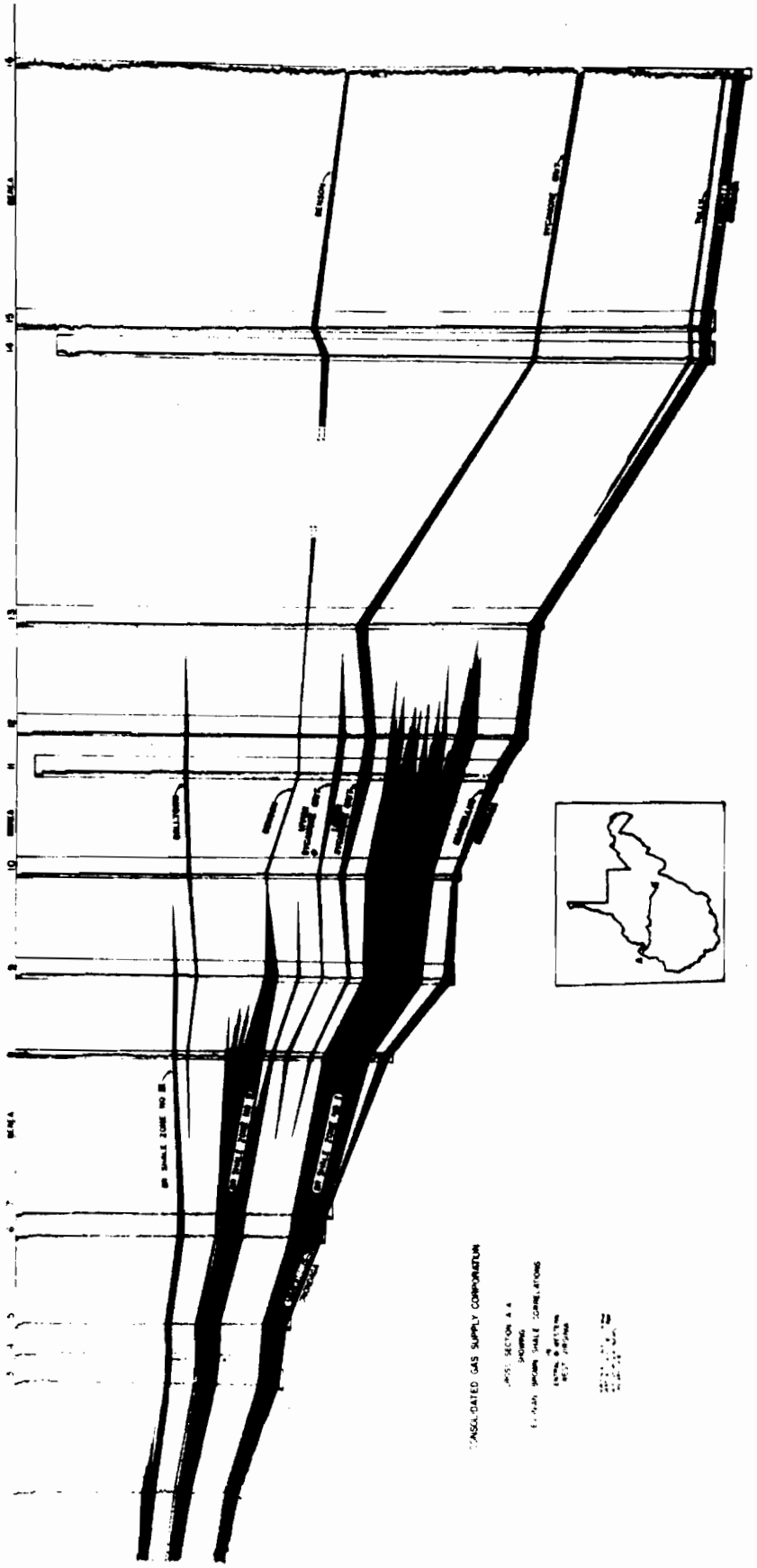

FIGURE 4

the Rome Trough, thereby indicating a change in the depositional environment.

The following stratigraphic exploration parameters must be satisfied if potential gas production is to be economically realized:

- To maximize the potential for gas production, the existence of several organic rich shale zones is required. The Cottageville Gas Field as seen on Figure 4 is located approximately where logs 3, 4 and 5 occur. Since the organic rich shale zones of the Lower Huron are the primary producer of natural gas in this region, the gas field is located strategically close to where the organic shale lithologies disappear to the east (into the Rome Trough). Therefore it is fortuitous that the gas field is located proximal to the maximum thickness of organic rich shales before they disappear.

- Regional shale gas producing horizones should be evaulated with the goal of obtaining maximum producing shale thickness. Gas production from the Cottageville area has primarily been associated with Zone II organic shales within the Lower Huron Shale Member (Figure 5). In addition gas shows within the field have predominantly been associated with Zone II organic shales (Figure 3).

- Geochemical composition and thermal maturity are also important factors which must be considered in exploration. A statistical zonation analysis of the Jackson - 1369 core (Figure 2) revealed that Zone II of the Lower Huron Shale Member of the Ohio Shale had a lower average porosity (2.93%); higher average residual oil saturation (7.31%); lower average residual water saturation; and lower average grain density (2.64 grams/cc) than either organic Zone III shales or the shale interval between Zone's II and III_1.

  An evaulation of the thermal maturity of The Lower Huron Shale Member was performed on cored Wells Jackson 1369 and 1371 (Figure 2). The results of these analysis are[2]:

  Oil Prone

  - The amorphous-herbaceous kerogen is the predominant type of organic matter.

  Moderately Mature

  - The kerogen coloration ranges from 2 to 2+ and the vitrinite reflectance values range from 0.8 to 1.10% R_o.

  - The thermal history places the organic matter in the early to middle stages of petroleum generation.

  Extremely Variable in Organic Richness

  - The organic carbon content ranges from 0.24% to 3.12%.

Structural Parameters

- Fracturing resulting from basement movement.

  A mega structural feature that is proximal to the Cottageville Field is the Rome Trough (Figure 6), which comprises a valley rift system on the Pre-Cambrian basement. This Cambrian age feature has influenced, in all likelihood, sedimentation and structural regimes from early Cambrian time up to Silurian and possibly through Devonian time. The western boundary of this feature may consist of en échelon faults that may have been reactivated throughout time, thus causing warping and fracturing of overlying sediments. Figure 7 shows the basement structure based on magnetic intensity values for the Cottageville area (Shumaker, 1978). The basement contours are closely correlated with the edge of the Rome Trough and give an appearance of en échelon blocks that step-up to the west. Martin and Nuckols (1976) postulated that fractures in the Devonian shales in the Cottageville gas-producing areas result from reactivation movement of the basement fault blocks comprising the trough.

1. Analysis performed by Lamey, Biabolok and Childers (1978).
2. Analysis performed by Geochem Laboratories, Inc.

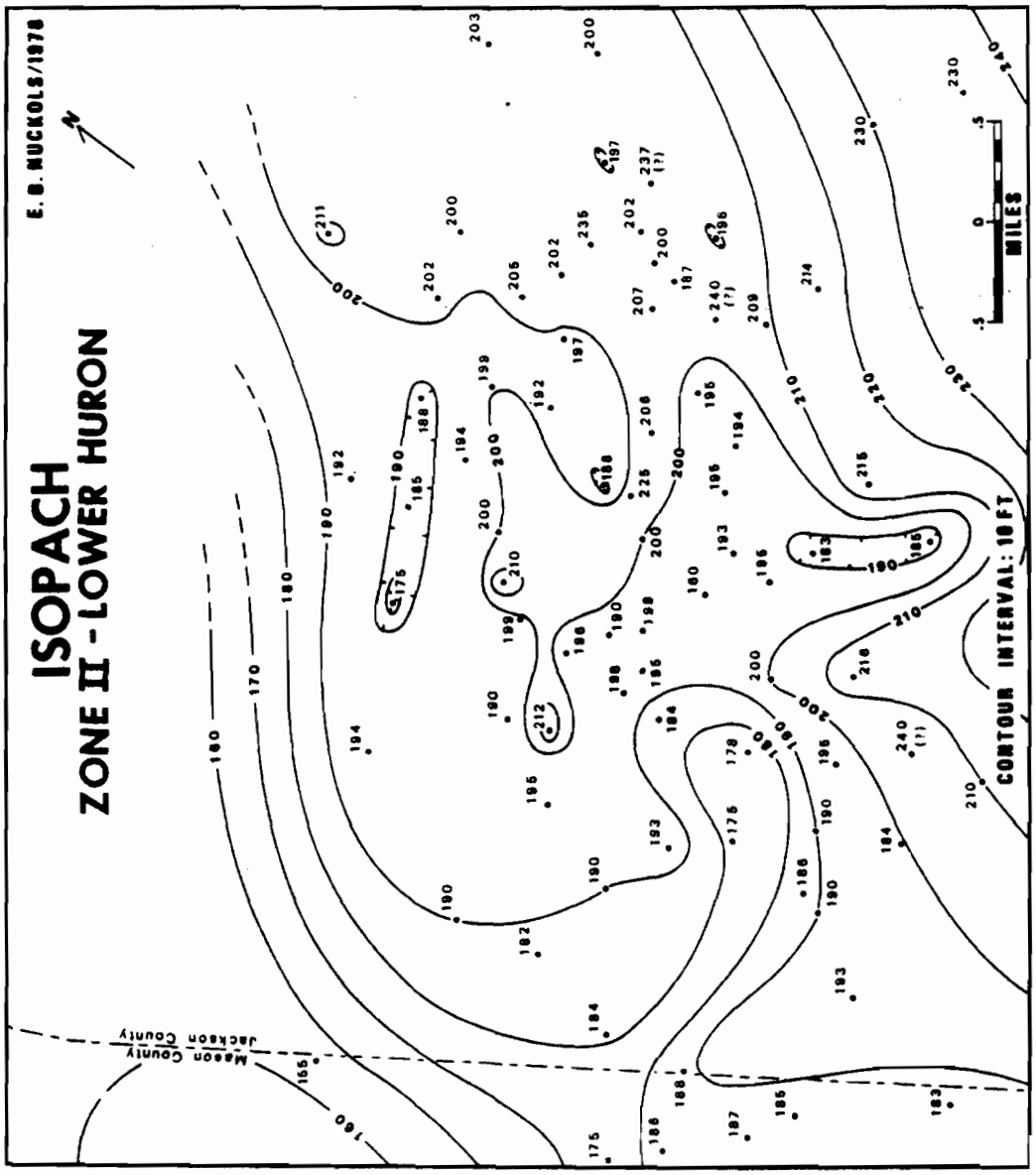
ISOPACH
ZONE II - LOWER HURON
E. B. NUCKOLS/1978
N
CONTOUR INTERVAL: 10 FT
MILES
Mason County
Jackson County

FIGURE 5

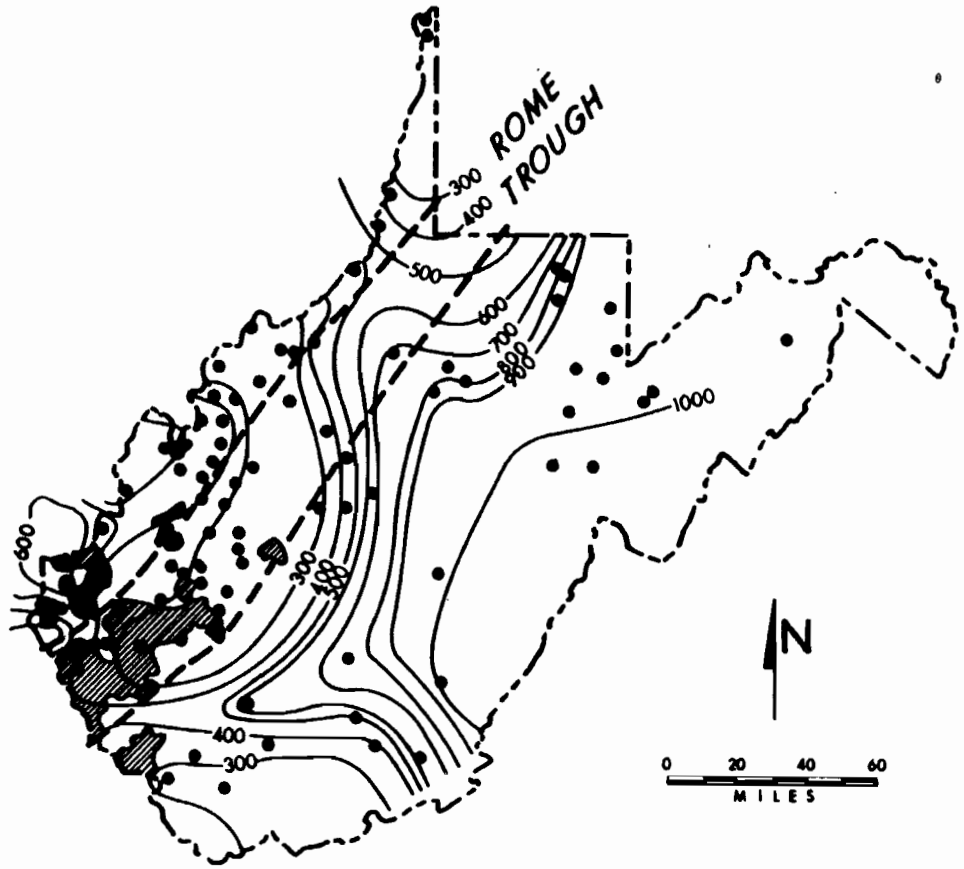

Figure 6 Brown shale gas fields, thickness of Brown shales (from deWitt, et al, 1975), and approximate position of the Rome Trough in West Virginia. Thick areas of dark organic-rich shale that overlie this Cambrian fault block may be the area of greatest potential for new exploration (after Patchen, 1977).

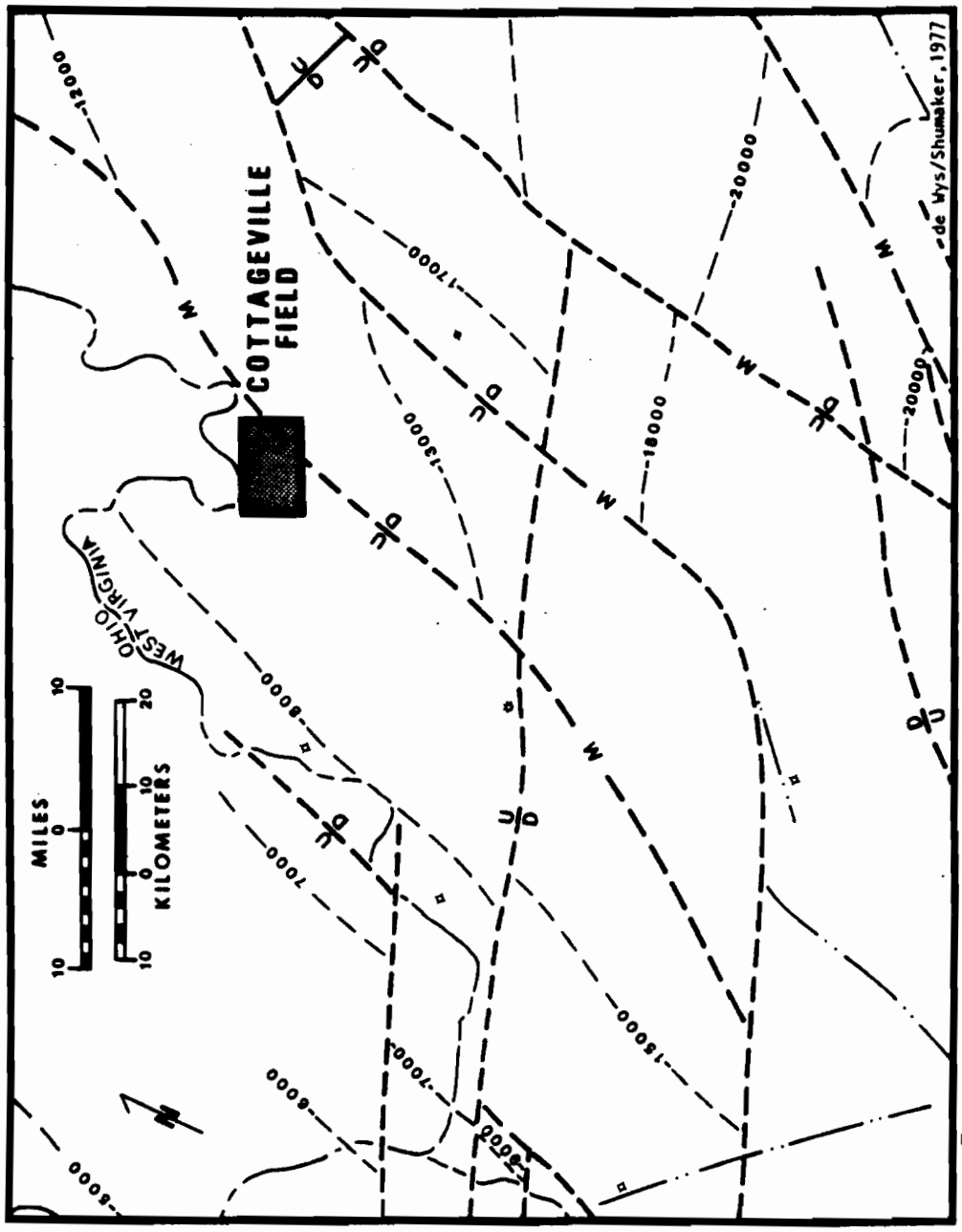

FIGURE 7— Cottageville Field Setting in Relationship to Basement Structures and Magnetic Intensity Contours.

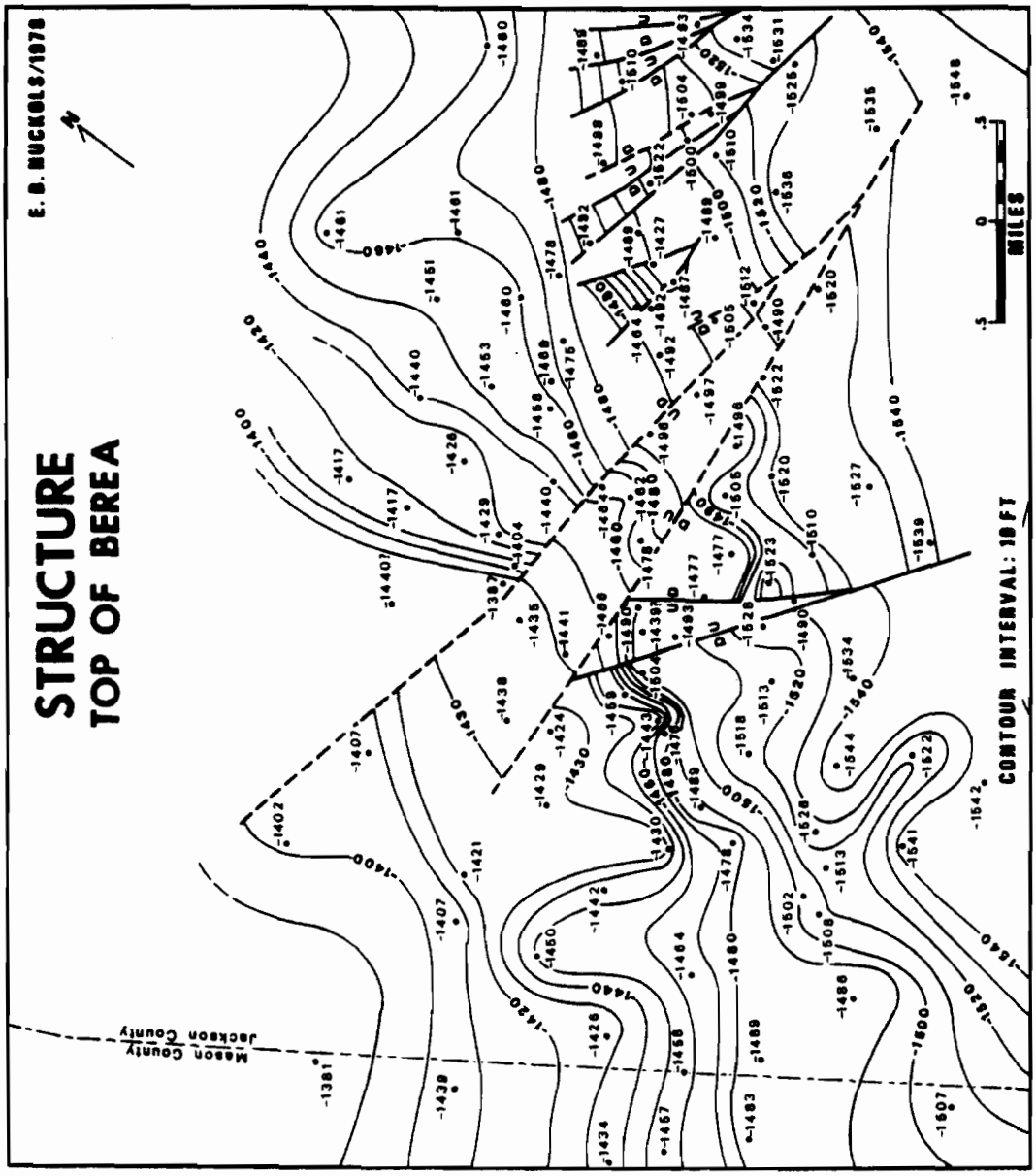
STRUCTURE
TOP OF BEREA
E. D. RUCKOLS/1978
N
Mason County
Jackson County
CONTOUR INTERVAL: 10 FT
MILES
.5
0
.5

FIGURE 8

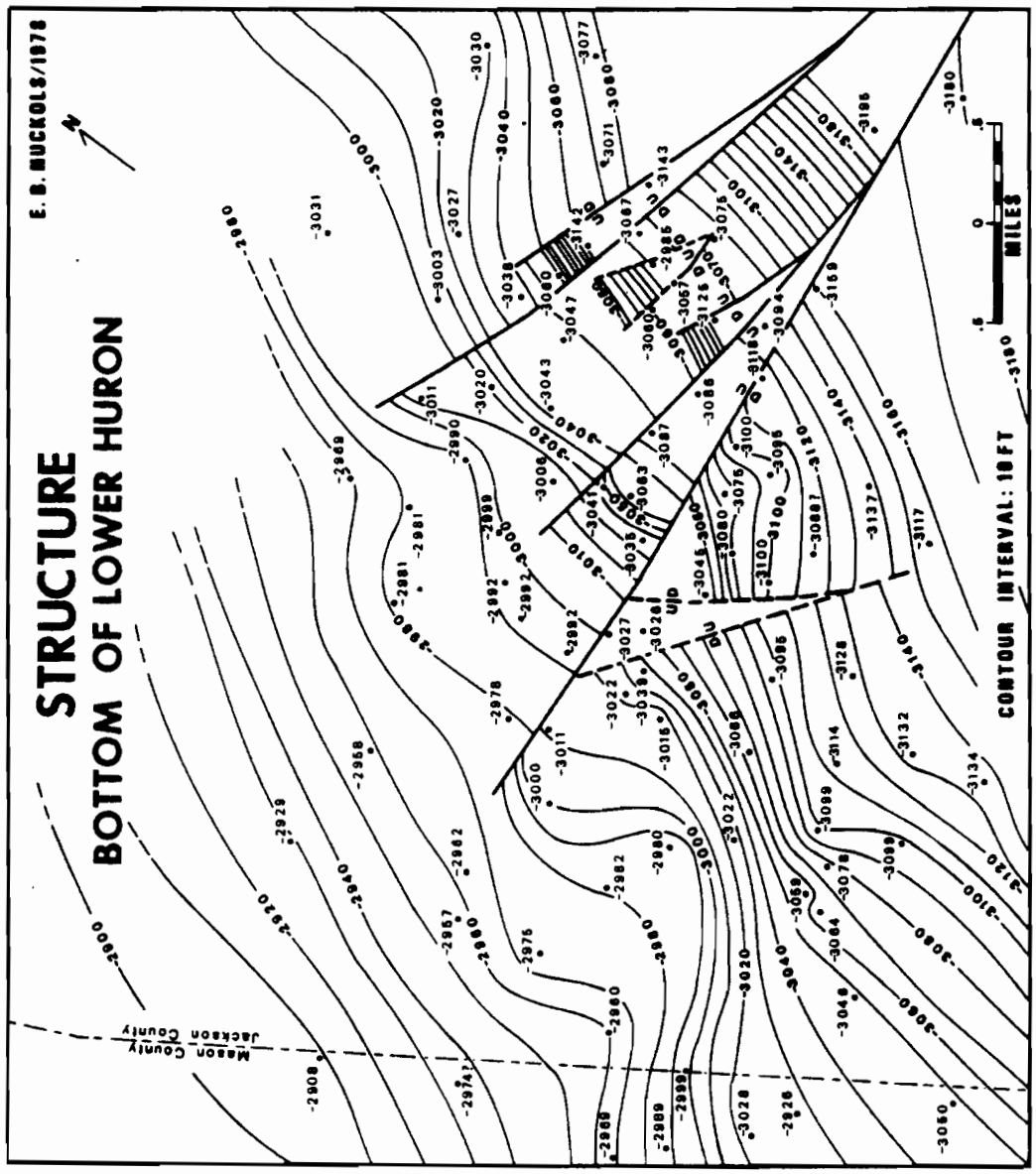
STRUCTURE
BOTTOM OF LOWER HURON
E. B. BUCKOLS/1978
N
CONTOUR INTERVAL: 10 FT
MILES
Mason County
Jackson County

FIGURE 9

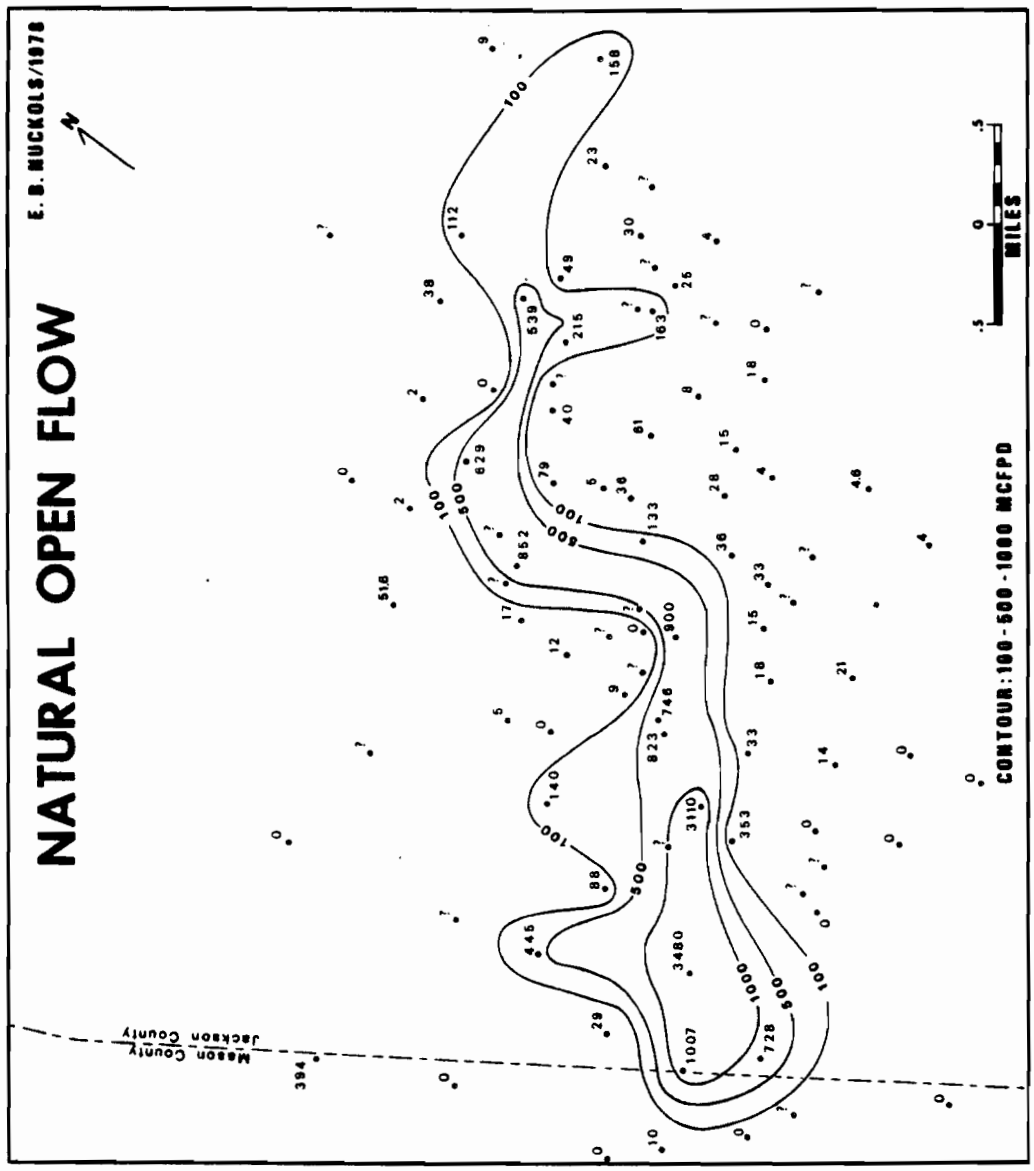
NATURAL OPEN FLOW
E. B. NUCKOLS/1978
CONTOUR:100-500-1000 MCFPD
MILES
Mason County
Jackson County

FIGURE 10

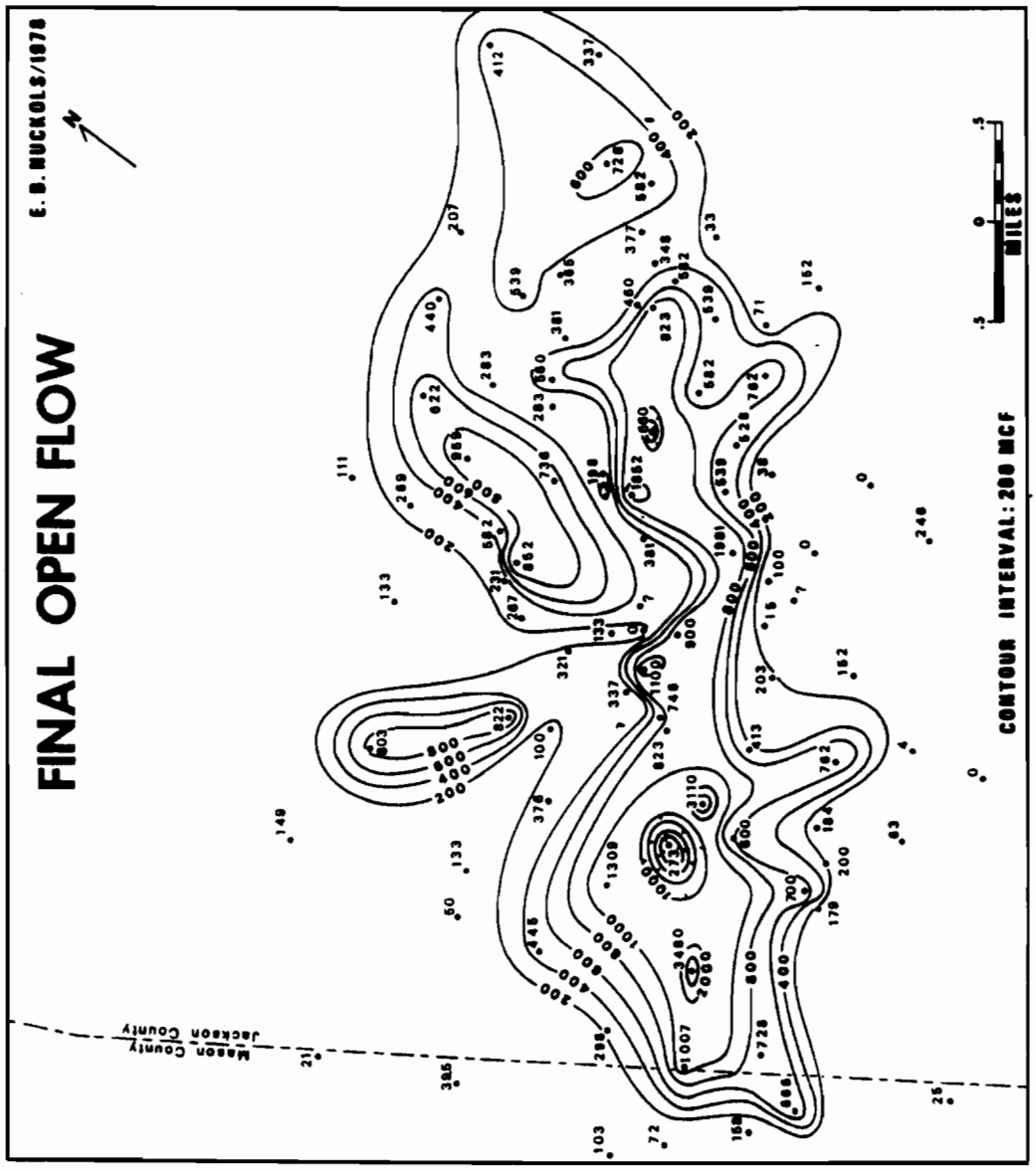
FINAL OPEN FLOW
E. B. NUCKOLS/1978
CONTOUR INTERVAL: 200 MCF
MILES
Mason County
Jackson County

FIGURE 11

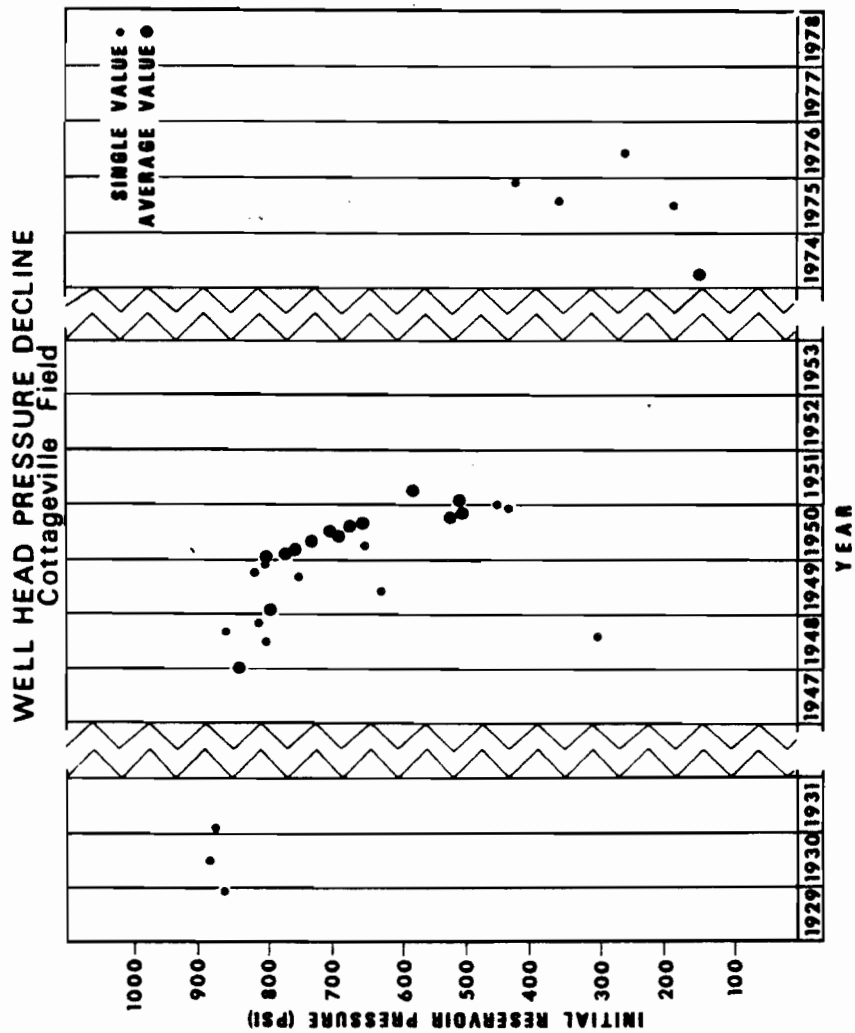
WELL HEAD PRESSURE DECLINE
Cottageville Field
SINGLE VALUE •
AVERAGE VALUE ●
INITIAL RESERVOIR PRESSURE (PSI)
1000
900
800
700
600
500
400
300
200
100
1929
1930
1931
1947
1948
1949
1950
1951
1952
1953
1974
1975
1976
1977
1978
YEAR

FIGURE 12

- Folding and/or faulting causing structural disruptions (fracturing) of rock units. Structural anomalies and disruptions are the main mechanisms for gas production in the Devonian Shales. Within certain areas of the Gas Field "bench-like" or "hinge-like" structural features can be discerned. These features appear as stair-step like features on structural cross sections and could possibly be the last reminents of basement associated en échelon faults of the west flank of the Rome Trough (Figures 8 and 9). In addition to this structural feature are the multiple cross faults that have created other fracture systems (Figures 8 and 9).

