METC/SP-79/8

SEMI-ANNUAL REPORT FOR THE UNCONVENTIONAL GAS RECOVERY PROGRAM

Period Ending March 31, 1979

Robert L. Wise, Editor

August 1979

UNITED STATES DEPARTMENT OF ENERGY
Morgantown Energy Technology Center
Morgantown, West Virginia

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METC/SP-79/8
Distribution Category UC-92a

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1. SUMMARY

This document is the second semi-annual report describing the technical progress of the U. S. Department of Energy (DOE) projects directed at gas recovery from unconventional sources. Currently the program includes:

- Methane Recovery from Coalbeds Project (MRCP)
- Eastern Gas Shales Project (EGSP)
- Western Gas Sand Project (WGSP)
- Geopressured Aquifers Project (GAP)

The Energy Technology activities in Western Tight Gas Sands, Eastern Gas Shales, and Coalbed Methane Projects are under the direction of the Fossil Energy Director of Fossil Fuel Extraction. The Geopressured Aquifer activities are under the Solar-Geothermal Director of Geothermal Energy. For each of the gas resources, the program implementation is accomplished by DOE field offices. The Western Tight Gas Sands, Eastern Gas Shales, and Coalbed Methane programs are being implemented by the Morgantown Energy Technology Center with technical support from the Bartlesville Energy Technology Center and Pittsburgh Mining Operations. The Geopressured Aquifers Project is being implemented by the Houston Office of Geothermal Energy.

This report is divided into five parts: a summary (Section 1), and a section devoted to each resource (Sections 2 through 5). Each resource section presents information which serves as an introduction to that project. Technical progress and status of the activities for each project's primary elements are presented in following paragraphs.

This report covers the period of October 1, 1978 through March 31, 1979.

1.1 METHANE RECOVERY FROM COALBEDS

The following is a summary of significant MRCP accomplishments for the period October 1, 1978 through March 31, 1979.

RESOURCE ENGINEERING

Resource Engineering activities for the reporting period focused primarily in three areas: finalizing the Methane Recovery from Coalbeds Resource Delineation Plan, defining a test program to determine the feasibility of producing methane from unminable coalbeds, and acquiring site-specific data on unmined coalbed methane resources.

A resource delineation plan was developed which shows the MRCP approach to providing a data base for determining the national resource and the reserve; disseminating the information that is developed; and guiding management of the overall effort. The plan encompasses examination of 380,000 square miles of coalbearing rocks in the conterminous United States, and of the quantity, distribution and production characteristics of some 700 trillion cubic feet of methane estimated to be contained in those rocks. Early efforts will concentrate on some 20 percent (80,000 square miles) of this area where the probabilities of finding, producing, and utilizing the methane are higher. Attempts will be made within this area of 80,000 square miles to supply one data point every 1,000 square miles.

Cooperative agreements or contracts for drilling, coring and logging were established with four companies: Belco Petroleum, Kinloch Exploration Company, Twin Arrow Drilling Company, and a company whose identity is confidential.

A simulation model was used to develop a comprehensive test program to characterize the potential of methane production from "unminable" coalbeds in the United States. The study identified the parameters that are most important to the production of methane from coal; these independent variables are:

- Coalbed thickness
- Coalbed permeability
- Initial pressure
- Initial gas content
- Relative permeability
- Hydraulic fracture length
- Hydraulic fracture conductivity.

The investigation of ten sites was ongoing in six basins during the reporting period. These tests are as follows:

- Arkoma Basin Site AA in Pittsburg County, Oklahoma with Arkla Exploration Company. Core sample desorption data are undergoing evaluation. Reservoir simulation was employed to estimate gas-in-place at 1.4 Bcf/640 acres and cumulative 10 yr. deliverability, Φ, for an isolated well at 3,500-40,000 Mcf.

- Green River Basin Site AA with a confidential cooperator. Preliminary conventional core desorption data indicate methane at 51.0-279.1 cu.ft./ton. Reservoir simulation was employed to estimate gas-in-place at 1.8-6.0 Bcf/640 acres and cumulative 10-yr. deliverability, Φ, for an isolated well at 16,000-65,000 Mcf.

- Green River Basin Site AB in Sublette County, Wyoming with Belco Petroleum Company. Preliminary desorption data indicate methane at 23.5-392 cu.ft./ton. Reservoir simulation was employed to estimate gas-in-place at 6.1 Bcf/640 acres and cumulative 10-yr. deliverability, Φ, for an isolated well at 25,000-90,000 Mcf.

- Illinois Basin Site AA in Clay County, Illinois with Hagen Oil Company. Core sample desorption data indicate methane at 32-48 cu.ft./ton. Reservoir simulation was employed to estimate gas-in-place at 200 MMcf/640 acre section and cumulative 10-yr. deliverability, Φ, for an isolated well at 1,000 to 2,000 Mcf.

- Northern Appalachian Site AA in Greene County, Pennsylvania with Kinloch Exploration Company. Core data are undergoing evaluation.

- Northern Appalachian Site AB in Wetzel County, West Virginia by Morgantown Energy Technology Center. Desorption data indicate methane at 50-100 cu.ft./ton.

- Piceance Basin Site AA in Rio Blanco County, Colorado with Fuel Resources Development Company. Desorption data indicate methane at 17.9-80.9 cu.ft./ton.

- Piceance Basin Site AB in Rio Blanco County, Colorado with Twin Arrow Drilling Company. Dry hole.

- Piceance Basin Site AC in Rio Blanco County, Colorado with Twin Arrow Drilling Company. Preliminary desorption data indicate methane at 33.1-146.9 cu.ft./ton. Reservoir simulation was employed to estimate gas-in-place at 157 MMcf/640 acres and deliverability, Φ, at zero.

- San Juan Basin Site AA in San Juan County, New Mexico with Western Coal Company. Preliminary desorption data indicate methane at 10.3-44.5 cu.ft./ton.

RESEARCH AND DEVELOPMENT

As of the end of the reporting period, two R&D projects were underway: manufacture of a 5-3/8" Turbodrill by Maurer Engineering, Inc. and evaluation of the feasibility of explosive fracturing of coal to increase permeability by Physics International Company. Firm planning was executed for two additional R&D projects: an investigation of water jet drilling for methane drainage by Sandia Laboratories and a study of fracture mechanics of coal by West Virginia University.

Five short-duration shakedown tests of the Turbodrill have been performed. No-load baseline performance data were obtained. Teardown and inspection of the drill motor has indicated a problem area in the pressure seal in the bearing package. Maurer Engineering instituted design modifications to the floating piston seal assembly in preparation for subsequent formal Phase I testing at TRW Mission Manufacturing. The option was exercised to proceed into a modified testing project using the flow-through version of the bearing pack. The flow-through bearing pack will be used in Phase I and Phase II. When an adequate pressure seal is obtained, an abbreviated Phase I test may be run. At that point, the project may proceed directly into Phase III testing in a rugged field environment.

Specific results derived from the three other R&D projects will be available for discussion in subsequent semi-annual reports.

TECHNOLOGY SYSTEMS TESTS

Five Technology Systems Tests were underway at the close of the reporting period:

- Westinghouse Electric Contract DE-AC21-77MC08098 for utilization of methane from coalbeds for on-site power generation (Cambria County, Pennsylvania)

    - The degasification Revloc #32-13 well was drilled in the virgin coal area through the seams of the Bethlehem Mines Corporation, Ebensburg Division lease to just above the "A" seam at 825 feet.

    - No testing was performed on this well. Data from adjacent wells and other cores are being sought.

- Westinghouse Electric Contract DE-AC21-78MC08332 for methane extraction from virgin coal and space heating/fuel cell application (Westmoreland County, Pennsylvania)

    - The #4 well was completed in December in four zones using a Kiel frac. An electric downhole pump was used to dewater the well. The frac water has been recovered, but the well is making 6,500 gpd.

    - The free flow (flared) over four or five days was 32-33 MCFD. The shut-in pressure ranged from 12 to 25 psi.

    - Cost/benefit analyses assuming a 25 MCFD flow, 850 total acres, and 10 wells show 13 years to amortize costs. Investment costs are estimated at $1.21/MMBtu and O&M at $0.14/MMBtu/year; with 30 MCFD, amortization period drops to 7 years.

    - Due to low gas content, a 3-well coring program at the northwest, southwest, and north boundaries is under consideration.

* <u>Mountain Fuel Supply Company Contract DE-AC21-78MC10734 for methane recovery from unminable coal and pipeline utilization</u>

  - Pertinent core data available from the Utah Geological and Mineral Survey were evaluated. Fourteen samples had gas contents between 101 and 200 cf/ton coal.

  - Three recovery well site locations were selected based on favorable coal depth, high methane content of the coal, access for drilling, proximity to an existing natural gas pipeline, and favorable coal, oil and gas lease ownerships.

  - A tentative drilling and completion plan was developed.

  - A preliminary environmental assessment has been made of the three demonstration well locations. Final assessments will be made and approval will be obtained during Phase II of the project.

  - A simulator was used to predict water and gas production with inputs which reflect current estimated coal seam parameters.

  - Cost of service analysis was performed for base case assumptions as well as for the effect of variations in production parameters. The gas production cost, using base case assumptions, was calculated to be $3.31/Mcf.

* <u>Intercomp, Inc./COSEKA Contract DE-AC21-78MC08384 for methane recovery from unminable coal and pipeline utilization</u>

  - No field activities were completed during the reporting period due to adverse weather.

* <u>United States Steel Corporation Contract ET-75-C-01-9027 for demonstration of degasification of a portion of the Mary Lee coal group</u>

  - Twenty-one boreholes have been fully completed at Oak Grove. Four of these were placed near the mine and have since been mined through. Seventeen boreholes have been completed on the test area located five years ahead of mining.

  - Approximately twelve boreholes were draining gas on a regular basis by October 1978. Total gas flow at that time averaged about 600 Mcfd.

  - By March 1979 total gas flow from 16 boreholes rose to approximately 1.2 MMcfd.

Negotiations were underway for three additional projects:

- Pennsylvania Energy Resources, Inc. contract for an anthracite coal drainage test project (Luzerne County, Pennsylvania)
- Waynesburg College contract for a multiple completion test project (Greene County, Pennsylvania)
- Occidental Research Corporation/Island Creek Coal Company contract for a long horizontal holes active mine test project (Buchanan County, Virginia)

PROJECT INTEGRATION

In addition to coordination of the Resource Engineering, Research and Development, and Technology Systems Tests efforts, the MRCP Project Plan Document (PPD) was prepared.

A Methane Recovery from Coalbeds Symposium was planned to be held April 18-20, 1979 in Pittsburgh, Pennsylvania.

1.2 EASTERN GAS SHALES

The following is a summary of significant EGSP accomplishments from October 1, 1978 through March 31, 1979.

RESOURCE CHARACTERIZATION AND INVENTORY

Seven Devonian Shale wells were drilled and logged during this reporting period, and four existing wells were logged. Details of these wells are given in Table 1-1. Figure 1-1 shows the location of all EGSP core wells to date.

Table 1-1. Summary of Coring and Logging Activities During the First Half of FY79.

DATE	CONTRACTOR	EGSP WELL NO.	COUNTY, STATE	TARGET FORMATION	DATA COLLECTED	SHALE CORE LENGTH (Ft.)
10/78	Rector and Stone Drilling Co.	Ill. #4	Hardin Co., ILL	Dev. Shale	Core/Log (W)	237
10/78	Ashland Expl. Co.	KY #4	Johnson Co., KY	Dev. Shale	Core/Log (W&D)	543
11/78	Tenn. Geol. Survey	TN #5	Hawkins Co., TN	Dev. Shale	Core/Log (D)	*200
12/78	Tenn. Geol. Survey	TN #6	Hawkins Co., TN	Dev. Shale	Core/Log (D)	*650
1/79	Tenn. Geol. Survey	TN #7	Hawkins Co., TN	Dev. Shale	Core/Log (D)	*750
3/79	Minard Run Oil Co.	PA #1	McKean Co., PA	Dev. Shale	Core/Log (W&D)	725
3/79	C. E. Power Systems	PA #2	Allegheny Co., PA	Dev. Shale	Core/Log (W&D)	570
3/79	Thurlow Weed & Assoc.	(4 existing wells)	Knox Co., OH	Dev. Shale	Log (W&D)	
					Total	3675

(W) - wet-hole suite
(D) - dry-hole suite
* - non-oriented core

Comparison of core analysis data and logs has shown that gamma ray and density logs can adequately locate black Devonian Shales in the Appalachian Basin that contain high kerogen and uranium concentrations. Initial efforts have been completed to define an optimum well logging suite. This study showed that temperature and sibilation logs provide the quickest and perhaps the most dependable means for locating gas-filled fracture systems in communication with a borehole.

By the end of FY79, most of the basic mapping for the stratigraphic and structural evaluation of the Appalachian and Illinois Basins will be completed. No mapping or other activity has yet been undertaken by the EGSP in the Michigan Basin, but the available data will be determined during the second half of FY79.

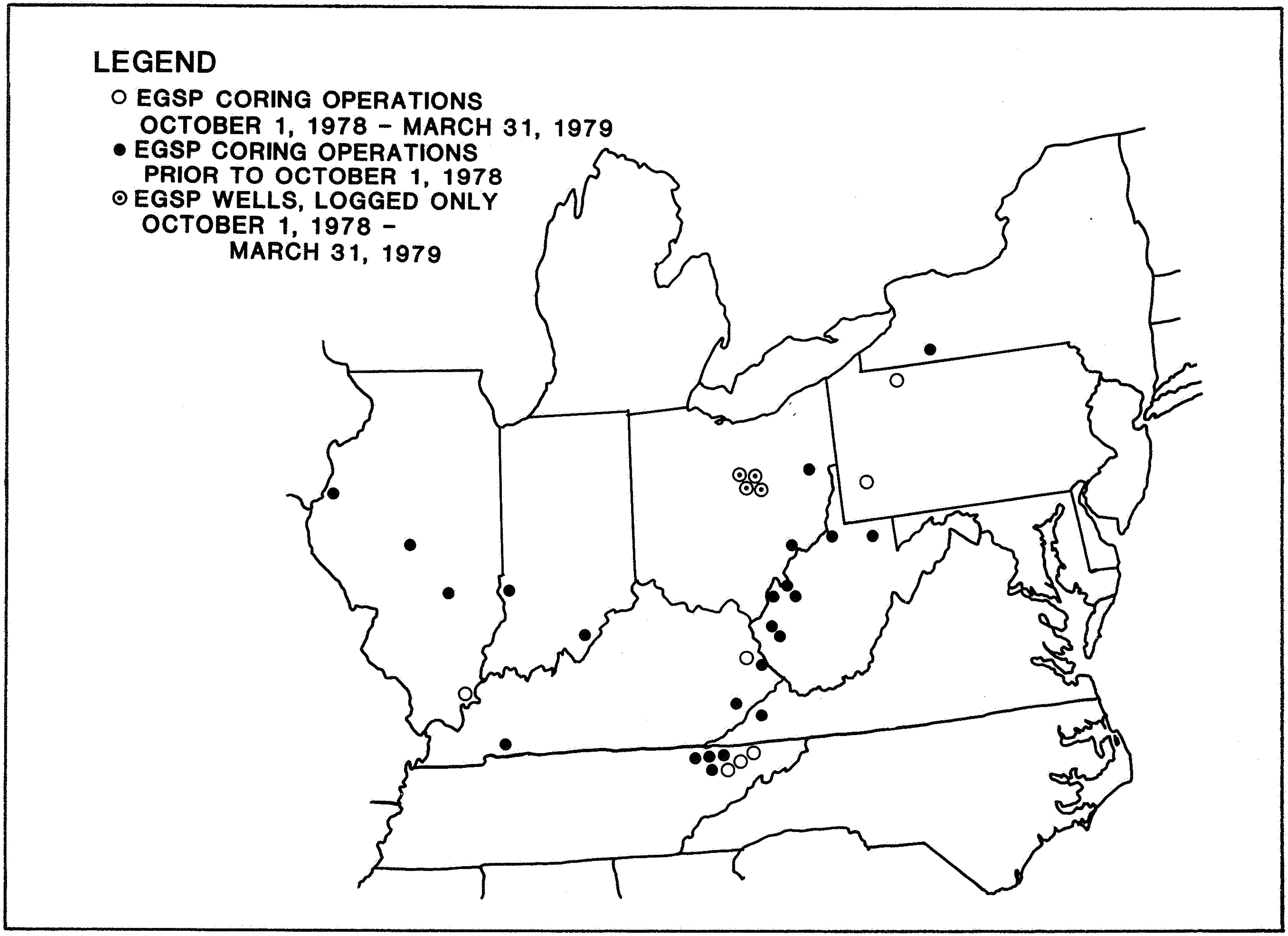


Figure 1-1. EGSP Core Wells

Physical and geochemical analyses of shale cores and well cuttings have shown:

- Porosity (as determined from core analysis) does not correlate with gas content on a sample-by-sample basis, but there does appear to be a relationship between zones of high porosity and high gas content within the same well.