  A direct consequence of these fracturing mechanisms can be exhibited in Natural Open Gas Flows (Figure 10) and Final Open Gas Flows (wells that have been stimulated - Figure 11). Another effect of fractures and faults upon the organic shale reservoir rock is the reservoir pressure decline after years of infield drilling. This can easily be illustrated by graphically plotting initial reservoir pressures against the year in which the wells were drilled (Figure 12). As displayed graphically in Cottageville, the shale reservoir appears to be somewhat pressure depleated after 1942 (Figure 12); i.e. fracture systems.

- Surface fracturing, principal stress directions and subsurface fracturing play key roles as direct indicators of potential shale gas production. Surface joint measurements in the Mt. Alto and Cottageville 7½ minute quadrangle, primary stress directions from shallow core sites in the southern portion of the gas field, along with mineral lined fractures found in core well Jackson - 1369 all indicate three primary directions of potential fracturing:

	DIRECTION		
	I	II	III
Surface Joints[3]	East - West	N - N 20° W	*N 50° - 60° W
Primary Stress Direction[4]	N 65° - 90° W(E-W)	N 10° W - N 15° E	N 40° - 60° E
Mineral Lined Fractures[5]	N 80° - 90° W(E-W)	N 10° - 20° W	N 40° - 50° E

From this data it is very apparent that surface fracture data (i.e. joints) can directly be correlated with subsurface fracture data.

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* From the original data a N 40° - 50° E set of joint data exists but has fewer data points that the N 50° - 60° W

3, 4 Analysis performed by E. D'Appolonia Consulting Engineers, Inc.

5 Analysis performed by Larese and Heald (1976).

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APPENDIX E

Hydrology Data

Henry W. Rauch
D. Scott Jones
Robert R. Beebe

LINEAMENTS AND GROUND-WATER QUALITY AS EXPLORATION TOOLS FOR GROUND WATER AND GAS IN THE COTTAGEVILLE AREA OF WESTERN WEST VIRGINIA

by

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and
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Dr. Rauch received his BA degree in Chemistry-Geology from Alfred University in 1965. He also received his Ph.D. degree in Geochemistry from The Pennsylvania State University in 1972. Since 1970 he has been employed by West Virginia University, Department of Geology and Geography, and is an Associate Professor of Geology. He is also a co-investigator on an Eastern Gas Shale Project contract at West Virginia University, which is funded by the U. S. Department of Energy. His primary research interests are in hydrogeology and geochemistry.

ABSTRACT

As part of a hydrogeologic study of west-central Jackson County, lineaments were mapped and water wells were characterized for physical and chemical parameters, especially in the Cottageville area. Short straight photolineaments are significantly associated with water well yields in gallons per minute, with wells closer than 100 feet having higher yields. Such lineaments act as anomalous zones about 200 feet in width with respect to water wells. Short photolineaments are not in general associated with gas well yield, but gas wells located within 0.5 miles of a short photolineament bearing N 60°W-N90°W (WNW) yield at significantly greater rates (as natural initial open flow) than wells near other photolineaments. The density of WNW photolineaments is also significantly and directly associated with gas well yield. Water well yield has no relationship to Landsat or curvilinear lineaments. However, gas wells located within 0.25 miles of one Landsat lineament or within 0.5 miles of a curvilinear lineament over one mile long yield at significantly lower rates. High concentrations of nitrate and sulfate, and especially of bicarbonate and total hardness in shallow ground water are significantly associated with high expected (interpolated) gas well yield. Tentative conclusions from sparce data indicate that gas well yield will be significantly higher when gas wells are located in areas having ground-water concentrations exceeding 500 mg/l, 250 mg/l, 13 mg/l, and 34 mg/l for bicarbonate, total hardness, nitrate, and sulfate respectively. In summary, short photolineaments make a good exploration tool for locating water wells; both WNW photolineament density and ground water quality may serve new exploration techniques for Devonian shale gas in the Cottageville, but Landsat and curvilinear lineaments should be avoided.

INTRODUCTION

A hydrogeologic investigation in the Cottageville area of Jackson County, West Virginia, was undertaken in part to explore the possibility of relating hydrogeology and aqueous geochemistry to the occurrence of Devonian shale gas. Any relationships established between near-surface hydrogeologic or geochemical parameters and gas yield would be useful in developing additional exploration techniques for Devonian shale gas.

Figure 1 depicts the study areas. The first phase of this study involved the investigation of 86 water wells and one spring in the hydrogeology study area.[1] Physical well parameters such as well depth, depth to water, well yield, and casing depth were obtained from well owners or drillers. The topographic setting and most probable aquifer unit were determined with the aid of topographic maps, a structural contour map of the Pittsburgh Coal, and a general stratigraphic column for the study area.

Short photolineaments were also mapped for the hydrogeologic study area from low altitude black and white photography having scales of 1:20,000 and 1:38,000. The photolineaments represent nearly straight stream channel or valley segments over 0.25 miles in length (but usually less than one mile long). These were identified and plotted on 7 1/2 minute topographic maps for the study area.[1] Also identified and plotted were a few Landsat lineaments defined by straight stream or valley sections or aligned stream meander bends. A third type of lineament is the curvilinear type. These lineaments are generally at least one mile in length and are defined by continuously curved valleys or streams which lack inflection points in their general curvature. They were determined from and plotted on the 7 1/2 minute topographic maps.

Water quality tests were also performed for 86 wells and one spring.[1] Temperature and specific conductance were measured in the field, and two water samples were taken from each well. One sample was treated with acid and later analyzed in the laboratory for iron, calcium, and magnesium concentrations. The second sample was treated with a biocidal agent which also retarded algae growth, and was kept cool until chemical analyses for pH, bicarbonate, nitrate, sulfate, chloride, and sodium could be performed in the laboratory.

PHOTOLINEAMENT ASSOCIATIONS

Mapped lineaments for the gas field study area are shown in Figure 2. Several short photolineaments, five curvilinear lineaments, and one Landsat lineament are evident in this area. Water well yield (in gallons per minute) was tested as a function of well proximity to each of the three types of mapped lineaments for the entire hydrogeology study area (see Figure 1).

Water wells located within 100 feet of a short photolineament yield water at significantly greater rates than more distant wells. This difference is significant with a 0.06 probability of error (probability that there is no significant difference between two groups of tested data), by the

Mann Whitney U (1-tailed) statistical test.[2] Of those wells within 100 feet of a short photolineament, wells within 50 feet yield water at significantly greater rates (about 50 percent greater) than wells 50-100 feet from such a lineament, This difference is significant with a 0.05 error probabilityby the Mann Whitney U test. These trends in well yield were expected and have been well documented by Lattman and Parizek as well as other researchers.[3] Apparently, short photolineaments often represent underlying fracture zones which are associated with significantly increased aquifer permeability. Hence water wells located on photolineaments usually have higher-than-average yields. The probable fracture zones under photolineaments of the study area are roughly 200 feet in width.

Landsat and curvilinear lineaments seem to have no definite relationships with water well yield. No significant associations were found between water well yield and well proximity to either Landsat or curvilinear lineaments, based on the Mann Whitney U test. Landsat lineaments (and other lineaments from high altitude imagery) mapped by Werner were tested in addition to those few Landsat lineaments mapped by the authors.[4] Water wells near the curvilinear lineaments produced at about the same rate as wells in other valleys. Whatever the reason for these non-associations, Landsat and curvilinear lineaments are both distinctly different from short photolineaments in both appearance and effects.

Gas well yield was next tested for possible associations with mapped lineaments in the gas field study area (see Figures 1 and 2). Figure 2 shows the locations of Devonian shale gas wells both within and surrounding the Cottageville gas field. Only depicted are those wells for which natural initial open flows are known (E. B. Nuckols III, personal communication, 1978). Natural initial open flow was judged to be the most reliable gas production variable representing relative gas reservoir and gas well potential. Therefore, only this variable was used in statistical tests of lineament associations. Significant research on gas well production trends and associations is reported by several researchers.[4,5,6,7,8,9]

Considering short photolineaments of Figure 2 first, there is no apparent relationship between natural open flow and the proximity of gas wells to short photolineaments. No significant flow difference exists (by the Mann Whitney U test) between gas wells within 0.5 miles and gas wells greater than 0.5 miles from a short photolineament. Natural open flow likewise does not change significantly for wells between 0.0 and 0.5 miles of a photolineament.

However, when short photolineament orientation is taken into account, it is evident from Figure 3 that natural open flow varies with the orientation of nearby photolineaments. Gas wells within 0.5 miles of short photolinraments bearing N 60°W to N 90°W, or WNW, have a greater proportion of high-yielding gas wells (over 100 MCF/day) than do gas wells within 0.5 miles of other short photolineaments. This difference is significant by the 2X2 Fisher contigency test, with an error probability of 0.03. Furthermore, Figure 3 indicated that gas wells within 0.5 miles of short photolineaments oriented N 75°E to N 90°E are relatively high producers, on average. Combining this class of gas wells with the WNW class produces a combined class within 0.5 miles of photolineaments bearing N 60°W to N 105°W, which has the maximum potential for high-yielding gas wells. A 2X2 chi-square contingency test comparison of this enlarged well class with other wells shows a significant difference at the 0.05 alpha probability.

Although WNW-bearing photolineaments have a significantly great proportion of high-yielding gas wells in their vicinity, a more direct test of such photolineaments was necessary to determine their usefulness as an exploration tool. The density of WNW photolineaments is compared to contoured trends for natural initial open flow in Figure 4. The 100 and 500 MCF/day contours for natural open flow were plotted assuming that the changes in gas flow rate would be linear between adjacent gas wells. These contours are partly a function of the density of gas wells; contours in areas with low gas well densities, such as the northwestern extension of the 100 MCF/day contour, are probably overly optimistic in their prediction of shale gas reserves. These contours therefore represent a liberally depicted version of the Cottageville gas field.

The density of plotted WNW photolineaments was calculated from Figure 2 by use of a moving average technique and an orthogonal grid of lines defining square sections. the grid was oriented parallel to the north-south and east-west directions, and had sections that were 0.5 miles long on each side. The WNW photolineament density was calculated for 1.0 square mile sections by the moving average technique, and was plotted at the center of each square mile section. This density was then contoured. Figure 4 illustrates WNW photolineament density contours of 1.0 mile length per square mile area, and of 50 percent by total length per square mile area. The highest WNW photolineament densities occur inside the depicted contours and within the Cottageville gas field.

Chi-square contingency (2X2) tests were then performed on the moving average data for WNW photolineaments. Eighty one sample points were classified in two 2X2 tests for each density variable. One test compared greater-than-100 MCF/day with less-than-100 MCF/day points, and the second test compared greater-than-500 MCF/day with less-than-500 MCF/day points. The statistical test results indicate that WNW photolineament density (both as miles length per square mile area and as percentage of lineament lenght per square mile) is significantly associated with both the greater-than-100 MCF/day and greater-than-500 MCF/day contoured areas of Figure 4, at alpha probability values ranging from 0.02 to 0.001. However, these tests are biased because the 81 tested points are not mutually independent samples, since they were generated by the moving average technique.

Therefore, a second set of contingency tests were performed on the four sets of independent 1.0 mile square sections that define the 81 points tested above. First, the number of tested points was increased from 20 to 80 by multiplying each box of the 2X2 contingency tables by 4. This step had the effect of increasing the sample frequencies to a hypothetical number of independent sample points which were about equal to the 81 non-independent points tested initially. This action was taken to overcome the biasing effect of 2X2 contingency tests against statistical significance for a low number of samples. The net result of these test sets was that at least 3 out of 4 tests of independent sample points were significant at a 0.05 or lower alpha probability, for associations between WNW photolineament density and gas well yield areas from Figure 4. Therefore, the association of high WNW photolineament density and high gas production areas (either greater-than-100 MCF/day or greater-than-500 MCF/day) is considered significant by the authors.

The WNW photolineament density could serve as the basis of a new exploration tool for Devonian shale gas in the Cottageville area. Figure 4 shows that if gas wells are located within areas having densities greater than 1.0 mile per square mile, about 75 percent of these wells would have natural open flows exceeding 100 MCF/day, and about 50 percent of these wells would have flows exceeding 500 MCF/day. When gas wells are located in areas with more than 50 percent of photolineaments bearing WNW per square mile, about 62 percent of the wells would have natural open flows exceeding 100 MCF/day and about 38 percent would exceed 500 MCF/day.

Statistical tests were also performed on gas well yield as a function of WNW photolineament densities of less-than-0.50 versus greater-than-0.50 miles length per square mile. The associations are again significant at the 0.05 alpha probability, but using the area within the 0.50 density contour (not shown in Figure 4) would not prove as successful as the area within the 1.0 density contour for gas exploration. Testing of gas wells within 0.5 miles of short photolineaments bearing N 60°W-N 105°W yielded similar results to those already described for the WNW photolineaments. However, the density of photolineaments in the enlarged orientation class do not associate quite as well with gas production rate as the WNW photolineaments previously described.

An explanation of the associations between WNW photolineaments and gas yield must involve the subsurface geologic structure represented by these photolineaments. It is reported that a major fracture orientation exists in the east-west direction in the Cottageville gas field, based on surface outcrop and core data.[8] Increased gas reservoir permeability, along fractures oriented approximately east-west, is probably a major cause for the high gas yields in the Cottageville field. A more extensive structural analysis of gas trends is given by Nuckols.[8]

Both Landsat and curvilinear lineaments were also tested against gas well yield for the gas field study area. The one Landsat lineament along Mill Creek appears to have a negative effect on gas production, as shown in Figure 4. Natural open flow is lower for gas wells located within 0.25 miles of this lineament than for wells 0.25 to 0.50 miles distant. This relationship is significant at the 0.05 alpha probability level by the Mann Whitney U test, but not by the contingency test. This result supports the conclusion of Werner, that Landsat lineaments appear to be detrimental to gas production in the Cottageville area.[4,5] A test of curvilinear lineaments shows gas yield to be significantly lower for gas wells located within 0.5 miles of such lineaments than for more distant wells. This difference is significant for a 0.01 alpha probability by the Mann Whitney U test. Therefore, Landsat and curvilinear lineaments are to be avoided in exploring for Devonian shale gas, at least in the Cottageville area. Perhaps deeply penetrating fractures have bled off the shale gas under these lineaments, as suggested by Werner.[4,5]

GROUND WATER-GAS YIELD ASSOCIATIONS

Water well yield and well water quality were next compared to the yields of nearby gas wells in the gas field study area, to see if water well data could provide new exploration techniques for Devonian

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shale gas. A hypothetical figure for expected gas well yield was generated by linear interpolation between the two gas wells nearest and on opposite sides of a water well or spring, for each of the 20 wells and one spring within the gas field area. Only one water well could not be assigned an expected gas yield value.

Results of plots and tests for water well (and spring) yield indicate that no apparent relationships exist between water yield (in gallons per minute) and expected natural open flow (in MCF/day).

Water quality parameters were next tested for possible associations with expected natural open flow. Figure 5 illustrates plots of concentration versus gas flow rate, for the four most promising parameters of those analyzed. The horizontal dashed lines on these four plots arbitrarily separate the gas yields into high and low classes, for comparison to concentration. Statistical tests, involving 2X2 contingency tables and the Fisher exact probability test, were used to identify any significant gas yield differences between high and low concentrations. Vertical lines were arbitrarily drawn to distinguish high from low concentration values. Although the data are sparce, statistically positive trends are evident from the statistical tests; expected gas yield tends to be higher near wells with high concentrations of bicarbonate, total hardness, nitrate, or sulfate. Test results are significant at the 0.007, 0.031, 0.079, and 0.094 error probabilities respectively, for bicarbonate, total hardness, nitrate, and sulfate. High concentration samples also show significantly higher gas yields than low concentration values, as determined by the Mann Whitney U test at the 0.05 alpha level. Other tested chemical parameters which did not significantly relate to expected gas yield are total iron, temperature, pH, chloride, and sodium.

The chemical parameters of ground water which seem to best relate to expected gas yield are bicarbonate and total hardness concentrations. These parameters show the strongest statistical associations which are least likely to be coincidental. These two ground water parameters may be applied with caution as exploration tools. From the tested data, about 83 percent of the selected well sites with over 500 mg/l bicarbonate have high expected gas open flows (over 100 MCF/day). An even higher percentage of wells with over 250 mg/l hardness would make good gas well sites, as defined above. These data suggest that some relationship exists between gas reservoir production potential and shallow ground water quality. However, the scarcity of data requires that these associations be considered tentative, until more water well information can be collected to further test the observed associations of Figure 5.

No explanations are apparent to the authors for the observed associations of ground water quality and expected natural open flow. Water wells with high concentrations of bicarbonate, total hardness, nitrate, or sulfate have no common factor in their hydrogeologic setting. These wells differ in aquifer type, well elevation, well depth, well bottom elevation, well yield, topographic setting, and lineament proximity.

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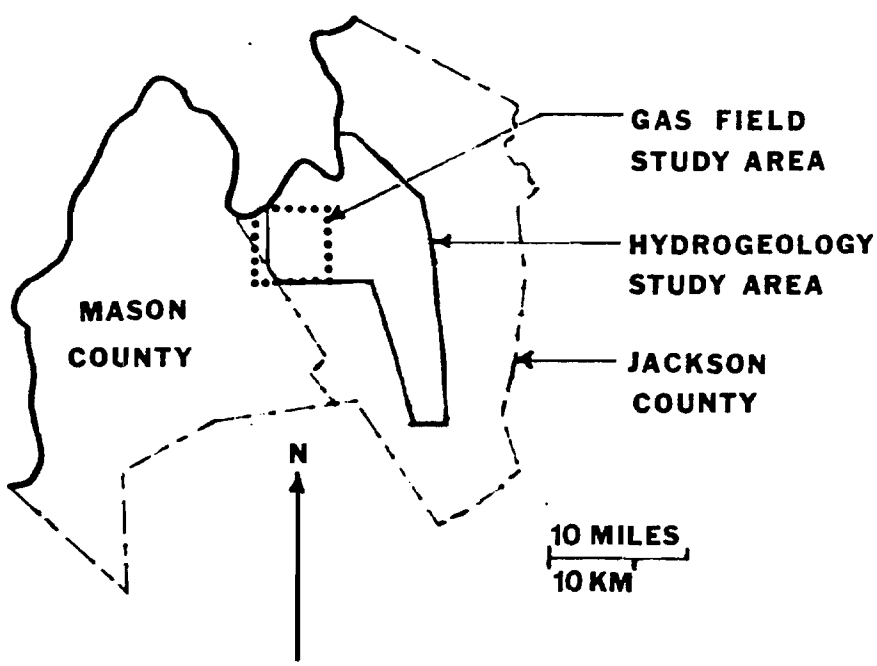


Fig. 1 - Location of study areas in West Virginia.

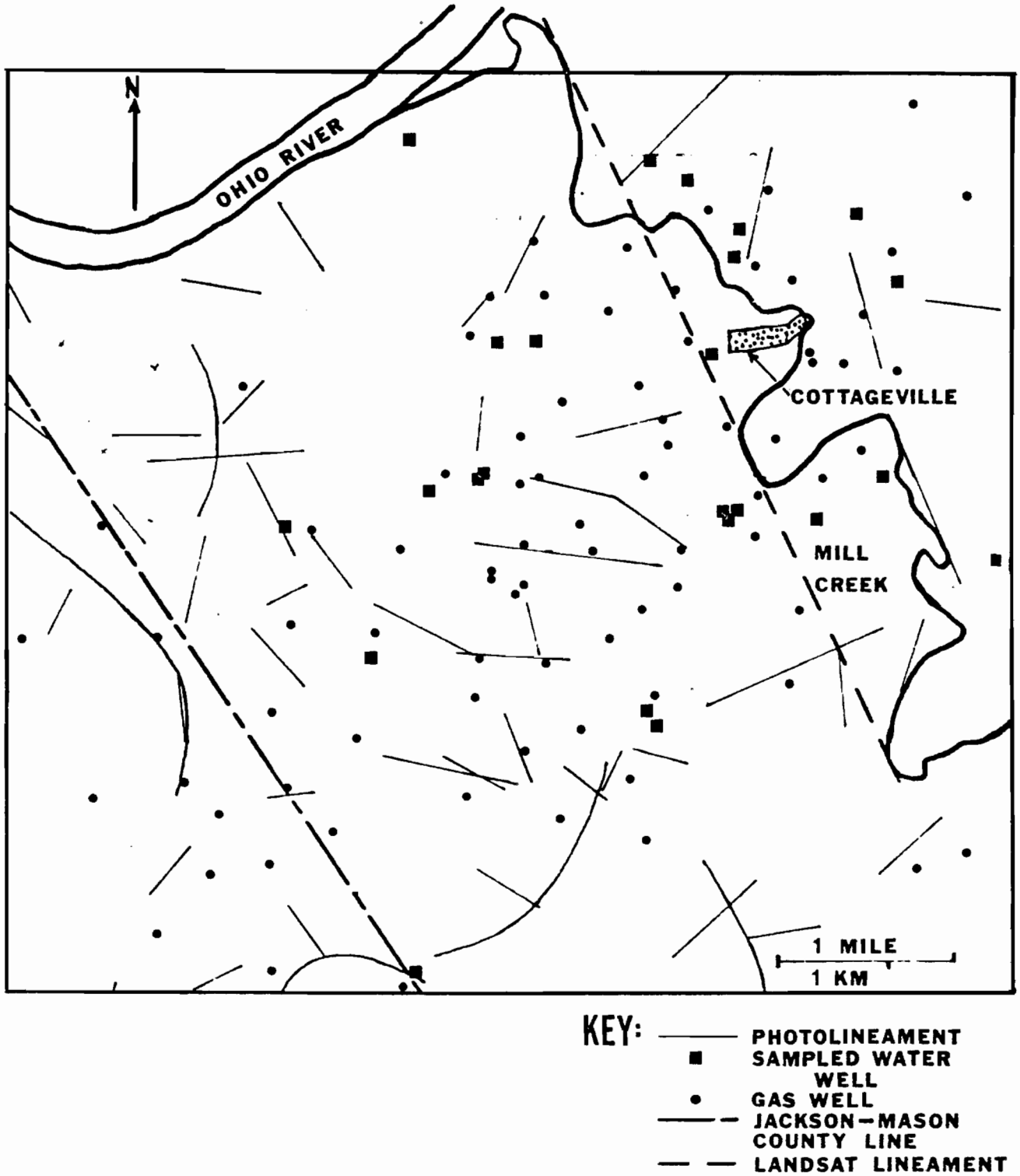


Fig. 2 - Map of gas field study area, near Cottageville.

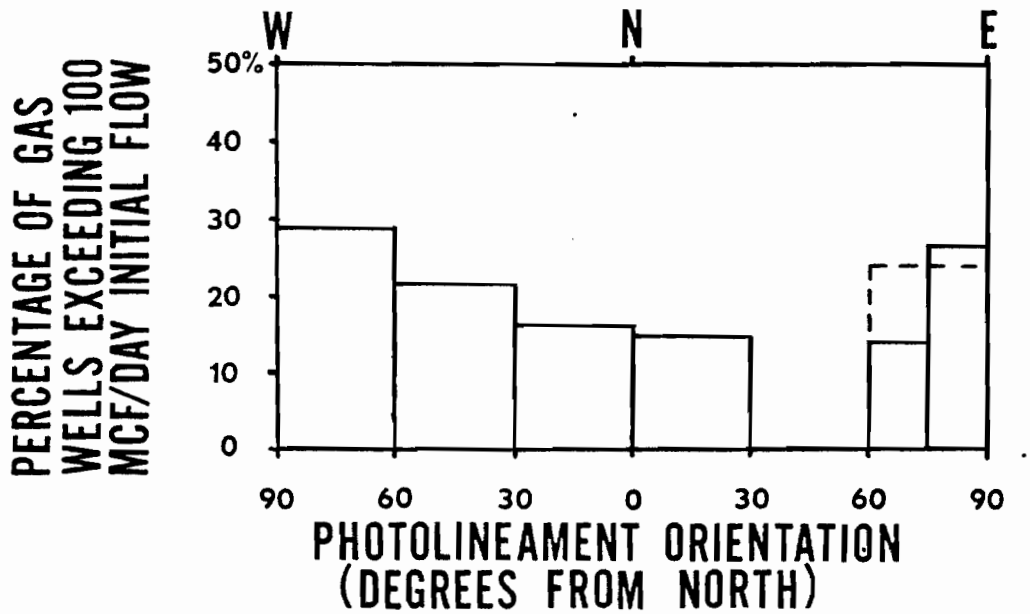
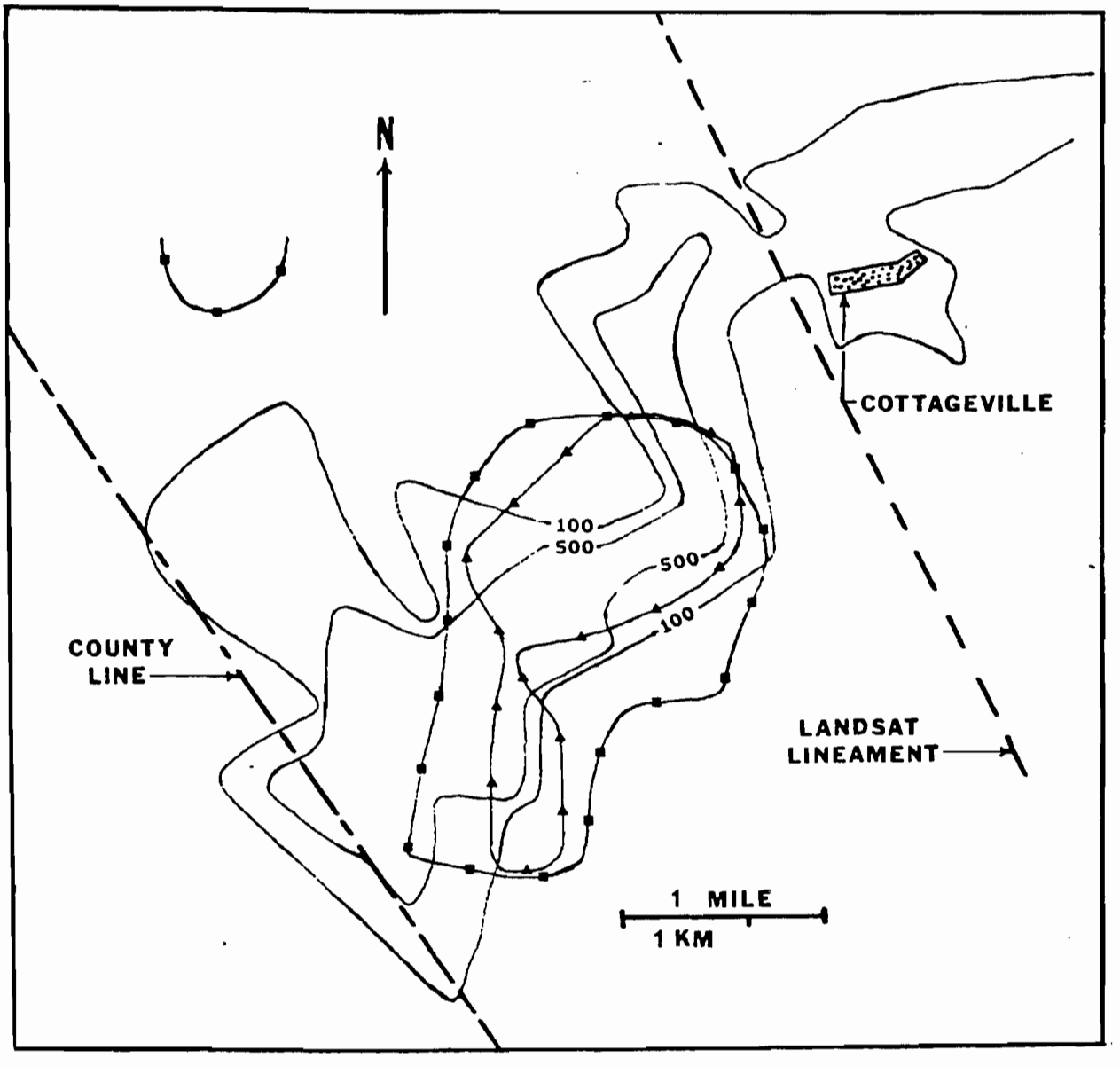


Fig. 3 - Gas well yield versus photolineament orientation.



KEY: -100-100 MCF/DAY CONTOUR FOR INITIAL GAS FLOW
-500-500 MCF/DAY CONTOUR FOR INITIAL GAS FLOW
—▲—1 MI/MI^2 DENSITY CONTOUR FOR SHORT PHOTOLINEAMENTS BEARING N 60° W–N 90° W
—■—50% CONTOUR FOR PERCENTAGE OF SHORT PHOTOLINEAMENTS PER SQUARE MILE BEARING N 60° W–N 90° W

Fig. 4 - Gas well yield related to photolineament density.

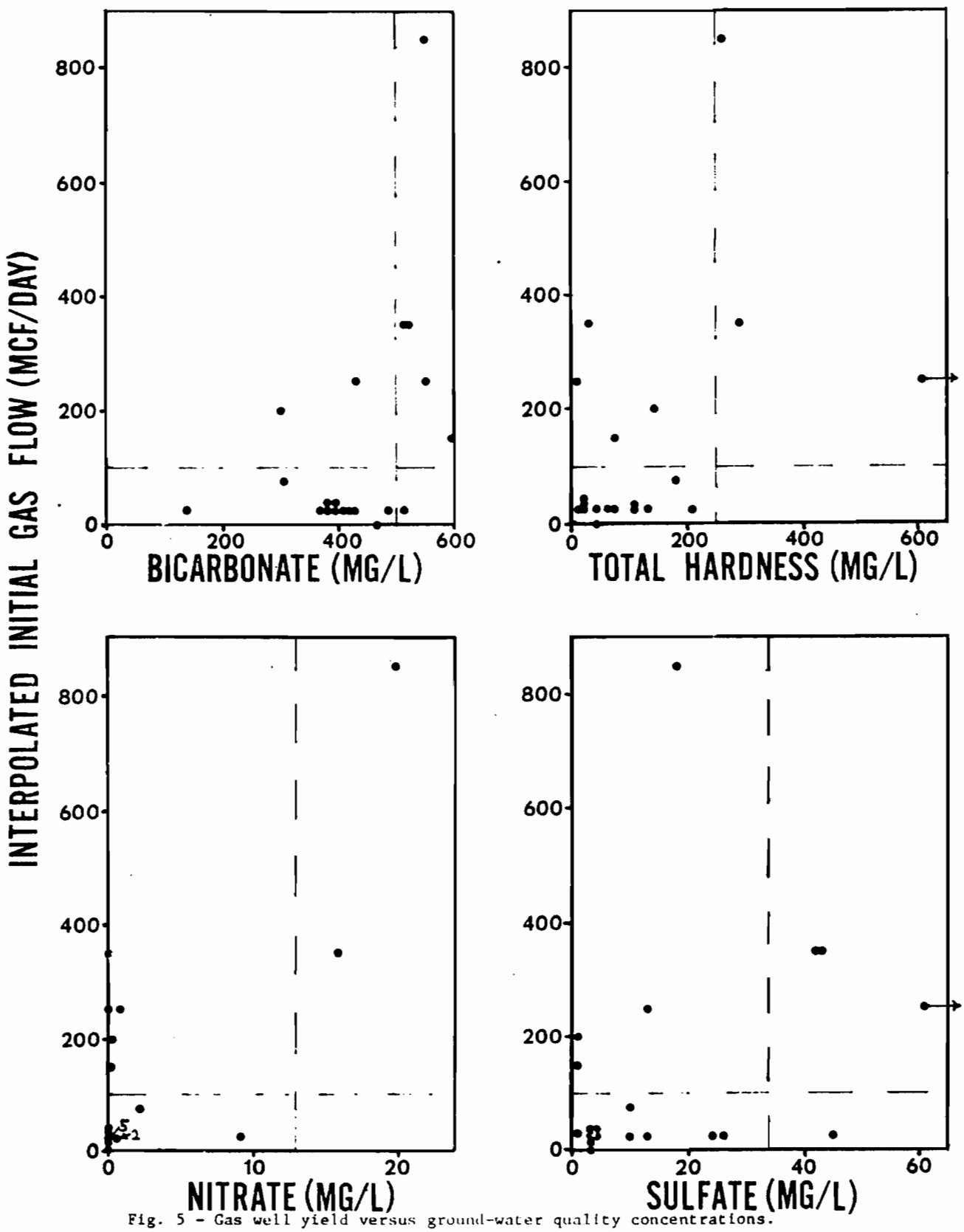


Fig. 5 - Gas well yield versus ground-water quality concentrations.

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A STUDY OF HYDROGEOLOGIC TRENDS IN EXPLORATION FOR DEVONIAN SHALE GAS IN THE MIDWAY-EXTRA GAS FIELD OF PUTNAM COUNTY, WEST VIRGINIA

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1979

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INTRODUCTION

PURPOSE AND SCOPE

There is an increasing demand for natural gas and other fossil fuels today. Locating sites of high-yielding Devonian shale gas wells would help satisfy future demands for natural gas. Developing new and inexpensive exploration techniques for Devonian shale gas based on hydrogeologic criteria would aid in locating such well sites. There is also an increasing demand for fresh ground water today. Developing ground-water exploration methods for high-yielding water wells with good quality water would help satisfy future fresh water needs. Future economic growth and rural quality of life are both dependent on securing increased supplies of adequate water.

The purpose of this study was to investigate for possible associations between near-surface hydrogeologic variables and Devonian shale gas production in the Midway-Extra field of northern Putnam County, West Virginia. The foremost goal of this research was to discover inexpensive exploration techniques for locating high-yielding Devonian shale gas wells. Other objectives were to determine what effect hydrogeologic setting has on water-well yield and ground-water quality. The major hydrogeologic parameters investigated were photolineaments, water-well yield, and shallow ground-water chemistry. Photolineament and stream proximity, topographic setting, and aquifer sequence were investigated for their influence on water-well yield

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and ground-water quality, as future aids in ground-water exploration.

LOCATION OF STUDY AREA

The study area lies in the northern portion of Putnam County and is covered by six 7 1/2 minute quadrangle maps (Figure 1). The northern boundary is the Mason County line; the western and southwestern boundary is the Kanawha River floodplain; the southeastern boundary is State Route 34; and the eastern boundary is the Jackson County line. Surface rocks of the study area are in the Dunkard and Monongahela groups (Wilmoth, 1966). The area is in the Appalachian Plateau physiographic province, and is characterized by high-relief terrain with elevations ranging from 500 to 1,500 feet. The population is primarily clustered in small communities along the Kanawha River, with scattered settlements occurring on ridge tops and valley floors.

GEOLOGY OF STUDY AREA

Stratigraphic Setting

The study area is underlain by basically horizontal strata, the Permio-Pennsylvanian Dunkard and Monongahela groups. These groups are composed primarily of cyclic sequences of sandstone, siltstone, red and grey shale, limestone and coal (Krebs, 1911). The Dunkard Group overlies the Monongahela Group. Quaternary alluvium that is present along the Kanawha River has been excluded from the study.

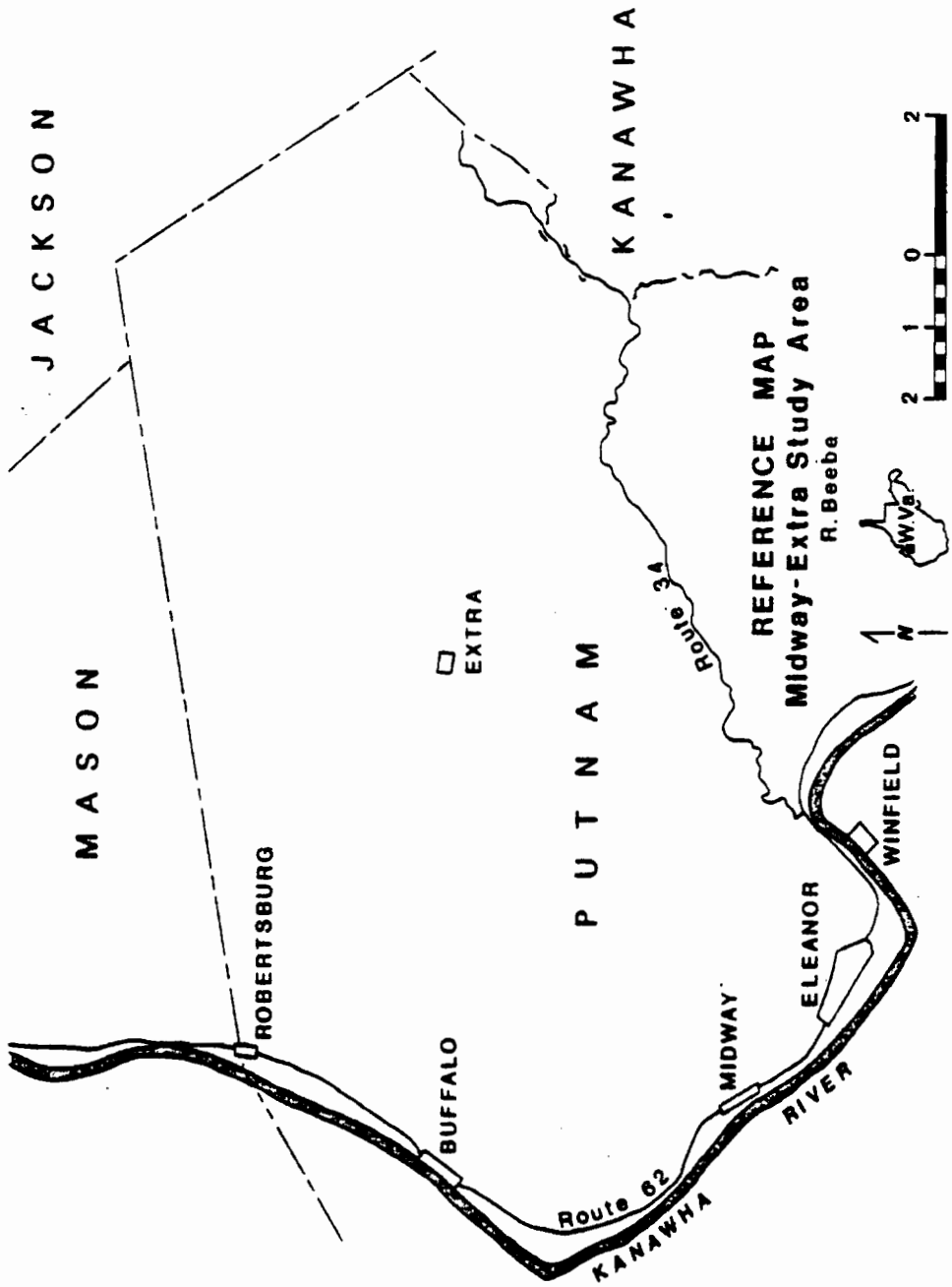

Figure 1 Midway-Extra study area location map.

The Dunkard Group is the youngest group of consolidated rocks in the area and is exposed in the northwestern portion of Putnam County. Only the lower 570 foot portion of the Dunkard Group is present (Wilmoth, 1966). It consists of interstratified red and varicolored sandy or limy shale, grey, green, and brown sandstone, some calcareous shale, a few thin beds of coal, and nodular fresh-water limestone (Wilmoth, 1966). The Dunkard Group reportedly has more red shale and less coal than the Monongahela Group. Owing to this lithologic feature, and its higher topographic position, the Dunkard Group is in general a poorer water-bearing formation than the Monongahela Group (Wilmoth, 1966).

The Monongahela Group is 230 to 320 feet thick in the study area and it occurs at the land surface throughout most of Putnam County. The Monongahela Group is composed of grey and brown sandstone, red and varicolored shales, minor beds of limestone, coal and fireclay. Several coal units occur in this group, including the Pittsburgh, Redstone, Sewickley, and Waynesburg coals (Wilmoth, 1966).

The rock units of these two groups are largely discontinuous laterally, which makes detailed analysis and construction of a generalized stratigraphic column difficult for Dunkard or Monongahela group strata (Wilmoth, 1966).

Structural Setting

The study area lies within the Plateau Province of the central

Appalachians. The structure of the surface rocks in the area is characterized by very low relief synclinal and anticlinal folds. The rocks generally range in dip from 7 to 145 feet per mile (Wilmoth, 1966).

The major structural features of economic importance in the study area are located at depth, and parallel Devonian brown shale gas production (Figure 2). The dominant structural features are the Midway anticline and adjacent synclines. The anticline can be traced in the subsurface from Kentucky into the study area, striking approximately N60°E and plunging northeastward into the Appalachian basin (Schaefer, 1979).

Separating the Midway and Extra sections of the Midway-Extra gas field is a low-relief anticline which strikes about N15°W. This structure intersects the Midway anticline near the center of the study area, and the structural relief is greatly reduced where the two structures merge (Schaefer, 1979).

Midway-Extra Gas Field

Located in Putnam County, West Virginia, the Midway-Extra gas field is defined for this study by a narrow band of 97 gas wells producing primarily from the Devonian brown shales. This field is approximately 100 square miles in area, with only about one third of the total area producing significant flows (Schaefer, 1979).

The first well in the area was drilled and completed in 1947. Of

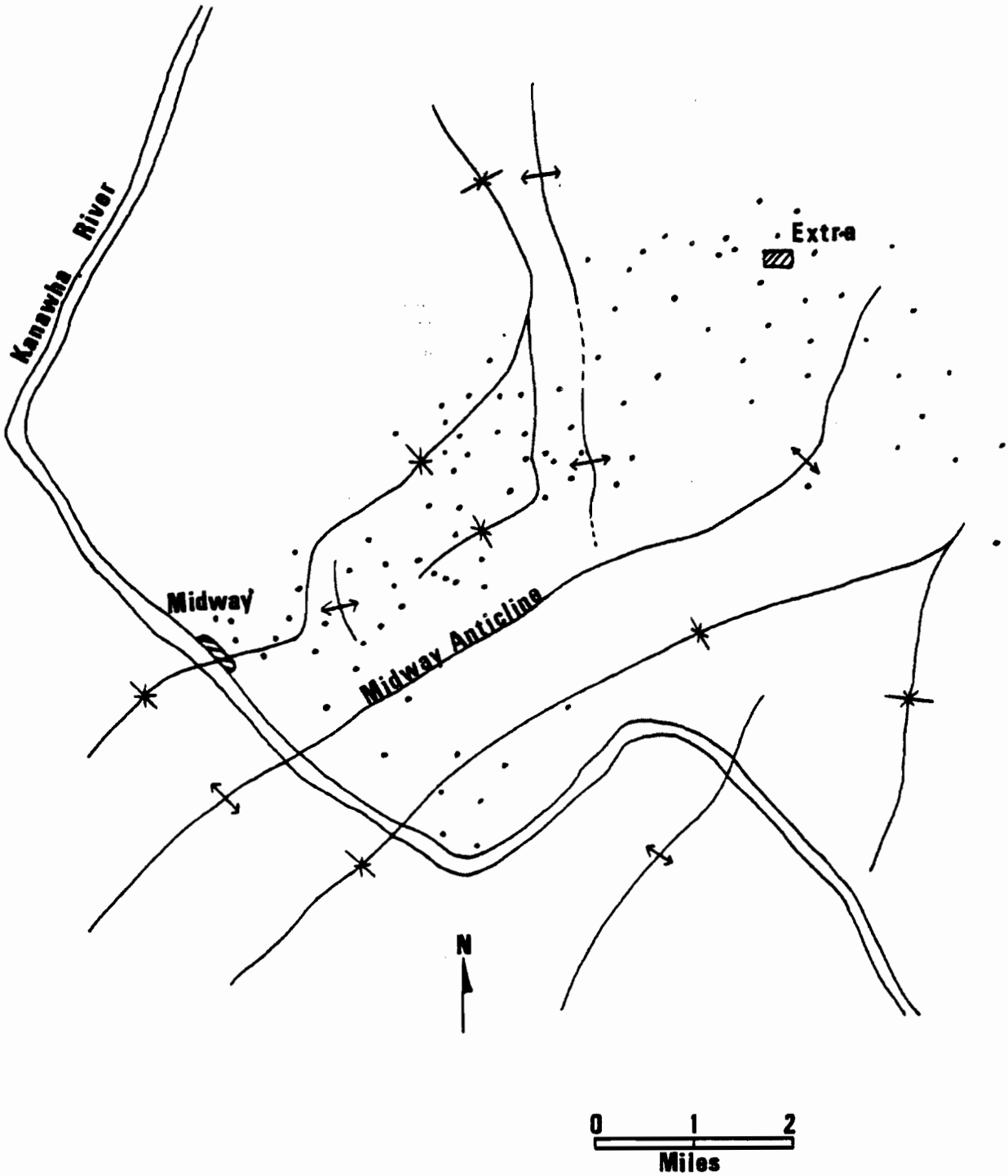

Figure 2 Structure on base of brown shale in Midway-Extra study area (after Schaefer, 1979).

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the 97 wells drilled within the producing margin of this field, slightly better than 50 percent were drilled during the period 1947 to 1952. This drilling completed the Midway section of the field. Current drilling in the Midway-Extra field is concentrated in the Extra portion of the area (Schaefer, 1979).

The Devonian brown shales referred to in this study occupy only a small part of the total Devonian shale section. These shales are commonly identified by their high radioactivity and low density, and are equivalent to the Lower Huron Shale Member of the Ohio Shale (Schaefer, 1979).

The overall thickness of the Upper and Middle Devonian shales ranges from less than 1,000 feet in the extreme western counties of West Virginia, to over 3,200 feet in eastern Kanawha County (Bagnall and Ryan, 1976). The entire Upper and Middle Devonian section changes facies eastward, generally becoming coarser in grain size (Schaefer, 1979).

As reported by Schaefer (1979) there appears to be a definite correlation between production and stratigraphy within the Devonian shales of the Midway-Extra field. Not only are the brown shales the more productive, but specific low-density, high-organic zones within these shales are the most productive. While there is not a precise one-to-one correlation between stratigraphy and shows from well to well, there is clearly a tendency for shows to correlate by stratigraphic

position.

PREVIOUS INVESTIGATIONS

With respect to previous investigations, only previous hydrogeologic and lineament studies which may relate directly or indirectly to natural gas production will be discussed. Reported studies are limited to the immediate study area or to similar terrains elsewhere in West Virginia.

Several studies by Werner (1976, 1977a, 1977b), Jones and Rauch (1978a), and Ryan (1976) involved investigations of possible associations of photolineaments with natural open flow gas production. Werner (1976, 1977a, and b) reported on the association of lineaments derived from Landsat imagery (Landsat lineaments) with natural open flow gas production. Werner (1977a) examined Landsat lineaments in Wayne, Mason, and Jackson counties of West Virginia, and concluded that the natural open flow is lower for gas wells located on or near such lineaments. Jones and Rauch (1978a) found that in the Cottageville area of Mason and Jackson counties, gas wells located within 0.25 miles of one Landsat lineament or within 0.50 miles of a curvilinear lineament over one mile long produced at significantly lower rates, and that in general Landsat and curvilinear lineaments should be avoided when locating Devonian brown shale gas wells.

Ryan (1976) found results that conflict with those of Werner

(1977a) with respect to Landsat lineaments and natural open flow gas production within the Haysi field of western Virginia and southeastern Kentucky. Geologically, the Haysi area is located at the northeastern end of the Pine Mountain overthrust, with the Haysi gas field located within the tear-faulted zone. The main producing formation in that area is in the Berea Siltstone at an average depth of 4,000 feet (Ryan, 1976). Considering only the hydraulically fractured Berea wells, Ryan (1976) stated that those gas wells located on or within 1,500 feet of major lineament zones have an open flow after fracturing greater than those wells more than 1,500 feet from a lineation. In conclusion, Ryan (1976) believes that better wells are associated with natural fracture zones in this type of geologic and topographic terrain. Werner (1977a) expressed several possible reasons for the discrepancy in findings of the two studies. First, the lithologies of the producing formations are different. The producing horizon in the Haysi field is the Berea Siltstone; the producing horizon in western West Virginia is the Devonian shale. The two rock types behave differently under stresses which produce fracturing. Second, the Haysi field is located in an area of Appalachian thin-skinned tectonics where the area in West Virginia is probably not. Another point which may have a bearing on this relationship is one indicated by Kulander, Dean, and Barton (1977); if the gas conduits in the Devonian shales were primarily horizontal fractures and those in the more competent silts and sands of the Berea (or similar

units) were nearly vertical fractures, the widely different associations observed between Landsat lineaments and gas production might be reasonable. Also, if horizontal fractures are the primary natural conduits of Devonian shale gas to wells, and if the lineaments studied represent major vertical fracture zones, then the vertical fractures may have vented sufficient gas to make rock in their immediate vicinity nonproductive (after Werner, 1977a).

Short photolineaments, defined by low-altitude black-and-white aerial photography, were studied by Jones and Rauch (1978a) in the Cottageville, West Virginia area. These photolineaments were shown to have a positive influence on natural open flow gas production. Their findings indicate that gas wells located within 0.50 miles of a short photolineament bearing N60°W-N90°W (WNW) yield at significantly greater rates than gas wells near other photolineaments, but that short photolineaments are not in general associated with gas well yield (Jones and Rauch, 1978a). The importance of these short WNW-oriented photolineaments may be in their relationship to mineralized fracture orientations dominant within the gas producing horizons at Cottageville. The primary reservoir in the Cottageville field is Brown Shale Zone II. Rock cores taken from a high-producing well in this field show that fracture orientations down through Zone II exhibit considerable dispersion in the orientation of mineral-lined fractures, however three directions predominate: N40°-50°E, N10°-20°W, and N80°-90°W

(Larese and Heald, 1976). Furthermore, the WNW photolineament trend is oriented about 60°-90° from the regional structural (fracture) trend of N40°-50°E in the Cottageville area as reported by Martin and Nuckols (1976). The combination of fracture orientations N40°-50°E and N60°-90°W might tend to maximize fracture permeabilities within the gas bearing formations.

Short photolineaments and their relationship to the occurrence of ground water in clastic rock terrains, within the Appalachian Plateau geologic province of West Virginia, have been investigated by several workers: Sole (1975), Jones and Rauch (1978a, 1978b), Holland, Rauch, and Werner (1977), and Steffy (1975). All of these reports agree on the original relationship cited by Lattman and Parizek (1964), that increased yields for wells in close proximity to photolineaments probably indicates a greater degree of weathering and therefore higher porosity and permeability for nearby rocks. Lattman and Parizek (1964) originally defined such photolineaments as fracture traces less than one mile in length, with a zone of influence about 400 feet wide in the carbonate rock terrain of central Pennsylvania. However, they also indicated that the distance within which a well must be located of a photolineament before its yield is greatly influenced is naturally dependent upon the width of the associated fracture zone, the rock lithology within the lineament, and the structural characteristics of this rock. Sole (1975), in studying the hydrogeology of the Pricetown,

West Virginia area, found that the water well productivity and well proximity to the nearest photolineament are significantly associated above the 90 percent probability level. Jones and Rauch (1978a, 1978b) tested water well yield as a function of well proximity to photolineaments. They found that wells located within 100 feet of a photolineament yield water at significantly greater rates than more distant wells at a 0.05 alpha probability level. Of those wells within 100 feet of a photolineament center line, wells within 50 feet yield water at significantly greater rates than wells 50-100 feet from the lineament, at an 0.05 alpha probability level. Holland, Rauch, and Werner (1977), in their hydrogeologic study of water well yields and ground-water quality in north-central Tyler County, West Virginia, tested well proximity to photolineaments against water well yield. Results show that wells located within 200 feet of a photolineament had significantly higher yields than all other wells. Furthermore, median yield differences indicate that near-lineament wells produce at about 2 1/2 times the rate of wells not near photolineaments. Steffy (1975), used nonparametric statistics to test for associations of well yield (gpm) with well proximity to the nearest photolineament in Tucker County, West Virginia; wells located within 100 feet of a photolineament in this area had significantly higher yields than more distant wells, at an 0.07 alpha probability level.

Some researchers have investigated the relationships between ground-water chemistry and photolineament proximity. Sole (1975), found no definite relationships between photolineaments and ground-water chemical parameters, except that the variable pH was significantly higher near photolineaments; he concluded that this association had no logical cause for its significance. Steffy (1975) found that iron and total hardness were both significantly greater in wells which are within 100 feet of a photolineament. Jones and Rauch (1978b) found that photolineaments appear not to be related to ground-water chemistry in their study area. Holland, Rauch, and Werner (1977) found that photolineaments appear to be minimally associated with ground-water chemistry; for wells within 200 feet of a photolineament, the iron and calcium concentrations were significantly higher at the 0.05 alpha probability level, magnesium concentrations were significantly higher for wells near photolineaments at the 0.10 alpha probability level. Explanations for these associations are uncertain (Holland, Rauch, and Werner; 1977). Steele et. al. (1976) however, found that wells located off of photolineaments had greater calcium and magnesium concentrations than those located on photolineaments. Steele et. al. (1976) conducted an investigation in carbonate rock terraine, which could explain why they found different associations between hardness and photolineaments than did Steffy and Holland et. al. for West Virginia clastic rock terrains. Steele et. al. (1976) also found that nitrate

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and phosphate were present in higher concentrations in wells located on photolineaments, probably because of the greater ease of entry of pollutants, such as fertilizer and animal wastes, into wells near photolineaments.

Jones and Rauch (1978a) also investigated possible relationships between shallow ground-water chemistry and natural open flow gas production from Devonian shales in the Cottageville, West Virginia area. Their findings indicate that certain ground-water chemistry parameters are significantly related to natural open flow gas production. Specifically, they found that concentrations of nitrate and sulfate, and especially of bicarbonate and total hardness are significantly associated with high expected (interpolated) gas well yield, near water well sites (Jones and Rauch, 1978a).

METHODS OF INVESTIGATION

LINEAMENT MAPPING

Landsat Lineaments

Lineaments derived from Landsat satellite imagery, termed Landsat lineaments, were located on images having scales of 1:1,000,000 and plotted on the appropriate 7 1/2 minute topographic quadrangle maps. The Landsat lineaments were defined as natural straight-line features, such as straight stream or valley segments, aligned stream meander bends, or tonal streaks in vegetation or soil cover. The instrument used to locate and identify such lineaments was the 12-Color Datacolor/ Edge Enhancer System. The four mapped Landsat lineaments were then ranked with regard to the certainty of their existence, with a rank of "1" indicating near certainty and a rank of "2" indicating questionable certainty. Furthermore, the Landsat lineaments were classified according to the nature of their appearance on the Landsat image; a classification of "T" indicates a tonal appearance derived during contrast mixing visual enhancement, and a classification of "E" indicates an edge appearance found during edge enhancement observation of the satellite image representing the study area.

Short Photolineaments

Short photolineaments were also mapped for the study area from

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low-altitude black-and-white photographs having scales of about 1:20,000 and 1:38,000. The photographs were examined with the aid of a pocket stereoscope which facilitated recognition of rectilinear surface features as defined by Rauch (1979, oral communication), and Lattman (1958). Lattman (1958) defined short photolineaments to be fracture traces, believing that such lineaments usually represent fracture zones. Approximately 270 short photolineaments were plotted on six 7 1/2 minute topographic quadrangles of the study area. The photolineaments represent rectilinear surface features corresponding to nearly straight stream channels, valley segments or tonal differences in soil cover or vegetation. Plotted photolineaments are at least 0.25 miles in length and are not generally more than 1.00 miles long. Each plotted photolineament was recorded and ranked in order of the certainty of its existence. A ranking of "1" indicates a most-certain photolineament location while a ranking of "3" indicates a least certain photolineament location; a ranking of "2" is intermediate, or indicates moderate certainty.

FIELD METHODS

Geophysical Techniques

Electrical resistivity surveying was used as a geophysical technique to test for the possible presence of a near-surface fracture zone under a selected short photolineament located within the study area. A class "1" photolineament, mapped from low-altitude black-and-white aerial

photographs, was tested. A perpendicular survey line was chosen across the selected photolineament, as shown in Figure 3.

A tri-potential resistivity survey was performed, as described by Kirk (1976). This type of survey involved four metal electrodes placed in line in the ground, with a 30 foot electrode spacing. A Soil Test resistivity meter was used to determine the electrical resistance of the ground area under the survey line. As a general rule, the penetration depth of the electrical current is about equal to the distance between adjacent electrodes (Kirk, 1976). Three electrode arrays were used, the CPPC, CPCP, and the CCPP arrays, where "C" represents a current electrode and "P" represents a potential electrode. Apparent electrical resistance was recorded from the resistivity meter for all three arrays at each survey station. The survey was run on nearly-level ground in order to minimize the effects of topography on the observed resistivities.

During electrical resistivity surveying, an electrical current is put into the ground artifically and the potential difference between the current that returns and the original current is measured. This enables one to calculate the apparent resistance of the medium in question. The apparent resistivity was then calculated from the apparent resistance values by use of equation (1), after Kirk (1976).

$$\rho = R(A/L) \qquad (1)$$

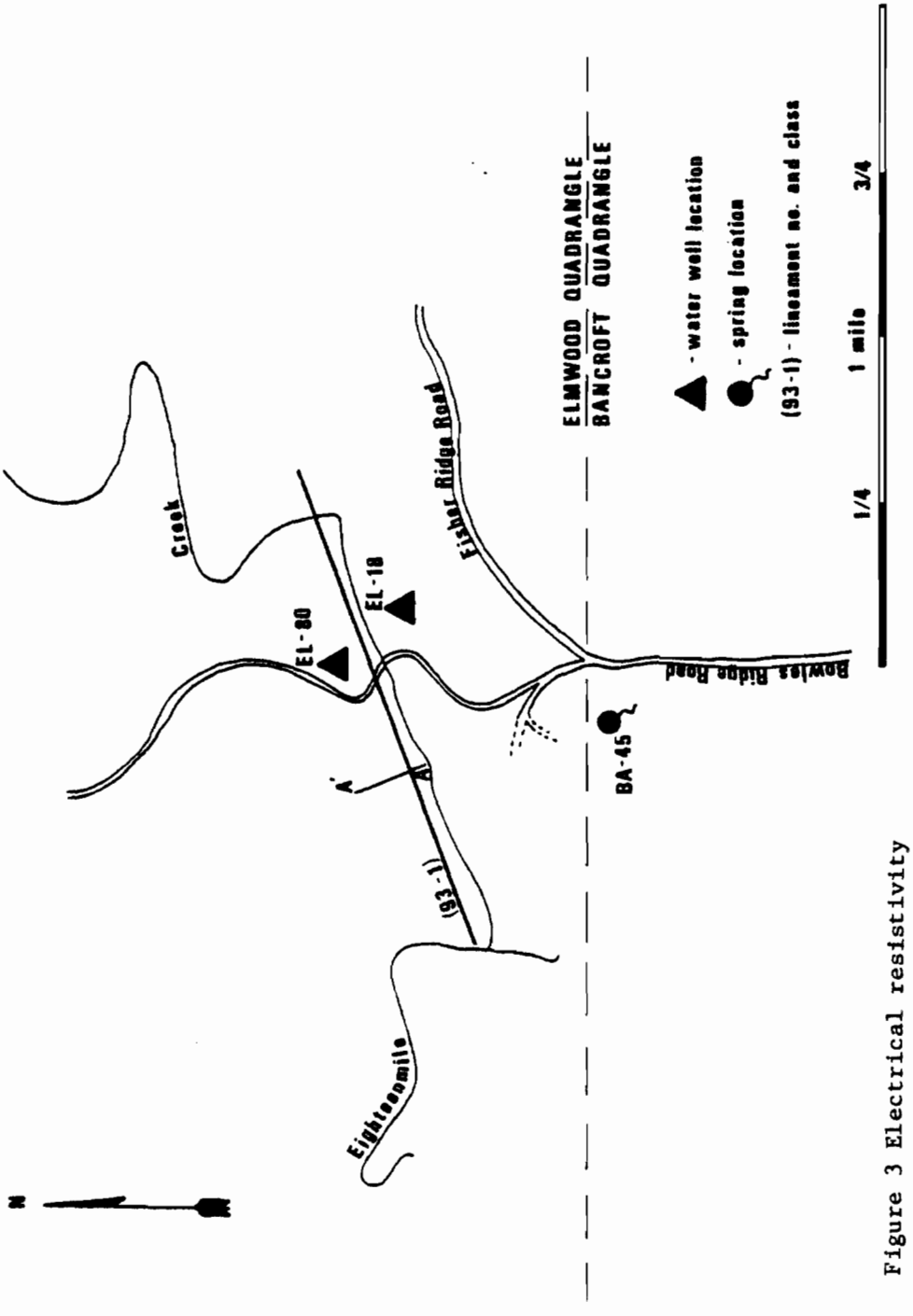

Figure 3 Electrical resistivity survey location map. Line A-A' is the survey trace.

where, ρ = apparent resistivity

R = resistance

A = cross-sectional area of medium in question

L = length of medium in question

The electrical resistivity is defined as the resistance of a given material of a given unit dimension (Kirk, 1976).

Several equations were utilized to correct data collected from the resistivity meter for non-homogenous geologic and geometric considerations. The correction factors from Kirk (1976) are as follows:

$$\rho_{CPPC} = 2\pi a \cdot R \qquad (2)$$

$$\rho_{CPCP} = 3\pi a \cdot R \qquad (3)$$

$$\rho_{CCPP} = 6\pi a \cdot R \qquad (4)$$

where, ρ = apparent resistivity

a = electrode spacing

R = resistance measured by resistivity meter

C = current electrode

P = potential electrode

In general, large differences among the apparent resistivity values for the three electrode arrays indicate anomalous resistivity zones.

Another useful quantity determined from an electrical resistivity survey is Δ %. This variable is a measure of the asymmetry of resistivity, and is determined by the following equation from Kirk (1976):

$$\Delta\% = \frac{\rho_{CPPC} - (\rho_{CCPP} + \rho_{CPCP})}{\rho_{CPPC}} \times 100 \qquad (5)$$

Large absolute values of Δ % generally indicate a resistivity anomaly zone.

A fracture zone may exhibit no discernible difference in resistivity from that of the surrounding rock, or it may raise or lower measured resistivity values (Kirk, 1976). For example, a clean sandstone with a fracture zone would tend to show a lower resistivity than the surrounding rock; this is due to the introduction of ground water with relatively high dissolved solids into the fracture porosity, replacing the relatively dilute ground water in the surrounding rotk. A fracture zone in shales, however, would tend to have a higher resistivity than that of the surrounding rock due to relatively fresh water being introduced in comparison to the water trapped in pore spaces within the shale. This trapped pore water would have a higher dissolved solids concentration than that for the more permeable sandstone. This latter case is similar in effect to that presumed to occur in the area of Figure 3, because of the predominant shale nature of the country rock in the study area.

Water Well Sampling

Seventy-three domestic water wells and 7 springs were inventoried in the study area. The inventoried wells and springs are located primarily along secondary roads. Wells to be inventoried were selected where available, within the heart of the Midway-Extra gas field, and a

spacing of at least one mile between adjacent wells was generally used for the whole study area. Figure 4 shows the locations of springs and water wells inventoried for this study. Wells that were sampled are limited to drilled wells only; dug wells and wells with water conditioners were avoided.

Water well data of this study were primarily obtained by the author. The data collected for each well were: well use; well depth; depth to static water level; well yield (gpm); well diameter; depth of casing; depth of pump placement; pump capacity; and a number or ranking of yield. These physical water well parameters were determined from interviews with well owners and/or well drillers. In addition, the topographic setting of each well (hill, slope, or valley) was obtained from on-sight inspection. Six 7 1/2 minute topographic quadrangles covering parts of the study area were used to determine the well-top elevation of each inventoried well. A complete list of physical water-well data is contained in Appendix A of this report.

Of the 73 water wells and 7 springs inventoried, 32 water samples were collected. Sampling sites were selected so as to permit about 50 percent of these sites to be located within the producing margin of the Midway-Extra gas field; the remaining well sites were located beyond the producing margin of the gas field. Before collecting each water sample, the water pump was allowed to run to empty the holding tank and pipes of standing water present; this allowed direct sampling of ground

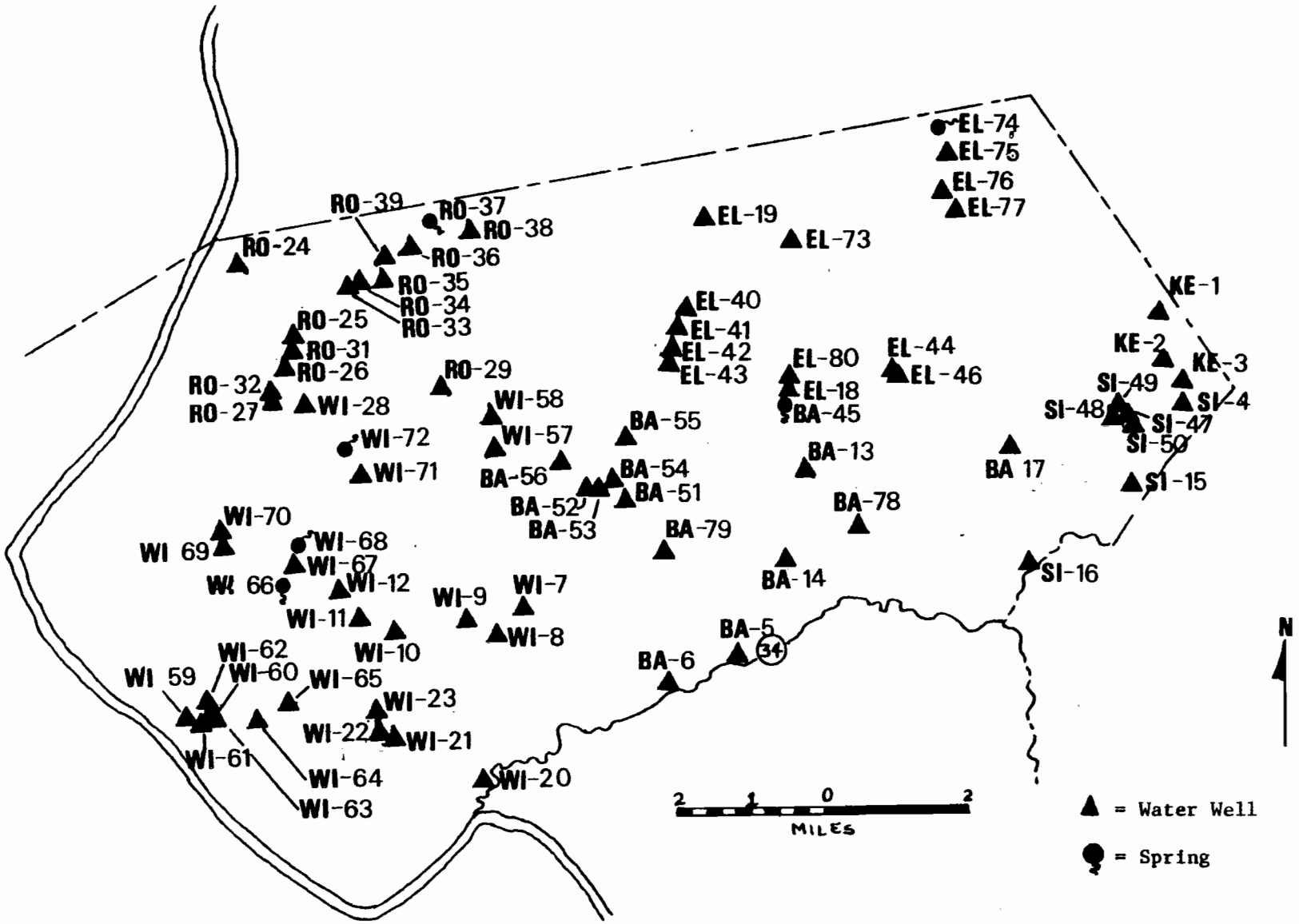

Figure 4 Location map of springs and water wells for Midway-Extra study area.

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water from the aquifer. For each well sampled two water samples were collected and stored in quart-sized containers. The water temperature was recorded with a standard Celsius thermometer, and the specific conductance was determined by a Beckman Solu-Bridge conductance meter in the field. Approximately 10 drops of concentrated HCl were added to one sample container to insure that dissolved iron, calcium, and magnesium would remain in solution. The unacidified samples were kept cool in a cooler while in the field, then in a refrigerator until chemical analyses were completed in the laboratory.

Pumping Tests

Pumping tests were performed on two water wells where access to the well top was possible. Pumping tests were performed for the purpose of obtaining more accurate determinations of water well yield and aquifer transmissivity for wells in the study area. Owner permission to conduct the pumping tests was difficult to obtain, since it was a cost and inconvenience to the well owner. Pumping tests were performed on wells EL-80 and RO-29. Data obtained from these pumping tests are contained in Appendix H of this report.

A Soil Test electric well line was used to first determine the depth of the static water level before pumping, and well water was not pumped or used for at least one hour prior to each pumping test. Next, the well was pumped continuously for 20 and 10 minutes time for wells

EL-80 and RO-29 respectively, and the pumping rate was periodically measured in gallons per minute with the aid of a watch and a 3 gallon measuring bucket. The depth to water was recorded and both the drawdown and specific capacity of the well were determined, using the following formulas:

$$\text{Drawdown} = (\text{static water depth}) - (\text{water depth after pumping}) \quad (6)$$

$$\text{Specific Capacity} = \frac{\text{Pumping Rate (gpm)}}{\text{Drawdown (ft)}} \quad (7)$$

Transmissivity is an indication of the permeability of an aquifer. It was determined by the following formula modified after Jacob (1963):

$$T = \frac{264\ Q}{s} \log_{10} t/t'$$

Where T is transmissivity in gallons per day per foot of aquifer width; Q is the pumping rate in gallons per minute; s is the drawdown in feet; t is the time in minutes since pumping began; and t' is the time in minutes since pumping stopped. This formula assumes that the coefficient of storage (S) remains constant during and after well pumping. In reality this does not necessarily occur. Jacob (1963) discussed the problem and offered an appropriate correction by modified equation (9):

$$T = \frac{264\ Q}{s} \left[(\log_{10} t/t') - \log_{10} (S/S')\right] \quad (9)$$

Where S is the coefficient of storage during pumping and S' is the coefficient of storage after pumping. The graphic plotting of drawdown (s) versus the common log of ratio t/t' can be expressed by equation (10) after Jacob (1963):

$$\text{Slope} = \Delta s/\Delta \log_{10} (t/t') \qquad (10)$$

After determining the slope of the line, the coefficient of transmissivity can be calculated by equation (11) modified after Jacob (1963):

$$T = 264\ Q/\text{Slope} \qquad (11)$$

When the coefficient of storage does not remain constant, the plotted slope line of equation (10) does not pass through the origin and the calculated value of T is somewhat inaccurate (Jacob, 1963).