- The only elemental combinations found to relate to gas content are vanadium/nickel and thorium/uranium ratios.

- Thermal maturity, along with organic carbon, are the major factors controlling gas content in the shale.

In exploration R&D, the following significant results were obtained:

- Lineaments in western Illinois are glacial in origin, and thus will provide little data for finding adequate fracture systems for gas production.

- Most of the New Albany Shale in Illinois has a negligible gas resource. However, a nineteen county area in southern Illinois has been identified as a possible area having a significant gas resource.

- Exploration rationales and supporting data for well site selection in areas affected by cross-strike structural discontinuities in West Virginia were developed.

- Seven well sites in Tennessee have been proposed for testing a recently developed exploration rationale.

SUPPORTING RESEARCH AND DEVELOPMENT

The main results achieved in Extraction Technology (excluding field tests) during the first half of FY79 are:

- Based on well testing of three wells, an orderly procedure has been established by which Devonian Shale wells can be tested and the pressure transient be analyzed. This method will be applied to approximately twenty wells in the next year.

- Sensitivity analyses carried out using a reservoir model indicate that matrix permeability and fracture length are the parameters having the greatest effect on production and recovery.

FIELD TESTS AND DEMONSTRATIONS

Field tests and demonstrations in the Eastern Gas Shales Project take place in both the Extraction Technology Testing and Verification elements.

Five new contracts (totalling 24 new wells) were signed in FY79 to test exploration and extraction rationales. The contractors involved are:

Columbia Gas System Service Corporation (10 wells)
Donohue, Anstey and Morrill (3 wells)
Mitchell Energy Corporation (5 wells)
Tetra Tech, Inc. (5 wells)
Thurlow Weed and Associates (1 new well, plus 3 existing wells to be stimulated)

During this reporting period, three wells were drilled under these contracts, two by Tetra Tech, and one by Thurlow Weed. None of the wells has yet been stimulated.

The only stimulation method tested in the last six months was foam fracture, which was tested in the deviated well (Cottageville Field), and on a well in Johnson County, Kentucky. The final open flow in the deviated well was 12 Mcfd, and in the other well was 43 Mcfd.

Based on two contracts with Columbia Gas involving a total of 16 (7 shale) wells, (see 3.4.3 and 3.4.4 for locations) the following conclusions were reached:

- Potentially recoverable Devonian Shale gas is 200 to 900 trillion cubic feet, depending on the estimating method used.
- A single, limited entry treatment in selected intervals with an energy assist fluid is the preferred stimulation approach.
- Large treatment sizes do not necessarily increase production proportionally and may cause extensive cleanup problems.
- Reservoir testing has not been effective in predicting production from hydraulically fractured wells.

1.3 WESTERN GAS SANDS

The following is a summary of significant WGSP accomplishments for the period October 1, 1978 through March 31, 1979.

RESOURCE ASSESSMENT

Geological and geophysical studies were continued by the USGS to characterize the resource base in the four primary study areas. Three wells were cored for the WGSP program:

- Pacific Transmission Supply (PTS, Federal No. 24-19 (section 19, T33N, R114W), Sublette County, Wyoming. The well is located at the eastern edge of the Wyoming overthrust belt near the western edge of the Green River Basin. About 220 ft of oriented 4-inch core was shipped to Core Laboratories for analysis. About 20 ft of this core was seal-peeled for study by LASL, LLL, and BETC. The core was probably taken in upper Mesaverde rocks, which lie below the thrust fault.

- Smokey Oil, 3-18 Bluewater Federal (section 18, T15N, R99W), Sweetwater County, Wyoming is scheduled for a 13,500 ft Mesaverde test in the Green River Basin. The lower part of the coring apparatus was twisted off in the hole and after extensive fishing operations, the operator decided against further attempts to core the well. No core was obtained, and the logging program for this well has been dropped.

- Twin Arrow C&K 4-14 (section 14, T3S, R101W), Rio Blanco County, Colorado. The complete cored interval was from lenticular sands and shales of the continental Williams Fork Formation (Mesaverde Group) in the Piceance Basin. The well was cored to recover sections from low permeability gas sandstones and coal stringers for on-site gas desorption (degassing) measurements. A total of 359 ft of 2-inch core was recovered and described on site. Selected intervals of core were seal-peeled for lab tests including whole core analysis, porosity, permeability, and grain density measurements over selected intervals, and a core gamma analysis over the entire core. Special analyses being performed include cation exchange capacity, resistivity index-formation factor and acoustic velocity measurements.

RESEARCH AND DEVELOPMENT BY ENERGY TECHNOLOGY CENTERS AND NATIONAL LABORATORIES

The Bartlesville Energy Technology Center (BETC) and participating National Laboratories, funded by DOE, continued their work in the area of research and development. The emphasis was on the development of new tools and instrumentation systems, rock mechanics, mathematical modeling and data analysis.

The design phase of the pressure coring system has been completed. Work is proceding on fabrication and testing of an improved system.

Resistivity measurements on core plugs from the Mesaverde Group continued, although repeated oil leaks into the cores required equipment modification to eliminate the problem. An apparatus for determining the cation exchange capacity (CEC) of clay-containing core samples was assembled. CEC determinations were subsequently made for a number of core samples. Porosity, permeability and conductivity measurements were made for cores from eight well depths from the Natural Buttes No. 21 well in Uintah County, Utah.

A three-dimensional, cylindrical coordinate, dry gas simulator is being used to simulate well behavior under the conditions of MHF tests. The simulator has been modified to account for the presence of a fracture. The third dimension, the z direction, is used to simulate the effect of various sands that may be open to the wellbore. Results of this work demonstrate that conventional pressure transient analysis techniques do not work with the buildup data from some zones. Since computer matching appears to give better results, all of the test data will be analyzed using computer matching.

Experiments were begun to study the effect of water saturation on crack growth across interfaces in Indiana limestone. The standard three-block experiments were performed in which fracturing fluid was injected into the central block of a three-block sandwich. The blocks were placed in a hydraulic press which produced a normal stress load across the two interior interfaces. The central block and one of the outer blocks were dry; the other outer block was water saturated. Earlier experiments showed that the threshold normal stress for cracks to cross an interface between dry limestone blocks was about 625 psi. The current experiments indicate that the threshold normal stress for cracks to grow from a dry to a saturated block is about 500 psi.

Additional analysis of the data from the Mobil Research and Development Corporation's Piceance Creek Unit Well F31-13G has been completed. The previous analysis used "scum", a fracture-formation resistance factor similar to skin damage, but on the fracture faces, to fit the data. This second model did not use "scum" but rather used a finite conductivity in the fracture. Good fit was achieved by the two models to the data. Where there is a difference in the models, the finite conductivity fracture model shows a slightly higher pressure.

FIELD TESTS AND DEMONSTRATIONS

The field test and demonstration program involves cooperation between industry and government and also interacts geologic studies with laboratory research and development. The following projects are in active status in the WGSP:

- A dry gas injection experiment in the Wattenberg Field, Colorado, by Colorado Interstate Gas Company. The Ajax "DPC-160/HZ" compressor and three Rolo dry bed dehydrators have been delivered and installed at the Sprague No. 1 well. Measurement of bottom-hole pressure in the Miller No. 1 and Sprague No. 1 wells is continuing. Bottom-hole pressure of the Miller No. 1 is increasing slowly at 4 to 6 lb per day and at an average of 3 lb per day in the Sprague No. 1 well. Since it is not advantageous to continue to measure BHP at this rate of buildup, the cycling process will be started as soon as all of the equipment is installed and working properly.

- MHF demonstrations by Gas Producing Enterprises in the Uinta Basin, Utah. The GPE wells, Natural Buttes Units 9, 14, 18 and 20 flowed to sales during March. Natural Buttes No. 19 and 22 were shut in and NBU No. 21 was temporarily abandoned.

- MHF treatment of the Cotton Valley Limestone Formation in Limestone County, Texas, by Mitchell Energy Corporation. Muse-Duke No. 1 was flowing 4,000 Mcfg and 25 BBL of frac water per day through a 24/64 in. choke with a flowing tubing pressure of 1,100 psi during March. Flow rates and pressures continued to drop at a slow rate. The scheduled post pressure transient tests and clean-out work have not been completed.

- MHF demonstrations in the Piceance Basin, Colorado, by Mobil Research and Development Corporation and Rio Blanco Natural Gas Company. Efforts to clean out well F31-13G continued through March. Junk from the top plug, partially drilled up, is resting on sand fill at about 8,829 ft. While attempting to mill-up this junk, the milling equipment, including a set of jars, became stuck. This was presumably due to influx of frac sand from the fractured intervals above. After backing off tools, the hole was circulated to remove sand and an overshot was run to retrieve the fish. During this attempt the fishing tools became stuck and also had to be backed off. Operations will be suspended until a thorough study can be made of the problem and a new plan of action formulated. Tubing was landed just above the fish and the well swabbed in an attempt to establish flow. After 5 days of swabbing the well did not flow and was shut in.

- A mineback testing program by Sandia Laboratories. There was no further work on the Hole No. 6, experiment during March. Work has commenced on the Interface Test Series, a series of small hydro-fractures that were conducted to test the effect of pump rate on the containment of a hydraulic fracture at a material property interface. Numerous zones in three different holes will be fractured at various flow rates.

PROJECT MANAGEMENT

A WBSP Logging Program meeting was held October 24, 1978. Representatives from DOE-BETC/NV, DOE-BETC, DOE-NV, CER, Intercomp, Lawrence Livermore Laboratory, Mobil Research, Sandia Laboratories, and the USGS attended.

In addition to the ongoing coordination of project activitites, the following project documentation was released or is in preparation:

- Western Gas Sands Project Status Reports for the months of October, November and December 1978 and January and February 1979 were completed and distributed.

- Progress reports for the months of February and March are in preparation.

- The fourth Quarterly Basin Activities Report for October, November, and December, 1978 was completed.

- The DOE Test Facility Operations Manual is in review.

The Williston Basin Symposium was held September 24-27, 1978 in Billings, Montana. Papers were presented by industry, government and service companies from Canada and the United States. These papers included discussions of the geology and the problems associated with producing oil and gas from the Williston Basin. Most of the papers were centered around the Paleozoic carbonates, which make up the greatest percentage of Williston Basin production. Mr. D.D. Rice, USGS, Denver, presented a paper on the natural gas resources of the Northern Great Plains Province and Mr. G.W. Shurr, St. Cloud State University, St. Cloud, Minnesota, presented a paper on the potential gas occurrence of the Upper Cretaceous in western South Dakota.

1.4 METHANE RECOVERY FROM GEOPRESSURED AQUIFERS

The following is a summary of significant activities in this program through April, 1979.

RESOURCE ASSESSMENT

Current resource assessment activity is focused on the onshore portion of the Texas-Louisiana Gulf Coast. The primary areas of study have been in the Frio, Wilcox, and Vicksburg formations. Initial work resulted in choosing the optimum test well site for the first designed well in Brazoria County, Texas. Further work has delineated five more sites in the Frio and four sites in the Wilcox Fairways.

Continuing work in Louisiana has resulted in the selection of the following five prospect areas on which a new test well can be drilled:

Atchafalaya Bay
LaFourche Crossing
Southeast Pecan Island
Johnson Bayou
Rockefeller Refuge

Five additional areas will be defined in the near future.

SUPPORTING RESEARCH

Methane solubility studies are continuing at Idaho State University. Equipment has been assembled and is being tested. Laboratory aquifer simulation studies at the University of Southern California are also in the assembly stage with first runs expected in June 1979. The assembly of high-temperature, high-pressure viscometer at the Institute of Gas Technology has been completed and its calibration is expected to start in May 1979.

The objective of legal and institutional research being supported by DOE is to identify legal and institutional barriers that may exist which may tend to delay or preclude geopressured resource production. A study by the Law Center of the Louisiana State University has been completed and a report entitled "Legal Problems Inherent in the Development of Geopressured and Geothermal Resources in Louisiana" has been issued. Work continues on keeping the public and government entities informed of geopressured aquifer development. To this end, two workshop-type meetings have been held in Alvin, Texas, to apprise all interested parties of the developments in Brazoria County, Texas, (first geopressured aquifer test) and to plan for growth should the pace of exploration accelerate.

FIELD TESTS AND DEMONSTRATIONS

The first well specifically designed to test geopressured aquifers over a long period was started in Brazoria County, Texas. After encountering mechanical difficulties, the original hole was plugged back and a new hole was started 500 feet southeast of the initial attempt. The plugged back hole will be used as a disposal well once production is started. Good progress is being made on the current well and completion is expected in June 1979.

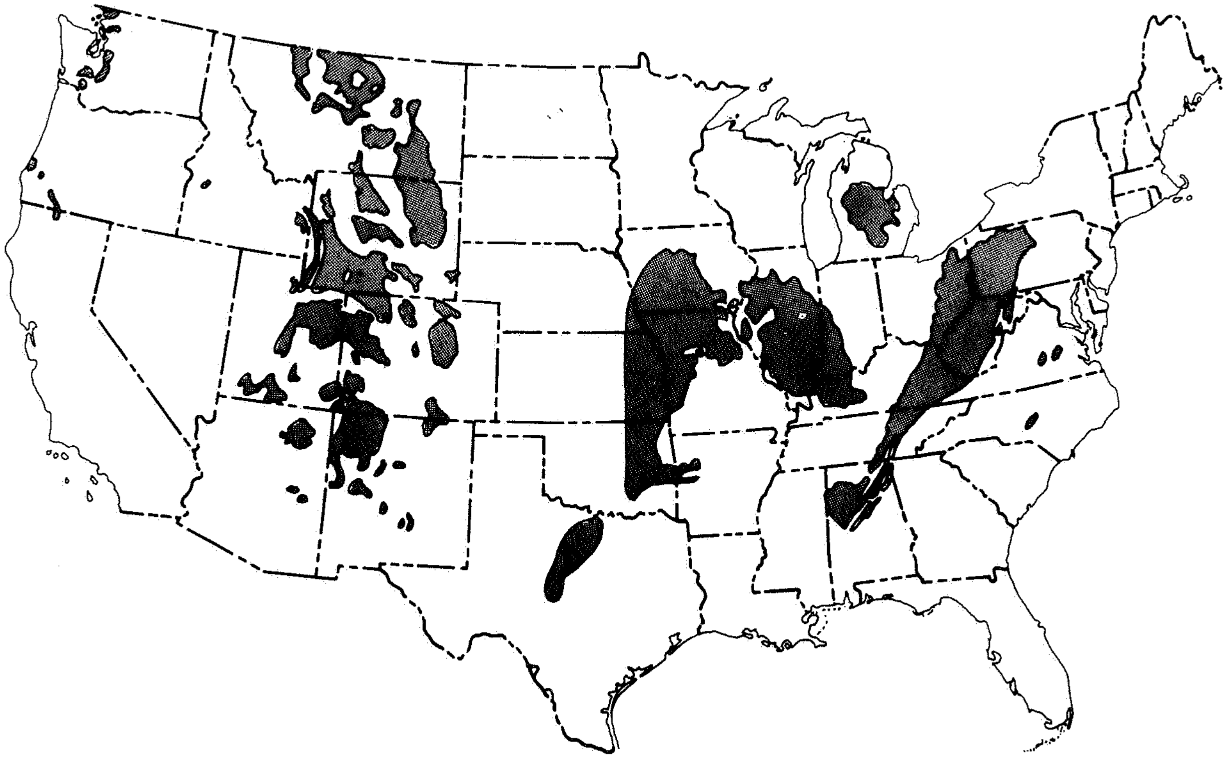
Under the wells of opportunity program the first well for a short-duration test has been completed in Louisiana. Surface testing facilities are on location and testing is to begin in late May.

TECHNOLOGY TRANSFER

The DOE/Industry geopressured geothermal forums have provided a good mechanism for informing all interested parties regarding the diverse research being carried out in the geopressured aquifer field. To date, 19 meetings have been held with excellent response from various industry participants.

Three geopressured geothermal symposia have been held and a fourth one is planned for FY79.

2. METHANE RECOVERY FROM COALBEDS



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2.1 INTRODUCTION

2.1.1 BACKGROUND

Methane, the major component of natural gas, is generated during the natural process of coal formation. Frequently, because of the low permeability of strata associated with coalbeds, it is trapped in the coal and associated strata. The total magnitude of the U. S. coal-associated methane resource has been estimated at approximately 700 trillion cubic feet. Given current and conservatively projected economic and technological factors, the recovery of some 300 trillion cubic feet of this resource appears to be feasible.

During mining operations in an underground mine, the removal of coal provides a free volume into which the methane can migrate and mix with air to form a potentially explosive or flammable mixture. The most widespread method of controlling methane concentrations to safe levels is dilution with ventilating air which sweeps the methane from the mine into the atmosphere. This is an expensive and relatively inefficient method of control.

The Federal Government and some mining companies have been investigating techniques for draining methane from coalbeds to prevent gas migration into the working area. The techniques investigated include drilling vertical or directional wells into virgin coalbeds in advance of the mine's working faces, and drilling horizontal boreholes into virgin coalbeds from a central shaft or heading. These drainage methods produce natural gas comparable to that from other gas reservoirs. Drainage from previously mined (gob) areas may be accomplished through vertical wells which provide gas diluted with air with mixtures ranging from 25 to 90 percent methane. Such techniques will significantly reduce ventilation requirements necessary to maintain concentrations at a safe level and at the same time will improve mining productivity by reducing downtime caused by hazardous levels of methane.

It has been estimated that mines in the Pittsburgh coal seam are currently venting over 100 million standard cubic feet of methane per day. The expansion of coal mining over the next 10 years, together with extensive adoption of predraining and gob draining techniques, will increase this rate considerably. At present, no commercial use is being made of this potential resource--the gas is wasted. The serious gas shortages and curtailment of industrial activity during recent winters emphasize the importance of utilizing this gas.

Preliminary studies indicate the feasibility of recovering and utilizing this resource profitably. The ranges of quantitative availability, gas quality, and geographic location of coalbed methane make it clear that no single solution is appropriate for all cases. The studies indicate a high probability of economic gas recovery/utilization for several approaches, including: direct pipeline injection; liquified natural gas (LNG) production; on-site power generation; heating applications; and petrochemical production. The technology necessary to use this valuable resource exists today, although some modification may be required to accommodate the requirements of the application.

2.1.2 METHANE RECOVERY FROM COALBEDS PROJECT

In order to avoid the waste of methane contained in coalbeds and to provide for its recovery and utilization, the Department of Energy (DOE) has initiated the Methane Recovery from Coalbeds Project (MRCP) implemented through the Morgantown Energy Technology Center (METC). The near-term objective of the project is to demonstrate through technology test projects viable methane recovery and utilization systems applicable to mining operations. The results of the tests are being disseminated to industry, to encourage increased commercial utilization of a significant gas resource now being wasted. Long-term objectives are expanded recovery and utilization from large coal deposits not associated with mining and the development/application of recovery/utilization technology or systems specifically for coalbed methane applications.

It is recognized that other efforts involving methane extraction/utilization are underway or planned. The activities and planning of this project are being coordinated with other agencies, particularly where mutual support or other interactivity would be beneficial to the overall goals of the DOE and national energy interests.

The MRCP is a planned sequence of research, development, and technology systems tests, designed to predict and test the economical extraction and utilization of gas associated with coalbeds and other sources. The project examines methane resources and matches extraction with utilization sub-systems to determine total system capability. Initially, state-of-the-art technology and off-the-shelf equipment are being utilized. Project results will guide ongoing R&D to advance the technology and develop appropriate equipment to maximize economic viability.

Project efforts are expected to result in significant advances in the state-of-the-art including:

- Location and delineation of coalbed gas resources, indicating economically feasible recovery possibilities,
- Coalbed methane productivity prediction techniques, and
- New technology systems and methods for commercial extraction and utilization of coalbed methane.

Although not part of the project per se, increased coal productivity and improved coal mine safety are anticipated through removal of gas which might seep into the mine, thereby avoiding shutdowns to eliminate dangerous methane buildup.

The MRCP is structured for implementation employing the following primary elements considered essential for success:

- Resource Engineering - Identification and definition of the coalbed methane resource so the most attractive targets may be selected,

- Research and Development - Development of improved, more cost-effective methods and subsystems for recovery/utilization of coalbed methane,

- Technology Systems Tests - Demonstration of the technical and economic viability of a number of different system--coalbed combinations to accommodate the variety of specific site conditions that will be encountered in large-scale commercialization, and

- Project Integration - Coordination of project functions: technical overview, systems planning, support studies/analyses, information management, and technology transfer.

The interrelationships of these elements over the project lifetime are designed to build on state-of-the-art technology and encourage eventual commercialization, as shown schematically in Figure 2-1. Each of these elements is further described below.

RESOURCE ENGINEERING

Delineation of the methane content of the nation's coalbeds has been done on a very limited basis, mostly in conjunction with active mining. Previous work includes only a very small percentage of the coal resource and does not provide the knowledge needed to locate recovery and utilization projects in coalbeds with the greatest potential for methane production.

Historically, about 70 to 80 percent of U.S. coal has been produced from the Pittsburgh seam. Thus, much of the delineation of coalbeds has been limited to one area and has addressed only minable coal. Some data obtained by industrial organizations are retained as proprietary. In addition, the data that have been acquired and are available are not centrally located, making acquisition difficult.

In accomplishing this project, data available from existing sources are being acquired and assimilated. The activities necessary to obtain similar data on the balance of the nation's coal resources also are underway.

The Resource Engineering effort includes:

- Development of an overall methane resource identification and definition plan (Resource Delineation Plan),

- Development of cooperative core/sample drilling plans,

- Acquisition of characterization information - existing data sources and cores/samples from additional coalbed locations,

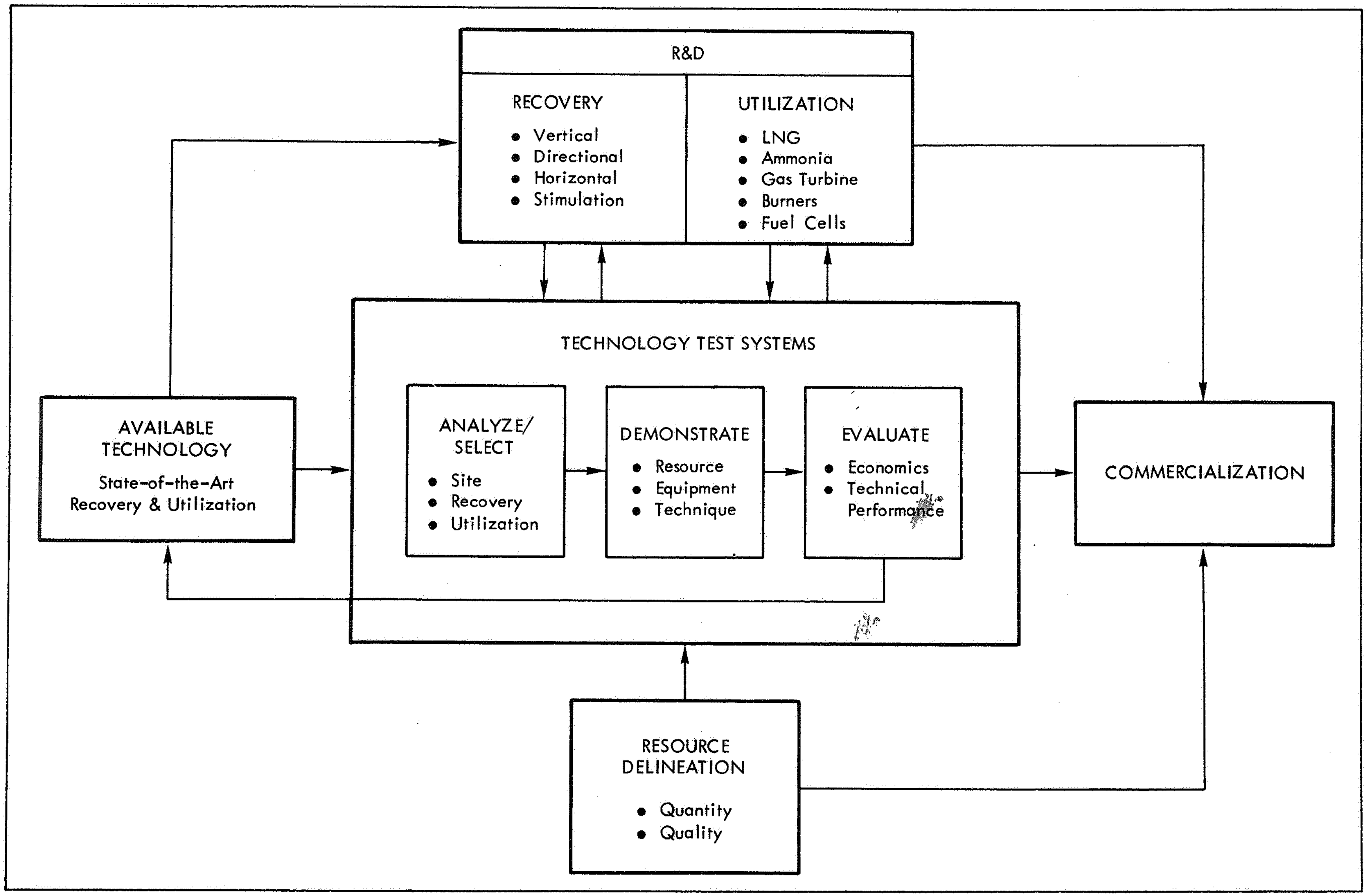


Figure 2-1. Methane Recovery from Coalbeds Project Interrelationships

- Analysis and evaluation of all available data,
- Identification of potential recovery system sites,
- Support to production prediction efforts, and
- Transfer of information to a repository available to potential users.

Within the Resource Engineering effort, attempts are made, wherever possible, to conduct well coring and testing operations in conjunction with private companies drilling to deeper objectives within the areas of interest. The operations to be conducted with cooperating companies are categorized by type:

Type I - Conventional gas or oil wells being drilled to potential reservoirs below the coal; available for short-term coring and testing operations,

Type II - Wells drilled for other purposes and ready for abandonment, and

Type III- Wells drilled specifically for completion as production wells from coalbeds.

RESEARCH AND DEVELOPMENT (R&D)

R&D planning includes development of technology for:

- Improved equipment and techniques for directional drilling,
- Advanced fracturing techniques to provide more effective stimulation with resultant increase in gas flow,
- Improved dewatering techniques to maintain more effective gas flow, and
- Improved drainage techniques for more economical recovery, and to assist productivity when active mining is involved.

Drilling technology is presently available for extracting methane from coalbeds. Specific techniques include:

- Drilling vertical wells with optional production stimulation via hydraulic or foam fracturing,
- Directional drilling of horizontal boreholes to intercept the natural fracture system of coalbeds combined with optional application of stimulation techniques, and
- Drilling of horizontal boreholes from the bottom of shafts or from headings.

Although the above techniques are available, none are developed to the degree that efficiency and cost are optimum. Multiple wells are required to drain the gas effectively prior to mining. The spacing and pattern of wells for the most effective methane drainage are essential to both safety and productivity when coal mining is involved. Optimum geometries, however, are not known. Current hydraulic or foam fracturing techniques will suffice for near-term demonstration projects to recover and utilize methane now wasted; however, they may not be optimum for longer-range commercial ventures. To provide for commercialization, proven prediction techniques and demonstrated results must apply to a sufficiently broad spectrum of the coalbed methane resource.

Possible utilization of the gas from coalbeds includes heat, power generation, and chemical feedstock. Early MRCP Technology System Tests are employing equipment developed for other applications and modified as necessary to adapt it for coalbed methane. To provide improved and efficient subsystem equipment for specific applications, design modifications and technology development are required. This includes development of equipment for:

- Gob gas feedstock to gas turbines,
- Gob gas burning for heating applications,
- Low quality gas preparation,
- Conversion to LNG, and
- Conversion to chemical feedstock (ammonia, etc.).

TECHNOLOGY SYSTEMS TESTS

Technology Systems Tests are planned to investigate and address the variables that will be encountered in field conditions. Collectively, these tests encompass both minable and unmined coalbeds and a number of different recovery and utilization methods and subsystems. A target set of planned projects is summarized in Table 2-1. The actual technology combinations which will be implemented may differ due to the requirements of the cooperating company. In all of these projects, actual operation of combined recovery and utilization subsystems is necessary to provide a total system overview. The subsystems interact and are therefore inseparable. Field tests are being fully integrated for optimum results. Economic, environmental and institutional factors are also considered in the selection of equipment and field test planning for each candidate project.

The test projects are in three phases:

- The conceptual phase where the projects are defined to the extent necessary to develop preliminary costs and benefits, to define technology advancements required to implement the projects, to evaluate the projects for suitability in meeting the objectives of the Methane Recovery from Coalbeds Project, and to select projects to be carried into the next phase.

- The detailed design and validation phase where the designs for selected projects are completed, the plans for implementation are developed, and costs are updated (tests or analysis efforts to validate designs or cost estimates also are performed in this phase).