DETERMINING ADEQUACY OF WATER WELL YIELD

Where possible, the author recorded well yield in gallons per minute (gpm). However, where gpm yield data were not available an ordinal measure of water well adequacy was recorded as an estimate of yield. The assigned adequacy rankings are as follows: IA = inadequate for owners' supply of water; BA = barely adequate for the owners' supply of water; A = adequate water supply; TD = more than adequate supply of water or supplies two dwellings; and AA = well driller reported inability to bail the well dry.

The adequacy ranking technique used was a modified version of that used by Friel and Bain (1971). The purpose of the adequacy ranking was to attempt to assign a median water well yield (gpm) to water wells without known or reported gpm yield data. Before assigning an adequacy rank to any well, certain important factors were considered. For instance, each well owner was questioned about his water well use, especially concerning appliances such as washing machines and dish washers which use large amounts of water. Furthermore, the number of residents and wash rooms were considered before an adequacy rank was assigned.

When the water well inventory was completed and adequacy ranks were applied to all wells, a list of known water well yields was constructed for each adequacy group as shown in Table 1. The median water well yield in gpm for each adequacy group was then recorded. These median values were then assigned to other wells of each adequacy group which lacked reported water gpm yield data. In this way every water well could be later used for nonparametric statistical tests of hydrogeologic or gas well variables which might possibly be associated with water well yield.

AQUIFER DETERMINATIONS

Inventoried water wells were located in the stratigraphic column to determine the rock units most likely to supply water to these wells. Because of the scarcity of published stratigraphic descriptions or geo-

TABLE 1

WATER WELL ADEQUACY RANKING

Adequacy rating for water well yield	IA	BA	A	TD	AA
No. of wells in each class	12	7	19	2	9
Median well yield (gpm) when known	0.0	0.58	1.0	12.5	no data

Key:

IA = inadequate supply of water

BA = barely adequate supply of water

A = adequate supply of water

TD = more than adequate supply of water or supplies two dwellings

AA = well driller reported inability to bail well dry

physical logs, and the complexity and extreme lateral variation of strata, unequivocal aquifer determinations for each water well were impossible. Indirect methods were therefore employed to determine the major stratigraphic sequence containing the aquifer for each inventoried water well in the study area. Two major sources of stratigraphic data were provided by Krebs (1911) and Wilmoth (1966), and limited amounts of stratigraphic data were also supplied by well drillers and well owners. A generalized stratigraphic column was then prepared from these data.

The data supplied by Krebs (1911) consisted of three stratigraphic sections: (1) the Pliney core section located in Pliny of the Buffalo District in Putnam County, at the mouth of Plantation Creek; (2) the Bear Branch section taken descending into Bear Branch of the Buffalo District in Putnam County, and joining the Henderson core drill hole (P-25); and (3) the Sigman section taken descending into Sycamore Branch, 1 1/2 miles south of Sigman of the Pocatalico District in Putnam County, and joining the O.P. Honaker core drill hole located on the Sycamore Branch of the Left Fork of the Poca River. From these data a generalized stratigraphic cross section was constructed through the study area. For each core of the stratigraphic cross section the top of the Pittsburgh Coal was used as datum.

The minimum elevation of the aquifer supplying water to each well was first determined by subtracting the well depth from the elevation

at the well top. Next, this well bottom elevation was translated on a perpendicular line to the stratigraphic cross section, and was corrected for structure by using the elevation of the Pittsburgh Coal at each well site, as determined from the structural contour map from Krebs (1911). After having located the well bottom within the stratigraphic cross section, the entire well depth was then constructed on this section, from which determinations of the most probable aquifer sequence was derived for each of the 74 water wells inventoried.

Because of the previously mentioned variability in thickness and lateral continuity of the individual rock units of northeastern Putnam County, a stratigraphic section or "aquifer sequence" was assigned to each well, rather then a single lithologic unit. Aquifer sequences range from 50 to 165 feet in total thickness, and each aquifer sequence contains at least one major sandstone unit capable of supplying water to a well. Relatively thin limestone beds are present in the study area (Wilmoth, 1966) but they are too discontinuous to be considered as major aquifers.

A generalized stratigraphic column was constructed from the stratigraphic cross section and is shown in Figure 5. This generalized stratigraphic column represents the defined aquifer sequences which were assigned to water wells of the study area. The Dunkard and Monongahela rock units considered in this study are commonly highly variable and largely discontinuous laterally. Caution must therefore be exercised

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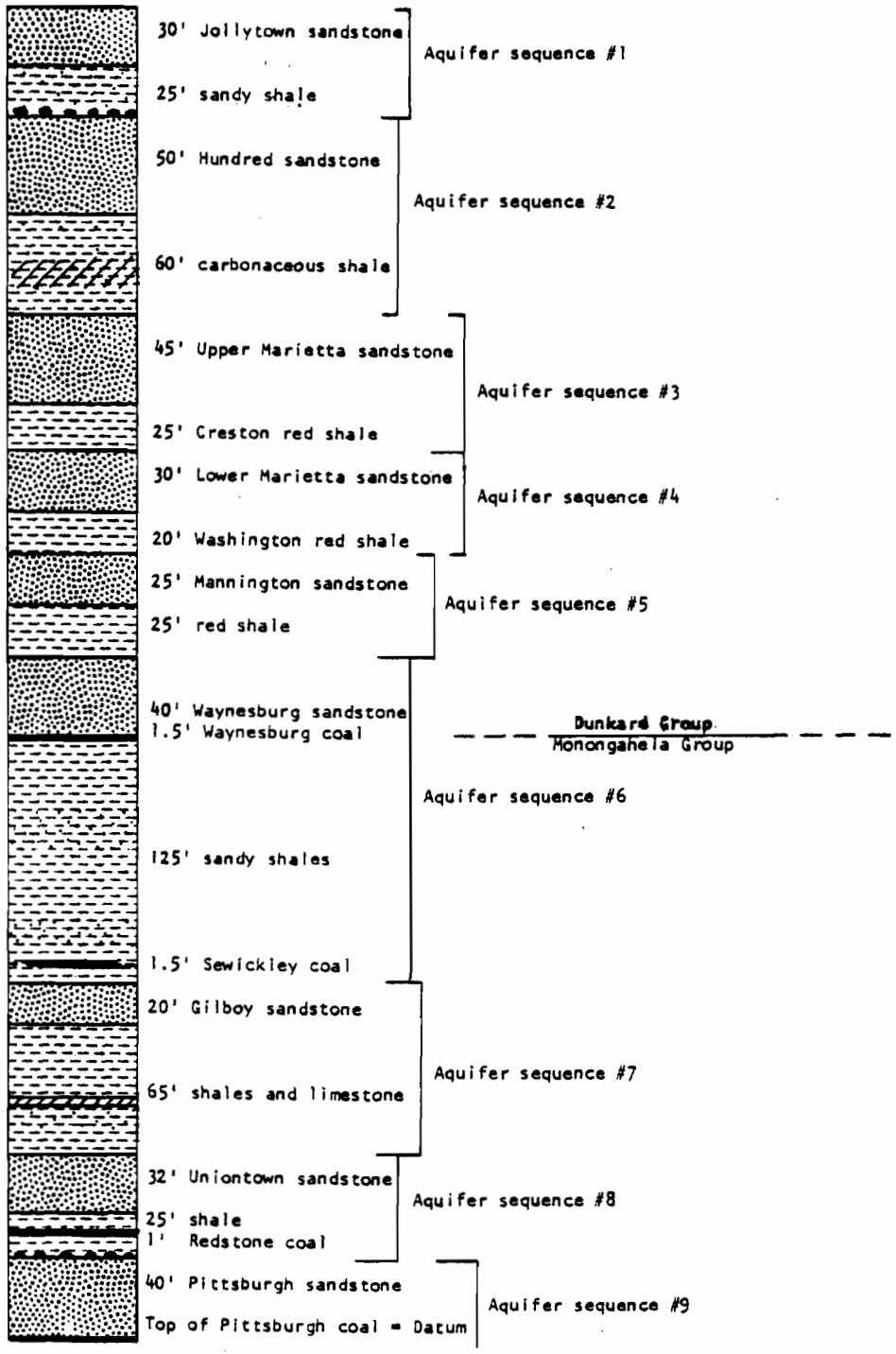

Figure 3 Generalized stratigraphic column, for the study area.

when making interpretations from Figure 5.

CHEMICAL ANALYSIS

Field measurements were made for each sampled water well for temperature and specific conductance. Each set of water samples was then analyzed in the laboratory for concentrations or values of the following aqueous geochemical parameters: pH, bicarbonate, total iron, nitrate, total hardness, calcium hardness, sulfate, chloride, and sodium. All parameters were measured within 48 hours after sampling to reduce the possibility of chemical changes before analysis.

The pH value of each unacidified water sample was determined by a Beckman Electromate pH meter in the laboratory. The probable error involved in determining the pH value is $\pm$ 0.10 considering analytical error and possible changes over time between field collection and laboratory analysis.

Bicarbonate (HCO_3^{-1}) was analyzed on the unacidified water samples, by titration for alkalinity with a standard HCl solution and a Beckman Electromate pH meter (after Brown et. al., 1970). The inflection point of the bicarbonate titration curve was then used to determine the titration endpoint (at approximately 4.5 pH). The bicarbonate concentration was then calculated, assuming bicarbonate is the only component of alkalinity. The probable error involved in determining the bicarbonate concentration is $\pm$ 3 percent, considering analytical error and possible

changes due to time.

Total iron (dissolved and suspended) was determined by colorimetry analysis with the Hach Chemical Company DR-EL chemical analysis kit, using the acidified water samples (Brown et. al., 1970). Final concentration values were determined after the initial values were adjusted for meter scale, reagent blank, and sample bottle corrections. The estimated precision error for iron is ± 3 percent.

Nitrate was analyzed on unacidified water samples using the Hach Chemical Company DR-EL unit. A cadmium-reduction method described by Brown et. al. (1970) was followed, according to instructions by Hach Chemical Company (1977). The initial nitrate values were also corrected in a similar fashion as those for iron to determine the final nitrate concentration values. The estimated precision error for nitrate concentrations is ± 10 percent.

Sulfate was determined using acidified water samples and the Hach Chemical Company DR-EL test kit (Hach Chemical Company, 1977). The turbidimetric method was used in this case, and after the tests were completed the initial concentrations were corrected in the same manner as for iron and nitrate. The estimated precision error for sulfate concentrations is ± 10 percent.

EDTA titration methods, modified after those described by the Hach Chemical Company (1973), were followed to determine the calcium and total hardness values for the acidified water samples. Hardness

was expressed as mg/l equivalents of dissolved calcium carbonate ($CaCO_3$). The estimated precision error for these chemical variables is $\pm$ 2 percent. The calcium concentration was then determined from the calcium hardness titration tests. Magnesium hardness was determined by subtracting the calcium hardness from total hardness values, and magnesium concentration was then calculated. It was assumed that only calcium and magnesium compose total hardness and that other alkali earth cations are negligible.

Chloride was analyzed for using the standard mercuric nitrate titration technique as outlined by the Hach Chemical Company (1973). Unacidified water samples were titrated with a standard $Hg(NO_3)_2$ solution. The estimated precision error for chloride concentrations measured in this study is $\pm$ 3 percent.

Sodium was analyzed for using an Evans Electoselenium Ltd. atomic absorption spectrophotometer (Brown et. al., 1970). NaCl standards were run before and after every five samples for calibration of the analysis technique. Unacidified water samples were used, and the estimated precision error for sodium concentrations is $\pm$ 5 percent.

A complete list of chemical variables for the analyzed waters is contained in Appendix B of this report.

DATA ANALYSIS

An exploratory data analysis, followed by appropriate statistical

tests, was conducted to investigate possible associations among the collected data. The author was specifically interested in determining what measured parameters might relate to water well yield, water well chemistry, and Devonian shale gas well yield. Several methods were used to detect possible association trends in the data. The exploratory analysis methods used involved visual data inspection, scattergrams, graphs, histograms, and 2x2 contingency tables.

Photolineaments were also considered with respect to statistical analysis. After the photolineaments were plotted on the appropriate maps, the proximity of each water well and gas well to the nearest photolineament was measured and recorded as was the photolineament class (see Appendicies E, F, and G). Statistical tests were then performed to determine the significance of any relationships of water well and gas well yields with photolineament proximity. Appropriate photolineament orientations were also recorded and later tested statistically for any significant associations with gas well yields. In addition to locating the short photolineaments on the appropriate 7 1/2 minute quadrangle maps, two photolineament density maps were constructed. The photolineament density maps depict class "1" photolineament density in miles per square mile, and N60°W-N30°E photolineament density in miles per square mile. The two photolineament density maps were constructed by placing a square-mile orthogonal grid overlay on the study area with grid lines parallel to the north-south and east-west

directions. The length of each photolineament in question was then measured, and the cumulative lineament length per square-mile section of grid was determined and plotted at the center point of each square-mile grid section. A total of 100 square-mile grid sections were considered. The center points of these grid sections were then hand contoured.

Nonparametric statistical tests were used to test for significant differences between sets of data which would indicate critical associations. These are "distribution free" tests and do not require many observations or samples. Also, few assumptions or criteria must be met by the data tested (Siegel, 1956). Two statistical tests were primarily used to test for differences between two sets of data - the Mann-Whitney U test, and the Yates-corrected chi-square test for two independent samples (Siegel, 1956).

Mann-Whitney U test

When at least ordinal data are involved, the Mann-Whitney U test may be used to test whether two independent groups of observations have been drawn from the same population. This is one of the most powerful of the nonparametric tests, and it is a most useful alternative to the parametric t test when one cannot meet the t test's assumptions, or when interval or ratio scale data are not available (Siegel, 1956).

Given two groups of observations from two populations, population

A and B, the null hypothesis (H_o) is that A and B have the same distribution. The alternative hypothesis (H_a) against which we test H_o is that A is stochastically larger than B, a directional hypothesis (Siegel, 1956). Next, ranks are assigned to each observation for the composite of both groups of observations, for a particular variable. Then H_a is tested to see if the observation ranks for the first group are significantly different from those of the second group. For group sample sizes greater than 20 the equations (from Siegel, 1956) for computing U are:

$$U = n_1 n_2 + \frac{n_1(n_1 + 1)}{2} - R_1 \tag{12}$$

$$U' = n_1 n_2 + \frac{n_2(n_2 + 1)}{2} - R_2 \tag{13}$$

where, R_1 = sum of the ranks assigned to the smaller group whose sample size is n_1; R_2 = sum of the ranks assigned to the larger group whose sample size is n_2.

The statistical significance of U or U', whichever is smaller, is then determined from the appropriate table (Siegel, 1956). Furthermore, as n_1 and n_2 increase in size, the sampling distribution of U rapidly approaches the normal distribution, and one may determine the significance of an observed value of U by calculating z (Siegel, 1956).

$$z = \frac{U - (n_1 n_2/2)}{\sqrt{\dfrac{n_1 n_2 (n_1 + n_2 + 1)}{12}}} \tag{14}$$

Tables provided by Siegel (1956) are used to determine the statistical significance of the observed z value. U' is calculated primarily to provide a check for the value of U; only U is used in determining the value of z.

Yates-Corrected Chi-Square Test

The Yates-corrected chi-square test is used for testing trends in observed frequencies of a 2x2 contingency table with respect to an H_o. The form of such a table is given in Table 2. The following formula is used to calculate the Yates-corrected chi-square value:

$$X^2 = \frac{N(AD - BC - N/2)^2}{(A+B)(C+D)(A+C)(B+D)} \qquad (15)$$

where, N = the total sample size; A, B, C, and D = observed cell frequencies (see Table 2). This formula has the additional advantage of incorporating a correction for continuity which makes this a conservative test and markedly improves the approximation of the computed X^2 values by the chi-square distribution (Siegel, 1956).

For each of the many tests run using either the Mann-Whitney U or the Yates-corrected chi-square test, the 0.05 alpha probability value was considered the upper limit for statistical significance for calculated error probabilities. However, other less significant probability results were often useful for interperting some data trends. The results of these statistical tests are presented under the RESULTS AND DISCUSSION section.

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TABLE 2

2x2 CONTINGENCY TABLE

Variable Tested

	Low	High	
Data Group I	A	B	A + B
Data Group II	C	D	C + D
	A + C	B + D	N

Key:

A, B, C, and D represent cell frequencies or number of observations corresponding to the four data classifications.

RESULTS AND DISCUSSION

LINEAMENTS

Lineaments were mapped and are plotted on Figure 6, both for Landsat and short photolineaments. Landsat lineaments are located primarily in the western and southwestern portion of the study area. Short photolineaments are more abundant and more evenly distributed throughout the area.

The geophysical resistivity survey was performed over a photolineament to determine the presence of any underlying fracture zones. Figure 3 shows the location of the short photolineament and perpendicular electrical resistivity survey line (A-A'). The overall setting of Figure 3 is also indicated on Figure 6. Figures 7 and 8 show the plotted resistivities and delta percent curves respectively. The most distinct features of the survey plots are the CCPP peaks and trough between stations 3 and 5 of Figure 7, and the delta percent peak centered about stations 3 and 4 of Figure 8. Kirk (1976) defined this type of resistivity display as being typical of the effect of a positive resistivity contrast created by an anomaly associated with a fracture trace, where fracture resistance exceeds rock resistance. This is logical since the photolineament is located within the dominantly shale lithologies of the area; the introduction of relatively dilute ground water into fracture porosity in shale would replace more

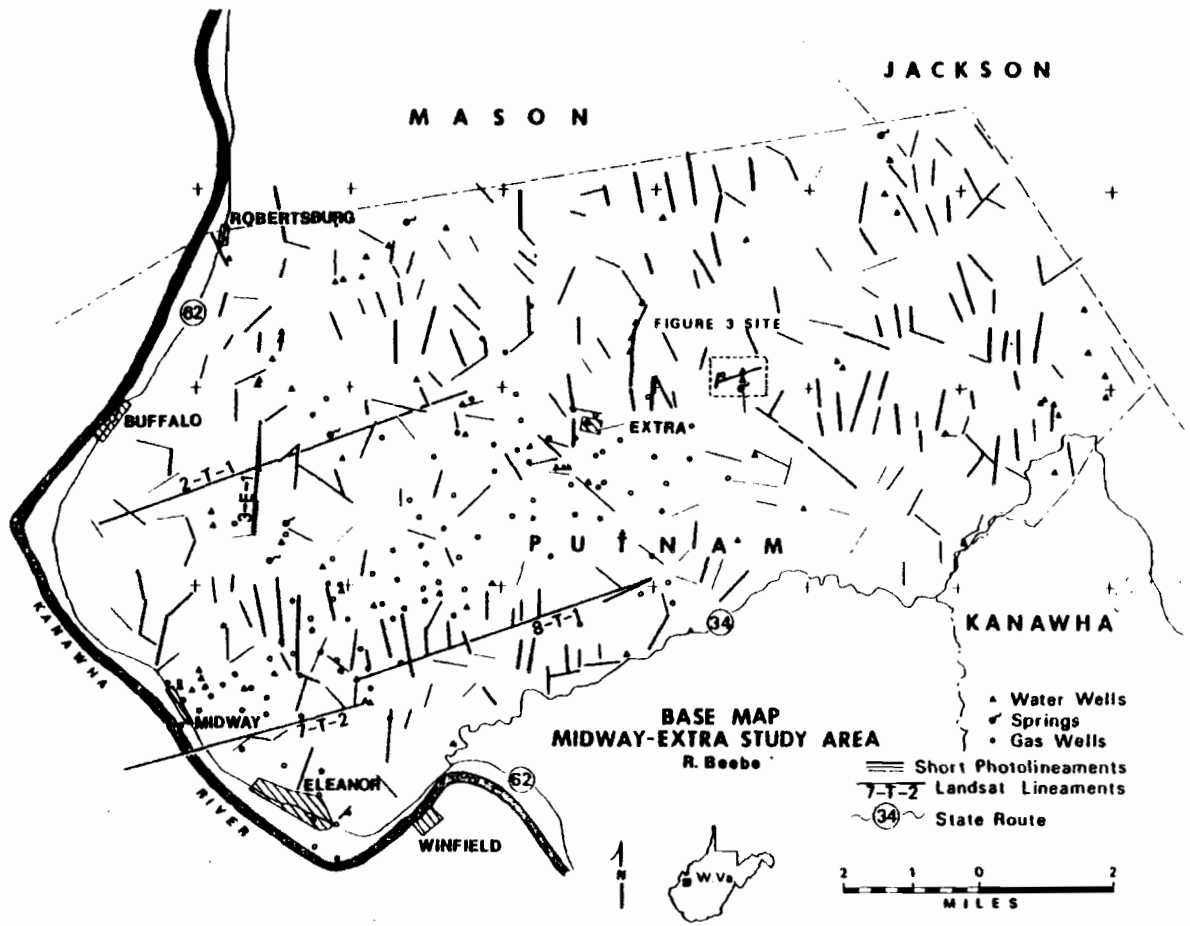

Figure 6 Base map of Midway-Extra study area, showing locations of wells and lineaments.

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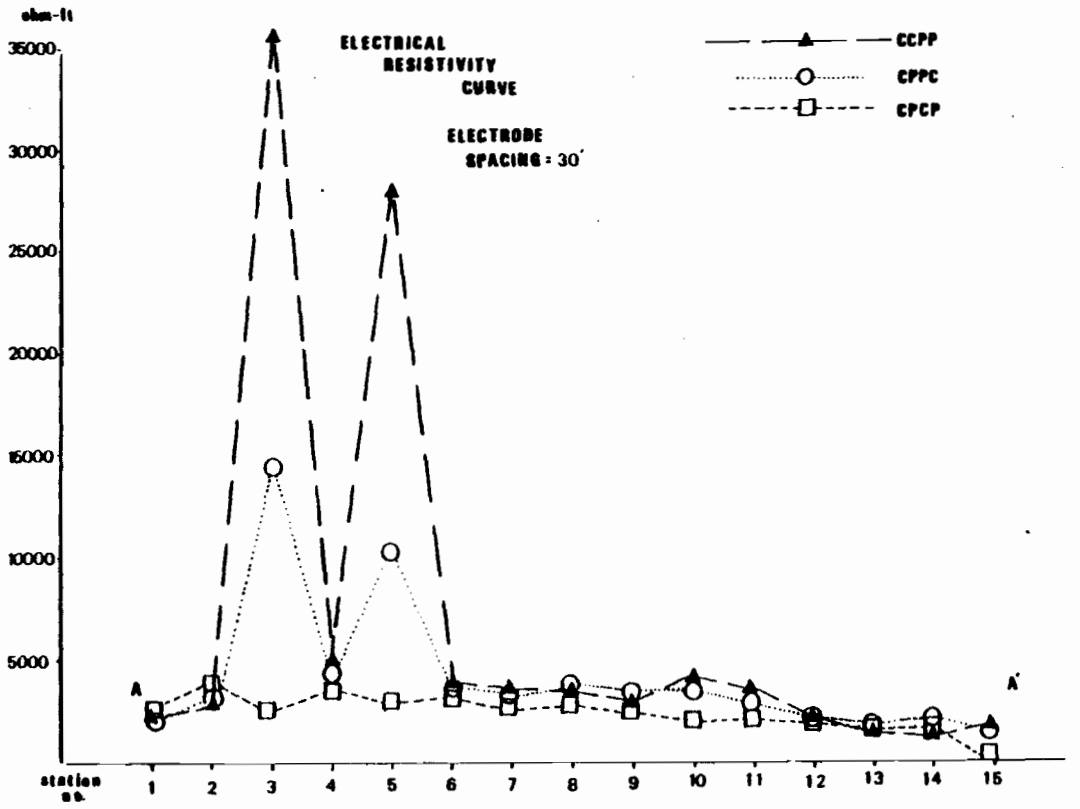

Figure 7 Resistivity plots from electrical resistivity survey of the Midway-Extra study area. The station numbers are spaced 30 feet apart.

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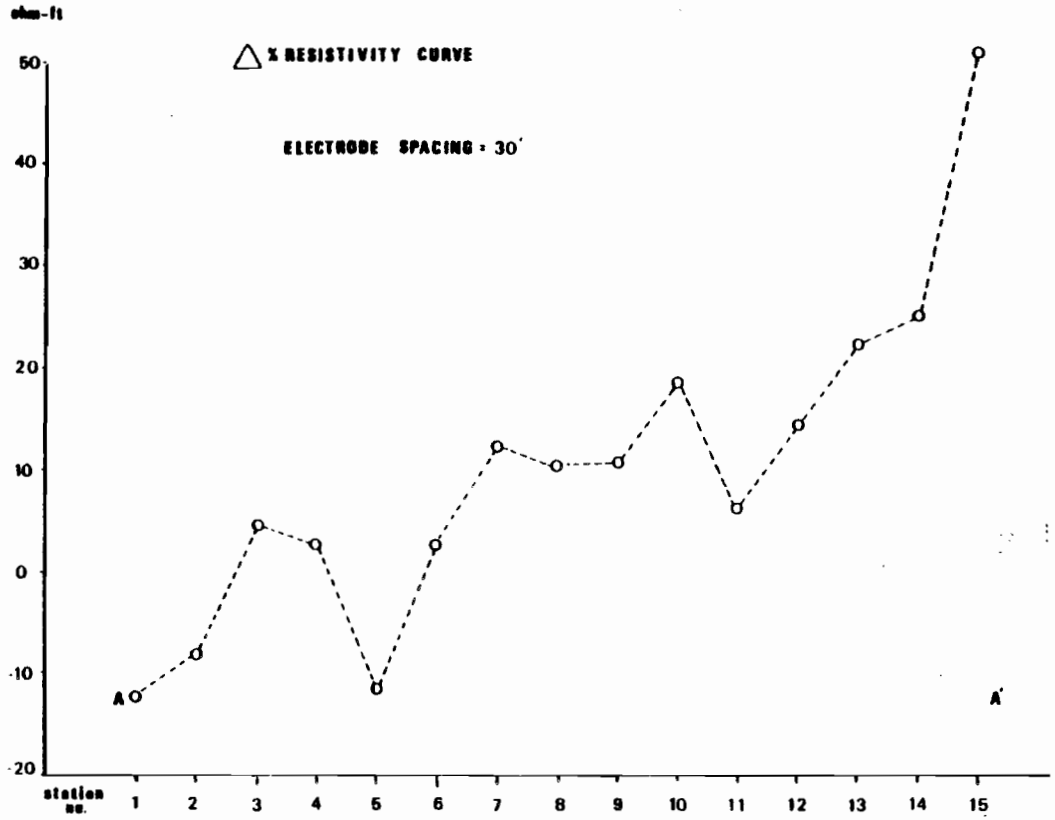

Figure 8 Delta percent plot from electrical resistivity survey for the Midway-Extra study area.

conductive ground water in the surrounding rock, creating a positive resistivity anomaly (Kirk, 1976). The relatively large positive response of the delta percent curve near station 4 of Figure 8 indicates that the probable fracture zone extends to a depth of at least 30 feet. However, no definite determination of the depth can be made since only one electrode spacing survey was run across the fracture zone (Kirk, 1976). The combined plots of Figures 7 and 8 tend to indicate the presence of a fracture zone centered near station 4, with a zone of influence of at least 60 feet in total width (Kirk, oral communication, 1979).

Although electrical resistivity surveys may be useful in locating and confirming surface fracture zones, factors reducing the usefulness of these surveys include topographic, lithologic, and ground-water storage variations as well as improper spacing of the electrodes. One or more of these factors could lead to an incorrect interpretation of the subsurface. For this reason, electrical resistivity surveying alone should not be relied upon to predict subsurface features. However, electrical resistivity surveying was useful in interpretating the subsurface nature of one photolineament in the study area.

WATER WELL YIELD ASSOCIATIONS

Water well yield data and other physical water well data are located in Appendix A of this report. Physical water well data were

collected for 74 domestic water wells and 7 springs in the study area. Reported depths of sampled water wells range from a minimum of 30 feet to a maximum of 300 feet, with a median depth of 140 feet. Reported depths to water varied from 4 feet to 154 feet with a median depth of 35 feet. Approximately 32 percent of the inventoried wells are located in valleys, with 43 percent located on hills, and the remaining 25 percent located on hill slopes. Generally, water well yields of the area are considered to be low with a median yield of about 1.0 gallons per minute (gpm). Inventoried well yields range from a high of 20.0 gpm to a low of 0.0 gpm. Median gpm yield values, obtained from the previously mentioned adequacy ranking technique, were assigned to wells without known gpm yield data. Specific capacity and aquifer transmissivity data are available for two wells in the study area and are contained in Appendix H of this report.

Lineament Proximity

Nonparametric statistical tests were performed to determine if any associations exist between water well yield (gpm) and water well proximity to the nearest lineament. Both Landsat lineaments and short photolineaments were investigated for associations with water well yield.

Landsat Lineaments

Only 6 water wells from the study area are located within a

distance of 2000 feet of a Landsat lineament. Water well yields were tested statistically for less than versus greater than specific distances from such lineaments. The distances tested were 500, 1000, and 2000 feet. The statistical tests show that wells located within 2000 feet of a Landsat lineament do not yield water at significantly different rates than wells beyond 2000 feet of such lineaments in the study area. Furthermore, no significant differences exist for yields of water wells within 500 and 1000 feet of such Landsat lineaments, compared to more distant wells. Whatever the reason for these non-associations, Landsat lineaments are distinctly different from short photolineaments in both appearance and effect.

Short Photolineaments

The Mann-Whitney U test was performed to test the effect of short photolineament proximity on water well yield. The test was performed for wells greater than versus less than a specific distance from the nearest photolineament, as indicated on Figure 6. The specific proximity distances tested were 100, 150, and 200 feet. Too few wells were located within 50 feet of a photolineament to warrant statistical analysis. Results of these tests are given in Table 3. The symbols H and L are used in these Mann-Whitney U test tables to indicate high and low median values.

It was found that photolineaments are excellent locations for high-

TABLE 3

WATER WELL PROXIMITY TO PHOTOLINEAMENT
VERSUS
WATER WELL YIELD

well proximity to
nearest photolineament

	≤ 100 feet	>100 feet	Probability of error
No. of wells in each class	6	65	
Median well yield (gpm)	12.5	1.0	
Mann-Whitney U Results (1-tailed)	H	L	0.0102

well proximity to
nearest photolineament

	≤ 150 feet	>150 feet	Probability of error
No. of wells in each class	9	62	
Median well yield (gpm)	12.5	1.0	
Mann-Whitney U Results (1-tailed)	H	L	0.0057

TABLE 3 (continued)

WATER WELL PROXIMITY TO PHOTOLINEAMENT
VERSUS
WATER WELL YIELD

well proximity to
nearest photolineament

	≤200 feet	>200 feet	Probability of error
No. of wells in each class	19	52	
Median well yield (gpm)	4.0	1.0	
Mann-Whitney U Results (1-tailed)	H	L	0.0015

well proximity to
nearest photolineament

	150-200 feet	>200 feet	Probability of error
No. of wells in each class	10	52	
Median well yield (gpm)	2.0-4.0	1.0	
Mann-Whitney U Results (1-tailed)	H	L	0.0329

well proximity to
nearest photolineament

	<150 feet	150-200 feet	Probability of error
No. of wells in each class	9	10	
Median well yield (gpm)	12.5	2.0-4.0	
Mann-Whitney U Results (1-tailed)	H	L	>0.05 (not significant)

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yielding water wells. The optimum zone of influence for photolineaments is approximately 400 feet wide. Water wells located within 200 feet of a plotted photolineament's center line have significantly higher yields than more distant wells, at a 0.01 alpha probability level. Median yields of wells 150-200 feet of a photolineament center line are less than median yields of wells 0-150 feet from such center lines, but significantly more than wells located greater than 200 feet from these center lines. Within 200 feet of a photolineament center line there are no significant changes in well yield as the center line is approached, at a 0.05 alpha probability level; however, water well yields do tend to increase as the center line of a plotted photolineament is approached. The higher yields for water wells located within 200 feet of a short photolineament are most likely the result of high fracture permeabilities associated with fracture zones.

Other Physical Features

Aspects of hydrogeologic setting, other than lineament proximity, were tested for possible associations with water well yield. The factors tested include topographic setting, stream proximity, and aquifer sequence.

Topographic setting shows a significant effect on water well yields within the 0.05 alpha probability level determined by the Mann-Whitney U test, with test results shown in Table 4. Yields are

TABLE 4

WATER WELL YIELD VERSUS TOPOGRAPHY

	Slope	Hill	Valley	Probability of error
No. of wells in each class	18	31	23	
Median well yield (gpm)	1.0	0.8	5.0	
Mann-Whitney U results (1-tailed)	L		H	0.0329
	H	L		0.0307
		L	H	0.001

WATER WELL YIELD VERSUS STREAM PROXIMITY

	well proximity to nearest stream		
	0-200 feet	>200 feet	Probability of error
No.of wells in each class	22	49	
Median well yield (gpm)	1.0-1.7	1.0	
Mann-Whitney U results (1-tailed)	H	L	0.0024

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significantly higher for wells in valleys when compared with yields from water wells located on hilltops, at a 0.001 alpha probability level; median water well yields for valley wells are six to seven times greater than those for hilltop wells. Furthermore, hillside-slope yields are significantly greater than hilltop yields at a 0.05 alpha probability level. Valley water well yields are also significantly greater than hillside-slope well yields at a 0.05 alpha probability level. The effect of well proximity to a stream on well yield was also tested, with test results shown in Table 4. Water wells located within 200 feet of a stream have significantly higher yields than more distant wells, according to Mann-Whitney U test results at a 0.01 alpha probability level.

Higher water well yields indicated for valley wells, and especially for wells within 200 feet of a stream, can be explained by the fact that: (1) the recharge area is larger for valley wells than for hilltop or slope wells; (2) the water table is generally closer to the surface in valleys; (3) valleys tend to be more greatly weathered with greater aquifer permeabilities resulting; and (4) recharge from streams may occur for nearby wells (Davis and DeWiest, 1966).

The majority of water wells located within 200 feet of a photo-lineament occupy low topographic positions. Statistical tests were performed to determine if a photolineament's effect on water well yield was strictly a function of topography. The Mann-Whitney U test was

used to determine if any significant relationships exist between increased well yield and short photolineament proximity for valley wells only. The specific distances tested were 100 and 200 feet, and the results of these tests are contained in Table 5. Median well yield differences tend to indicate that valley wells located near photolineaments do yield more on average than other valley wells, but they do not yield significantly more. These results tend to indicate that a photolineament's observed effect on water well yield is not strictly a function of topography.