Table 2-1. Technology Systems Tests

TECHNOLOGY SYSTEM TEST	PREDRAIN	GOB	EXTRACTION TECHNIQUE: VERTICAL WELL	EXTRACTION TECHNIQUE: DIRECTIONAL BOREHOLE	EXTRACTION TECHNIQUE: HORIZONTAL BOREHOLE	EXTRACTION TECHNIQUE: HYDRAULIC FRACTURING	EXTRACTION TECHNIQUE: FOAM FRACTURING	EXTRACTION TECHNIQUE: GAS FRACTURING	UTILIZATION: PIPELINE INJECTION	UTILIZATION: POWER GENERATION	UTILIZATION: HEATING APPLICATION	UTILIZATION: LNG CONVERSION	UTILIZATION: AMMONIA CONVERSION
MINABLE													
ONGOING		X	X							X			
ONGOING	X	X	X								X		
A	X		X			X			X				
B	X	X	X				X		X			X	
C	X				X		X		X				
UNMINABLE													
ONGOING	X		X			X			X				
ONGOING	X		X			X			X				
A	X			X			X					X	
B	X			X			X						X
C	X		X				X					X	

- The implementation phase, which provides for site development, construction installation, site operations, operational tests, data acquisition, analysis and evaluation. The project benefits and costs are disseminated via technology transfer activities.

Technology systems are being selected to accommodate the characteristics of differing coalbeds relative to the recovery of the methane resource. Results of these field tests will be incorporated into a statistical model to be used for gas deliverability projection.

Feasibility studies have been performed to define the Pittsburgh coalbed resource and project the technical and economic viability of recovering and utilizing methane from this coalbed. Similar studies will be accomplished for other coalbeds to assist in establishing targets for Technology Systems Tests.

PROJECT INTEGRATION

Integration plays an important part in the implementation and management of this project. In addition to normal project planning and coordinating functions, a large amount of information exchange, or "cross-feeding", will necessarily take place between the several individual technology system tests and their supporting activities. Also "feedback" of information resulting from one project frequently will be used as input to other projects. Much of this information will be technical and continually pressing the state-of-the-art. The large amount and variation in kinds of information require the use of an orderly system to maintain orderly flow and ready availability. The selected system must accommodate a rather complex flow of data and frequent input/output and retrieval from storage.

Information obtained during Resource Engineering is being used to support the selection of suitable recovery system sites. To acquire the characterization data, a number of wells are being drilled. Core samples from the drillings are being analyzed to support gas production estimating. Core sample data indicating unfavorable sites may result in the need for additional exploratory drilling and sampling. A number of different organizations and personnel are involved in these activities, creating a requirement for the coordination and integration of technical activities (in addition to the information flow coordination described above). A common integrating function is being used to facilitate the correlation of all these variables and to plan and develop guidelines. For example, criteria for site selection are needed to enable logical selection from the large number of potential sites and related factors.

Methane utilization subsystems will be employed in conjunction with many of the recovery subsystems. Integrated planning is mandatory for these projects to assure selection of optimum overall systems design and operations. Trade-offs involving site locations and design features are inevitable. Factors in these trades include: the distance to a gas gathering line or end use item, site accessibility, methane quantity/quality, cost-sharing opportunities, environmental suitability, project priorities and confidence in the expected results. These are very different factors, requiring diverse technical and administrative knowledge, and a common integrating function is required to provide "single-point" coordination. Documented planning systems are being used wherever appropriate. Because of the multiple locations of the individual projects, true single-point control may not be possible. In this event, as many activities as practicable are organized under a single integrating point and one or more subordinate integration functions are established as required. For some of the subsystem combinations or site locations, detailed supporting studies and analyses are required to provide the knowledge needed to enable good decisionmaking and the selection of viable pilot systems and site locations.

R&D projects will be in progress during the field test operations, and promising new information resulting from the R&D efforts will be provided to an appropriate ongoing technology test or support activity, if any, for test and proof under field conditions. On the other hand, the field operations are likely to identify problems that may be resolved in a timely manner by immediate assignment to a related ongoing R&D activity. R&D functions will be integrated from an overall planning and management viewpoint and not operated as separate entities.

2.2 RESOURCE ENGINEERING

2.2.1 GENERAL

Resource Engineering activities for the reporting period focused primarily in three areas: finalizing the Methane Recovery from Coalbeds Resource Delineation Plan, defining a test program to determine the feasibility of producing methane from unminable coalbeds, and acquiring site-specific data on unmined coalbed methane resources. The following sections discuss these activities in more detail. Sections 2.2.2 through 2.2.9 review efforts of various groups participating in project Resource Engineering activities. Sections 2.2.9 through 2.2.14 summarize by basin the results obtained by investigating specific well sites.

2.2.2 METHANE FROM COALBEDS RESOURCE DELINEATION

TRW Energy Systems McLean, Virginia	Status: Active
Contract:	DE-AC21-78MCO8089
Contract Date:	December 12, 1977
Anticipated Completion Date:	February 12, 1981
Principal Investigator:	A.D. Starbird
DOE Technical Project Officer:	R.L. Wise

OBJECTIVE

To provide technical management and analysis support for the MRCP and related gas recovery projects.

SCOPE OF WORK

As part of Contract DE-AC21-78M08089, TRW Resource Engineering efforts include:

- Project documentation,
- Negotiation of subcontracts as necessary to obtain core samples; performance of fracture-stimulation and drill stem tests, etc.; and arrangement for necessary laboratory analyses, and
- Assimilation and evaluation of the acquired data.

SUMMARY OF PROGRESS

A resource delineation plan was developed which shows the MRCP approach to providing a data base for determining the national resource and the reserve; disseminating the information that is developed; and guiding management of the overall effort. The plan encompasses examination of 380,000 square miles of coalbearing rocks in the conterminous United States, and of the quantity, distribution and production characteristics of some 700 trillion cubic feet of methane estimated to be contained in those rocks (Figure 2-2). Early efforts will concentrate on some 20 percent (80,000 square miles) of this area where the probabilities of finding, producing, and utilizing the methane are highest. Attempts will be made within this area of 80,000 square miles to supply one data point every 1,000 square miles.

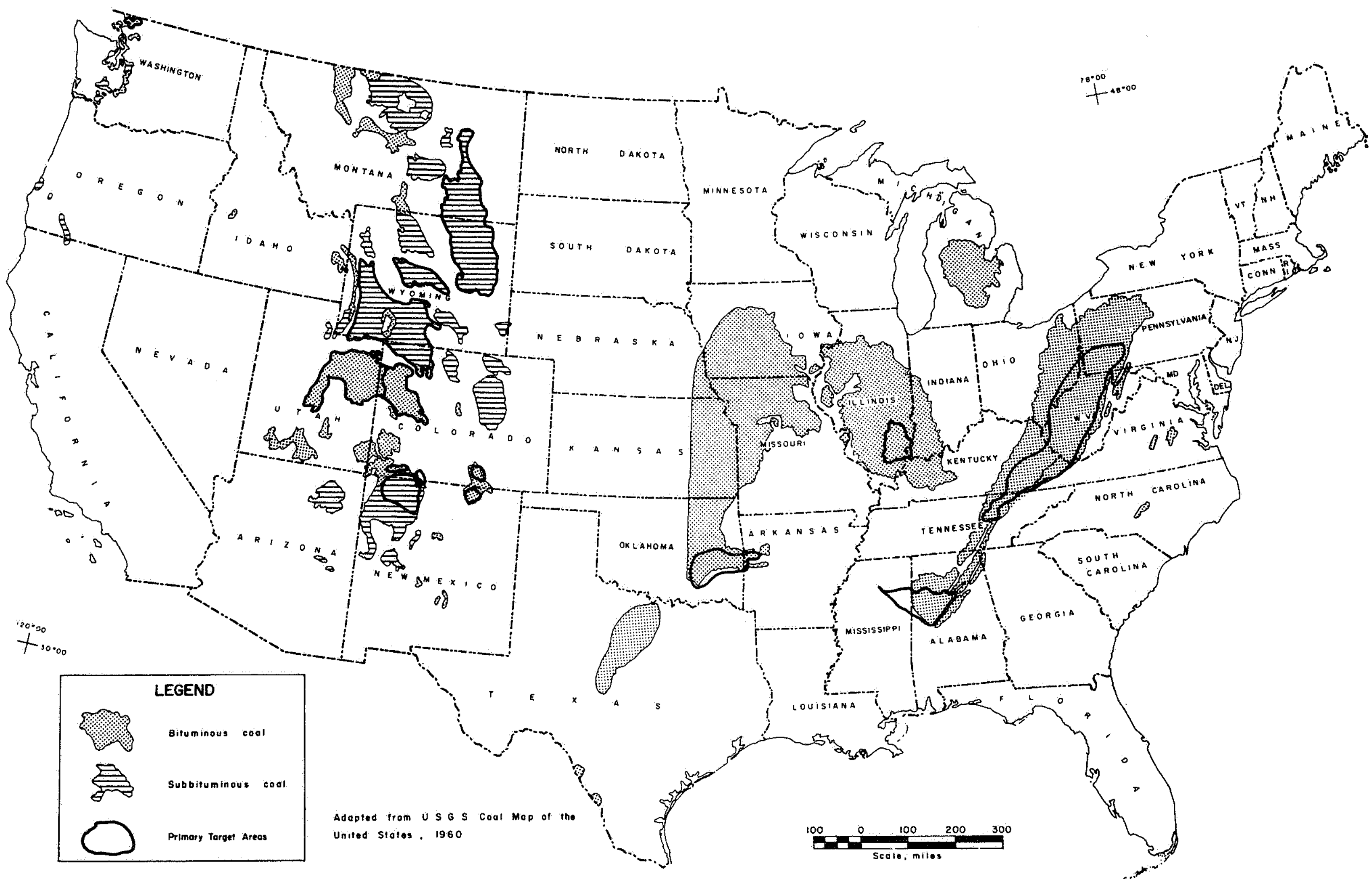


Figure 2-2. Bituminous and Subbituminous Coal Fields of the Conterminous United States

The basic approach utilized in the development of this plan was:

- To operate in a reconnaissance mode and use a basic 1,000 square mile sampling pattern within the areas of interest, and

- To operate first in those areas which are geologically best known and have the highest probability of early commercialization.

Basin selections were guided by the following general criteria:

- Physical and chemical characteristics of coal (i.e., fixed carbon, percent volatiles, percent sulfur, etc.)--Higher rank coals generally contain more methane.

- Seam depth (East: 400 ft; West: 700 to 800 ft)--Deeper coals are more likely to have retained the methane.

- Total effective coal thickness (East: 20 ft for high rank; West: 30 ft. Both related individual thickness and depth)--Higher total production per well possible on basis of multiseam completion.

- Individual seam thickness (minimum of 5 to 10 ft for shallow beds; multiple coalbeds considered as one if separated by permeable rock units)--Minimize need for multiple fracturing.

- Extent (contiguous basin)--Allow extrapolation of results to a wider area.

Based upon the criteria, portions of major basins (Table 2-2) were selected as the targets for initial resource delineation activities. The target areas investigated through the end of the reporting period are discussed and illustrated in Sections 2.2.9 through 2.2.14.

Additional Resource Engineering Activities focused on establishing cooperative agreements for drilling, coring, and logging. Companies were contacted and sent example letters of agreement. Prospective cooperative companies which showed interest in the project are listed below with the drilling area of interest:

Company	Drilling Area
Amoco Production	Green River, San Juan Basin
Anschutz	Uinta, Powder River Basins
Asamera Oil	Various
Belco Petroleum	Green River, Uinta, Williston Basins
Castlewood Corporation	Green River Basin
Chancellor Exploration	Piceance Basin
Chandler and Associates	Piceance Basin
CIG Exploration	Uinta Basin
Cities Service Gas	Green River, Piceance Basins
Colorado Interstate Gas	Powder River, Green River Basins
Consolidated Oil and Gas	San Juan Basin

Table 2-2. Relationship of Size of Potential Target Area to Total Area Underlain by Coal-Bearing Rock.

Region	Total Area (Sq.Mi.)	Target Area (Sq.Mi.)
Eastern	51,400	9,100 (Illinois Basin)
Northern Appalachian	47,900	19,600
Middle Appalachian	18,300	5,500
Southern Appalachian	14,400	6,800
Western	90,700	5,300 (Arkoma Basin)
San Juan	19,000	4,900
Raton Mesa	2,400	1,600 (700 - Trinidad) (900 - Raton)
Uinta	19,300	11,100 (Uinta Basin) 8,200 (Piceance Basin)
Green River	21,200	21,100
Wind River	3,800	3,800
Powder River	22,700	12,800
Bellingham, Washington	400	400

Company	Drilling Area
Davis Oil	Green River, Powder River Basins
Equity Oil	Green River Basin
Fuelco	San Juan, Piceance Basins
Gas Producing Enterprises (Coastal States)	Williston Basin
GeoWest, Inc.	Illinois Basin
Kinloch Exploration Company	Northern Appalachian Basin
Knight and Associates	Arkoma Basin
McKnight Oil	Piceance Basin
Reserve Oil and Minerals	San Juan Basin
Rocky Mountain Energy	Green River Basin
SOHIO Natural Resources	San Juan Basin
Southland Royalty	Powder River, San Juan Basins
Twin Arrow Drilling Company	Piceance Basin
Webb Resources	Powder River Basin
Western Fuels	Piceance Basin

Four cooperative agreements were reached--one each with Belco Petroleum; Kinloch Exploration Company; Twin Arrow Drilling Company; and a company whose identity is confidential. Well test plans and results for these and other active field investigations are presented by basin in Sections 2.2.9 through 2.2.14.

2.2.3 PRELIMINARY TEST PROGRAM

Status: Active

Intercomp, Inc.
Houston, Texas

Contract:	DE-AC21-79MC10641
Contract Date:	March 31, 1978
Anticipated Completion Date:	April 30, 1980
Principal Investigator:	H.S. Price
DOE Technical Project Officer:	R.L. Wise

OBJECTIVE

To develop an engineering program to test, evaluate, and characterize coal as a potential source of methane gas production and to evaluate and recommend suitable sites for the implementation of the testing program.

SCOPE OF WORK

Contracts EW-78-C-21-8352 and DE-AC21-79MC10641 with Intercomp, Inc. provide for the identification of the critical parameters and the reduction in uncertainties related to methane extraction from unmined coalbeds. These contracts crosscut other Resource Engineering projects, assisting in the characterization of unmined coalbeds by providing particular emphasis on methane producibility. Specific activities include:

- Defining a comprehensive test program for collection of the required data to characterize the potential for methane production from unmined coalbeds,
- Performing initial simulation modeling, and updating the model with actual data as appropriate, and
- Assisting in the identification and selection of drilling sites which are most desirable for resource characterization activities.

SUMMARY OF PROGRESS

A simulation model was used to develop a comprehensive test program to characterize the potential of methane production from "unmined" coalbeds in the United States. The study identified the parameters that are most important to the production of methane from coal; these independent variables are:

- Coalbed thickness
- Coalbed permeability
- Initial pressure
- Initial gas content
- Relative permeability
- Hydraulic fracture length
- Hydraulic fracture conductivity.

The range of values over which each independent variable may vary was estimated together with the frequency distribution within the range. A sensitivity study was made which varied the independent variables over their ranges and calculated a characterization parameter, Ø. The definition of Ø is the cumulative discounted gas production deliverability for ten years at a discount rate of 15% per year.

In order to quantitatively evaluate the effect of each independent variable on the characterization parameter, Ø, a large number of simulator runs was made. In order to do this certain assumptions had to be made. These are listed below.

a. All testing will be done with vertical wells. While this is probably a valid assumption for the test program, other configurations should be investigated for demonstration and commercial projects. These other configurations, such as directional holes and horizontal holes from the bottom of shafts, are either not proved technology or an order of magnitude more expensive than vertical wells for sampling and testing.

b. Symmetry exists about the wellbore so that a 90° segment of the reservoir represents one-fourth of the well. The values of Ø reported are thus for one-fourth of a total well.

c. Mechanical water removal equipment will be available at each site which will be adequate to prevent a hydrostatic head to be built-up on the coal. This assumption is that the well boundary condition can be maintained at atmospheric pressure.

d. All results are normalized for a 10 ft thick coalbed and 100% methane gas. Thickness changes or gas-containing inert components can be rigorously accounted for external to the simulator by direct ratio.

e. Each test well is assumed to be completed in an infinite acting relatively flat lying coal seam. Both these requirements appear to be valid for the basins to be studied.

The methods of measurement and sequence of tests were established together with costs of the various tests. These were connected sequentially into test modules. Each test module has an array of the independent variables which are determined and an associated measurement error. A regression equation was calculated for each module which quantified the ability of that module to predict the production characterization parameter, Ø. The module which included determination of all the independent variables was the best predictor of Ø. By calculating the standard deviation of the distribution of $\emptyset$ as a function of number of observations for each module, the rate of change of standard deviation with increased observation, i.e. dollars expended, was plotted. The result is that at least 25 observations of the most precise module were necessary to adequately describe the distribution of the production characterization parameter, $\emptyset$.

Since the distributions and ranges of the independent variables were estimated, an additional number of tests is necessary to independently describe these distributions. Because none of the measurements are perfect, further independent measurements are necessary to quantify the measurement error. These requirements concern the individual variables themselves and not the gas deliverability itself; therefore, a less expensive survey type test module will suffice for these measurements. A total of 60 survey type test modules is required with specific spatial considerations as to location of those 60 modules.

The program defines the tests that need to be made (Table 2-3). These tests need not be new tests. If data exists from previous testing either by government or the private sector, which fulfills the requirements of a test, that test need not be run.

TABLE 2-3.

POTENTIAL TEST ACTIVITIES
COAL DEGASIFICATION FIELD TEST PROGRAM

TEST OR ACTIVITY	PARAMETERS MEASURED	PARAMETERS DETERMINED AND PRECISION	RECOMMENDED FREQUENCY	CONSTRAINTS
CORE				
FIELD	THICKNESS, GAS CONTENT	SORBTION COEFFICIENT	EVERY OPPORTUNITY	QUICK CORE RETRIEVAL
LAB	PROXIMATE ANALYSIS	YOUNG'S MODULES	EVERY OPPORTUNITY	SAMPLE NEEDS PRESERVATION
	ULTIMATE ANALYSIS	POISSON'S RATIO	INFREQUENT	SAMPLE NEEDS PRESERVATION
	SORBTION ISOTHERM		INFREQUENT	SAMPLE NEEDS PRESERVATION
	POROSITY, PERMEABILITY		INFREQUENT	NONE
LOGS	DEPTH, THICKNESS, DENSITY, RESISTIVITY, GAMMA RAY, CEMENT BOND, CALIPER	POROSITY, WATER SATURATION, COAL QUALITY	EVERY OPPORTUNITY	ASSUMES VERTICAL WELL
DRILL STEM TEST	FLOWS, PRESSURE, TEMPERATURE	PRESSURE, ± 10 PSI PERMEABILITY ± 50%	AS DETERMINED BY OPTIMIZATION	ACCEPTABLE FORMATION FOR PACKER SEATS, ETC
WATER LEVEL MEASURE	WATER LEVEL	PRESSURE ± 1 PSI	EVERY OPPORTUNITY	ASSUMES NO GAS SATURATION
BOTTOM-HOLE PRESSURE	PRESSURE, TEMPERATURE	PRESSURE ± 1 PSI TEMPERATURE ± 1°F	INFREQUENT	ALTERNATIVE BHP WHEN THERE IS GAS PRESSURE

TABLE 2-3. - Continued

POTENTIAL TEST ACTIVITIES
COAL DEGASIFICATION FIELD TEST PROGRAM

Test of Activity	Parameters Measured	Parameters Determined and Precision	Recommended Frequency	Constraints
Water Injection Test	Water Injection Rate, Pressure, Time	Pressure ± 1 psi Permeability ± 10% Saturations, P_{ERROR} = .2, Porosity	As determined by optimization	Assumes virgin reservoir
Natural Production Test	Water Rate, Gas Rate, Flowing Pressure, Time Gas and Water Quality	Relative Permeability, ±.07, Saturations, P_{ERROR} = 0, Porosity	As determined by optimization	
Stimulated Production Test	Water Rate, Gas Rate Flowing Pressure, Time	Hydraulic Stimulation Parameters, (Length ±20% and Conductivity ±50%)	As determined by optimization	Can be done only in stimulated wells
Gas Analysis	Gas Composition		Regular scheduled basis	Should be taken during stable production
Water Analysis	Water Impurities		One time each well	Should be taken prior to stimulation
Echo Meter Survey	Water Level	Bottom-hole flowing Pressure ± 5 psi	Regular scheduled basis	

2.2.4 EVALUATION OF COLORADO COALBED METHANE POTENTIAL

Status: Active

Colorado Geological Survey
Denver, Colorado

Contract:	DE-AC21-79MC10643
Contract Date:	April 1, 1978
Anticipated Completion Date:	March 31, 1980
Principal Investigator:	D. Keith Murray
DOE Technical Project Officer:	R.L. Wise

OBJECTIVE

To provide technical assistance and support for resource delineation activities in Colorado and the Rocky Mountain area.

SCOPE OF WORK

The Colorado Geological Survey was awarded Grants EW-78-G-21-8377, and DE-AC21-79MC10643 for support in characterization of coalbeds, primarily those in the State of Colorado and the Rocky Mountain area. This work provides for the following activities:

- Selection, evaluation, and recommendation of favorable drill and test sites,
- Synthesis and summary of pertinent geological information,
- Monitoring of industry activity and determination of the potential for cooperative agreements for core sampling/methane desorption/flow testing,
- Performance of well-site geologic supervision, and
- Performance of methane desorption measurements.

SUMMARY OF PROGRESS

The Colorado Geological Survey was actively involved in the selection of potential operators and sites for drilling/coring activities within Colorado. Coal samples received from this geographic area are presently undergoing long-term desorption.

2.2.5 EFFECT OF PREDRAINAGE STIMULATION TECHNIQUES ON COAL RECOVERY

Colorado School of Mines
Golden, Colorado

Status: Active

Contract:	DE-AC21-78MC08089
Contract Date:	January, 1979
Anticipated Completion Date:	December 31, 1979
Principal Investigator:	A.A. Lee (TRW)
DOE Technical Project Officer:	R.L. Wise

OBJECTIVE

To evaluate the effect of premining methane drainage stimulation techniques on later coal recovery operations.

SCOPE OF WORK

The expected effect of premining methane drainage stimulation techniques on later coal recovery by conventional (room-and-pillar, shortwall, and longwall) mining techniques is being evaluated through an extensive literature review and structural/analytical/finite element model. The following activities are being conducted:

1. Review, summary and evaluation of all previous experience and proposed techniques for degasifying coalbeds prior to mining with particular attention to those factors which would affect mine stability.

2. Review of the major coal producing areas in the U. S. and categorization of them with respect to methane content. Summary of the geological/structural data for the most important high gas content areas.

3. Summary of the mining methods/layouts/roof control plans/stability problems for the major mines in each area.

4. Identification and description of the types of pre-existing and artificially induced structural features that might be affected by (a) removing the gas and (b) the process of gas removal.

5. Preparation of structural, analytical and finite element models for use in simulating the mining of typical high gas content formations. The major use of these models is to evaluate the sensitivity of opening and mine stability under a variety of natural and degasification conditions.

6. Application of the stability models developed to actual mines presently using degasification techniques. Comparison of the predicted and actual results.

7. Recommendation of procedures/techniques for evaluating stability changes due to degasification procedures.

SUMMARY OF PROGRESS

The activities described above were initiated during the reporting period. Results of these activities will be presented in subsequent semi-annual reports.

2.2.6 EVALUATION OF UTAH COALBED METHANE POTENTIAL

Utah Geological and Mineral Survey
Salt Lake City, Utah

Status: In Negotiation

Contract:	To be determined
Contract Date:	To be determined
Anticipated Complete Date:	To be determined
Principal Investigator:	A.D. Smith
DOE Technical Project Officer:	H.D. Shoemaker

OBJECTIVE

To provide technical assistance and support for resource delineation activities in the state of Utah.

SCOPE OF WORK

Beginning in the second half of FY79, the Utah Geological and Mineral Survey will collect available coal core samples for desorption of methane by the direct method and for proximate and ultimate analyses. In addition, a new Utah coal map will be prepared which will show the rank of coal as defined by more up-to-date data. All available information to support the findings will be recorded, i.e., depth, formation, interval, coal zone or bed, location, and coal description. The acquisition of 30 to 60 samples is anticipated.

SUMMARY OF PROGRESS

Results of the above-described planned activities will be presented in subsequent semi-annual reports.

2.2.7 EVALUATION OF SOUTHERN COALFIELDS

Virginia Polytechnic Institute & State University
Blackburg, Virginia

Status: In Negotiation

Contract:	DE-AC21-78MC08089
Contract Date:	To be determined
Anticipated Completion Date:	To be determined
Principal Investigator:	A.A. Lee (TRW)
DOE Technical Project Officer:	R.L. Wise

OBJECTIVE

To determine the methane production potential of southern coalfields.

SCOPE OF WORK

The evaluation of promising coal areas, basins, and seams in the southern coalfields is a planned activity beginning in the second half of FY79. Emphasis will be directed to the seams which are currently unmined, unlikely to be mined in the near future, and currently not minable for one reason or another. The activities are divided into the following three categories for study and development:

1. Preparation of a data bank to determine the methane potential of nine select coal areas and localities. At the same time a smaller data bank and a recommendation on the methods for sampling unminable coal seams for their methane content will be produced.

2. Investigation of areas of information shortage and determination of the priorities for the high-potential unminable coal seams that have been indicated in the study.

3. Development of an exploration program in the high priority unminable coal seams to determine the methane potential of the seams.

SUMMARY OF PROGRESS

Results of the above-described planned activities will be presented in subsequent semi-annual reports.

2.2.8 RESERVOIR FRACTURING AND MINING THROUGH FRACTURED AREAS

Pennsylvania State University
State College, Pennsylvania

Status: In Negotiation

Contract:	DE-AC21-78MCO8089
Contract Date:	To be determined
Anticipated Completion Date:	To be determined
Principal Investigator:	A.A. Lee (TRW)
DOE Technical Project Officer:	R.L. Wise

OBJECTIVE

To evaluate the recovery of methane from fractured coal deposits and the impact of fracture stimulation on the subsequent mining of coal.

SCOPE OF WORK

A study concerning reservoir modeling, fracturing, and mining through fractured areas is planned for the second half of FY79. Efforts would include the following individual stages of project development:

1. Data base information collection on methane recovery parameters.
2. Literature survey on fracturing methods and techniques.
3. Development of a rational scientific concept or methodology for determining the best method(s) for fracturing a bed.
4. Actual in-mine investigations and mapping of stimulation results.
5. Actual on-site validation of successful scientific and laboratory development for fracturing coal seams. Assistance in implementing such tests with independent analysis of test results.
6. An evaluation of coal seam degasification impact on mine ventilation costs.

SUMMARY OF PROGRESS

Results of the above-described planned activities will be presented in subsequent semi-annual reports.

2.2.9 ARKOMA BASIN (OKLAHOMA AND ARKANSAS)

Coals in the Arkoma Basin are found in cyclothems of Desmoinesian (Allegheny) and Atokan and Morrowan (Pottsville) series of Pennsylvanian age. The coal-bearing rocks are sandstone, shale, and limestone. Coal in the area is found in the Upper and Lower Hartshorne seams which total 3 to 7 feet in thickness and contain estimated resources of less than 15 billion tons. Individual seams are 3 to 4 feet thick and are preserved in synclinal basins as narrow belts parallel to steeply dipping outcrops. The coal is of low to high volatile bituminous rank and both seams are known to contain methane. The area is intensely folded and faulted with very steeply dipping beds. Overburden is less than 3,000 feet in about 610 square miles of Oklahoma and Arkansas.

The initial target area of interest within the Arkoma Basin is shown in Figure 2-3. As of the end of the reporting period, one site had been investigated in the Arkoma Basin. Results for this field test are summarized in the following paragraphs.