Of the 69 water wells for which aquifer sequence could be determined, 28 wells are located in the Dunkard Group and 41 wells are located in the Monongahela Group. Yields from water wells located within the aquifer sequences shown in Figure 5 were statistically tested for possible significant differences in well yield as a function of aquifer sequence. Table 6 contains the results of these tests. Aquifer sequences 1 and 4 were excluded from testing because they contain too few wells for proper tests. No significant differences are apparent between the six aquifer sequences tested against aquifer sequence number 6, the highest-yielding sequence, at a 0.05 alpha probability level. Included in aquifer sequence 6 is the Waynesburg Sandstone; median well yields tend to indicate that this unit is the best aquifer for most of the study area. Possible reasons for the importance of rock sequence 6 as an aquifer unit are: (1) the lateral continuity of

TABLE 5

WATER WELL PROXIMITY TO PHOTOLINEAMENT

VERSUS

VALLEY WATER WELL YIELD

valley well proximity to nearest photolineament

	0-100 feet	>100 feet	Probability of error
No. of wells in each class	5	18	
Median well yield (gpm)	12.5	1.0-5.0	
Mann-Whitney U results (1-tailed)	H	L	>0.05 (not significant)

valley well proximity to nearest photolineament

	0-200 feet	>200 feet	Probability of error
No. of wells in each class	11	12	
Median well yield (gpm)	12.5	1.0-5.0	
Mann-Whitney U results (1-tailed)	H	L	>0.10 (not significant)

TABLE 6

WATER WELL YIELD VERSUS AQUIFER SEQUENCE

	Aquifer Sequence Number							
	2	3	5	6	7	8	9	Probability of error
No. of wells in each class	8	10	4	17	7	8	8	
Median well yield (gpm)	0.0-0.8	0.6	0.8-1.6	1.8 17.0	2.0-7.0	1.0	0.8	(all tests non-significant)
Mann-Whitney U results (1-tailed)	L			H				>0.05
		L		H				>0.05
			L	H				>0.05
				H	L			>0.05
				H		L		>0.05
				H			L	>0.05

the Waynesburg Sandstone throughout the study area; (2) a lower stratigraphic position for the Waynesburg Sandstone than for the majority of sandstone lithologies in the stratigraphic column; and (3) a thick sequence of shales interstratified with thin sandstone beds underlying the Waynesburg Sandstone in sequence 6, increasing the possibility of multiple aquifers within this sequence.

GROUND WATER CHEMISTRY

Ten water chemistry variables were measured for 32 tested water wells and springs to determine if any important chemical trends or associations are present that might aid in exploration for ground water or Devonian shale gas in the Midway-Extra study area. The water chemistry parameters analyzed were concentrations of total iron, chloride, total hardness, calcium, magnesium, bicarbonate, sulfate, and sodium, as well as pH and specific conductance; data for these sampled wells are located in Appendix B. These water chemistry variables were selected because they represent the major chemical parameters of ground water, and they are relatively inexpensive and easy to analyze. The following is a brief report on each water chemistry variable, including its sources and general nature of occurrence in ground water.

Nitrate

Nitrate was selected for analysis because of its role in indi-

cating pollution from surface contaminants such as sewage or nitrogen fertilizers (Hem, 1970). Also, nitrate was shown to be significantly associated with increased gas well yield in the Cottageville, West Virginia area by Jones and Rauch (1978a).

In this study, nitrate did not exceed the maximum recommended level of 45 mg/l recommended by the United States Public Health Service (1962). The maximum concentration observed occurred in well WI-59 which had 13.6 mg/l nitrate. The data suggest that although high concentrations of nitrate are not common it is a persistent water quality parameter. Nitrate concentrations that are noticeably above background values for this study area (above about 5 mg/l) may well indicate ground-water pollution; this occurs for wells BA-5, WI-9, EL-45, BA-55, and WI-59.

In this study, the highest concentration of nitrate occurred in well WI-59. At the time of sample collection the owner was in the process of relocating his septic tank. His septic system had been located approximately 100 yards directly uphill from the water well. Domestic sewage may have contributed nitrate to the ground-water system. The organic portion of sewage is a source of ammonium ions which is oxidized to form nitrate (Hem, 1970). As nitrate is easily leached from the soil, and readily permeates an aquifer, the high nitrate concentration of well WI-59 may be the result of domestic sewage pollution. The probable sources of high-nitrate values for the remaining wells

could not be determined from field observations, however.

Total Iron

Iron is an abundant and widespread constituent of rocks and soils. Dissolved iron in excess of 0.3 mg/l is objectionable in water for it causes reddish-brown stains on clothing, utensils, and plumbing fixtures (Johnson, 1975).

In the study area, pyritic shales and pyrite in coal seams are probably responsible for significant amounts of iron in sampled ground water. Iron concentrations (for dissolved and colloidal iron combined) vary from 0.04 to 11.20 mg/l for sampled well waters. In this study, the highest concentration of total iron occurred in well WI-8. The owner of this well has reported that a coal seam was encountered during drilling of the well. Seven of the 32 sampled wells have iron contents exceeding 0.3 mg/l. Five of these wells are located in aquifers of the Monongahela Group which reportedly has more coal than the Dunkard Group; this possibly accounts for the high total iron values of these wells.

Sodium and Chloride

Chloride occurs as Cl^- in solution and is present in all natural waters. Sodium is generally in the form of the Na^+ ion (Hem, 1970). The most likely sources for Cl^- and Na^+ in well waters are: (1) connate brines trapped during marine sedimentation; and (2) road salts infil-

trating into the ground-water system from the surface (Davis and DeWiest, 1966).

Three study area wells (RO-24, RO-26, and WI-58) have excessive chloride concentrations (over 250 mg/l), according to U.S.P.H.S. (1962) standards. These same wells have the highest sodium concentrations of those studied, and are in general located in lower Monogahela Group rocks, and in low-elevation areas (with elevations not exceeding 610 feet). Upconing of connate marine brines that were trapped during marine sedimentation is the single most probable source of the high chloride and sodium concentrations for these three wells.

Total Hardness, Calcium and Magnesium

Hardness is a qualitative term representing the soap-consuming capacity of water. The greater the amount of alkaline earth metals dissolved in water, of which calcium and magnesium are the most important, the greater is the amount of soap required to overcome the complexing action of hardness ions. Hardness is expressed in terms of an equivalent concentration of calcium carbonate (Hem, 1970). In the tabulated data "Total Hardness" represents the sum of calcium and magnesium hardness. Calcium and magnesium occur as Ca^{++} and Mg^{++} cations in water (Hem, 1970).

Most dissolved calcium and magnesium are probably derived from the dissolution of carbonate-bearing cement or thin limestone

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units in rock strata of the study area. Calcareous shales also constitute a major source of calcium and especially magnesium to ground water (Hem, 1970). The two highest total hardness wells (greater than 400 mg/l as $CaCO_3$) are located in aquifer sequences 2 and 3. This seems logical since sequence 2 is largely composed of calcareous shale. The well located in sequence 3 may quite possibly be obtaining high total hardness concentrations from sequence 2.

Bicarbonate

There are two important sources of bicarbonate in natural ground waters. Dissolved bicarbonate (HCO_3^-) may originate directly or indirectly from the dissolution of carbonate bearing rocks or minerals (especially in carbonic acid), and from the decay of organic matter (hence H_2CO_3). These sources are shown by equation (16):

$$CaCO_3 + H_2CO_3 \rightleftharpoons Ca^{++} + 2HCO_3^- \qquad (16)$$

Ten of 14 wells with bicarbonate concentrations exceeding 400 mg/l are located in aquifers of the Monongahela Group. Wilmoth (1966) described both the Dunkard and Monongahela group waters as being of the sodium and calcium bicarbonate type. A third probable source of bicarbonate relating to methane gas will be discussed later.

Sulfate

The most common form of sulfate under normal Eh conditions is the $SO_4^{=}$ ion (Hem, 1970). Pyrite (FeS_2), a major source of sulfate in ground water, can occur in all lithologies present in the study area but is primarily associated with coal (Hem, 1970). When pyrite weathers as a result of contact with aerated ground water, the sulfide mineral is oxidized to yield sulfate ions. This is probably the reason for the high sulfate (and total iron) concentration of well WI-8, mentioned earlier with respect to "total iron".

Excessive sulfate concentrations greater than the recommended value of 250 mg/l (U.S.P.H.S., 1962) can corrode plumbing fixtures and act as a laxative (Hem, 1970). However, sulfate does not usually create any serious health problems. The maximum sulfate content for sampled well waters was 145 mg/l. No adverse effects should be present due to sulfate in ground waters of the study area.

Specific Conductance

Specific conductance represents the total effect of all dissolved ions in ground water, and it is proportional to total dissolved solids. Specific conductance values greater than 750 micro-mhos/cm indicate excessive dissolved solids according to the U.S.P.H.S. (1962) standards, and Hem (1970). Specific conductance ranged from 85 to 6025 micro-mhos/cm in ground waters of the study area. High specific conductance values

are associated with high dissolved NaCl contents, or with high total hardness or bicarbonate concentrations. Most wells with very high conductances (over about 1000 micro-mhos/cm) are located in valleys and are characterized by excessive dissolved NaCl, especially well WI-58. The most likely source of the poor water quality for these wells is upconing of connate marine brines in response to water well pumping.

pH

Values of pH for ground water in the study area range from 5.80 to 8.13. These values are all of acceptable quality. Differences in pH reflect variations in the lithology and mineralogy of rocks located near the well and aquifer. Pyrite and carbonate minerals probably have the greatest potential to affect pH values in the study area. Pyrite reacts to give off H^+ ions into solution when in contact with aerated water, effectively lowering the pH value of water; carbonate-bearing rocks in contact with ground water react to release bicarbonate, effectively raising pH values. The values of pH were determined in the laboratory only, and may differ slightly from the original field pH values because of a 24 hour delay in laboratory measurement.

TRENDS IN GAS YIELD

Initial open flow refers to gas production prior to fracturing of the gas producing horizon. Final open flow refers to gas production after fracturing of the producing horizon. No standard procedure for measuring these flows is believed to have been followed; although somewhat suspect, these flow values are the best that are available. Both initial and final open flows were used in the statistical analysis of possible associations between Devonian shale gas well yield and hydrogeologic setting. When this study began, it was intended that only initial open flow data be used. The assumption was that initial open flow would more nearly represent the geologic environment of the gas producing portion of the study area. However, Schaefer (oral communication, 1979), who has done extensive work on the producing characteristics of the Midway-Extra gas field, asserts that final open flow is a more dependable and representative measure of gas production rate with respect to geologic controls. Furthermore, he suggests that final open flow is more representative of the commercial success for gas wells and of productivity from gas reservoirs. For this reason final open flow gas production was considered with respect to possible associations with lineaments and hydrogeologic parameters. Initial and final open flow for gas wells are in Appendix C of this report and are from Schaefer (1979).

Figure 9 shows the locations of Devonian shale gas wells in the

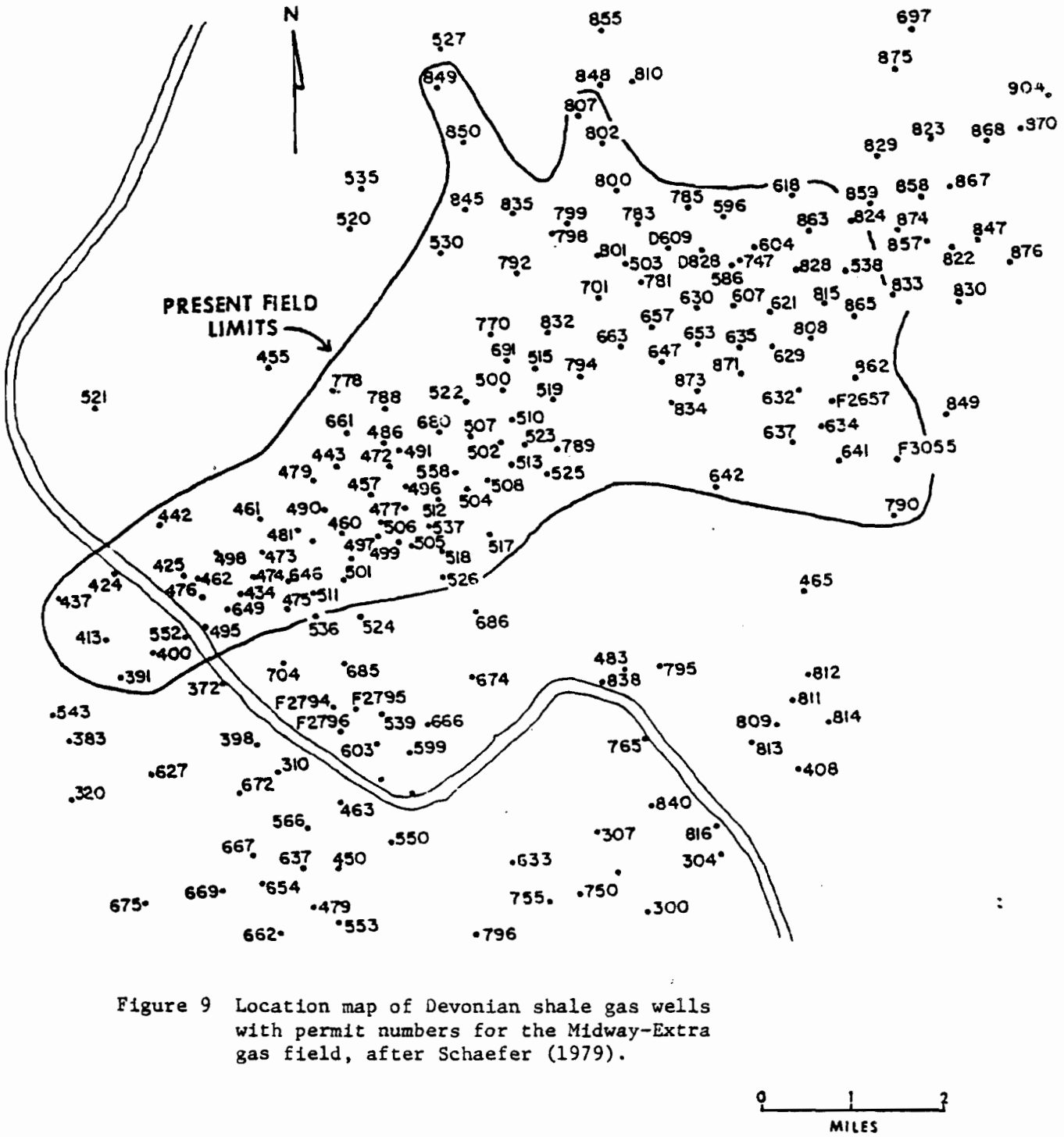

Figure 9 Location map of Devonian shale gas wells with permit numbers for the Midway-Extra gas field, after Schaefer (1979).

Midway-Extra gas field. Figure 6 shows the location of Devonian shale gas wells, domestic water wells, Landsat lineaments, and short photo-lineaments in the study area. Figure 10 shows a polygonal area defining the Midway-Extra gas field portion of the study area. The polygonal area was constructed for the purpose of delineating the area to be tested in the statistical analyses for possible lineament-hydrogeologic trends with gas well yield. The polygonal boundaries were constructed by connecting the outermost gas well locations in the study area as shown. The 8 gas wells shown outside the polygonal area of Figure 10 were not considered because they are outside the defined limits of the Midway-Extra gas field (Schaefer, 1979). Other wells of Figure 9 were excluded from the polygonal area of Figure 10 because they either lacked production data or lay outside the limits of the study area.

Figure 11 shows contoured initial open flow for the study area, and Figure 12 shows final open flow contoured for the study area. Both initial and final open flow contour trends are expressed in terms of thousands of cubic feet of gas per day (MCF/day). The contours were drawn assuming that the changes in gas flow rate would be linear between adjacent wells. The position and trend of the contours are therefore partly a function of gas well density; contours in areas of low gas well density are probably optimistic in their prediction of shale gas reserves.

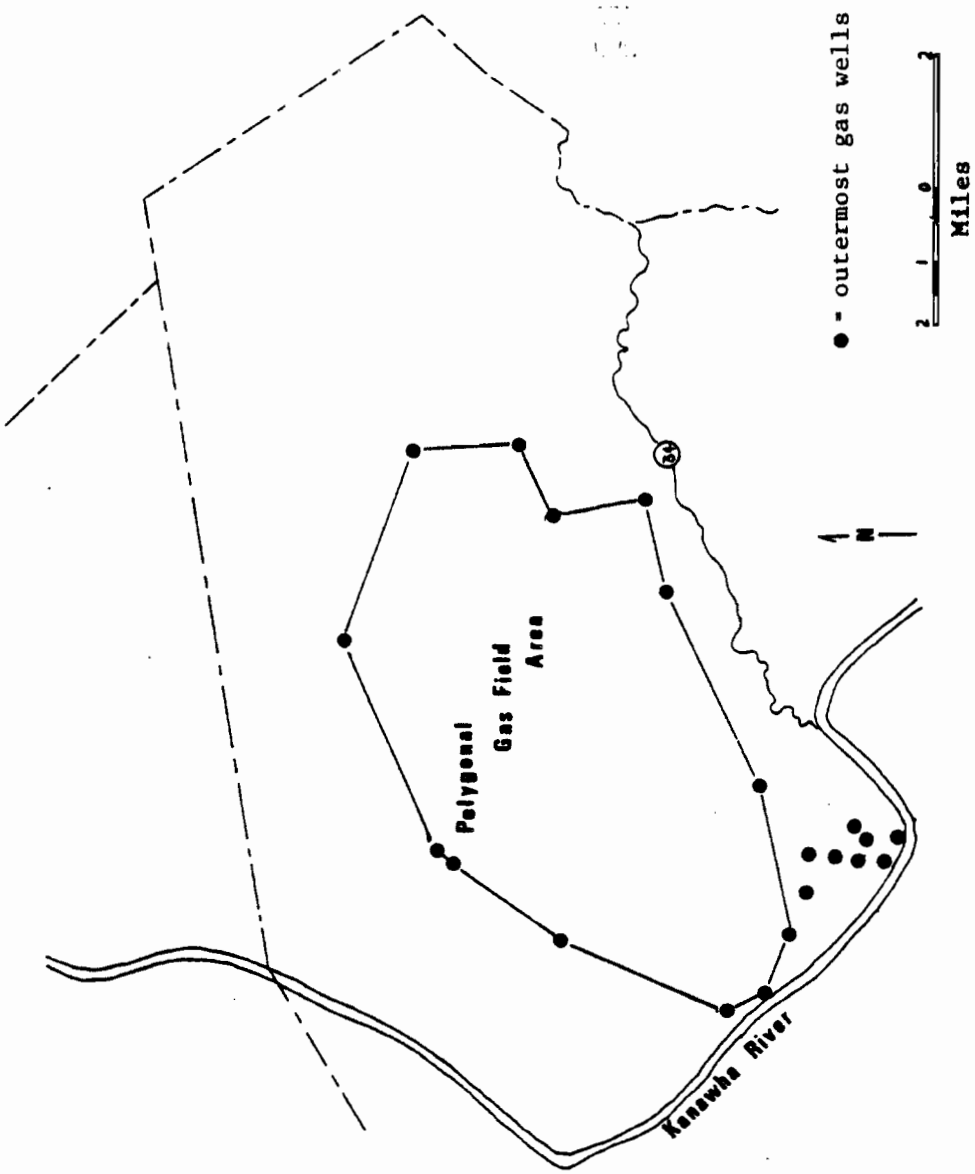

Figure 10 Polygonal gas field area, used to define the Midway-Extra gas field within the study area.

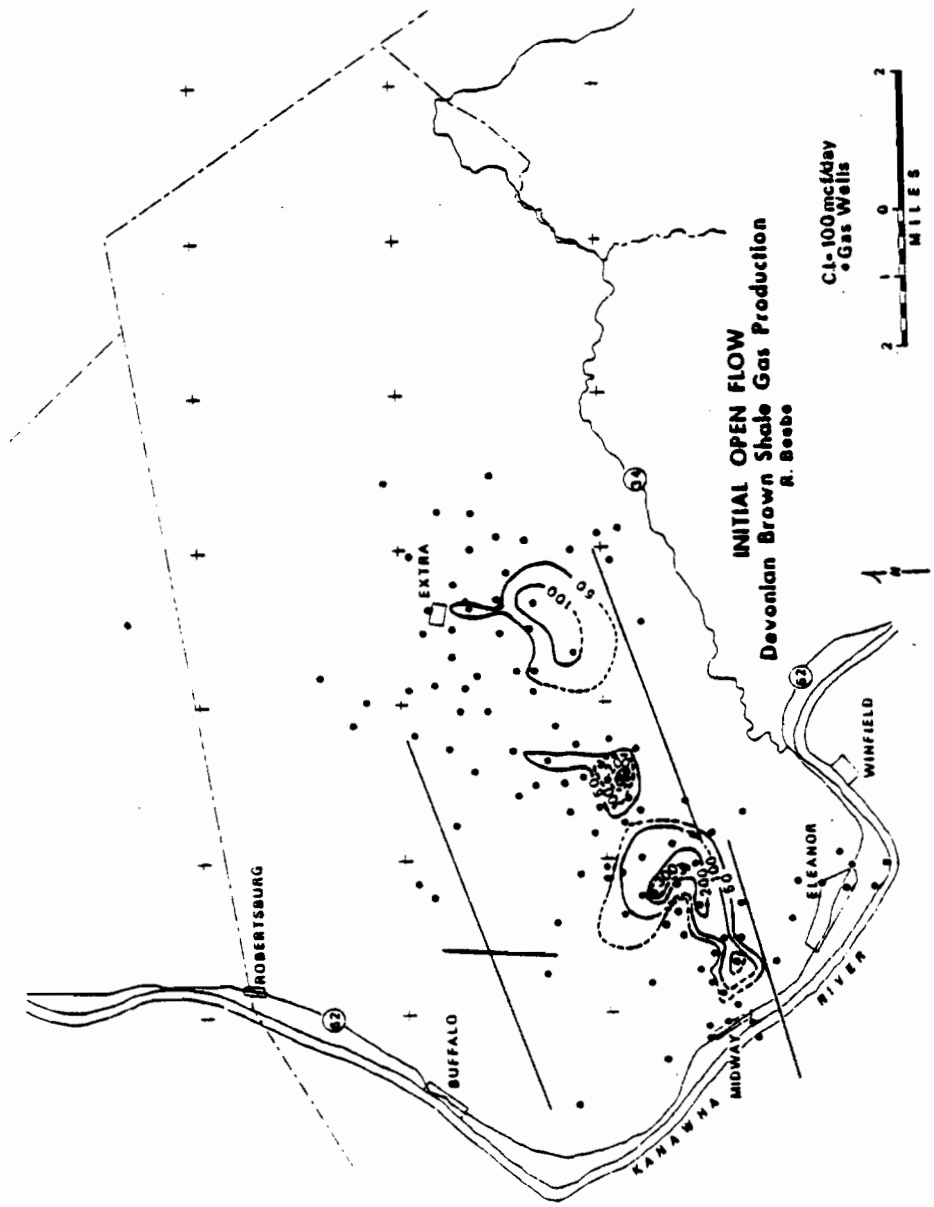

Figure 11 Initial open flow gas production for Devonian shale wells in the study area.

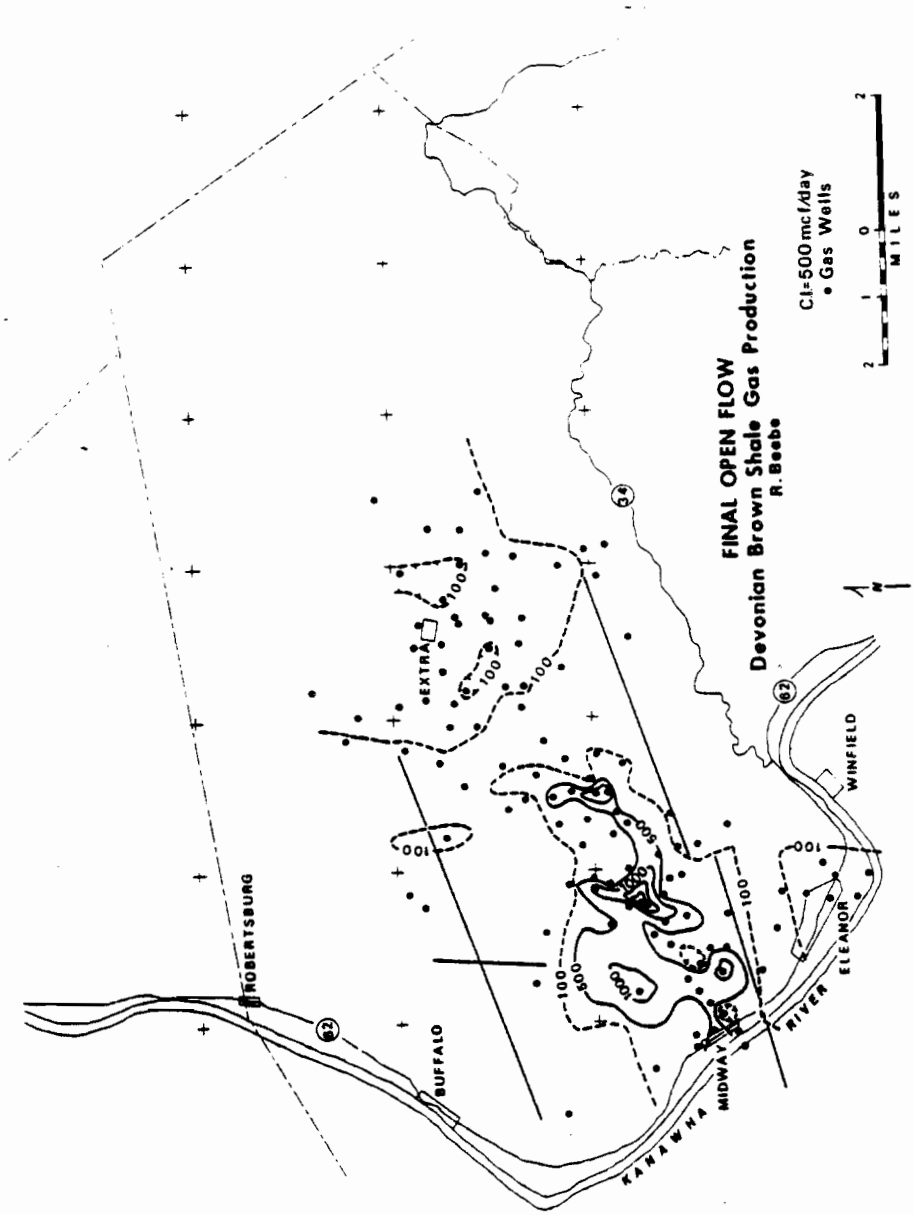

Figure 12 Final open flow gas production for Devonian shale wells in the study area.

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LINEAMENT ASSOCIATIONS WITH GAS WELL YIELD

Landsat Lineaments

The effect of Landsat lineaments was considered with respect to initial and final open flow gas production for the Midway-Extra study area. In addition to contoured production trends, Figures 11 and 12 show locations of Landsat lineaments. These figures show that Landsat lineaments do not intersect high-producing areas of the gas field, but rather appear to bound these areas to the north and south, and are generally parallel to the general gas-producing trend. As suggested by Werner (1977a), perhaps these lineaments represent deeply-penetrating fractures that have bled off Devonian shale gas to the surface. In the Midway-Extra area Landsat lineaments are poor locations for Devonian shale gas wells, and are to be avoided. Werner (1977a), and Jones and Rauch (1978a) have indicated in these studies that Landsat lineaments are associated with poor-yielding gas wells in the Cottageville area.

Photolineaments by Orientation

Short photolineaments were next tested for possible associations with initial and final open flow gas production data within the study area. Appendices F and G contain initial and final open flow gas well yields, as well as the orientation, proximity,

and class of the nearest short photolineament for each gas well with production data.

Initial open flow gas well yield is higher for wells near a photolineament, but the association is not a strong one. It was therefore decided to test gas well yield against photolineament orientation. Figure 13 shows plots of initial open flow gas well yield versus photolineament orientation. Median trends for 30° classes, shown in Figure 13, indicate that photolineaments oriented N60°W-N30°E are associated with higher average gas well yields than are photolineaments of other orientations. Statistical test results of Table 7 indicate that gas wells located near photolineaments oriented N60°W-N30°E are relatively high producers when compared to wells located near photolineaments of other orientations. This association is statistically significant at a 0.05 alpha probability level. Short photolineaments bearing N60°W-N0°W show a somewhat less certain association with initial open flow gas well yield, while N0°E-N30°E oriented photolineaments are not significantly associated with open flow at the 0.10 alpha probability level. These results indicate that N60°W-N30°E oriented photolineaments, representing approximately 61 percent of the photolineaments within the gas field, are significantly associated with increased initial open flow gas well yield. However, subdivisions of this optimum 90° photolineament class do not show strong associations with initial open flow, and are not useful.

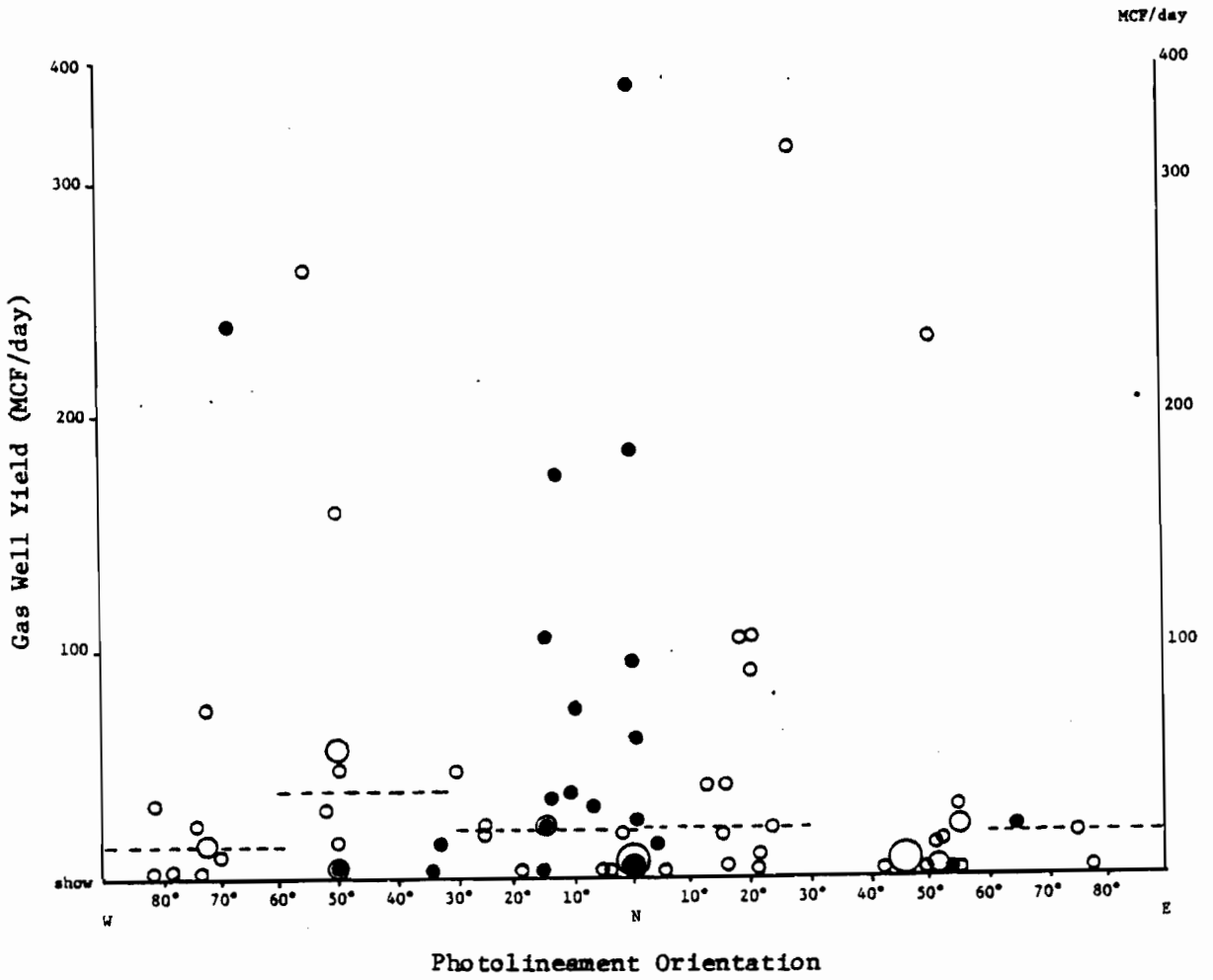


Figure 13 Plots of initial open flow gas well yield (in MCF/day) versus orientation of the nearest photolineament to a gas well. Solid dots indicate class "1" photolineaments, larger dots indicate more than one well.

TABLE 7

INITIAL OPEN FLOW GAS WELL YIELD VERSUS PHOTOLINEAMENT ORIENTATION

(Measured to nearest photolineament)

Photolineament Orientation

	N60°W-N30°E	Others	Probability of error
No. of wells in each class	46	30	
Median well yield (MCF/day)	21-24	14-15	
Mann-Whitney U results (1-tailed)	H	L	0.026

	N60°W-N0°W	Others	Probability of error
No. of wells in each class	35	41	
Median well yield (MCF/day)	24	15	
Mann-Whitney U results (1-tailed)	H	L	0.078

	N0°E-N30°E	Others	Probability of error
No. of wells in each class	21	55	
Median well yield (MCF/day)	21	18	
Mann-Whitney U results (1-tailed)	H	L	0.179 (not significant)

Final open flow is higher on the average for wells near a photolineament, but the relationship appears not to be strong. Photolineament orientation was also investigated for stronger associations with final open flow. Figure 14 shows plots of final open flow gas well yield versus photolineament orientation. Again, median yields are greatest for the three photolineament orientation classes between N60°W-N30°E. Short photolineaments bearing N60°W-N30°E and N60°W-N0°W were tested to see if the same associations for initial open flow also show up for final open flow data. Table 8 shows the Mann-Whitney U tests for photolineament orientation by final open flow; gas wells located nearest photolineaments oriented N60°W-N0°W are on the average relatively high producers. This is a statistically significant association, at the 0.05 alpha probability level. Short photolineaments oriented N60°W-N30°E show a somewhat less certain relationship to increased final open flow, that would be significant at a 0.10 alpha probability level. The tests of Table 8 indirectly indicate that N0°E-N30°E oriented photolineaments are not so important with respect to increased final open flow as are N60°W-N0°W oriented photolineaments. Approximately 42 percent of the photolineaments in the gas field area are oriented N60°W-N0°W.