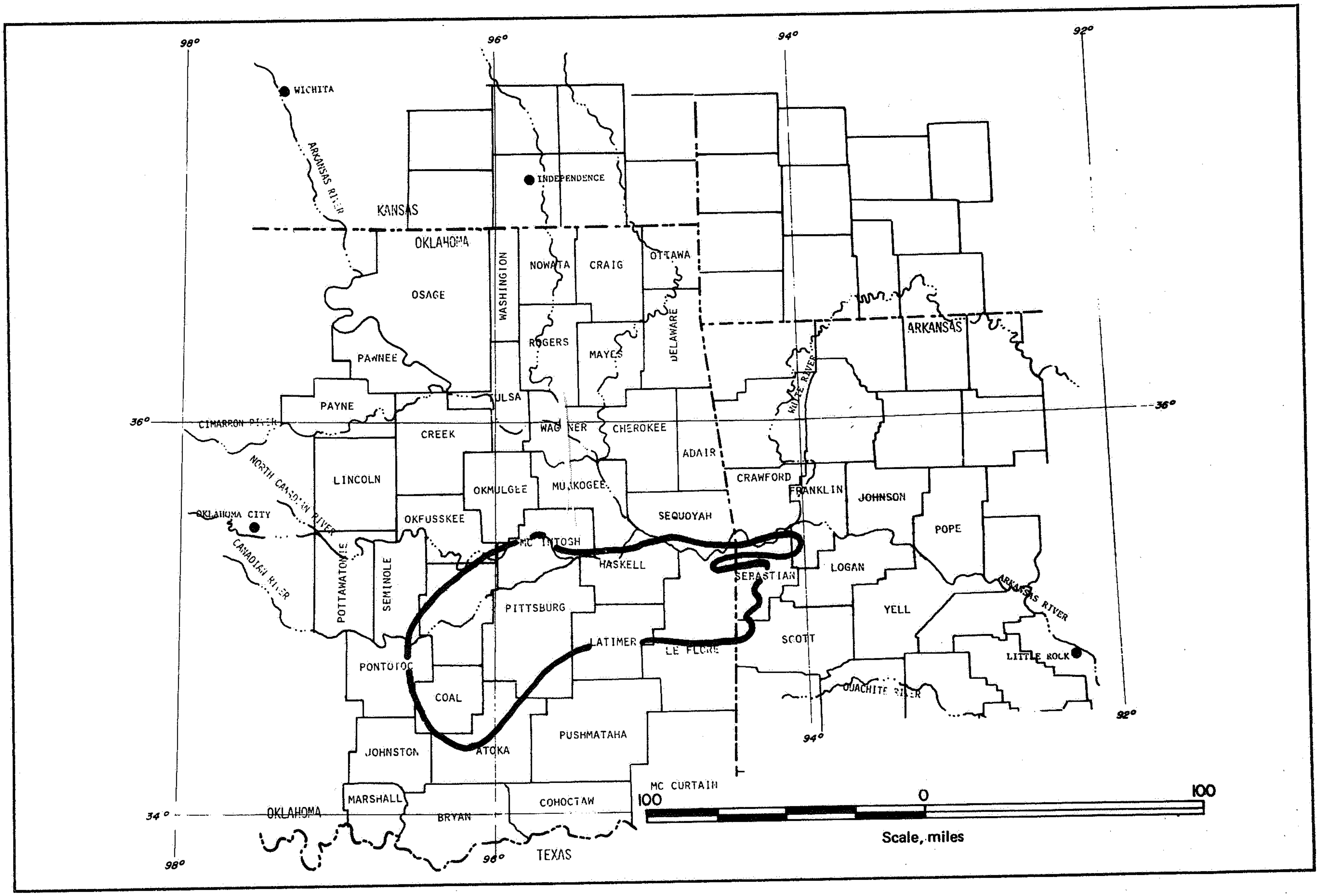


Figure 2-3. Arkoma Basin Target Area

ARKOMA BASIN, SITE AA
PITTSBURG COUNTY, OKLAHOMA

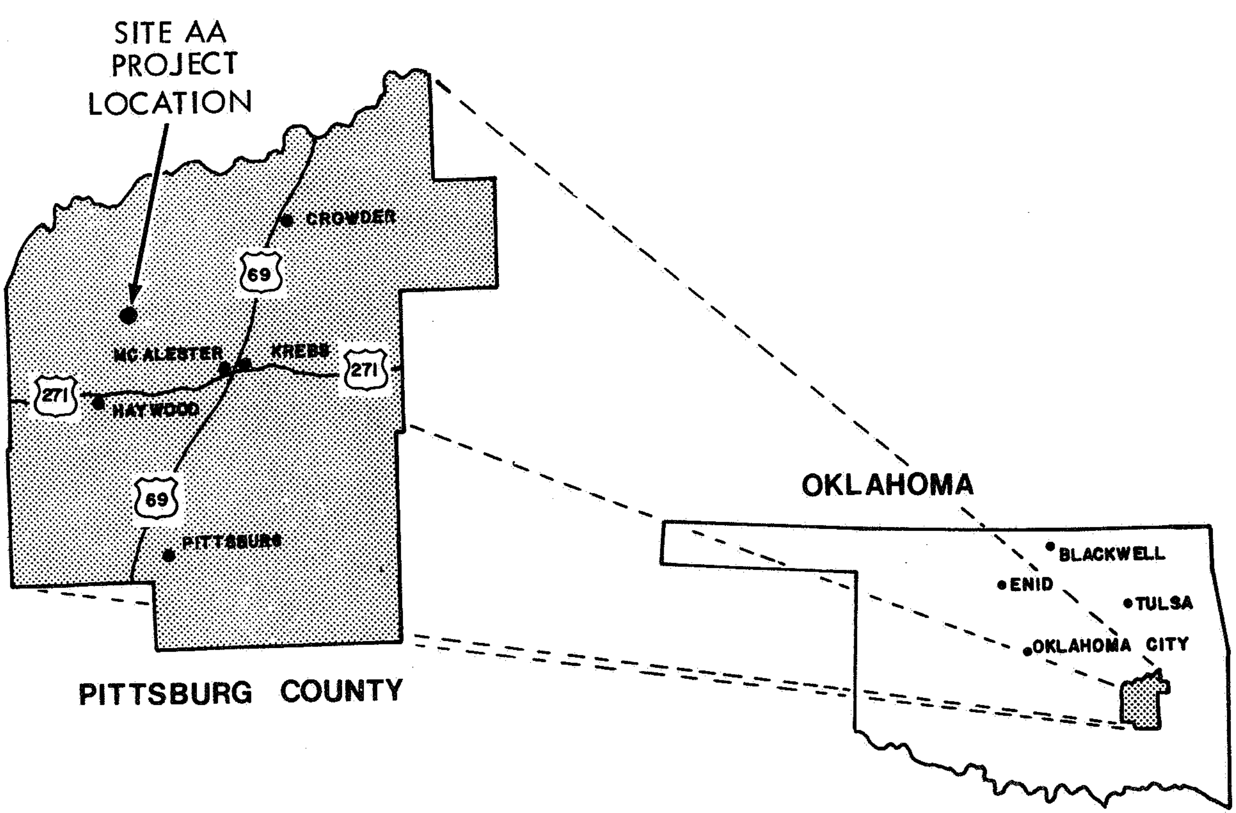
Status: Active

Cooperating Company:
Arkla Exploration Company
Shreveport, Louisiana

Field Work Performance Period: October, 1978
Principal Investigator: A. A. Lee (TRW)
DOE Technical Project Officer: R. L. Wise

OBJECTIVE

To determine the methane content and reservoir properties of the Lower Hartshorne Seam in the Arkoma Basin as part of an effort to delineate the potential for production from this resource area.



SCOPE OF WORK

The Arkla Exploration contract provides for sidewall coring and drill stem testing of the Lower Hartshorne seam in the Arkoma Basin in Pittsburg County, Oklahoma.

SUMMARY OF PROGRESS

Arkla Exploration Company well Brown #1-2 located in Section 2, Township 6N, Range 13E, Pittsburg County, Oklahoma (Arkoma Basin) was sidewall cored and drill stem tested between October 9 and October 13, 1978.

- The following intervals were sidewall cored:

Interval	No. Shots	No. Cores Recovered	Lithology
1820.0 - 1821.0	2	2	Shale
1890.0 - 1893.5	4	2	Coal W/Shale
2110.5 - 2118.5	8	6	Shale
2114.0 - 2117.5	4	4	Coal
2708.0 - 2711.5	3	1	Coal
2708.0 - 2713.5	5	3	Coal
2708.5 - 2710.0	3	3	Shale
2709.5 - 2714.5	4	2	Shale W/Coal
2710.0 - 2715.5	8	7	Shale W/Coal
2710.5 - 2715.5	7	6	Coal

--Individual core samples were obtained and combined into 3 coal samples which were analyzed by GeoChem. The data from these analyses are presently undergoing evaluation.

- Drill stem tests were conducted October 9 and October 11, 1978 in the Upper Hartshorne seam at a depth interval of 2700 feet to 2740 feet.

--The October 9 test was unsuccessful due to packer failure.

--A good mechanical drill stem test was conducted on October 11, 1978. The following reservoir parameters were calculated by Johnston using the Horner method:

Flow Test:	9.0 bbls/day	
Reservoir Pressure:	Initial Shut-in:	716 psig
	Final Shut-in:	710 psig
Permeability:	4.5 md average	
Well Bore Damage:	None	
Radius of Investigation:	206 feet	

- Reservoir simulation was performed resulting in a gas-in-place estimate of 1.4 Bcf per 640 acre section and an estimate for the discounted 10 yr. gas deliverability for an isolated well of between 3,500 and 40,000 Mcf. This range for deliverability, Ø, was established using a maximum permeability of 1.0 md and a maximum relative permeability curve; and 0.1 md and a minimum relative permeability curve. See section 2.2.3 for a discussion of Ø.

2.2.10 GREEN RIVER BASIN (WYOMING AND COLORADO)

Coal in the Green River Basin is of Eocene, Paleocene, and late Cretaceous age. It is found interbedded with sandstones and shales of the Wasatch, Lance, and Mesaverde formations. There are approximately 20 seams in the center of the basin with an aggregate thickness of more than 200 feet. Coal resources in the basin are estimated at 16 billion tons. Individual seams are lenticular to relatively continuous and up to 30 feet thick. They average 5 to 10 feet in thickness. The coal is of subbituminous to bituminous rank. Beds are horizontal in the basin center, but are steeply dipping and faulted along the basin margins.

The initial target area of interest within the Green River Basin is shown in Figure 2-4. As of the end of the reporting period, one site had been investigated in the Green River Basin. Results for this field test are summarized in the following paragraphs.

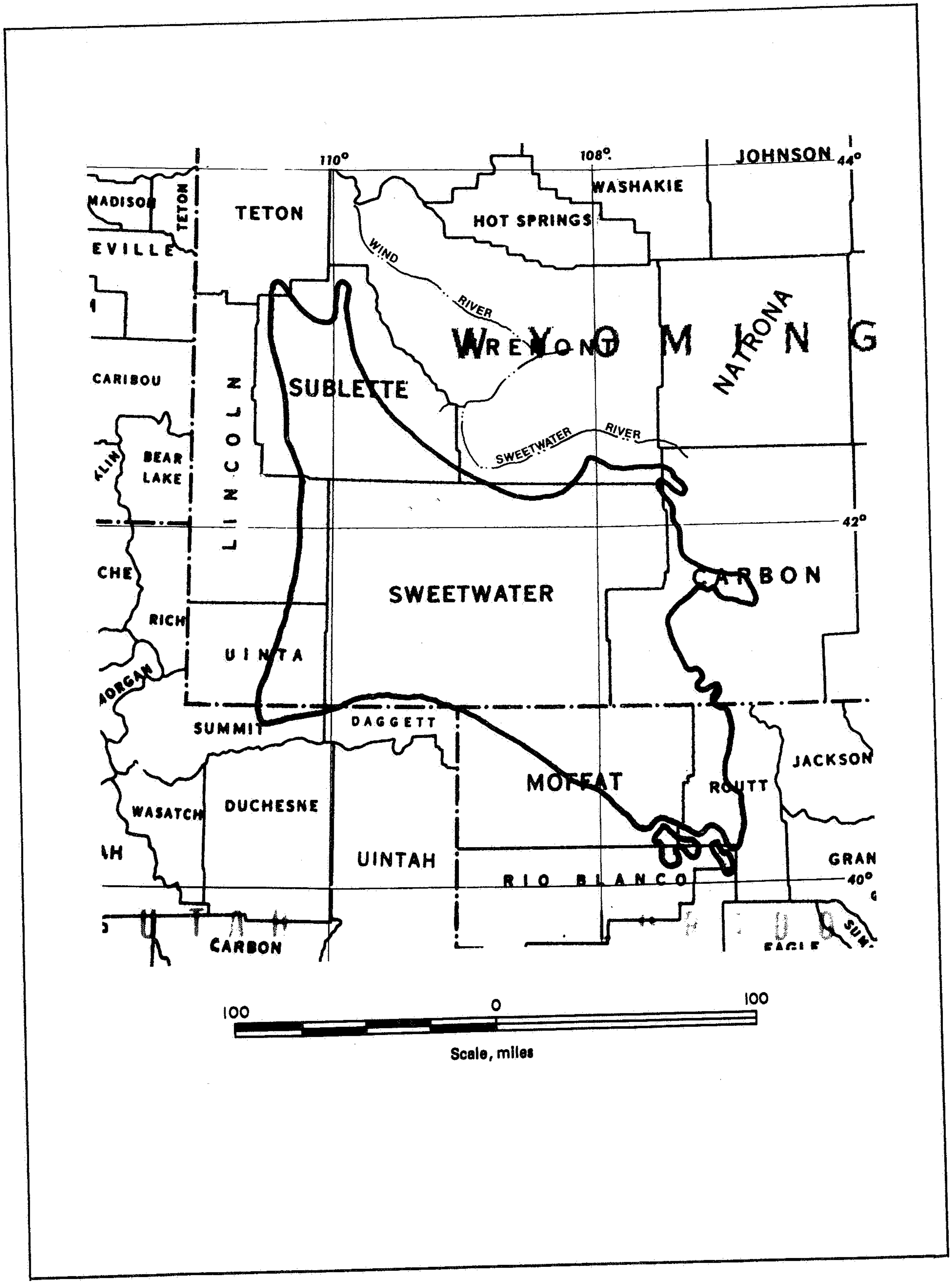


Figure 2-4. Green River Basin Target Area

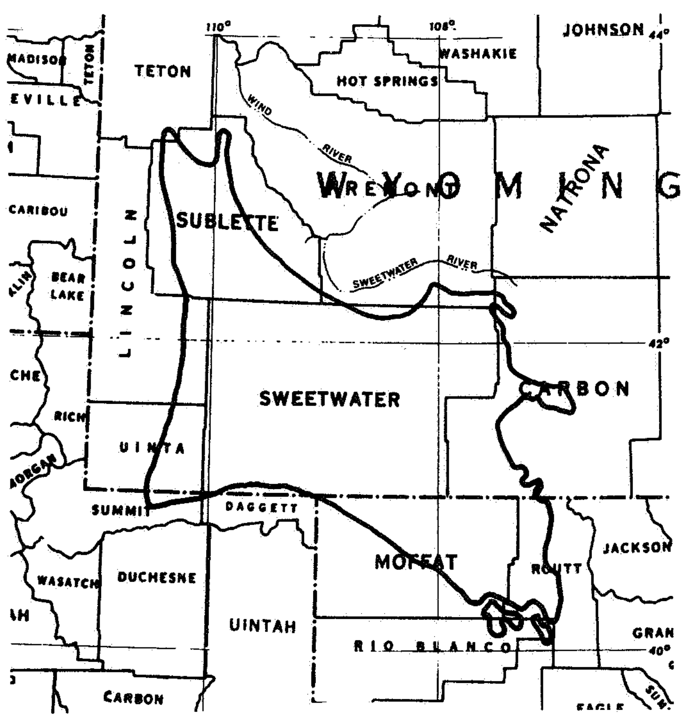
Cooperating Company: Confidential

Status: Active

Field Work Performance Period: November, 1978
Principal Investigator: A. A. Lee (TRW)
DOE Technical Project Officer: R. L. Wise

OBJECTIVE

To determine the methane content and reservoir properties of the Mesaverde Formation in the Green River Basin as part of an effort to delineate the potential for production from the resource area.



GREEN RIVER BASIN TARGET AREA
SPECIFIC PROJECT LOCATION CONFIDENTIAL

SCOPE OF WORK

This cooperative agreement provides for the conventional coring, drill stem testing, sidewall coring and logging of coals from the three coal zones of the Mesaverde Formation in the Green River Basin. The specific location of the well and the identity of the cooperating company are currently confidential.

SUMMARY OF PROGRESS

- Conventional Coring:

- Intervals Cored:	3642' - 3702' 3923' - 3953' 4649' - 4709'
- Percent Recovery:	92.0
- Number of Coal Seams:	8
- Total Coal Cored:	16.2 feet
- Number of Samples for Desorption:	13

- Preliminary desorption data for conventional and sidewall cores are summarized in Tables 2-4 and 2-5.

- Reservoir simulation was performed resulting in gas-in-place estimates for the upper zone tested of 1.8-4.0 Bcf per 640 section and an estimated value for the discounted 10 yr. gas deliverability, Ø, for an isolated well of between 16,000 and 65,000 Mcf. Since the permeability calculated for the lower zone far exceeded anything anticipated in the model, no attempt was made to calculate deliverability for that zone. See section 2.2.3 for a discussion of Ø.

- Drill Stem Tests

DST #1 - 11/19/78 - 8:00 am
Interval Tested 3700-3800'

Description	Pressure	Period
Initial Hydrostatic Mud	1763.2	
Initial Flow #1	60.9	
Initial Flow #2	66.0	5 min
Initial Shut-In	420.1	20 min
Final Flow #1	82.9	
Final Flow #2	113.9	60 min
Final Shut-In	1589.2	240 min
Final Hydrostatic	1758.1	
Bottom Hole Temp - 112°F		

Table 2-4. Preliminary On-Going Conventional Core Desorption Data from Green River Basin Site AA as of January 26, 1979

SAMPLE DEPTH (FT)	DESORBED GAS (CC)	"LOST GAS" (CC)	RESIDUAL GAS (CC)	TOTAL GAS (CC)	TOTAL GAS PER UNIT WT CC/GM	TOTAL GAS PER UNIT WT FT^3/TON
3675	9,260	1050	--	10,310	6.3	203.1
3921	1,455.1	480	--	1,935	1.7	53.3
3930	627.5	410	--	1,037.5	2.0	64.9
3948	1,110	465	--	1,575	1.6	51.0
4655	7,514	690	--	8,204	5.8	186.2
4656	7,970	640	--	8,610	4.8	154.3
4657	11,246	1100	--	12,346	7.0	225.3
4658	8,844	900	--	9,744	6.9	222.2
4659	10,410	800	--	11,210	6.5	208.7
4660	9,715	680	--	10,395	7.5	239.4
4708	11,975	1835	--	13,810	8.1	259.8
4709	10,254	1510	--	11,764	9.3	279.1

Table 2-5. Preliminary On-Going Sidewall Core Desorption Data from Green River Basin Site AA as of January 26, 1979

SAMPLE DEPTH (FT)	DESORBED GAS CC/GM	"LOST GAS" CC/GM	RESIDUAL GAS CC/GM	TOTAL GAS CC/GM	TOTAL GAS FT^3/TON
4984	1.683	0.92	--	2.6	83.3
4982	0.987	0.62	--	1.6	51.4
4980	1.77	0.97	--	2.74	87.8
4978	1.77	1.09	--	2.86	91.7
4976	1.43	0.73	--	2.16	69.3
4872	1.76	1.09	--	2.85	91.2
4868	1.46	0.92	--	2.38	76.2
4864	1.075	1.29	--	2.36	75.7
4986	0.791	0.7	--	1.49	47.7
4814	1.034	0.87	--	1.9	60.9
4720	0.561	0.4	--	0.961	30.7
4666	1.070	1.07	--	2.14	68.5

DST #2 - 11/29/78 - 2:30 pm
Interval Tested 4634-4714'

Description	Pressure (psi)	Period
Initial Hydrostatic Mud	2197	
Initial Flow #1	118	
Initial Flow #2	331	5 min
Initial Shut-In	2011	20 min
Final Flow #1	313	
Final Flow #2	1964	60 min
Final Shut-In	2020	240 min
Final Hydrostatic	2197	
Bottom Hole Temp - 138°F		

In DST #2, there was a slight show of gas to surface at the end of the final flow period (min. 58).

GREEN RIVER BASIN, SITE AB
SUBLETTE COUNTY, WYOMING

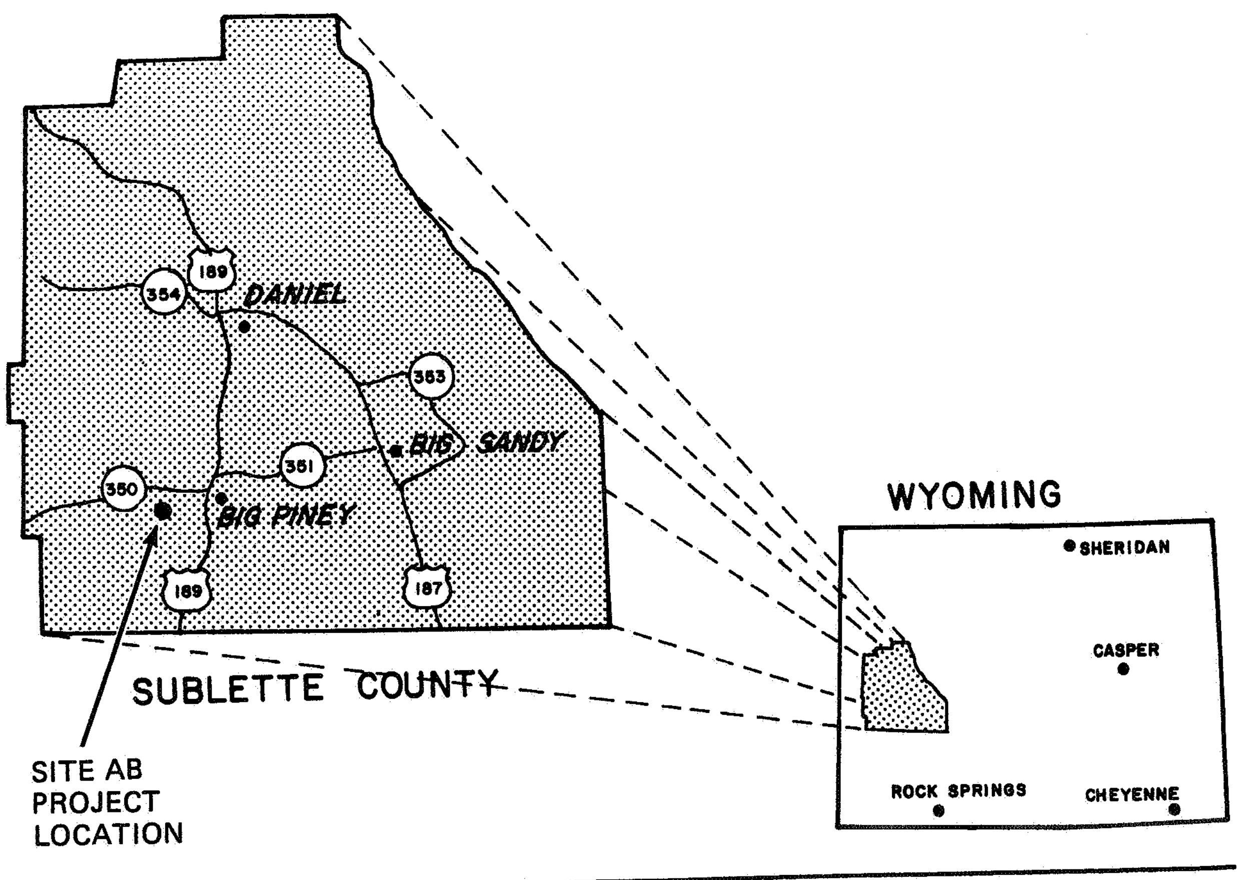
Status: Active

Cooperating Company:
Belco Petroleum Company
Lakewood, Colorado

Field Work Performance Period:	January, 1978
Principal Investigator:	A. A. Lee (TRW)
DOE Technical Project Officer:	R. L. Wise

OBJECTIVE

To determine the methane content and reservoir properties of the Mesaverde Formation in the Green River Basin as part of an effort to delineate the potential for production from this resource.



SCOPE OF WORK

This cooperative agreement provides for logging and conventional and sidewall coring of the Mesaverde formation of the Green River Basin. Gas content is to be estimated via desorption studies subsequent to collection of samples.

SUMMARY OF PROGRESS

Belco Petroleum well, S-29-27, located in Sublette County, Wyoming (Green River Basin) was tested January 2-13, 1979. Data were provided on approximately 13.8 feet of coal ranging from 3435' to 3527' in depth. Preliminary gas desorption data were good, indicating Belco to have one of the best gas-in-place contents in wells tested to date. These cores are currently being desorbed.

- Conventional Coring:

- Intervals Cored:	3450' - 3540'
- Percent Recovery:	100
- Number of Coal Seams:	3
- Total Coal Cored:	5.6 feet
- Number of Samples for Desorption:	9

- Sidewall Coring:

- Sample Depths:	3498' - 3500' 3484' - 3487' 3438' - 3440'

- Logs Produced:

  Borehole Compensated Sonic/Gamma Ray

  Dual Induction - SFL

  Compensated Neutron/Formation Density

  Caliper

- Preliminary Desorption Data are Presented in Table 2-6.

- Reservoir simulation was performed resulting in a gas-in-place estimate of 6.1 Bcf per 640 acre section and an estimated value for discounted 10 yr. gas deliverability for an isolated well of between 25,000 and 90,000 Mcf. The range for deliverability, Ø, is based on 1.0 and 10.0 md permeability and maximum and minimum relative permeability curves. Fracture length and conductivity are estimated to be 1000 ft and 50,000 md-in, respectively. Pressure was estimated at hydrostatic. See section 2.2.3 for a discussion of Ø.

Table 2-6. Preliminary Summary - On-Going Desorption of Conventional Core Samples for Green River Site AB as of January 26, 1979

SAMPLE DEPTH (FT)	DESORBED GAS (CC)	"LOST GAS" (CC)	RESIDUAL GAS (CC)	TOTAL GAS (CC)	TOTAL GAS PER UNIT WT		COMMENT
					CC/GM	FT^3/TON	
3478	7,233	805	--	8,038	9.4	300.5	
3479	11,232	1090	--	12,322	9.7	310.7	
3480	11,225	710	--	11,935	9.1	291.1	
3494	15,200	1615	--	16,815	12.1	387.0	
3495	11,506	870	--	12,376	11.7	374.6	
3506	7,159	1035	--	8,194	4.4	140.7	CARB. SHALE
3519	1,199	315	--	1,514	0.73	23.5	CARB. SHALE
3525	12,728	1740	--	14,468	10.8	345.0	
3526	12,524	180	--	14,324	12.3	392.0	

2.2.11 ILLINOIS BASIN (ILLINOIS, INDIANA, AND WESTERN KENTUCKY)

Coal in the Illinois Basin is found in sequences of shale, siltstone, and sandstone in the Conemaugh, Allegheny, and Pottsville groups of Pennsylvanian age. There are about 20 coal seams which usually total 15 to 25 feet of coal in any one location. Total coal resources in the basin are estimated at approximately 354 billion tons. Individual seams range from a few inches to 10 feet in thickness and may average 4 to 5 feet. They are thin and continuous in the Conemaugh strata, up to 10 feet thick and continuous in the Allegheny strata, and thin and discontinuous in the Pottsville strata. The coal is predominantly high volatile bituminous. Mine emission data suggest potential methane from at least 4 seams. The beds are gently dipping to horizontal with a few faults in the south portion of the basin. All the coal is covered by less than 3,000 ft of overburden.

The initial target area of interest within the Illinois Basin is shown in Figure 2-5. As of the end of the reporting period, one site had been investigated in the Illinois Basin. Results for this field test are summarized in the following paragraphs.

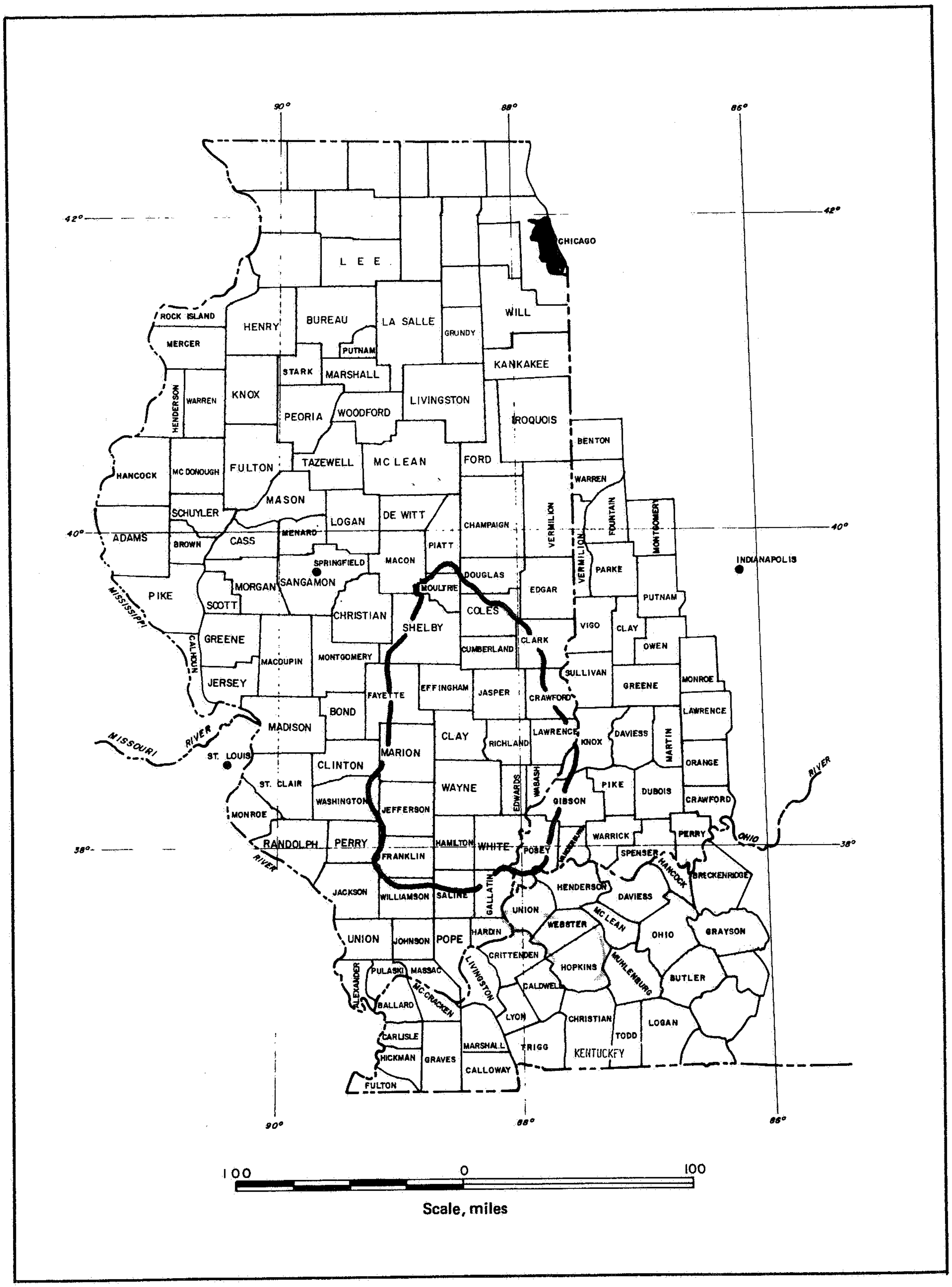


Figure 2-5. Illinois Basin Target Area

ILLINOIS BASIN, SITE AA
CLAY COUNTY, ILLINOIS

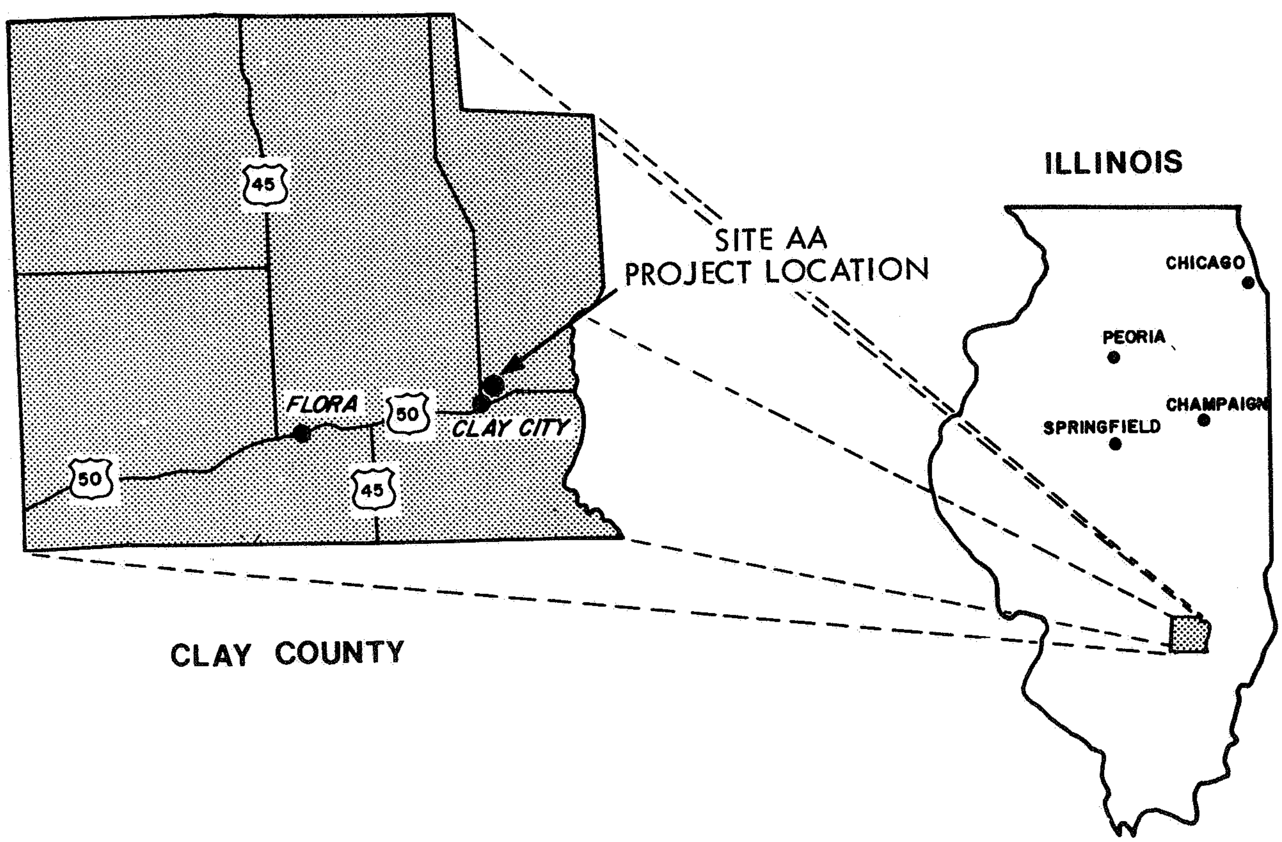
Status: Active

Cooperating Company:
Hagen Oil Company
Clay City, Illinois

Field Work Performance Period:	October, 1978
Principal Investigator:	A. A. Lee (TRW)
DOE Technical Project Officer:	R. L. Wise

OBJECTIVE

To determine the methane content and reservoir properties of numerous coal horizons within the Illinois Basin as part of an effort to delineate the potential for production from this resource area.