Photolineament Proximity

Initial open flow gas well yield was compared with the proximity

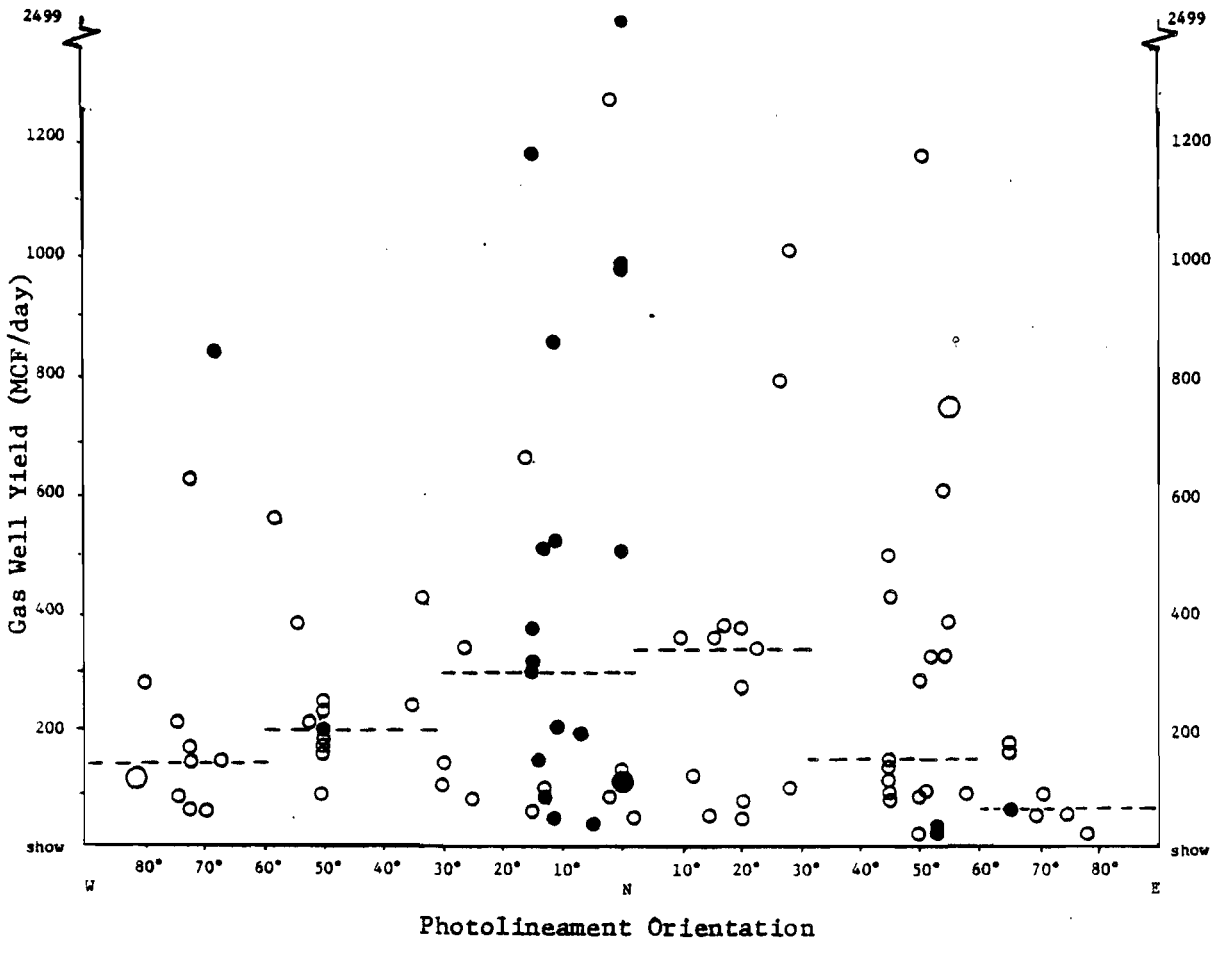


Figure 14 Plots of final open flow gas well yield (in MCF/day) versus orientation of the nearest photolineament to a gas well. Solid dots indicate class "1" photolineaments; larger dots indicate more than one well.

TABLE 8

FINAL OPEN FLOW GAS WELL YIELD VERSUS PHOTOLINEAMENT ORIENTATION

(Measured to nearest photolineament)

Photolineament Orientation

	N60°W-N0°W	Others	Probability of error
No. of wells in each class	40	56	
Median well yield (MCF/day)	202-207	146	
Mann-Whitney U results (1-tailed)	H	L	0.048

Photolineament Orientation

	N60°W-N30°E	Others	Probability of error
No. of wells in each class	55	41	
Median well yield (MCF/day)	207	146	
Mann-Whitney U results (1-tailed)	H	L	0.071

of photolineaments oriented N60°W-N30°E as shown in Figure 15. Statistical tests were performed that compared yields for gas wells within 0.4 kilometers of such photolineaments, with yields for wells located greater than 0.4 kilometers from the nearest photolineament. A critical distance of 0.4 kilometers was chosen because this distance appears to represent a natural break in the plotted yields. Only class "1" and "2" photolineaments were plotted in Figure 15 because they represent better than 95 percent of these photolineaments, and the most certain photolineament locations. It appears from the statistical results of Table 9 that Devonian shale gas wells located within 0.4 kilometers of photolineaments oriented N60°W-N30°E yield at significantly higher rates than do wells located greater than 0.4 kilometers distance of these photolineaments, in the gas field study area.

A direct test of final open flow gas well yield versus photolineament proximity by orientation was not conducted. However, results of other tests concerning final open flow and photolineament proximity by class indicate the importance of photolineament proximity to final open flow gas well yields. These associations are discussed later in this report with respect to 'Photolineaments by Class'.

Photolineament Density

Although photolineaments oriented N60°W-N30°E have a greater proportion of high-yielding gas wells in their vicinity, a more direct

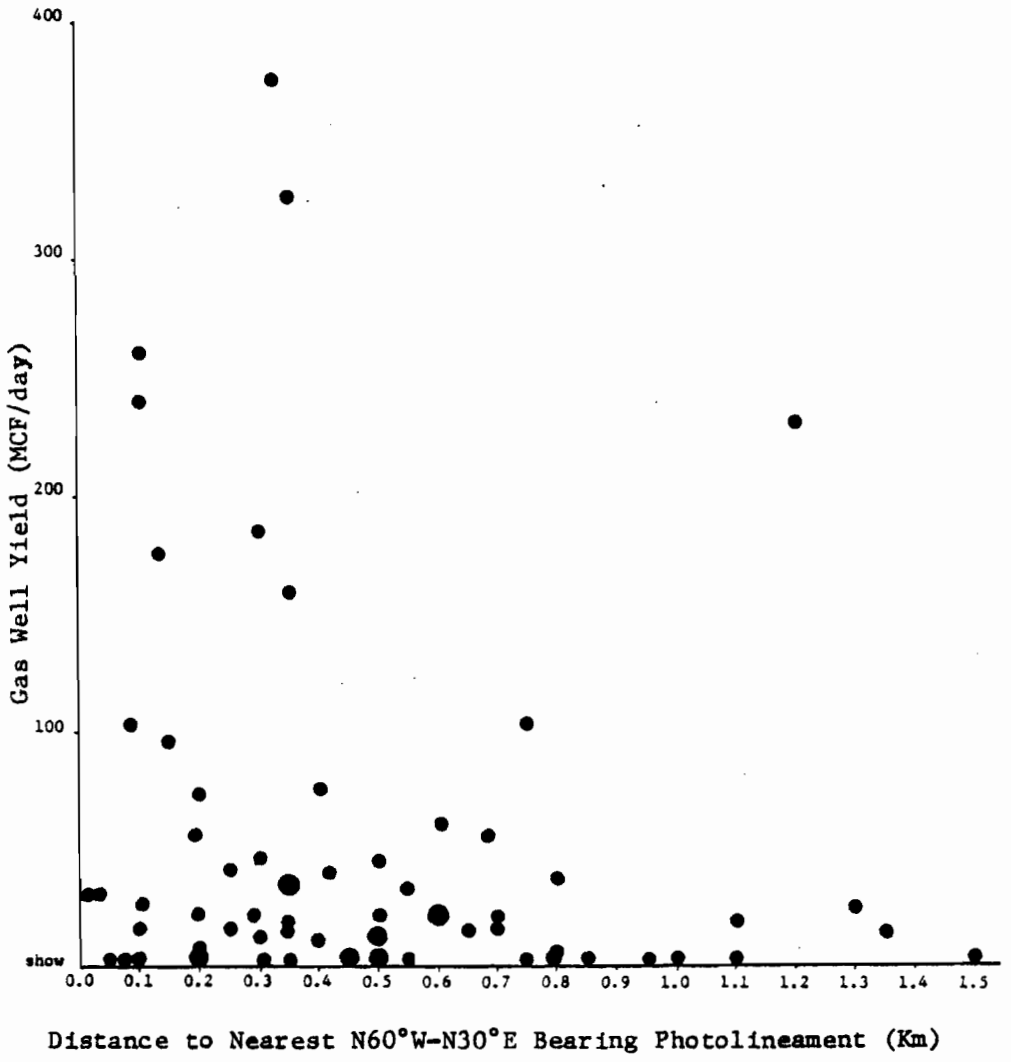


Figure 15 Plot of initial open flow gas well yield (in MCF/day) versus the well proximity to the nearest photolineament oriented N60°W-N30°E. Larger dots indicate more than one well.

TABLE 9

INITIAL OPEN FLOW GAS WELL YIELD VERSUS PHOTOLINEAMENT PROXIMITY

Distance to nearest class "1"
photolineament oriented N60°W-N30°E

	≤0.4 Km.	>0.4 Km.	Probability of error
No. of wells in each class	17	13	
Median well yield (MCF/day)	30	15	
Mann-Whitney U results (1-tailed)	H	L	0.05

test of such photolineament associations was necessary to determine their usefulness as an exploration tool. In order to test the usefulness of N60°W-N30°E bearing photolineaments in exploration for Devonian shale gas, a density map was prepared for these lineaments and compared to the gas yield trends of Figures 11 and 12. The density map of Figure 16 was prepared as previously indicated in 'Data Analysis' of this report. Figure 16 represents hand-contoured density in miles per square mile, based on 100 square-mile sections. The photolineament density map of Figure 16 was superimposed on the gas yield maps of Figures 11 and 12, to determine if significant overlaps occur between high photolineament density and high gas yield areas. A second orthogonal grid defining square sections 2000 feet long on a side was superimposed on the overlays of Figure 16 on Figures 11 and 12; grid line intersections were then counted as points occurring in one of four type areas - high photolineament density and high gas yield; high photolineament density and low gas yield; low photolineament density and high gas yield; and low photolineament density and low gas yield. The 221 grid points were categorized, totaled for each area type, and plotted in 2x2 contingency tables. Chi-square contingency tests with the Yates correction were then performed to determine if any significant associations exist between N60°W-N30°E photolineament density and gas yield, for both initial and final open flows and for various definitions of high versus low density and gas yield. The only data tested were for

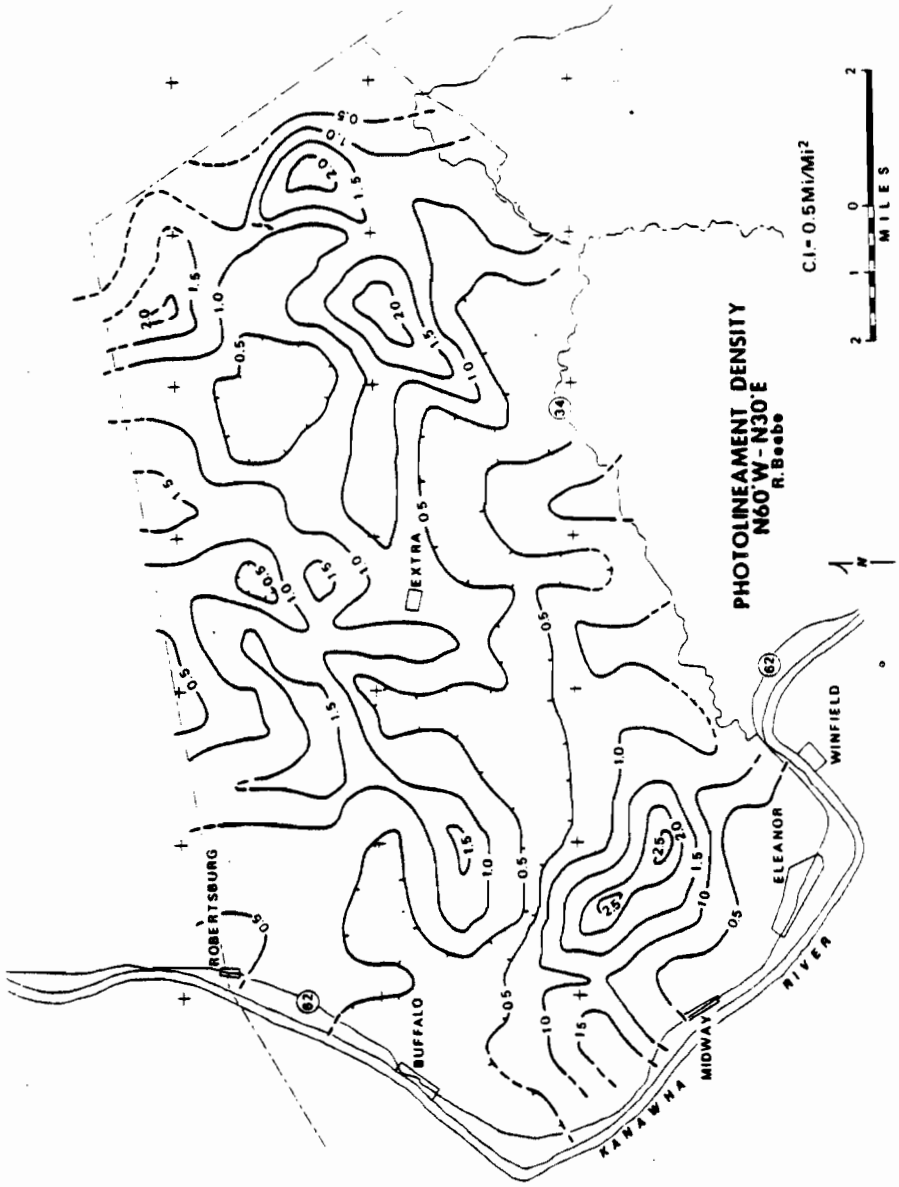


Figure 16 Contoured density of photolineaments bearing N60 -N30 E of the Midway-Extra study area. Density is in miles of photolineament length per square mile area.

grid points located within the polygonal area of Figure 10.

A second point counting technique was also used to test for associations between photolineament density and open flow gas production. This technique consisted of classifying individual Devonian shale gas wells within the polygonal area into 2x2 contingency tables for testing. However, statistical tests based on this technique are considered to be more biased than those based on the orthogonal-grid method of point counting, since gas wells are not randomly located; a greater number of gas wells have been drilled close to other successful gas wells. For this reason results from tests performed by this technique are not reported for all cases.

The Yates-corrected chi-square contingency tests (Siegel, 1956) were first performed on initial open flow production data for N60°W-N30°E photolineament density within the polygonal area. The 221 sample points were classified in two 2x2 contingency tests, comparing initial open flow gas yield greater than versus less than 100 MCF/day, with photolineament densities greater than versus less than 1.50 and 2.00 miles per square mile. Both statistical tests of Table 10 indicate that initial open flow gas well yield is significantly associated with N60°W-N30°E photolineament density at a 0.001 alpha probability level. A second set of 2x2 contingency tests were performed similar to those of Table 10, but considering 97 sample points represented by the individual gas well locations instead

TABLE 10

INITIAL OPEN FLOW GAS WELL YIELD
VERSUS
DENSITY OF N60°W-N30°E BEARING PHOTOLINEAMENTS

(Based on orthogonal grid point-counting method)

Photolineament Density

Gas Well Yield	Low	1.50 mi/mi^2	High	
Low	190	11		201
100 MCF/day				
High	11	9		20
	201	20		N=221

Probability of error < 0.001

chi-square = 29.9

Success rate= 45%

Photolineament Density

Gas Well Yield	Low	2.00 mi/mi^2	High	
Low	199	2		201
100 MCF/day				
High	15	5		20
	214	7		N = 221

Probability of error < 0.001

chi-square = 26.8

Success rate = 71%

of the orthogonal grid of points. Statistical test results of Table 11 indicate that initial open flow gas well yield is significantly associated with photolineament density with regard to the 1.50 and 2.00 miles per square mile density contours at the 0.001 and 0.01 alpha probability levels respectively. Although this last technique is considered biased with respect to its test results, it does tend to confirm observed trends found using the orthogonal grid method of point counting.

Tests were also performed for determination of possible associations between N60°W-N30°E photolineament density and final open flow gas production. A total of 221 orthogonal grid points, within the polygonal area, were classified into 2x2 contingency tables and the Yates-corrected chi-square tests were then performed. The test results of Table 12 indicate that N60°W-N30°E photolineament density is significantly associated with final open flow gas production for a critical density of 1.50 miles per square mile and critical production rates of 100, 500, and 1,000 MCF/day, at alpha probability values of 0.01, 0.001, and 0.05 respectively. Furthermore, N60°W-N30°E photolineament density is significantly associated with final open flow gas well yield for a critical density of 2.00 miles per square mile and critical production rates of 100 and 500 MCF/day, at alpha probabilities of 0.05 and 0.01 respectively. Another chi-square contingency test indicated that N60°W-N30°E photolineament

TABLE 11

INITIAL OPEN FLOW GAS WELL YIELD
VERSUS
DENSITY OF N60°W-N30°E BEARING PHOTOLINEAMENTS

(Based on gas well locations as points)

Photolineament Density

Gas Well Yield	Low (1.50 mi/mi^2)	High		
Low (100 MCF/day)	75	5	80	Probability of error < 0.001
High	9	8	17	chi-square = 16.8
	84	13	N = 97	Success rate = 62%

Photolineament Density

Gas Well Yield	Low (2.00 mi/mi^2)	High		
Low (100 MCF/day)	79	1	80	Probability of error < 0.01
High	13	4	17	chi-square = 10.0
	92	5	N = 97	Success rate = 80%

TABLE 12

FINAL OPEN FLOW GAS WELL YIELD
VERSUS
DENSITY OF N60°W-N30°E BEARING PHOTOLINEAMENTS
(Based on orthogonal grid point-counting method)

Gas Well Yield	Photolineament Density: Low (1.50 mi/mi^2)	Photolineament Density: High		
Low 100 MCF/day	96	2	98	Probability of error < 0.01; chi-square = 9.0
High	106	17	123	Success rate = 89%
	202	19	N = 221	

Gas Well Yield	Photolineament Density: Low (1.50 mi/mi^2)	Photolineament Density: High		
Low 500 MCF/day	186	8	194	Probability of error < 0.001; chi-square = 35.9
High	16	11	27	Success rate = 58%
	202	19	N = 221	

Gas Well Yield	Photolineament Density: Low (1.50 mi/mi^2)	Photolineament Density: High		
Low 1,000 MCF/day	200	17	217	Probability of error < 0.05; chi-square = 4.3
High	2	2	4	Success rate = 11%
	202	19	N = 221	

TABLE 12 (continued)

Photolineament Density

Gas Well Yield	Low (2.00 mi/mi^2)	High		
Low 100 MCF/day	96	0	96	Probability of error < 0.05
High	118	7	125	chi-square = 3.9
				Success rate = 100%
	214	7	N = 221	

Photolineament Density

Gas Well Yield	Low (2.00 mi/mi^2)	High		
Low 500 MCF/day	186	3	189	Probability of error < 0.01
High	28	4	32	chi-square = 7.4
				Success rate = 57%
	214	7	N = 221	

density is not significantly associated with gas well yield when critical values of 2.00 miles per square mile and 1,000 MCF/day final open flow gas production are considered, at the 0.10 alpha probability level.

Results of statistical tests indicate that N60°W-N30°E photolineament density could serve as the basis for a new exploration tool for Devonian shale gas, especially in the Midway-Extra area. The success rate of each 2x2 contingency test was determined by the percentage of gas wells in high photolineament density areas that have high yields. Success rate is in this way a measure of the probability of successfully locating 'high' yielding gas wells as a function of a specific photolineament density contour. Table 10 indicates that if gas wells are located within areas having N60°W-N30°E photolineament densities greater than 2.00 miles per square mile, about 71 percent of these wells would have initial open flows exceeding 100 MCF/day. If gas wells were located in areas having N60°W-N30°E photolineament densities greater than 1.50 miles per square mile, about 45 percent of these wells would have initial open flows exceeding 100 MCF/day. Table 12 indicates that if gas wells were located within areas having N60°W-N30°E photolineament densities greater than 1.50 miles per square mile, about 89 percent of these wells would have final open flows exceeding 100 MCF/day; about 58 percent of these wells would have final open flows exceeding 500 MCF/day; and about

11 percent of these wells would have final open flows exceeding 1,000 MCF/day. If gas wells were located in areas having N60°W-N30°E photolineament densities greater than 2.00 miles per square mile, about 100 percent of these wells would have final open flows exceeding 100 MCF/day, and about 57 percent of these wells would have final open flows exceeding 500 MCF/day. These test results indicate that the 2.00 miles per square mile photolineament density contour is the more successful for gas exploration of the two N60°W-N30°E photolineament density contours tested. However, photolineament density areas exceeding 2.00 miles per square mile are smaller than those exceeding 1.50 miles per square mile, which would place greater restrictions on gas exploration.

Photolineaments by Class

The possible effects of photolineament class on photolineament-gas well yield associations were next tested for initial and final open flow gas well yields. These tests were conducted by comparing the yield of each gas well within the polygonal area to the class of the nearest photolineament to each well. Appendix F contains a list of initial open flow data tested, and Appendix G contains a list of final open flow data tested. These data consist of gas well yield in MCF/day, the distance in kilometers from each of these wells to the nearest photolineament, and the photolineament orientation

and classification.

The effect of photolineament class was determined by the Mann-Whitney U test, with test results shown in Table 13 for initial open flow data. Although initial open flow is usually higher for wells located nearest a class "1" (most certain) photolineament, it is not significantly higher, at the 0.05 alpha probability level, when considering photolineaments of any orientation. However, when N60°W-N30°E photolineament orientation alone is considered, Table 13 indicates that class "1" photolineaments are significantly associated with increased initial open flow gas well yield at a 0.05 alpha probability level, when compared to class "2" and "3" photolineaments.

Final open flow data were next tested for possible associations of gas well yield with photolineaments based on class. The Mann-Whitney U test results of Table 14 indicate that final open flow is not significantly higher for gas wells near class "1" photolineaments at a 0.05 alpha probability level, when photolineament orientation is ignored. However, when just photolineaments oriented N60°W-N0°W are considered, class "1" photolineaments are significantly associated with high final open flows for nearby gas wells at a 0.10 alpha probability level, when compared to yields of wells near class "2" and "3" photolineaments. These combined test results tend to indicate that the class or certainty of expression of photolineaments may be important in associations with gas well yield, but that photolineament class should be used in con-

TABLE 13

INITIAL OPEN FLOW GAS WELL YIELD VERSUS PHOTOLINEAMENT CLASSIFICATION

(Measured to nearest photolineament)

Photolineaments of any orientation

	Class "1"	Class "2" & "3"	Probability of error
No. of wells in each class	23	53	
Median well yield (MCF/day)	24	17	
Mann-Whitney U results (1-tailed)	H	L	>0.05 (not significant)

Photolineaments oriented N60°W-N30°E

	Class "1"	Class "2" & "3"	Probability of error
No. of wells in each class	21	28	
Median well yield (MCF/day)	24	21	
Mann-Whitney U results (1-tailed)	H	L	0.048

TABLE 14

FINAL OPEN FLOW GAS WELL YIELD VERSUS PHOTOLINEAMENT CLASSIFICATION
(measured to the nearest photolineament)

Photolineaments of any Orientation

	Class "1"	Class "2" & "3"	Probability of error
No. of wells in each class	29	67	
Median well yield (MCF/day)	298	163	
Mann-Whitney U results (1-tailed)	H	L	> 0.10 (not significant)

Photolineaments Oriented N60°W-N0°W

	Class "1"	Class "2" & "3"	Probability of error
No. of wells in each class	23	17	
Median well yield (MCF/day)	315	189	
Mann-Whitney U results (1-tailed)	H	L	0.064

junction with other more important geologic criteria, such as photolineament orientation, for gas exploration in Devonian shales.

Photolineament Proximity

Initial and final open flow gas well yields were next tested for possible associations with the proximity of gas wells to the nearest photolineament of a certain class. Figure 17 shows plots of initial open flow gas well yield versus gas well proximity to the nearest class "1" or "2" photolineament. A natural break in this plot may occur at 0.4 kilometers, with most high-yielding wells located within 0.4 kilometers of a class "1" or class "2" photolineament. However, Mann-Whitney U test results of Table 15 indicate that gas wells located within 0.4 kilometers distance of class "1" or "2" photolineaments are not significantly associated with higher initial open flow, at the 0.05 alpha probability level. The same test results occurred for wells near class "1" photolineaments, as shown in Table 15. However, Table 9 also indicates that gas wells located within 0.4 kilometers of class "1" photolineaments oriented N60°W-N30°E yield significantly greater amounts of natural gas than do wells located further than 0.4 kilometers from such photolineaments, at a 0.05 alpha probability level.

Figure 18 illustrates plots of final open flow gas well yield versus class "1" photolineament proximity. Again, it appears that high yields are associated with wells located within 0.4 kilometers of a

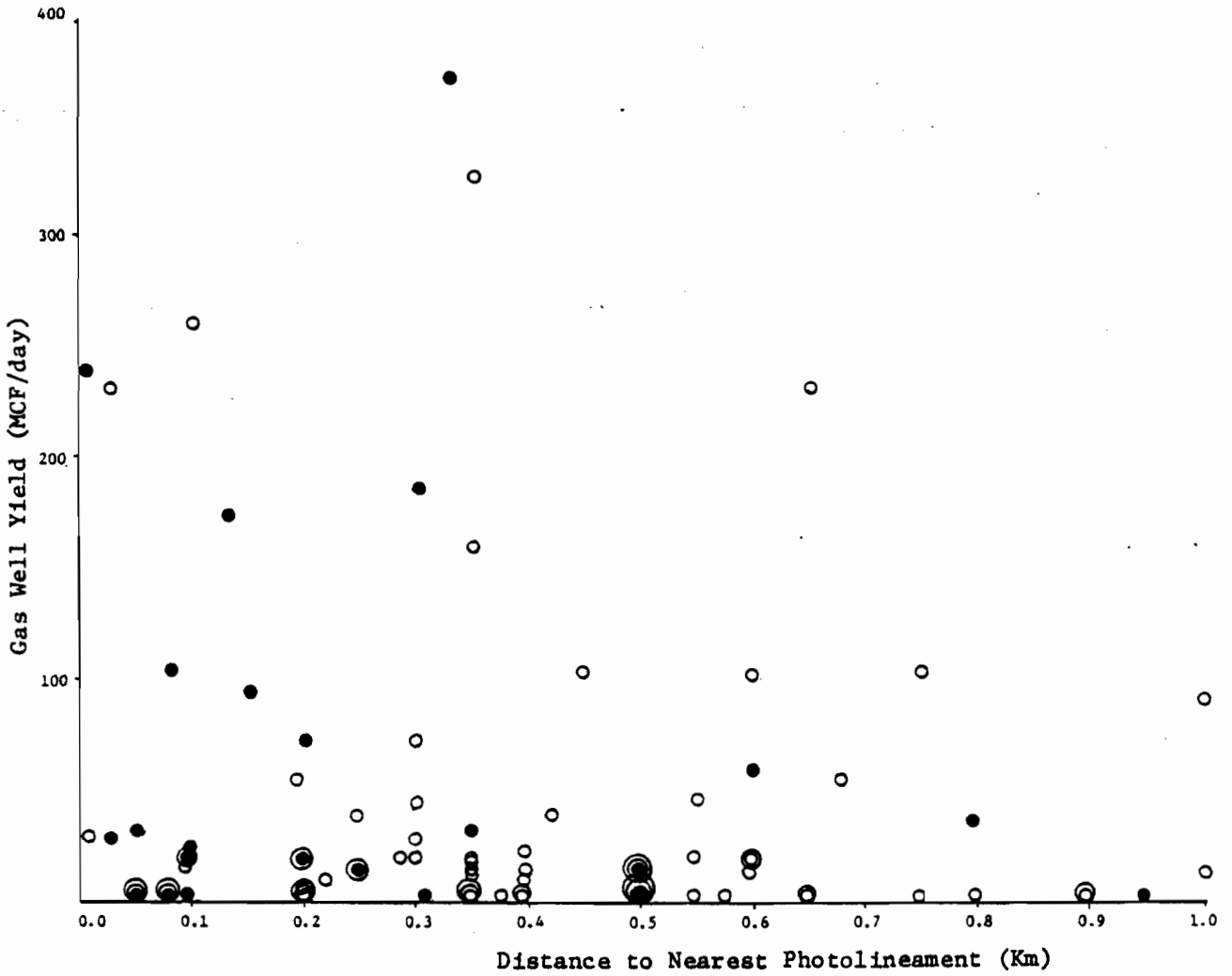


Figure 17 Plot of initial open flow versus gas well proximity to the nearest class "1" or "2" photolineament. Larger dots represent more than one well. Black dots represent wells near class "1" photolineaments.

TABLE 15

INITIAL OPEN FLOW GAS WELL YIELD
VERSUS
PROXIMITY OF PHOTOLINEAMENTS BY CLASS
(measured to the nearest photolineament)

class "1" or "2" photolineaments

	≤0.4 Km.	>0.4 Km.	Probability of error
No. of wells in each class	44	21	
Median well yield (MCF/day)	21	15	
Mann-Whitney U results (1-tailed)	H	L	>0.05 (not significant)

class "1" photolineaments

	≤0.4 Km.	>0.4 Km.	Probability of error
No. of wells in each class	17	6	
Median well yield (MCF/day)	30	show-15	
Mann-Whitney U results (1-tailed)	H	L	>0.05 (not significant)

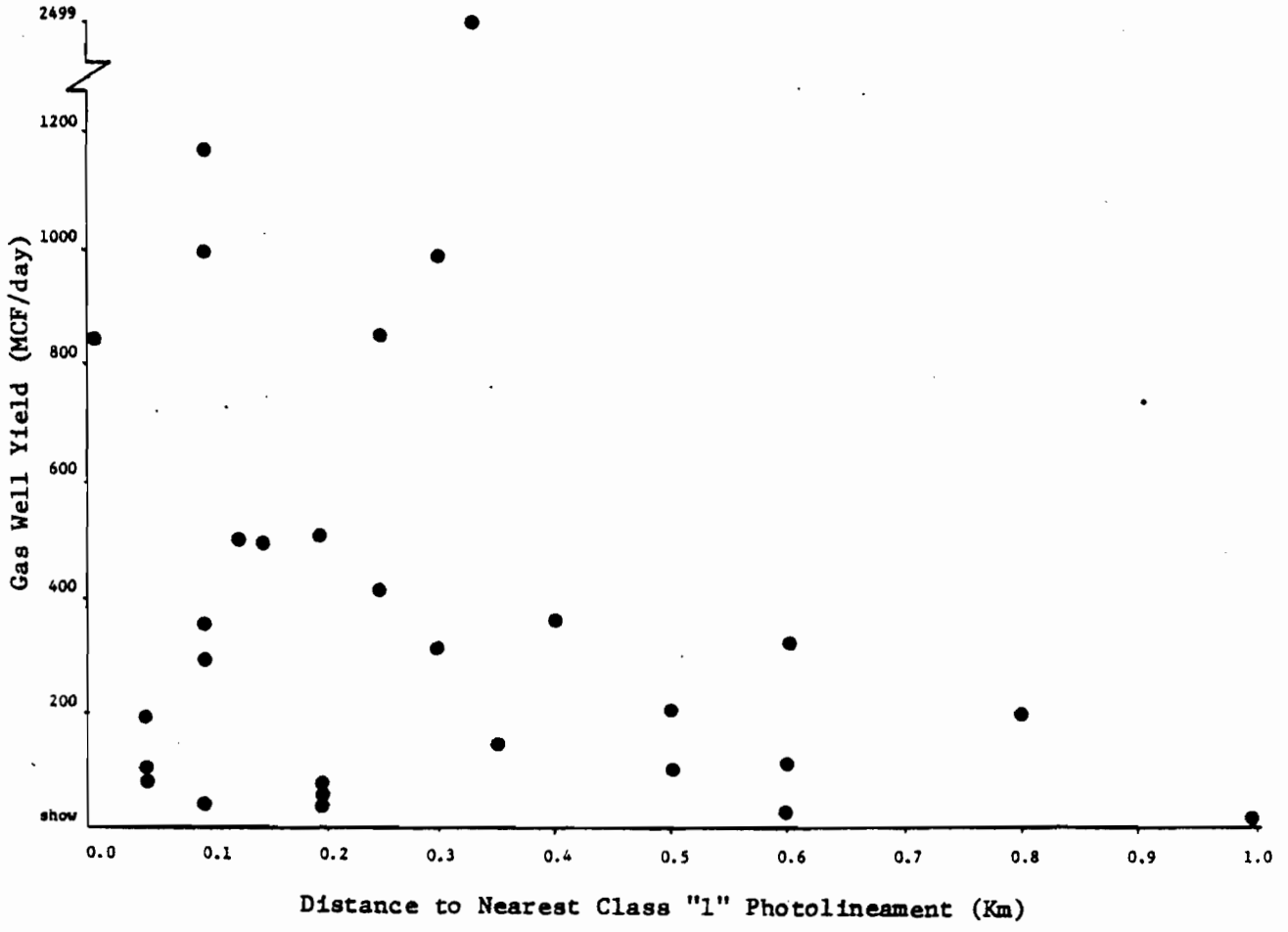


Figure 18 Plots of final open flow versus gas well proximity to the nearest class "1" photolineament.

class "1" photolineament. The Mann-Whitney U test was used to determine if any significant associations exist between final open flow gas well yield and photolineament proximity. The statistical test results of Table 17 indicate that class "1" photolineaments do relate to final open flow for nearby gas wells, whereas class "2" and "3" photolineaments do not. Table 17 indicates that only gas wells located within 0.4 kilometers of a class "1" photolineament yield at significantly higher rates (at a 0.05 alpha) than do gas wells located greater than 0.4 kilometers from class "1" photolineaments. However, it should be noted that approximately 86 percent of these class "1" photolineaments have N60°W-N0°W orientations. The significant test result for class "1" photolineaments may therefore be a function of photolineament orientation more than photolineament class.

Photolineament Density

Although class "1" photolineaments appear to have a greater proportion of high-yielding gas wells in their vicinity, a more direct test of such photolineament associations was necessary to determine their usefulness as an exploration tool. In order to test the usefulness of class "1" photolineaments in exploration for Devonian shale gas, a density map was prepared for these lineaments and compared to the gas yield trends of Figures 11 and 12. The density map of Figure 19 was prepared as previously indicated in "Data Analysis" of this re-

TABLE 16

FINAL OPEN FLOW GAS WELL YIELD VERSUS PROXIMITY OF PHOTOLINEAMENTS BY CLASS
(Measured to nearest photolineament)

Class "1" Photolineaments

	≤0.4 Km.	>0.4 Km.	Probability of error
No. of wells in each class	22	7	
Median well yield (MCF/day)	367-377	103	
Mann-Whitney U results (1-tailed)	H	L	0.018

Class "1" & "2" Photolineaments

	≤0.4 Km.	>0.4 Km.	Probability of error
No. of wells in each class	52	28	
Median well yield (MCF/day)	211-207	169-189	
Mann-Whitney U results (1-tailed)	H	L	>0.10 (not significant)

Class "1", "2", & "3" Photolineaments

	≤0.4 Km.	>0.4 Km.	Probability of error
No. of wells in each class	63	33	
Median well yield (MCF/day)	169	163	
Mann-Whitney U results (1-tailed)	H	L	>0.10 (not significant)

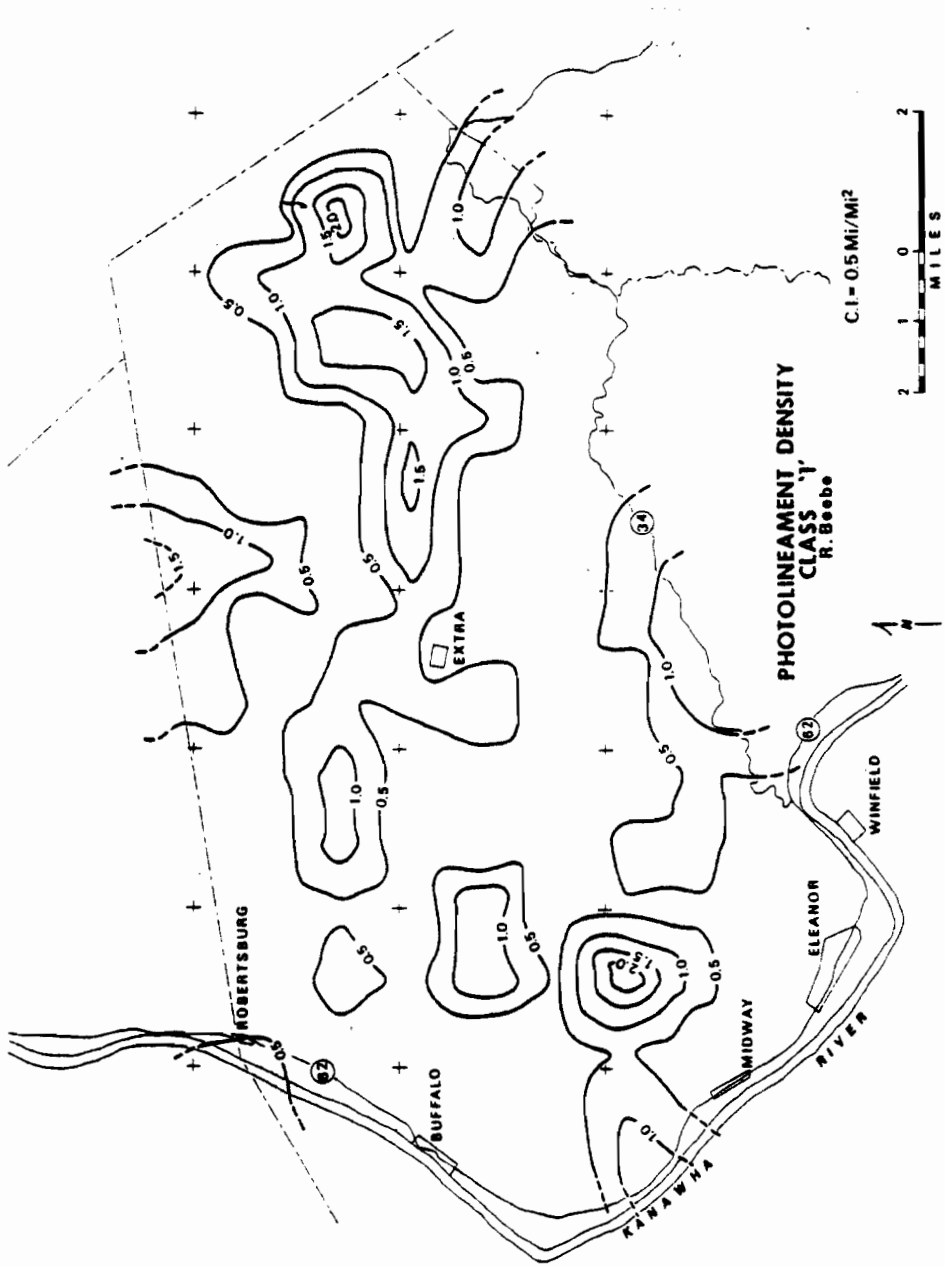


Figure 19 Contoured density map of class "1" photolineaments for the Midway-Extra study area.

port. Figure 19 represents hand-contoured density in miles per square mile, based on 100 square-mile sections. The class "1" photolineament density map of Figure 19 was superimposed on the gas yield maps of Figures 11 and 12, to determine if significant overlaps occur between high photolineament density and high gas yield areas. A second orthogonal grid defining sections 2000 feet square was superimposed on the overlays of Figure 19 on Figures 11 and 12; grid line intersections were then counted as points occurring in one of four type areas - high photolineament density and high gas yield; high photolineament density and low gas yield; low photolineament density and high gas yield; and low photolineament density and low gas yield. The 221 grid points were categorized, totaled for each area type, and plotted in 2x2 contingency tables. Chi-square contingency tests with the Yates correction were then performed to determine if any significant associations exist between class "1" photolineament density and gas yield, for both initial and final open flows and for various definitions of high versus low density and gas yield. The only data tested were for grid points located within the polygonal area of Figure 10.

A second point counting technique was also used to test for associations between photolineament density and open flow gas production. This technique consisted of classifying individual Devonian shale gas wells within the polygonal area into 2x2 contingency tables for testing. However, statistical tests based on this technique are considered to be

more biased than those based on the orthogonal-grid method of point counting. For this reason results from tests performed by this technique are not reported for all cases.

Yates-corrected chi-square (2x2) contingency tests were performed with respect to initial open flow gas well yield and the density of class "1" photolineaments shown in Figure 19. Density contours of 0.50 and 1.00 miles per square mile were used and test results are shown in Table 17. These test results indicate that class "1" photolineament density is not significantly associated with high initial open flow gas well yield at a 0.10 alpha probability level. Furthermore, the calculated rate of success is less than 10 percent for each case.

Chi-square (2x2) contingency tests were also performed to determine the existence of possible associations between class "1" photolineament density and final open flow gas well yield by comparing Figure 19 with Figure 12. A total of 221 sample points, obtained from the orthogonal grid within the polygonal area, were classified into four 2x2 contingency tables for the Yates-corrected chi-square tests. The results of Table 18 indicate that class "1" photolineament densities greater than 0.50 miles per square mile are significantly associated with final open flow gas well yield exceeding 100 and 500 MCF/day, with alpha probabilities of 0.10 and 0.01 respectively. Table 18 indicates that class "1" photolineament densities greater than 1.00 miles per

TABLE 17

INITIAL OPEN FLOW GAS WELL YIELD
VERSUS
DENSITY OF CLASS "1" PHOTOLINEAMENTS

(Based on orthogonal grid point-counting method)

Photolineament Density

Gas Well Yield	Low 0.50 mi/mi^2	High		
Low 100 MCF/day	128	72	200	Probability of error >0.10 (not significant) chi-square = 0.0
High	14	7	21	Success rate = 9%
	142	79	N = 221	

Photolineament Density

Gas Well Yield	Low 1.00 mi/mi^2	High		
Low 100 MCF/day	180	20	200	Probability of error> 0.10 (not significant) chi-square = 0.2
High	19	2	21	Success rate = 9%
	199	22	N = 221	

TABLE 18

FINAL OPEN FLOW GAS WELL YIELD
VERSUS
DENSITY OF CLASS "1" PHOTOLINEAMENTS

(Based on orthogonal grid point-counting method)

Gas Well Yield	Photolineament Density: Low (0.50 mi/mi^2)	Photolineament Density: High		
Low (100 MCF/day)	63	32	95	Probability of error < 0.10
High	67	59	126	chi-square = 3.3
	130	91	N = 221	Success rate = 65%

Gas Well Yield	Photolineament Density: Low (0.50 mi/mi^2)	Photolineament Density: High		
Low (500 MCF/day)	121	72	193	Probability of error < 0.01
High	9	19	28	chi-square = 8.2
	130	91	N = 221	Success rate = 21%

TABLE 18 (continued)

Photolineament Density

Gas Well Yield	Low	High		
	1.00 mi/mi^2			
Low	124	8	132	Probability of error < 0.05
100 MCF/day				chi-square = 5.5
High	74	15	89	Success rate = 65%
	198	23	N = 221	

Photolineament Density

Gas Well Yield	Low	High		
	1.00 mi/mi^2			
Low	180	14	194	Probability of error < 0.001
500 MCF/day				chi-square = 14.7
High	18	9	27	Success rate = 39%
	198	23	N = 221	

square mile are significantly associated with final open flow gas well yields exceeding 100 and 500 MCF/day, with alpha probability levels of 0.05 and 0.001 respectively. A similar set of tests were performed with the 104 individual gas wells having final open flow production data as points. The test results of Table 19 indicate that class "1" photolineament densities greater than 0.50 miles per square mile are significantly associated with final open flow gas well yield exceeding 500 MCF/day, at a 0.10 alpha probability level. Also, class "1" photolineament density areas of greater than 1.00 miles per square mile are significantly associated with final open flow gas well yields exceeding 500 MCF/day, at a 0.01 alpha probability level. The statistical test results of Table 18 are considered to be more trustworthy than those of Table 19. As mentioned earlier in this report, the technique of point counting individual gas wells is biased because the points represented by these wells are not mutually independent observations in the statistical sense.

Results of these statistical tests indicate that class "1" photolineament density could serve as the basis for a moderately successful exploration tool for locating Devonian shale gas wells in the Midway-Extra area. Table 18 indicates that if gas wells are located within areas having class "1" photolineament densities exceeding 0.50 miles per square mile, about 65 percent of these wells would have final open flows exceeding 100 MCF/day, and only about 20 percent of

TABLE 19

FINAL OPEN FLOW GAS WELL YIELD
VERSUS
DENSITY OF CLASS "1" PHOTOLINEAMENTS

(Based on gas well locations as points)

Photolineament Density

Gas Well Yield	Low (0.50 mi/mi^2)	High		
Low (500 MCF/day)	60	25	85	Probability of error < 0.10; chi-square = 2.8
High	9	10	19	Success rate = 29%
	69	35	N = 104	

Photolineament Density

Gas Well Yield	Low (1.00 mi/mi^2)	High		
Low (500 MCF/day)	81	4	85	Probability of error < 0.01; chi-square = 10.0
High	13	6	19	Success rate = 60%
	94	10	N = 104	

these wells would have flows exceeding 500 MCF/day. Table 18 indicates that if gas wells are located in areas with class "1" photolineament densities exceeding 1.00 miles per square mile, approximately 64 percent of these wells would have flows exceeding 100 MCF/day, and about 39 percent of these wells would have final open flows exceeding 500 MCF/day. Table 19 indicates that gas wells located in areas with class "1" photolineament densities exceeding 0.50 miles per square mile, about 29 percent of these wells would have final open flows exceeding 100 MCF/day. In areas with class "1" photolineament densities exceeding 1.00 miles per square mile, about 60 percent of these wells would have flows exceeding 500 MCF/day. Analysis of Table 19 indicates that the proportion of wells yielding over 500 MCF/day exceed the proportion of random grid points in these categories (from Table 18). This fact supports the argument for biased statistical tests involving gas wells as points, since gas wells are not independently located.

A comparison of test results indicate that N60°W-N30°E photolineament density is a better and more accurate exploration tool for locating successful Devonian shale gas wells than is class "1" photolineament density. This might be explained by the fact that classifications of certainty is subjective in nature, while photolineament orientation is not. Also, most class "1" (most certain) photolineaments have the critical N60°W-N30°E orientation.

Summary and Interpretation of Lineament Associations

Test results from both the Mann-Whitney U and the Yates-corrected chi-square (2x2) contingency tests indicate that N60°W-N30°E (and N60°W-N0°W) oriented photolineaments would be important exploration tools for locating successful Devonian shale gas wells in the Midway-Extra area. Locating wells near one or more photolineaments of the right orientation should aid in gas exploration, but all photolineaments (of any orientation or class) are not in general useful. Locating wells near one or more class "1" (most certain) photolineaments, would also appear to be less useful for locating successful Devonian shale gas wells than locating wells near photolineaments oriented N60°W-N30°E and especially N60°W-N0°W. Furthermore, Landsat lineaments appear to have adverse effects on production rates from Devonian gas shale reservoirs.

Test results concerning photolineament orientation and increased Devonian shale gas production, are consistent with the results of Jones and Rauch (1978a) in the Cottageville field of Jackson County, West Virginia. Their findings indicate that gas wells located nearby short photolineaments bearing N60°W-N90°W (WNW) yield at significantly greater rates than do gas wells located near other photolineaments. Martin and Nuckols (1976), found the fracture orientations to be primarily N40°E-N50°E in geologic cores taken from the gas producing horizons (Zones II and III) within the cottageville field. More importantly Larese and Heald (1977) noted that in part of Zone II (the primary reservoir in the

Cottageville field), the primary mineralized fracture trend is about N80°-90°W. The N60°-90°W bearing photolineaments studied by Jones and Rauch (1978a) may therefore represent permeable fractures of the same orientation within Zone II of the Devonian shales. Seismic evidence indicates the presence of Basement faulting, associated with the west side of the Rome trough, dissipating upward into the Devonian shales; this may be the source of fracturing in these shales (Shumaker, et. al., 1979).

The optimum WNW photolineament trend in the Cottageville area is oriented at about a 60° angle to the regional structural trend of N40°-50°E. The regional structural trend in the Midway-Extra area is approximately N60°-70°E, and the optimum photolineament orientation of N60°W-N30°E (or N60°W-N0°W) is about 60°-90° different from this regional structural trend. It appears that the northerly change in regional trend from Midway-Extra to the Cottageville gas field may be consistent with the westerly change in optimum photolineament orientation between Midway-Extra and Cottageville gas fields. This suggests that fractures oriented 60°-90° off strike are critical in defining the cross-strike extent of these shale gas fields.

GROUND-WATER ASSOCIATIONS WITH GAS WELL YIELD

Water-Well Yield

Water well yield was compared to initial and final open flow gas well yields to determine if any associations exist that would suggest a new gas exploration tool based on water well yield. Yields in gallons per minute were obtained and tested for a total of 29 water wells in the polygonal gas field area. The Mann-Whitney U test was used to statistically test these possible associations. In constructing data for the Mann-Whitney U tests of Table 20, yields of the nearest gas well to each of the 29 water wells were considered, and water well yield was treated as the independent variable in classifying water well-gas well pairs into one of two groups for testing. Two groups of well pairs were compared for gas well yield, pairs with water well yield exceeding 1.0 gpm (the median yield) versus pairs with water well yield equal to or less than 1.0 gpm. Statistical test results of Table 20 indicate that water well yield is not significantly associated with gas well yield at a 0.05 alpha probability level. Likewise, no definite trends between water well yield and gas well yield were discovered for the Cottageville gas field (Jones and Rauch, 1978a).

Ground-Water Chemistry

The ground-water chemical parameters of Appendix B were next tested

TABLE 20

INITIAL OPEN FLOW GAS WELL YIELD VERSUS WATER WELL YIELD

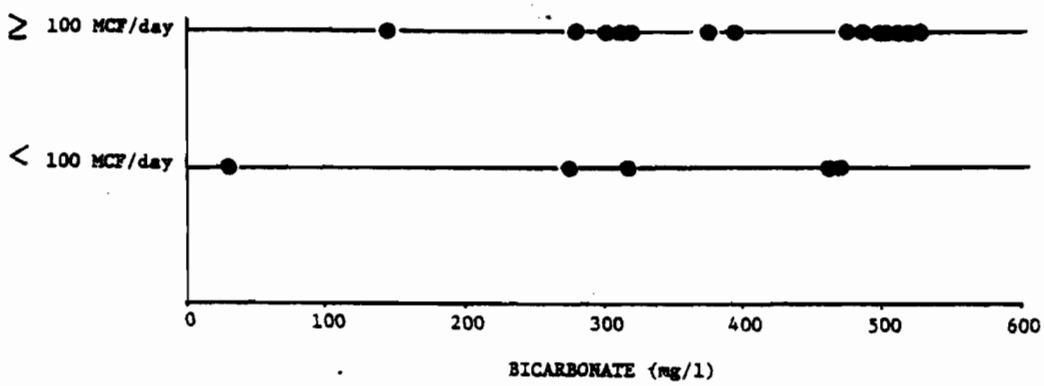
	≤ 1.0 gpm	>1.0 gpm	Probability of error
No. of wells in each class	12	17	
Median well yield (MCF/day)	17	show-15	
Mann-Whitney U results (1-tailed)	H	L	> 0.10 (not significant)

FINAL OPEN FLOW GAS WELL YIELD VERSUS WATER WELL YIELD

	≤1.0 gpm	>1.0 gpm	Probability of error
No. of wells in each class	12	17	
Median well yield (MCF/day)	47	145-280	
Mann-Whitney U results (1-tailed)	L	H	>0.10 (not significant)

against expected (contoured) initial and final open flow gas well yield, to determine if any associations are present. These chemical parameters were tested for 19 water wells sampled within the Midway-Extra gas field. Of all the chemical parameters tested, none show statistically significant associations with initial open flow and just two exhibit significant associations with final open flow. Figure 20 shows plots of chemical concentrations for bicarbonate and nitrate versus final open flow gas well yield. These are the only two chemical parameters displaying strong associations with final open flow. The two horizontal lines of the scattergram in Figure 20 separate the gas well yields into high and low classes, for comparison with chemical concentrations of bicarbonate and nitrate. Table 21 contains the Mann-Whitney U test results for the data plotted in Figure 20. The test results indicate that bicarbonate and nitrate are significantly higher for water wells located in gas field areas exceeding 100 MCF/day final open flow. These associations are statistically significant at alpha probabilities of 0.05 and 0.025 for bicarbonate and nitrate respectively. Other chemical parameters of Appendix B do not significantly relate to expected gas well yield in the study area. Chemical concentrations were not tested with respect to 500 MCF/day contoured areas because too few water wells are located in such areas.

The plotted data of Figure 20 indicate that optimum sites for



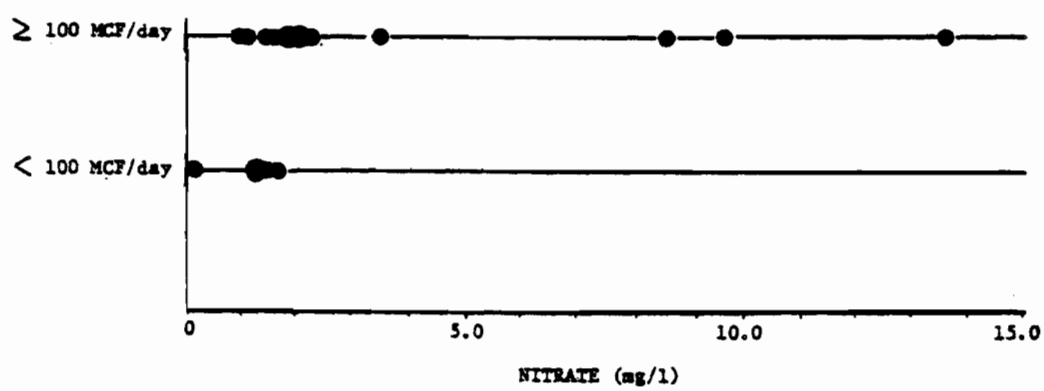


Figure 20 Plots of chemical concentrations of bicarbonate and nitrate versus final open flow gas well yield, within the polygonal area of the Midway-Extra gas field. Larger dots indicate more than one well.

TABLE 21

FINAL OPEN FLOW GAS WELL YIELD VERSUS BICARBONATE CONCENTRATION

	≥100 MCF/day	<100 MCF/day	Probability of error
No. of wells in each class	14	5	
Median Bicarbonate Concentration (mg/l)	397-474	319	
Mann-Whitney U results (1-tailed)	H	L	< 0.05

FINAL OPEN FLOW GAS WELL YIELD VERSUS NITRATE CONCENTRATION

	≥100 MCF/day	<100 MCF/day	Probability of error
No. of wells in each class	14	5	
Median Nitrate Concentrations (mg/l)	1.87-1.98	1.32	
Mann-Whitney U results (1-tailed)	H	L	< 0.025

high-yielding Devonian shale gas wells would be near water wells having at least 470 mg/l bicarbonate or at least 1.75 mg/l nitrate. From the data tested, about 43 percent of the tested water well sites in high-yielding gas areas (with over 100 MCF/day final open flow) exceed 470 mg/l bicarbonate. Likewise, approximately 70 percent of the water wells in high-yielding gas areas exceed 1.75 mg/l nitrate. On the other hand, no tested wells in low yielding gas areas (with less than 100 MCF/day final open flow) have chemical concentrations over 470 mg/l bicarbonate or over 1.75 mg/l nitrate.

Jones and Rauch (1978a), in their study of water quality parameters and expected natural open flow for gas wells in the Cottageville area, found that expected gas yield tends to be higher near water wells with high concentrations of bicarbonate, total hardness, nitrate, and sulfate. The chemical parameters of ground water which seem to best relate to expected gas yield in the Cottageville area are bicarbonate and total hardness concentrations (Jones and Rauch, 1978a). These parameters show the strongest statistical associations which are least likely to be coincidental, according to Jones and Rauch (1978a). From their tested data, they found that about 83 percent of the selected well sites with over 500 mg/l bicarbonate have high expected initial open flows (over 100 MCF/day). The similarities in research findings between this study and that of Jones and Rauch (1978a) strongly suggest that some relationship exists between gas production potential and shallow

ground-water chemistry, for at least bicarbonate and nitrate.

A possible explanation may be offered for the extraordinarily high concentrations of bicarbonate in shallow ground waters of the high-producing gas areas; some bicarbonate in these cases may be generated by the oxidization of methane gas by bacteria to form bicarbonate (Rauch, oral communication, 1979). It is possible that trace amounts of methane gas could be migrating upward from the Devonian shales along fracture zones. Once in shallow ground water, such gas would be unstable and oxidize with the help of bacteria, creating high concentrations of bicarbonate over a prolonged time period. No explanations are readily apparent for the observed association between high ground-water nitrate concentration and high final open flow gas well yield. It is possible that this relationship is coincidental, and nitrate may be concentrating in shallow ground water from surface contamination sources, such as septic tanks. However, it is also possible that high nitrate concentrations are tied up in some way with Devonian shale gas production, since Jones and Rauch (1978a) also found nitrate to be associated with high expected gas well yield (over 100 MCF/day). From results obtained so far, ground water chemistry may well prove to be useful in the future as a new exploration tool for locating successful Devonian shale gas wells.

SUMMARY OF CONCLUSIONS

Based on the data collected for this report and statistical analyses performed on that data, the following conclusions concerning hydrogeologic criteria and Devonian shale gas production can be drawn.

1] Landsat lineaments have no apparent effect on water well yields, and are associated with low natural gas production in the Midway-Extra gas field.

2] Water well yields are greater for wells within 200 feet of a short photolineament than for wells located greater than 200 feet from such photolineaments.

3] Topographic position significantly affects water well yields in the study area. Valley wells yield at significantly greater rates than do hillside, slope, or hilltop water wells.

4] In general, ground-water quality in northeaseern Putnam County is good, with only a few cases where the maximum recommended concentrations were exceeded.

5] Gas wells located nearest short photolineaments oriented N60°W-N30°E and especially N60°W-N0°W are relatively high producers on the average, with respect to initial and final open flow gas well yields. Short photolineament orientation is therefore useful to con-

sider for locating high-yielding Devonian shale gas wells.

6] Gas well proximity to short photolineaments is not significantly associated with gas well yield in general. However, when photolineaments oriented N60°W-N30°E are considered, there is a significant association between gas well yield and photolineament proximity. Specifically, when gas wells are located within 0.4 kilometers of such a photolineament, they tend to yield significantly greater amounts of natural gas in the Midway-Extra area.

7] High N60°W-N30°E photolineament density areas, when compared to contoured trends for initial and final open flow gas well yields, show a significant association with high Devonian shale gas production. Photolineament density could therefore serve as the basis for a new exploration tool for locating successful Devonian shale gas wells in the Midway-Extra area.

8] Initial and final open flows are not significantly greater for gas wells near class "1" (most certain) photolineaments compared to wells near less certain photolineaments. However, class "1" photolineaments oriented N60°W-N30°E are especially well associated with high producing gas wells.

9] High density areas for class "1" photolineaments are significantly associated with high initial and final open flow gas well yield, but these results are less significant and less useful than associations for N60°W-N30°E photolineament density.

10] Water well yield shows no significant relationship with initial or final open flows for nearby gas wells.

11] Statistical tests indicate that final open flow gas well yield tends to be higher near water wells with high concentrations of bicarbonate and nitrate. Sites where ground-water concentrations exceed 470 mg/l for bicarbonate or 1.75 mg/l for nitrate are especially well associated with high-yielding gas wells. These two ground-water parameters might be applicable in exploration for Devonian shale gas in other areas. Other chemical parameters did not significantly relate to increased expected gas well yield.

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APPENDIX A

PHYSICAL WATER WELL DATA

Appendix A

PHYSICAL WATER WELL DATA

Data Code:

* - v = valley location, h = hilltop location, s = slope or hillside location.

** - Specific capacity measured as gallons per minute per foot of water drawdown.

*** - Aquifer sequence numbers refer to stratigraphic units described in Figure 4.

**** - Adequacy; IA = inadequate water supply; BA = barely adequate water supply; A = adequate water supply; TD = more than adequate water supply or supplies two dwellings; AA = driller reported inability to bail well dry.

Well Code:

(BA-) = Bancroft 7-1/2 minute topographic quadrangle
(EL-) = Elmwood 7-1/2 minute topographic quadrangle
(RO-) = Robertsburg 7-1/2 minute topographic quadrangle
(KE-) = Kenna 7-1/2 minute topographic quadrangle
(SI-) = Sissonville 7-1/2 minute topographic quadrangle
(WI-) = Winfield 7-1/2 minute topographic quadrangle

WELL NUMBER	OWNER	TOPOGRAPHIC SETTING*	SURFACE ELEVATION (FT.)	WELL DEPTH (FT.)	WELL DIAMETER (IN.)	DEPTH TO WATER (FT.)	DEPTH OF CASING (FT.)	WELL YIELD (GPM)	SPECIFIC CAPACITY**	AQUIFER SEQUENCE***	ADEQUACY****
KE-1	H.R.Bailey	h	1080	220	6			0.0		2	IA
KE-3	D.Jones	h	980	90	6		20	3.3		2	A
SI-4	E.Monday	h	960	150	6	20		0.5		3	BA
BA-5	T.Gibson	h	939	103	6	27		3.0		4	A
BA-6	J.Casto	h	960	200	6			0.0		6	IA
WI-7	H.Hill	h	920	250	6					6	IA
WI-8	C.King	h	920	200	6	30	12			6	A
WI-9	M.Levins	h	930	100	6		12	0.8		5	A
WI-10	M.Hopkins	h	890	150	6					6	A
WI-11	G.Parsons	s	840	152	6	20	20	1.0		7	A
WI-12	S.Workman	h	920	230	6		12	0.0		6	IA
BA-13	D.Starcher	h	960	86	6					2	TD
BA-14	D.Lukiert	h	910	125	6	65	11	0.7		4	BA
SI-15	F.Arthur	v	860	30	6	4	10	0.5		3	BA
SI-16	E.Hanna	s	840	125	6	40	11	0.7		5	BA
BA-17	F.Clendenin	v	700	35	6	5	18			6	AA
EL-18	D.Smalley	s	660	85	6	20	15	17.0		6	TD
EL-19	J.Withrow	h	1000	150	6		11			2	BA
WI-20	V.Casto	s	900	240	6	100	11	0.0		7	IA
WI-21	B.Lukiert	v	600	100	6	30	30			9	A
WI-22	T.Noffsinger	v	620	100	6	20	25	0.8		9	A
WI-23	R.Goddard	v	610	85	6			0.8		9	A
RO-24	J.Grimes	s	600	80	10	10		0.8		8	A
RO-25	G.Martin	v	590	86	6		32			8	A
RO-26	A.Stover	v	600	157	6					8	AA
RO-27	H.Martin	v	610	75	6	30				7	AA
WI-28	D.Weare Sr.	v	620	50	6	20				7	A
RO-29	L.Pennington	s	580	80	6	37	44	2.0	0.74	7	A
RO-30	M.Gates	v	620	70	6	35				6	A
RO-31	W.Boese	v	590		6						A
RO-32	G.Stanley	v	600	90	6		30	5.0		8	A
RO-33	H.Blackshire	h	930	175	6			0.0		4	IA
RO-34	C.Bailes	h	900	112	6	60				3	TD
RO-35	J.Bailes	h	830	150	6		30	1.0		3	A
RO-36	T.Bailes	h	920	145	6	60	13	0.8		3	A
RO-38	W.Jividen	h	950	102	6		20	0.8		2	A
RO-39	D.Lukiert	h	900	235	6			0.1		6	IA
EL-40	J.Frye	v	680	42	6	15				5	TD
EL-41	A.Null	v	640		6						A

WELL NUMBER	OWNER	TOPOGRAPHIC SETTING*	SURFACE ELEVATION (FT.)	WELL DEPTH (FT.)	WELL DIAMETER (IN.)	DEPTH TO WATER (FT.)	DEPTH OF CASING (FT.)	WELL YIELD (GPM)	SPECIFIC CAPACITY**	AQUIFER SEQUENCE***	ADEQUACY****
EL-42	M.Frye	v	655								TD
EL-43	E.Null	v	660	40	6					6	AA
EL-44	D.Smalley	h	1000	210	6	110	25	0.5		3	BA
EL-46	D.Arsten	h	980	180	6	120		1.0		3	A
SI-47	A.Smith	h	1050	267	6	37	25			3	IA
SI-48	J.King	h	1020	132	6	60		0.8		2	BA
SI-49	W.Green	h	1030	300	6			0.0		4	IA
SI-50	G.Goldizen	s	950	140	6		20	0.6		3	BA
BA-51	M.Milam	h	840								TD
BA-52	C.French	s	820	175	6	142	25	1.7		6	A
BA-53	R.French	s	820	136	6	120	15	4.0		5	A
BA-54	D.French	s	820	175	6	154	15	1.6		6	A
BA-55	L.Null	s	720	150	6					6	A
BA-56	P.Parsons	s	690	110	6	45	21	1.8		6	A
WI-57	T.Richardson	v	610	79	6	15				6	AA
WI-58	C.Blackenship	v	610	105	6					7	AA
WI-59	T.Cobb	s	670	144	6	17	19	1.0		8	A
WI-60	R.Blackshire	v	600	65	6	18	30			9	AA
WI-61	D.Johnson	v	630	75	6	18	32			9	A
WI-62	R.Blackshire	s	690	125				0.0		8	IA
WI-63	D.Blackshire	v	590	86						9	TD
WI-64	M.Jeromes	v	650	70	6					8	A
WI-65	M.Cobb	v	840	150	6					7	TD
WI-67	H.Gritt	h	840	155	6		21			6	A
WI-69	J.Morton	s	760	250	6			0.0		9	IA
WI-70	B.Morton	s	670	165	6	35	35			8	TD
WI-71	L.Priddy	v	590	200	6					9	AA
EL-73	L.Bush	h	960	102	6	52		0.0		2	IA
EL-75	O.Stone	h	1040	150	6			1.0		1	A
EL-76	S.Arbough	h	1050	125	6		8	0.1		1	IA
EL-77	W.Thompson	h	970	90	6			0.0		2	IA
BA-78	V.Smith	h	1000	200						3	A
BA-79	K.Casto	h	850	130	6		13			6	BA
EL-80	O.Stone	v	640	78	6	25	12	20.0	3.13	6	A
SPRINGS											
KE-2	D.Jones	s	1000								A
RO-37	D.Johnson	s	940								A
EL-45	R.Willard	s	680								A
WI-66	R.Reedy	s	740								A
WI-68	L.Gritt	s	800								A
WI-72	C.Harmon	s	760								A
EL-74	W.May	s	1000								A

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APPENDIX B

CHEMICAL WATER WELL DATA

Well No.	Temperature (Celsius)	Specific Conductance (uMHO/cm)	pH (pH units)	Bicarbonate (mg/l)	Total Iron (mg/l)	Nitrate (mg/l)	Total Hardness (mg/l) *	Calcium (mg/l)	Magnesium (mg/l)	Sulfate (mg/l)	Chloride (mg/l)	Sodium (mg/l)
KE-3	15	1080	7.00	425	0.07	1.32	488	120.0	45.7	7	157	48
SI-4	13	1400	7.20	432	0.13	1.76	548	136.0	51.0	13	186	55
BA-5	13	680	6.78	282	0.05	5.94	282	73.0	24.0	13	64	30
WI-8	18	315	7.05	32	11.20	1.32	130	26.0	16.0	81	9	9
WI-9	17	710	7.71	376	0.07	8.65	220	47.0	25.0	6	52	59
WI-10	16	460	7.99	280	0.12	1.87	280	50.0	22.0	34	5	50
WI-11	18	715	8.13	479	0.04	1.69	198	50.0	18.0	10	5	92
EL-18	13	600	7.30	334	0.15	1.76	119	35.0	8.0	22	17	94
WI-21	20	535	7.99	319	0.10	1.69	158	42.0	13.0	8	9	52
WI-23	14	480	7.90	305	0.52	0.99	120	39.0	5.0	8	28	71
RO-24	14	2100	8.04	587	0.43	1.10	22	6.0	2.0	5	367	546
RO-25	10	1200	7.92	449	0.04	1.54	64	18.0	5.0	5	156	254
RO-26	13	4025	7.90	408	0.08	1.10	58	18.0	4.0	6	974	801
RO-29	11	990	7.10	460	0.92	0.05	149	39.0	13.0	9	133	185
RO-32	12	560	5.80	55	1.68	1.32	206	64.0	11.0	3	167	45
RO-34	9	1100	7.50	596	0.04	0.88	78	22.0	6.0	17	67	234
RO-37	7	340	6.73	156	0.31	0.80	100	26.0	9.0	28	13	30
BA-45	14	85	5.98	13	0.16	5.28	32	8.0	3.0	14	4	4
SI-48	8	240	6.39	109	0.21	1.76	98	29.0	6.0	12	10	8
BA-51	13	300	7.18	144	0.12	1.10	124	31.0	11.0	16	14	11
BA-52	15	860	7.96	508	0.30	3.41	22	5.0	2.0	8	35	234
BA-55	16	650	7.36	313	0.08	9.68	242	66.0	19.0	16	37	22
BA-56	16	560	7.65	311	0.08	2.20	201	54.0	16.0	7	23	34
WI-57	15	520	7.18	278	0.85	1.32	215	71.0	9.0	11	24	19
WI-58	16	6025	7.89	469	0.11	1.54	83	22.0	7.0	7	2032	1722
WI-59	22	1060	7.55	521	0.06	13.60	238	74.0	31.0	145	20	115
WI-60	15	1000	7.89	474	0.21	1.76	68	20.0	4.0	6	90	193
WI-61	19	895	8.13	529	0.05	1.98	86	25.0	6.0	25	34	167
WI-63	17	1275	7.91	495	0.09	1.45	52	15.0	3.0	5	139	234
WI-64	20	800	8.03	499	0.10	1.76	29	8.0	2.0	12	23	162
WI-65	9	650	7.61	397	0.05	1.98	75	21.0	6.0	10	13	113
WI-66	9	195	6.50	68	0.29	4.18	78	20.0	7.0	18	26	6

Well Code - BA = Bancroft 7.5-minute topographic quadrangle, EL = Elmwood 7.5-minute topographic quadrangle,
RO = Robertsburg 7.5-minute topographic quadrangle, KE = Kenna 7.5-minute topographic quadrangle
SI = Sissonville 7.5-minute topographic quadrangle, WI = Winfield 7.5-minute topographic quadrangle.

* - Total Hardness is expressed as mg/l $CaCO_3$.

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APPENDIX C

MIDWAY-EXTRA GAS PRODUCTION DATA

(FROM SCHAEFER, 1979)

KEY:

Elevations are in feet with respect to sealevel.

IOF = initial open flow gas production,

FOF = final open flow gas production,

BR. SH. = Brown shale.

All data after Schaefer, 1979.

WELL PERMIT NUMBER	WELL TOP ELEV.	SUB-SEA ELEVATION TOP BEREA	TOP BR. SH.	BASE BR. SH.	IOF	FOF/HR	PRESS/HR
300	882	-1495	-2683	-3137	58	246/13	820/18
304	566	-1532	-2726	-3169	24	60/16	NA
307	926	-1524	-2734	-3135	NA	NA	NA
310	589	---	---	---	---	---	---
320	572	-1474	---	---	---	---	---
372	584	-1539	-2696	-3066	NA	150/NA	NA
383	634	-1527	---	---	---	---	---
389	584	-1608	-2801	-3186	26	327/27	880/24
391	593	-1615	-2735	-3134	150	251/NA	850/96
398	658	-1550	-2738	-3122	84	111/NA	NA
400	573	-1620	-2728	-3099	NA	313/NA	NA
408	602	-1533	-2768	-3246	54	133/1	885/72
413	594	-1629	-2739	-3137	NA	1007/3	NA
424	579	-1645	-2771	-2966	Show	329/3	NA
425	618	-1637	-2782	-3132	Show	329/8	900/48
434	613	-1659	-2767	-3162	NA	553/6	NA
437	604	-1632	-2771	-3086	NA	520/1	NA
442	592	-1641	-2773	-3148	Show	103/NA	NA
443	952	-1679	-2798	-3218	94	495/NA	900/24
444	857	-1659	-2823	-3188	NA	800/1	NA
445	798	-1648	-2767	-3156	15	24/19	NA
450	601	-1582	---	-3149	NA	500/4	NA
455	889	-1696	-2931	-3431	12	NA	NA
457	888	-1680	-2804	-3231	184	987/NA	900/72
460	839	-1641	-2801	-3168	Show	989/NA	950/24
461	622	-1688	-2758	-3193	18	1265/1	NA
462	729	-1626	-2761	-3126	15	325/NA	650/NA
463	627	-1599	-2797	-3193	18	377/2	NA
465	939	-1610	-2888	-3336	7	152/1	780/96
472	750	-1675	-2805	-3234	103	298/30	900/46
473	706	-1679	-2807	-3209	30	750/2	NA
474	707	-1703	-2852	-3249	21	750/NA	NA
475	661	-1599	-2759	-3147	231	1164/NA	180/1
476	591	-1691	-2784	-3227	Show	603/NA	NA
477	928	-1647	-2837	-3212	377	2499/NA	NA
479	755	-1592	-2753	-3125	NA	152/NA	NA
481	898	-1662	-2809	-3167	45	140/NA	200/2
482	655	-1600	-2760	-3157	238	848/2	175/1
483	591	-1584	-2769	-3189	NA	NA	NA
486	835	-1717	-2725	-3065	21	1175/1	NA
490	700	-1663	-2831	-3195	30	193/11	200/3
491	893	-1670	-2837	-3237	Show	315/NA	300/2
495	572	-1630	-2743	-3124	60	NA	NA
496	901	-1657	-2829	-3209	NA	367/NA	738/21
497	662	-1642	-2773	-3198	30	60/NA	NA
498	603	-1657	-2767	-3077	21	200/NA	NA
499	787	-1624	-2797	-3165	NA	377/NA	200/1
500	876	-1657	-2819	-3239	15	620/NA	120/2
501	835	-1597	-2770	-3151	327	827/NA	125/1
502	870	-1662	-2820	-3230	NA	1009/NA	800/24
503	621	-1691	-2899	-3311	15	412/NA	130/2
504	920	-1641	-2815	-3221	NA	852/NA	750/24
505	811	-1599	-2729	-3139	260	NA	NA
506	678	-1628	-2776	-3181	NA	499/NA	245/1

WELL PERMIT NUMBER	WELL TOP ELEV.	SUB-SEA ELEVATION TOP BEREA	TOP BR. SH.	BASE BR. SH.	IOF	FOF/HR	PRESS/HR
507	886	-1654	-2838	-3252	37	202/18	787/92
508	864	-1658	-2836	-3226	73	511/NA	NA
510	811	-1618	-2779	-3209	21	660/NA	95/1
511	838	-1592	-2746	-3117	103	379/NA	NA
512	914	-1636	-2815	-3222	158	1961/NA	NA
513	923	-1652	-2882	-3218	326	781/NA	800/NA
515	865	-1647	-2822	-3235	73	169/10	405/13
517	654	-1578	-2746	-3158	NA	48/51	865/240
518	637	-1596	-2729	-3153	NA	84/NA	NA
519	880	-1641	-2830	-3248	20	78/30	850/168
520	820	-1645	-2820	-3180	NA	21/NA	NA
521	712	-1547	-2613	-2 78	NA	NA	NA
522	873	-1645	-2762	-3232	15	145/NA	810/72
523	901	-1619	-2796	-3109	NA	100/NA	710/24
524	834	-1549	---	-3076	5	358/NA	NA
525	932	-1594	-2801	-3208	Show	NA	NA
526	910	-1566	-2735	-3124	Show	NA	NA
527	925	-1622	-2740	-3185	Show	23/15	NA
530	620	-1655	-2825	-3203	21	336/1	960/26
535	715	-1649	-2803	-3209	Show	14/23	NA
536	897	-1577	-2695	-3112	21	381/NA	70/1
537	920	-1623	-2794	-3196	174	500/NA	NA
538	955	-1671	-2853	-3339	24	211/1	930/96
539	621	-1604	-2724	-3199	15	327/NA	420/16
543	540	-1644	-2740	-3130	24	250/1	NA
550	823	-1566	-2752	-3147	39	79/15	NA
552	581	-1614	-2740	-3109	NA	876/1	NA
553	662	-1543	-2728	-3144	NA	152/NA	700/NA
558	897	-1661	-2828	-3209	33	146/NA	41/1
566	916	-1597	-2778	-3185	NA	70/24	NA
586	854	-1716	-2926	-3336	60	103/NA	825/48
596	684	-1704	-2941	-3346	33	119/NA	850/62
599	601	-1612	-2766	-3194	7	158/25	800/96
603	598	-1610	-2782	-3188	28	424/8	NA
604	596	-1715	-2927	-3335	18	60/NA	855/72
607	813	-1702	-2909	-3347	15	198/29	880/72
613	608	-1508	-2742	-3237	Show	158/NA	710/NA
618	634	-1694	-2920	-3344	24	73/29	870/72
621	628	-1677	-2893	-3305	47	189/24	890/48
624	933	-1557	-2769	-3247	Show	NA	NA
627	638	-1475	-2622	-2959	Show	15/48	NA
629	840	-1663	-2865	-3308	56	246/NA	920/42
630	848	-1694	-2892	-3304	Show	84/NA	790/72
632	668	-1627	-2849	-3295	29	207/NA	840/24
633	604	-1507	-2708	-3126	NA	43/NA	400/44
634	913	-1622	-2845	-3272	11	61/NA	760/72
635	830	-1685	-2873	-3295	158	231/NA	875/48
637	923	-1620	-2826	-3292	21	60/28	820/72
638	575	-1583	-2719	-3171	8	158/30	790/96
639	647	-1604	-2788	-3172	Show	103/NA	NA
641	907	-1638	-2856	-3320	Show	57/29	680/72
642	992	-1604	-2806	-3247	NA	43/21	NA
646	660	-1635	-2784	-3170	Show	85/NA	480/168
647	905	-1685	-2879	-3315	89	273/NA	800/96
649	777	-1626	-2748	-3159	14	94/32	NA

WELL PERMIT NUMBER	WELL TOP ELEV.	SUB-SEA ELEVATION TOP BEREA	TOP BR. SH.	BASE BR. SH.	IOF	FOF/HR	PRESS/HR
653	918	-1678	-2877	-3320	56	169/NA	765/96
654	921	-1536	-2736	-3119	Show	163/NA	NA
657	909	-1710	-2901	-3336	Show	103/32	750/96
661	915	-1679	-2790	-3225	10	60/NA	780/144
662	841	-1504	-2691	-3069	NA	110/NA	NA
663	833	-1688	-2887	-3292	Show	84/23	640/72
666	646	-1609	-2749	-3198	Show	146/24	745/Max
667	956	-1609	-2814	-3214	24	NA	NA
669	737	-1673	-2813	-3208	Show	55/NA	NA
672	924	-1557	-2724	-3096	133	231/NA	NA
674	917	-1600	-2993	-3208	NA	56/NA	NA
675	656	-1589	---	---	NA	NA	NA
680	672	-1675	-2845	-3228	39	112/29	540/120
685	864	-1544	-2706	-3077	Show	39/3	NA
686	584	-1565	-2758	-3164	NA	NA	NA
691	862	-1661	-2818	-3238	Show	66/NA	585/192
697	970	-1705	-2915	NA	NA	NA	NA
701	601	-1686	-2874	-3305	Show	119/NA	740/264
704	604	-1544	-2696	-3066	Show	25/19	NA
747	896	-1706	---	---	NA	NA	NA
750	828	-1490	---	---	NA	NA	NA
755	592	-1478	-2680	-3098	Show	NA	NA
765	584	-1543	-2716	-3141	NA	NA	NA
770	844	-1665	---	---	Show	NA	NA
778	849	-1662	---	---	NA	NA	NA
781	608	-1698	-2892	-3327	Show	60/24	660/168
783	809	-1713	-2907	-3339	Show	202/24	855/168
785	629	-1706	-2905	-3347	Show	119/19	775/168
788	914	-1672	-2836	-3232	Show	84/24	675/168
789	911	-1625	-2804	-3226	Show	127/24	595/168
790	912	-1645	-2866	-3344	Show	119/24	715/72
792	842	-1650	---	---	17	47/NA	NA
794	838	-1646	-2828	-3258	Show	73/11	565/192
795	609	-1589	---	---	NA	NA	NA
796	629	-1486	---	---	NA	NA	NA
797	799	-1510	-2718	-3153	NA	26/NA	NA
798	595	-1658	-2836	-3257	NA	94/18	950/Max
799	782	-1677	-2849	-3276	NA	94/13	900/168
800	879	-1719	-2911	-3344	NA	239/NA	950/168
801	612	-1680	-2876	-3294	NA	119/17	785/168
802	628	-1676	-2862	-3292	NA	283/16	950/NA
807	634	-1644	-2822	-3244	NA	84/NA	925/NA
808	644	-1644	-2846	-3306	NA	179/NA	760/NA
809	635	-1566	-2782	-3237	NA	315/NA	785/NA
810	696	-1690	-2886	-3304	Show	36/24	NA
811	666	-1590	-2804	-3268	Show	492/NA	650/NA
812	739	-1611	-2829	-3293	Show	103/NA	750/NA
813	732	-1546	-2764	-3220	NA	73/NA	700/NA
814	928	-1572	-2782	-3250	Show	73/NA	720/NA
815	958	-1662	-2862	-3322	NA	163/NA	710/NA
816	583	-1536	-2743	-3192	NA	60/18	560/NA
822	975	-1695	-2899	-3335	NA	386/4	890/NA
823	660	-1680	-2887	-3366	NA	160/4	770/NA
824	852	-1693	-2898	-3368	NA	329/5	830/NA

WELL PERMIT NUMBER	WELL TOP ELEV.	SUB-SEA ELEVATION TOP BEREA	TOP BR. SH.	BASE BR. SH.	IOF	FOF/HR	PRESS/HR
828	942	-1684	-2888	-3346	NA	82/NA	725/NA
829	625	-1720	-2935	-3405	NA	350/4	865/NA
830	711	-1661	---	---	NA	280/4	860/NA
832	852	-1648	-2816	-3235	40	NA	530/NA
833	910	-1695	-2905	-3380	NA	270/5	840/NA
834	897	-1669	-2871	-3313	103	NA	649/NA
835	---	---	---	---	NA	NA	NA
838	---	---	---	---	NA	NA	NA
840	---	---	---	---	NA	NA	NA
845	---	---	---	---	NA	NA	NA
847	650	-1688	-2906	-3395	Show	332/24	925/NA
848	927	-1665	-2851	-3282	NA	NA	NA
849	---	---	---	---	NA	NA	NA
850	---	---	---	---	NA	NA	NA
855	980	-1638	-2820	-3250	NA	NA	NA
857	949	-1695	-2906	-3388	42	322/5½	850/NA
858	662	-1695	-2904	-3383	25	385/4½	800/NA
859	833	-1695	-2906	-3378	27	582/3½	850/NA
862	920	-1655	-2860	-3328	NA	200/4	895/NA
863	800	-1688	-2890	-3350	NA	NA	NA
865	850	-1663	-2870	-3333	NA	120/4	705/NA
867	926	-1703	-2918	---	NA	NA	NA
868	990	-1694	-2910	---	18	120/4	810/NA
870	925	-1707	-2927	---	13	395/4	860/NA
871	863	-1615	-2815	-3262	NA	NA	NA
873	918	-1660	-2844	-3282	NA	NA	NA
874	666	-1684	-2896	-3372	8	170/4	780/NA
875	980	-1709	-2918	-3392	16	280/4	920/NA
876	673	-1685	-2905	-3403	15	280/4	920/NA
904	---	---	---	---	NA	NA	NA
D609	612	-1708	-2794	-3293	NA	146/24	900/Max
D828	618	-1700	-2898	-3343	Show	103/24	525/15
F2657	---	-1626	---	---	NA	NA	NA
F2794	590	-1578	---	---	NA	NA	NA
F2795	573	-1591	---	---	NA	NA	NA
F2796	590	-1599	---	---	NA	NA	NA
F3055	---	---	---	---	NA	NA	NA

APPENDIX D

ELECTRICAL RESISTIVITY FIELD DATA

ELECTRICAL RESISTIVITY FIELD DATA

Station number	CPPC Resistance	CCPP Resistance	CPCP Resistance	Delta percent
1	12.7	4.3	10.0	-12.6
2	17.0	5.0	13.4	-8.24
3	77.0	64.1	9.5	+4.54
4	21.4	8.8	12.0	+2.80
5	55.3	50.2	11.4	-11.4
6	19.7	6.7	12.5	+2.54
7	18.0	6.2	9.6	+12.2
8	18.7	6.0	10.7	+10.7
9	17.5	5.5	10.1	+10.8
10	18.6	7.6	7.6	+18.3
11	15.1	6.4	7.8	+6.00
12	13.3	3.9	7.5	+14.3
13	11.2	2.7	6.0	+22.3
14	10.8	2.4	5.7	+25.0
15	9.2	3.2	1.3	+51.5

Resistance units are in ohm/feet.

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APPENDIX E

WATER WELL-PHOTOLINEAMENT PROXIMITY DATA

Proximity of Water Wells to Nearest Photolineament

0-100 feet	101-150 feet	151-200 feet	Greater than 200 feet
BA-17	WI-60	WI-58	RO-26
EL-43	EL-41	EL-18	RO-27
EL-42	RO-25	EL-40	WI-51
WI-63		BA-51	WI-71
RO-30		BA-53	BA-13
RO-31		RO-29	RO-34
		WI-23	WI-70
		RO-24	WI-65
		RO-36	RO-32
		SI-16	KE-3
			BA-5
			BA-56
			BA-52
			BA-54
			WI-8
			WI-10
			WI-11
			WI-21
			WI-28
			RO-35
			EL-46
			BA-55
			WI-59
			WI-61
			WI-64
			WI-67
			EL-75
			BA-78
			RO-38
			SI-48
			WI-9
			WI-22
			BA-14
			EL-19
			SI-50
			SI-4
			SI-15
			EL-44
			EL-76
			RO-39
			BA-6
			KE-1
			WI-7
			WI-12
			WI-20
			RO-33
			SI-47
			SI-49
			WI-62
			WI-69
			EL-73
			EL-77

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APPENDIX F

INITIAL OPEN FLOW-PHOTOLINEAMENT DATA

PHOTOLINEAMENT DATA AND INITIAL OPEN FLOW FOR GAS WELLS

Gas Well Yield (MCF/day)	Distance to Nearest Photolineament (Km)	Photolineament Class	Photolineament Orientation
377	0.33	1	N
326	0.35	2	N27°E
260	0.10	2	N55°W
238	0.00	1	N68°W
231	0.65	3	N51°E
184	0.30	1	N
174	0.13	1	N13°W
158	0.35	2	N50°W
103	0.60	3	N20°E
103	0.10	1	N15°W
103	0.75	2	N18°E
94	0.15	1	N
89	1.00	3	N20°E
73	0.30	2	N72°W
73	0.20	1	N11°W
60	0.60	1	N
56	0.68	2	N50°W
56	0.19	2	N50°W
47	0.55	2	N50°W
45	0.30	2	N30°W
40	0.42	2	N15°E
39	0.25	2	N12°E
37	0.80	1	N11°W
33	0.05	2	N81°W
33	0.35	1	N14°W
30	0.03	1	N7°W
30	0.30	2	N55°W
29	0.00	2	N52°W
24	0.40	2	N74°W
24	0.10	1	N
21	0.20	1	N65°E
21	0.60	2	N15°W
21	0.30	2	N23°E
21	0.10	1	N15°W
21	0.55	2	N55°E
21	0.60	2	N55°E
20	0.20	2	N25°W
18	0.35	3	N75°E
18	0.10	2	N2°W
17	0.35	3	N15°E
15	0.35	2	N50°W
15	0.25	1	N33°W
15	0.50	1	N4°E
15	0.25	2	N72°W
15	0.60	2	N72°W
15	0.50	2	N52°E

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Gas Well Yield (MCF/day)	Distance to Nearest Photolineament (Km)	Photolineament Class	Photolineament Orientation
14	1.25	3	N51°E
11	0.22	3	N70°W
10	0.40	2	N21°E
5	0.20	2	N16°E
show	0.40	2	N52°E
show	0.90	2	N52°E
show	0.75	2	N55°E
show	0.10	3	N50°E
show	0.50	2	N21°E
show	0.05	3	N43°E
show	0.10	1	N
show	0.31	1	N15°W
show	0.35	3	N5°E
show	0.40	3	N46°E
show	0.20	2	N5°W
show	0.55	2	N
show	0.65	2	N46°E
show	0.38	2	N73°W
show	0.20	3	N
show	0.35	2	N46°E
show	0.95	1	N54°E
show	0.50	1	N50°W
show	0.10	2	N78°E
show	0.05	2	N81°W
show	0.05	1	N
show	0.20	2	N50°W
show	0.18	2	N19°W
show	0.08	1	N4°W
show	0.50	1	N34°W
show	0.90	2	N46°E

APPENDIX G

FINAL OPEN FLOW-PHOTOLINEAMENT DATA

PHOTOLINEAMENT DATA AND FINAL OPEN FLOW
FOR GAS WELLS

Gas Well Yield (MCF/day)	Distance to Nearest Photolineament (Km)	Photolineament Class	Photolineament Orientation
2499	0.33	1	N
1265	0.10	2	N2°W
1175	0.10	1	N15°W
1164	0.65	3	N51°W
1009	0.50	2	N28°E
989	0.10	1	N
987	0.30	1	N
852	0.25	1	N11°W
848	0.00	1	N68°W
781	0.35	2	N27°E
750	0.55	2	N55°E
750	0.30	2	N55°E
660	0.60	2	N15°W
620	0.25	2	N72°W
603	0.90	2	N54°E
553	0.90	2	N58°E
511	0.20	1	N11°W
500	0.13	1	N13°W
499	0.00	3	N45°E
495	0.15	1	N
424	0.65	3	N45°E
412	0.25	1	N33°W
381	0.60	2	N55°E
379	0.75	2	N18°E
377	0.10	2	N54°W
372	0.50	2	N20°E
367	0.40	1	N15°W
358	0.20	2	N16°E
350	0.10	1	N10°E
336	0.29	2	N23°E
329	0.40	2	N54°E
329	0.60	1	N26°W
325	0.50	2	N52°E
315	0.30	1	N15°W
298	0.10	1	N15°W
283	0.10	2	N50°E
273	1.00	3	N20°E
270	0.10	3	N80°W
246	0.20	2	N50°W
239	0.80	2	N35°W
231	0.35	2	N50°W
211	0.40	2	N74°W
207	0.00	2	N52°W
202	0.50	1	N50°W

Gas Well Yield (MCF/day)	Distance to Nearest Photolineament (Km)	Photolineament Class	Photolineament Orientation
202	0.80	1	N11°W
198	0.35	2	N50°W
193	0.05	1	N7°W
189	0.55	2	N50°W
179	0.25	3	N65°E
169	0.30	2	N72°W
169	0.70	2	N50°W
163	0.75	3	N65°E
158	0.20	3	N45°E
146	0.05	3	N45°E
146	0.35	1	N14°W
146	0.10	2	N67°W
145	0.60	2	N72°W
140	0.30	2	N30°W
127	0.55	2	N
119	0.50	2	N81°W
119	0.40	2	N45°E
119	0.05	2	N81°W
112	0.25	2	N12°E
103	0.50	1	N30°W
103	0.05	1	N
103	0.60	1	N
100	0.40	2	N28°E
94	1.25	3	N51°E
94	0.15	2	N13°W
94	0.10	2	N71°E
85	0.75	2	N58°E
84	0.05	1	N13°W
84	0.40	3	N50°E
84	0.90	2	N45°E
84	0.20	2	N50°W
84	0.10	2	N3°W
82	1.20	2	N74°W
78	0.20	2	N25°W
73	0.10	3	N20°E
73	0.60	2	N45°E
66	0.40	2	N72°W
61	0.22	3	N70°W
60	0.10	2	N70°E
60	0.20	1	N65°E
60	0.35	3	N75°E
57	0.20	2	N15°W
48	0.20	1	N11°W
47	0.35	2	N15°E
43	0.60	2	N2°E
39	0.50	2	N20°E
36	0.10	1	N5°W
25	0.10	3	N50°E
24	0.30	3	N78°E
21	0.60	1	N53°E
14	1.00	1	N53°E
60	0.40	2	N20°E

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APPENDIX H

PUMPING TEST DATA

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Pumping Test Data

Well Number and Owner	Probable Aquifer	Static Water Level (feet below surface)	s	Q	C	T	Pumping Time
RO-29 (L.Pennington)	Gilboy (ss)	44.0	8.83'	6.51	0.74	311.68	[illegible]
EL-80 (O.Stone)	Waynesburg (ss)	19.25	2.58'	8.09	3.13	1615.55	20 min

s = drawdown in feet after maximum duration of pumping,

Q = pumping rate in gallons per minute,

C = specific capacity in gallons per minute per foot of drawdown,

T = transmissivity in gallons per day per foot of aquifer width.

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ABSTRACT

A hydrogeologic study was conducted in the Midway-Extra gas field where gas wells tap Devonian shales in northern Putnam County, West Virginia. Lineaments were mapped and shallow ground water was surveyed for physical and chemical parameters, to determine if lineaments or ground water may be useful for shale gas exploration. Landsat lineaments, defined from satellite imagery, have no apparent effect on water well yield and are associated with low gas well yields. Short photolineaments, defined from low-altitude stereo photography, are excellent sites for high-yielding water wells and good sites for high-yielding gas wells in general. These lineaments appear to represent permeable zones about 400 feet wide at shallow depth. The density of photolineaments orientated N60°W-N30°E is especially well associated with high-yielding gas well trends. Final open flow is especially great for gas wells near water wells or springs having high bicarbonate or nitrate concentrations. High bicarbonate content is in part likely to be caused by oxidation of methane gas in shallow ground water. Photolineaments and ground water chemistry may well prove to be valuable exploration tools for Devonian shale gas in other areas.

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APPENDIX F

Geophysical Data

Richard T. Williams
James E. Ruotsala

USGS File #0248/A78, V.2
WVU Dept. of Geology & Geography
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A Review of the report by K. G. Kirk which appeared in the 1977-1978 Devonian Shales Project Annual Report under the title "A Petite High Resolution Seismic System for Coal Investigation"

by

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October 1979

A seismic reflection survey was conducted at the Pricetown, West Virginia, in-situ coal gasification site during the 1977-1978 fiscal year. The data and an interpretation were presented in a paper by K. G. Kirk appended to the 1977-1978 annual report. One part of that paper is re-examined here. While similar comments apply to the remainder of the paper, the present discussion is limited to the Pricetown II data.

The Pricetown data were recorded using the Bison 1580 seismograph in a slightly different configuration from its present one. However, the modifications to the system, made since the Pricetown data were recorded, are of a technical nature and do not affect the discussion presented.

Serious problems are readily identifiable in the Pricetown II interpretation, on the basis of fundamental considerations from the theory of reflection profiling. Each of these is treated in a separate paragraph below.

The horizontal scale is incorrect. In the simple case of horizontal subsurface reflectors and lateral homogeneity, reflection depth-points are located midway between the shot-point and geophone. Thus, the horizontal interval at which the subsurface is mapped is one-half the geophone spacing. In this survey the geophone spacing was 40 feet; so the distance between traces on the seismic section should be 20 feet. Because of this error, subsurface features will be incorrectly located, and their horizontal dimension will be distorted. In addition, it is possible that incomplete subsurface coverage was obtained, with gaps between adjacent six-trace records.

Apparent acoustic energy arrives at zero-time. In a seismic reflection survey the first event to arrive on the field record will be either the direct ray, or a critically refracted ray, depending on the local geology and shooting geometry. At the Pricetown II site there is a sandstone that has velocity (V_p) near 7400 ft/sec essentially at the surface, and the first arrival will be the direct ray moving across the geophone spread at that velocity. Prior to this event, the seismic trace will be quiescent. On the Pricetown data, there is apparent acoustic energy from the start of the trace, indicating a severe noise problem at an amplitude as great as any of the events identified as reflections. If this noise persisted throughout the recording interval, it would mask any seismic signals. An alternative explanation of the event at time-zero is that the seismograph was starting late, and that zero-time is incorrectly located on the seismic time section.

Events having opposite polarity on the seismic section are identified as coals. Coal has a very low acoustic impedance compared to most other rocks. For that reason, it will consistently exhibit a negative reflection polarity, as defined by the direction of the first excursion of the reflection wave form. On the Bison system, polarity from trace to trace for a single shot may not be consistent, but on a particular trace the polarity should not change. On the Pricetown II section, reflection events having opposite polarities are both identified as coals, which is impossible.

There are several seismic events missing from the section. Each of the reflection events identified in the previous report coincides with a change in the seismic velocity on a nearby continuous velocity log (CVL). However, a comparison of the section with a synthetic trace, formed by the convolution of a simple wavelet with a reflectivity function derived from the CVL, shows primary events that are not present on the seismic data. The data and synthetic trace are shown for side-by-side comparison in Figure 1. Also missing from the data are the various first-order surface multiples and peg-leg multiples that should be associated with good reflectors, like coals. Multiples are not included in the synthetic trace.

The seismic expression of the interpreted fracture zone is inappropriate. If there were a fracture zone open to near the depth of the Pittsburgh coal, it is quite unlikely that it would completely mask reflections from coals above the Pittsburgh. The expected effect of the fracture zone is to decrease the seismic velocity, and in terms of the reflection travel times it could be manifested in one of two ways:

1. If the subsurface coverage is greater than 36%, ray paths that lie only partially within the fracture zone must exist. On these traces, the normal-move-out (NMO) will not have the usual hyperbolic form, and the NMO correction would be unsuccessful. However, it would be possible to estimate the extent of the fracture zone by modeling the observed move-out.

2. If the subsurface coverage is less than 36%, it would be possible (but unlikely) that ray paths from one shot could lie entirely within the fracture zone, while no other traces were affected. In that case, the NMO correction would be successful and subsurface reflectors would be correctly positioned on the time section, and the resulting anomaly could be interpreted either as an anomaly in vertical velocity or a subsurface structure.

While these two cases illustrate the problem with the previous interpretation of the data as a velocity anomaly, it is the opinion of the authors that neither of the above cases are likely to apply to the Pricetown II data for reasons outlined in the following paragraphs.

The most reasonable explanation of the anomaly previously interpreted as a fracture zone is that it is the result of an inadvertent halving of the sampling interval in the upper 200 milliseconds (ms) of data, either by operator error or instrument malfunction. Close examination of the six anomalous traces on the Pricetown II section shows that the apparent frequency above 200 ms is about 300 Hz. Below 200 ms, and on all other traces on the section, the apparent frequency is exactly double, about 600 Hz. Postponing questions about how it could happen, if the first 205 ms of the six traces is compressed to half that, 102 ms, and the event at 209 ms is moved up unchanged, that event, identified as the Pittsburgh, aligns perfectly with the Waynesburg. Consideration of the character of the anomalous event (polarity and number of cycles in the wave form) supports this alignment. The event has the wrong polarity and perhaps one cycle too many to be the "Pittsburgh" but is consistent with the "Waynesburg," and no other. To understand how 102 ms of data could be represented as 205 ms, some understanding of the operation of the Bison seismograph is required. The seismograph uses an analog-to-digital converter (A/D) to store 256 values of the seismic trace in solid-state memory. The values

are samples of the trace, taken at equal time intervals, for a total record length which is switch-selectable. The switch that controls the record length has seven positions: 10.24 ms, 20.48 ms, 51.2 ms, 102.4 ms, 204.8 ms, 512 ms, and battery check. The last position activates a voltmeter to check the batteries, and must be used frequently. It would be quite easy to accidentally set the record length to 51.2 ms rather than 102.4 ms (labeled 100 ms) after checking the battery, and then to correct the error after checking the battery later, and never notice that the switch had been in the wrong position. At Pricetown the six-trace record was played onto a strip-chart recorder one trace at a time, from the digital memory through a digital-to-analog converter (D/A). The digital record itself was not preserved. The physical length of the analog record from the chart recorder remains constant, regardless of the time length of the record. Thus the sampling interval can be halved on one or more records, and the error can be detected only by a critical examination of the data. Although the problem has been described in terms of operator error, it could also result from an electrical/mechanical malfunction of the record length switch.

In summary, it is clear that no fracture zone was detected on the Pricetown II seismic profile. No statement concerning the existence or nonexistence of a fracture zone can be based on that data. Further, it is unlikely that the events on the data, identified as reflections, have seismic origin. More likely, in the opinion of the authors, the events are fortuitous and optimistic correlations of noise bursts with velocity lows on a nearby CVL. It is possible that this opinion would have to be modified after an examination of the original strip-chart records, but these appear to be lost. It is certain that actual seismic data could not be "cleaner" than the synthetic trace in Figure 1.

In addition to the presentation of the Pricetown data, the report last year also contains unsupportable, optimistic statements concerning the capabilities and value of the seismic system currently under development at West Virginia University. The authors feel that it is necessary to correct any misconceptions resulting from those statements at this time.

It is emphasized that the fundamental concept of a high resolution reflection seismic tool is considered to be very valuable, and attainable. It is only in the technical aspects that the authors consider the earlier report to be unrealistic. This subject has been partially treated in the Executive Summary of the Annual Report containing this paper, and those remarks will not be repeated.

In his report Kirk expresses the opinion that a high resolution seismic system that is inexpensive was demonstrated to work well, and that the data from the system required substantially no processing prior to interpretation. Both of these ideas are wrong. The system has been very expensive, in terms of cost per mile of seismic line. Although the system now appears to be ready for field tests (scheduled for October 16) no usable seismic reflection data has been obtained with it during the past two years. (Its present state

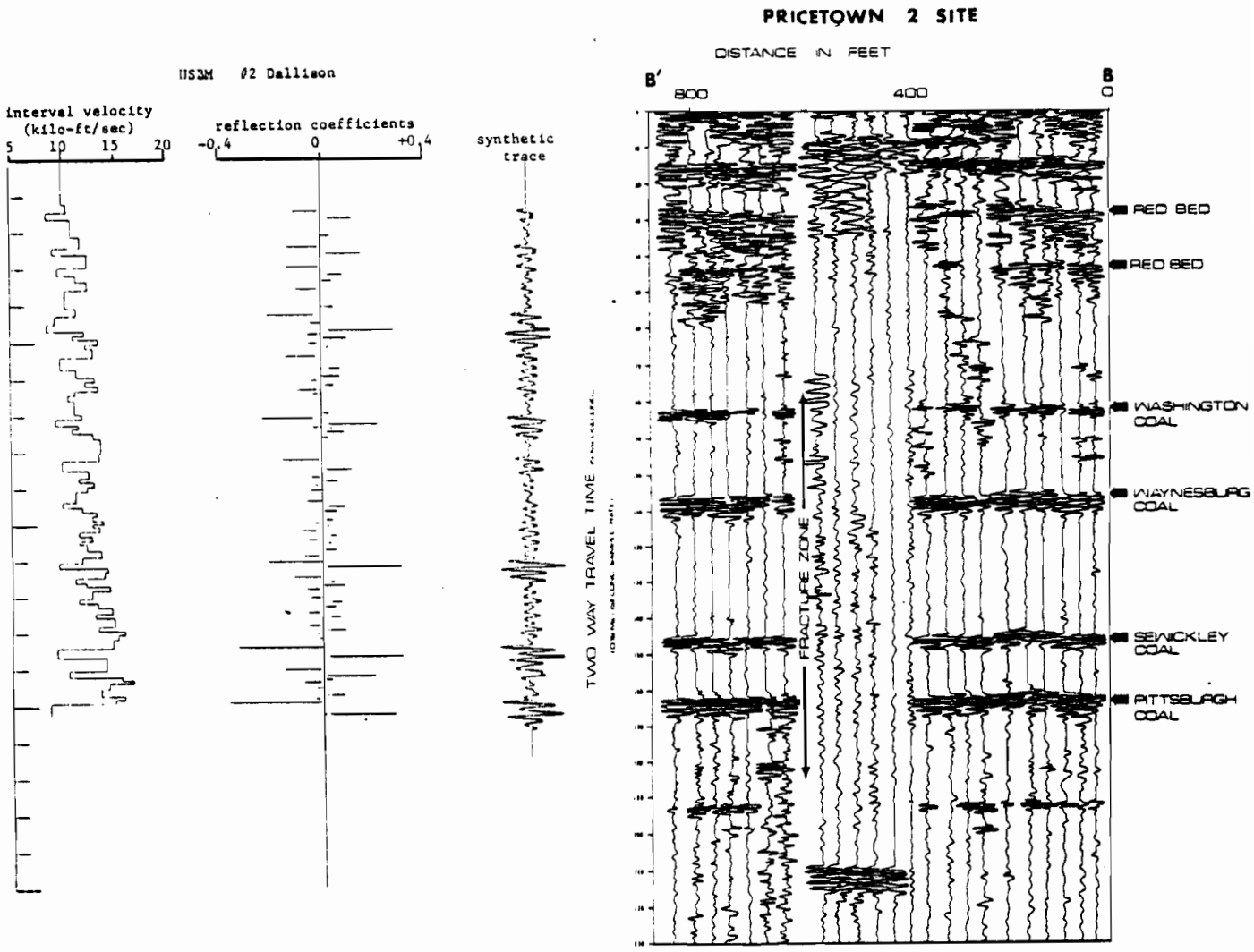

Figure 1. A symthetic seismic trace generated using the sonic log of a well on the seismic line (USBM #2 Dallison) is compared to the data recorded at the Pricetown II site by K. Kirk. The synthetic trace differs from real data in that it does not exhibit the exponential amplitude decrease with two-way time caused by spherical divergence of the wave front, and multiples are not included.

of readiness can be directly attributed to an electronics technician, who has worked with it on a full time basis for the past month.) Further, the capabilities of the present system are limited, as discussed in the Executive Summary. A full-featured seismic field system capable of recording the highest quality data would require a larger initial expenditure, about $250,000 based on a Texas Instruments DFS-V, plus the cost of the shot-hole drill. It would not involve larger personnel costs since it can be operated by the same four-man crew required by the Bison-based system. Since the TI system is delivered tested, and with training for the operators, there need be no delay between the hardware purchase and the start of data collection. The TI system, and similar ones by other manufacturers, are petite in petroleum industry terms, and are as portable as the present WVU system. Their true cost, in terms of their ability to produce geologic information, is less than the cost of the system under development.

The opinion expressed in the previous report, that high resolution seismic data can be processed by microcomputers, is also unrealistic. High resolution processing is more demanding than conventional applications. However, it is not necessarily true that a full size computer is needed, or even that a large computing system will be capable of even modest reflection-seismic processing tasks. (See the discussion of WVNET in the Executive Summary.) In recent years the cost of computing hardware has decreased dramatically (witness calculators and digital watches), and minicomputer-based seismic data processing systems have appeared on the market. In such systems the actual processing is done by specialized peripheral devices (array processors) while the minicomputer itself merely moves the data from tape or disk to the array processor, and finally to the plotter. The cost of such systems can be much less than processing charges on a nonspecialized large system. The low-cost TIMAP by Texas Instruments, for example, costs approximately $160,000 which includes a complete package of processing software and user training.

In reflection seismology, as elsewhere, one gets what one pays for. The method is expensive in absolute terms, but it is the least expensive tool for mapping in detail potential oil and gas reservoirs. It is the method by which virtually all new discoveries are made, and its cost must be balanced against its capabilities. The idea that the resolution can be increased so that the method can be applied to the exploration problems of potential eastern gas shale production seems quite promising. Within the limits of available resources, work towards this goal is continuing at WVU.

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AN ANALYSIS OF THE STRUCTURAL PARAMETERS THAT INFLUENCE GAS PRODUCTION FROM THE DEVONIAN SHALE

1978 - 1979

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