SCOPE OF WORK

This contract provides for coring and well testing of a well in Clay County, Illinois. The horizons of interest lie between depths of 975 feet and 1,525 feet. Gas content is to be estimated via desorption studies subsequent to collection of samples.

SUMMARY OF PROGRESS

- Hagen Oil Company well, Henderson No. 2, located in NE, SE, Section 19, Township 3N, Range 8E, Clay County, Illinois was cored, drill stem tested, logged, and sidewall cored.

  - A total of 194 feet was cored at the following intervals:

    990 - 1020 ft
    1023 - 1053 ft
    1053 - 1067 ft
    1067 - 1097 ft
    1330 - 1360 ft
    1400 - 1430 ft
    1480 - 1510 ft

  - Coal was observed as noted below:

Depth	Thickness (ft)	Seam
994	2.75	Danville #7
1035	2.00	Herrin #6
1075	1.30	Briar Hill #5A
1090	1.50	Harrisburg #5
1352	0.50	Seelyville

An undetermined thickness of coal was probably drilled through and would include the Summum No. 4 Coal, the Shawneetown No. 2A Coal and the Colchester No. 2 Coal. These seams are projected to have been in the interval from 1150' - 1300'.

- Desorption data are summarized in Table 2-7.

- Drill stem test summary:

  - Test Type - Straddle
    Packer Type - Inflatable
    Intervals Tested:

    DST No. 1 - 1342 - 1354
    Coal Seam - Seelyville

    DST No. 2 - 1071 - 1083
    Coal Seam - Briar Hill #5A

    DST No. 3 - 1026 - 1038 Misrun - No packer seats
    Coal Seam - Herrin #6

Table 2-7. Desorption Data from Conventional Cores, Site AA, Illinois Basin

DEPTH OF SAMPLE (ft)	SEAM NAME	WEIGHT OF SAMPLE (g)	GAS CONTENT cm^3/g	GAS CONTENT ft^3/ton
994	Danville No. 7	1723	1.3	42
995.3	Danville No. 7	1669	1.2	38
1035	Herrin No. 6	2055	0.9	29
1036	Herrin No. 6	1901	1.1	35
1075	Briar Hill No. 5A	1825	1.0	32
1090	Harrisburg No. 5	1379	1.2	38
1352	Seelyville	899	1.5	48

- DST No. 1 - The shut-in pressure build-up curves indicate a relatively high degree of permeability in the formation within the test interval. However, because of the limited volume and the nature of the fluid (drilling mud) which was recovered, it was not possible to calculate meaningful values for transmissibility and permeability. It is hypothesized that the permeable portion of the reservoir may be due to fracture porosity with the width of the fractures being extremely small. This would seriously limit any fluid productivity.

- DST No. 2 - The pressure data obtained during this test indicated that the formation tested had essentially no effective permeability.

- DST No. 3 - The pressure record obtained during this test indicated that no packer seats were obtained.

Desorption of the coal samples obtained show gas content ranging from 32 $ft.^3$/ton to 48 $ft.^3$/ton. These are considered low. Results of the drill stem tests of those intervals tested indicate low effective permeability and transmissibility.

On the basis of preliminary interpretation of all desorption and drill stem test data, it is concluded that the coal seams tested in this portion of the Illinois Basin are not attractive as potential coalbed methane sources or reservoirs.

- Reservoir simulation was performed resulting in a gas-in-place estimate of 200 MMcf per 640 acre section and an estimate for discounted 10 yr. gas deliverability, Ø, for an isolated well of between 1,000 to 2,000 Mcf. The estimates for deliverability were based on a permeability of less than 2 md, and a pressure of 569 psia. See section 2.2.3 for a discussion of Ø.

2.2.12 NORTHERN APPALACHIANS (PENNSYLVANIA, OHIO, WEST VIRGINIA)

Coal in the northern Appalachians is found in Permian Dunkard Group rocks, and the Pennsylvanian Conemaugh, Allegheny, and Pottsville Group strata. These rock units contain approximately 198 billion tons of coal reserves in about 90 minable coal seams. The total coal thickness varies from 20 to 60 feet. The individual seams are thin, less than 10 feet thick, but continuous over large areas. In a few areas, individual seams may exceed 20 feet in thickness. The coal is low to high volatile bituminous in rank and is known to have methane production potential. Gas emission data exists for mines in at least 15 different seams. The beds in the area range from gently to tightly folded and faulted in the east to nearly horizontal in the west. Most of the coal is covered by less than 3,000 feet of overburden.

The initial target area of interest within the Northern Appalachian Basin is shown in Figure 2-6. As of the end of the reporting period, two sites had been investigated in the Northern Appalachian Basin. Results for these field tests are presented in the following paragraphs.

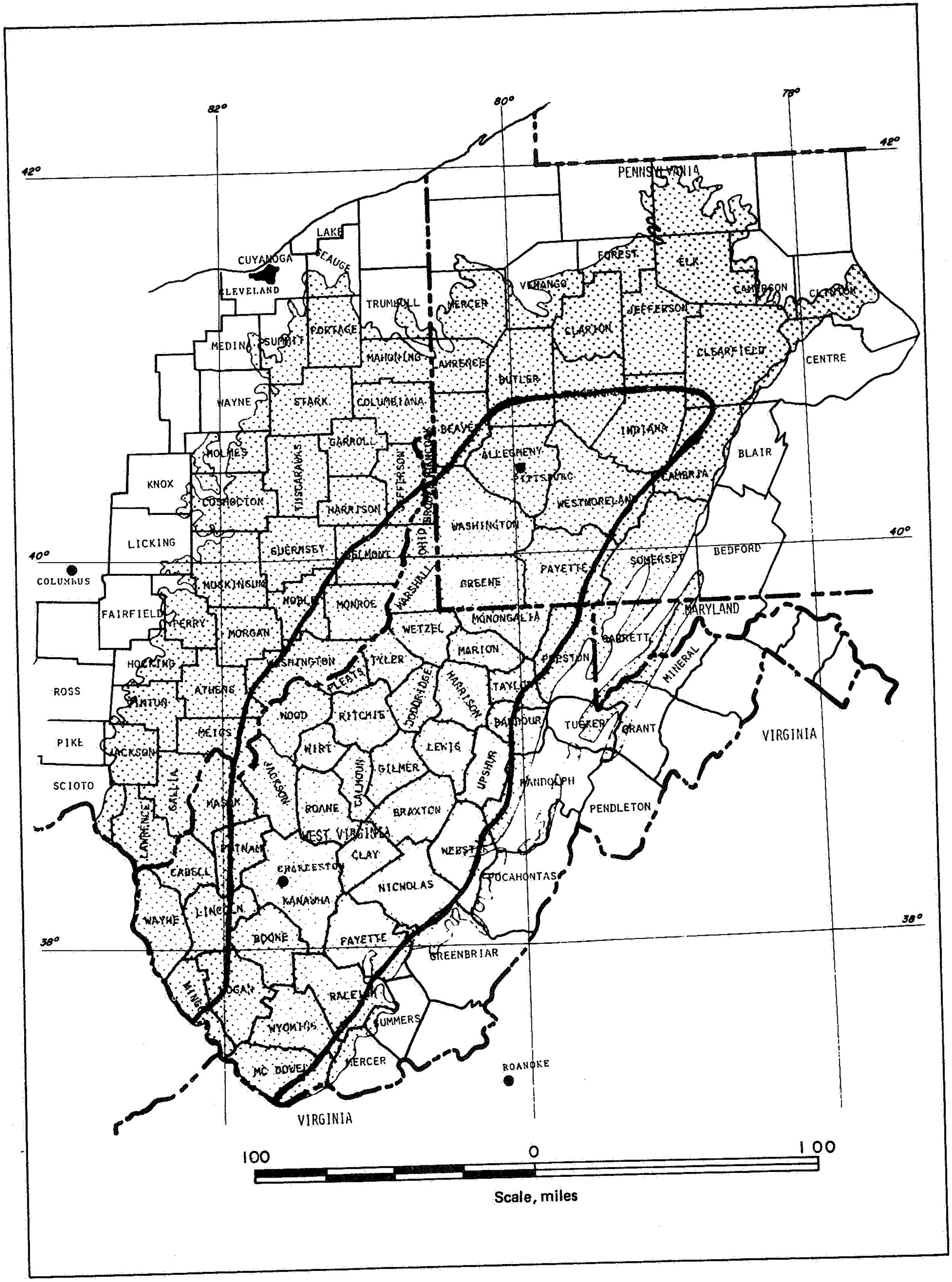


Figure 2-6. Northern Appalachian Basin Target Area

NORTHERN APPALACHIAN BASIN, SITE AA
GREENE COUNTY, PENNSYLVANIA

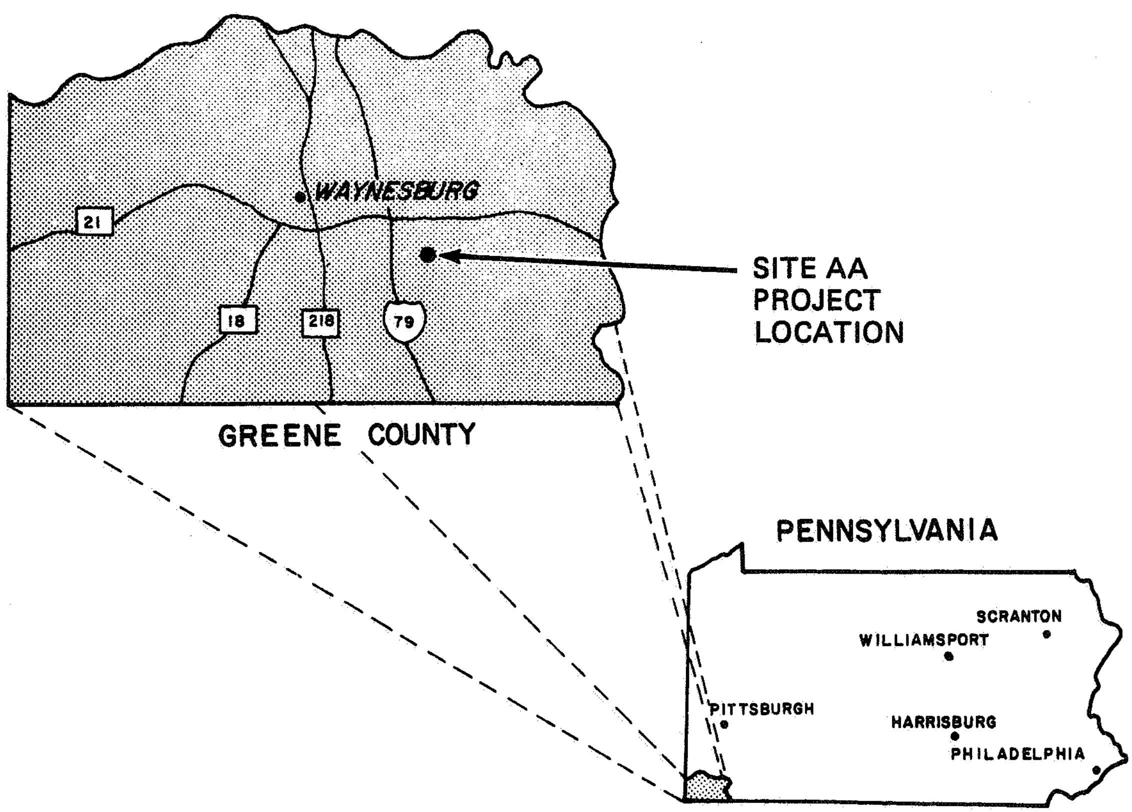
Cooperating Company:
Kinloch Exploration Company
Langley Park, Maryland

Status: Active

Field Work Performance Period: April, 1978
Principal Investigator: A. A. Lee (TRW)
DOE Technical Project Officer: R. L. Wise

OBJECTIVE

To determine the methane content and reservoir properties of the several coal horizons within the Northern Appalachian Basin as part of an effort to delineate the potential for production from this resource area.



SCOPE OF WORK

This cooperative agreement provides for the DOE use of data obtained on the Harry A. Murdock, Jr. #1 well in Greene County, Pennsylvania. The following report will be supplied:

A. Introductory paragraphs describing drilling procedures, depth of drilling, terrain, location and name of well. This section is to include a drawing of the well to include casing sizes, etc.

B. Data gathered before cementing

1. Well logs
2. Stratigraphic column at the well location
3. Description of coalbeds by names and depth
4. Drill stem test description data
5. In situ pressures and flow rates

C. Data gathered after cementing and before fracturing

1. Cementing procedure and problems
2. Description of perforations, location and procedures
3. Description of acid use
4. Description of pre-frac injection tests and procedure

D. Fracturing data

1. Type of hydraulic fracturing
2. Pressure, amounts of materials used and periods used
3. Flow-back information and significant events

E. Post-fracturing data

1. Post-fracturing injection test data and procedures
2. Production data for water and gas
3. Production procedures
4. Pressure and water level data with significant events

F. Laboratory data

1. Sorption isotherms
2. Gas content of different coalbeds
3. Procedures and significant lessons learned.

In addition to the report, access to the well and permission for its use for further testing by the Methane from Coalbeds Project will be provided as a consideration of this cost-sharing agreement.

SUMMARY OF PROGRESS

The acquired data are undergoing evaluation and will be discussed in subsequent semi-annual reports.

NORTHERN APPALACHIAN BASIN, SITE AB
WETZEL COUNTY, WEST VIRGINIA

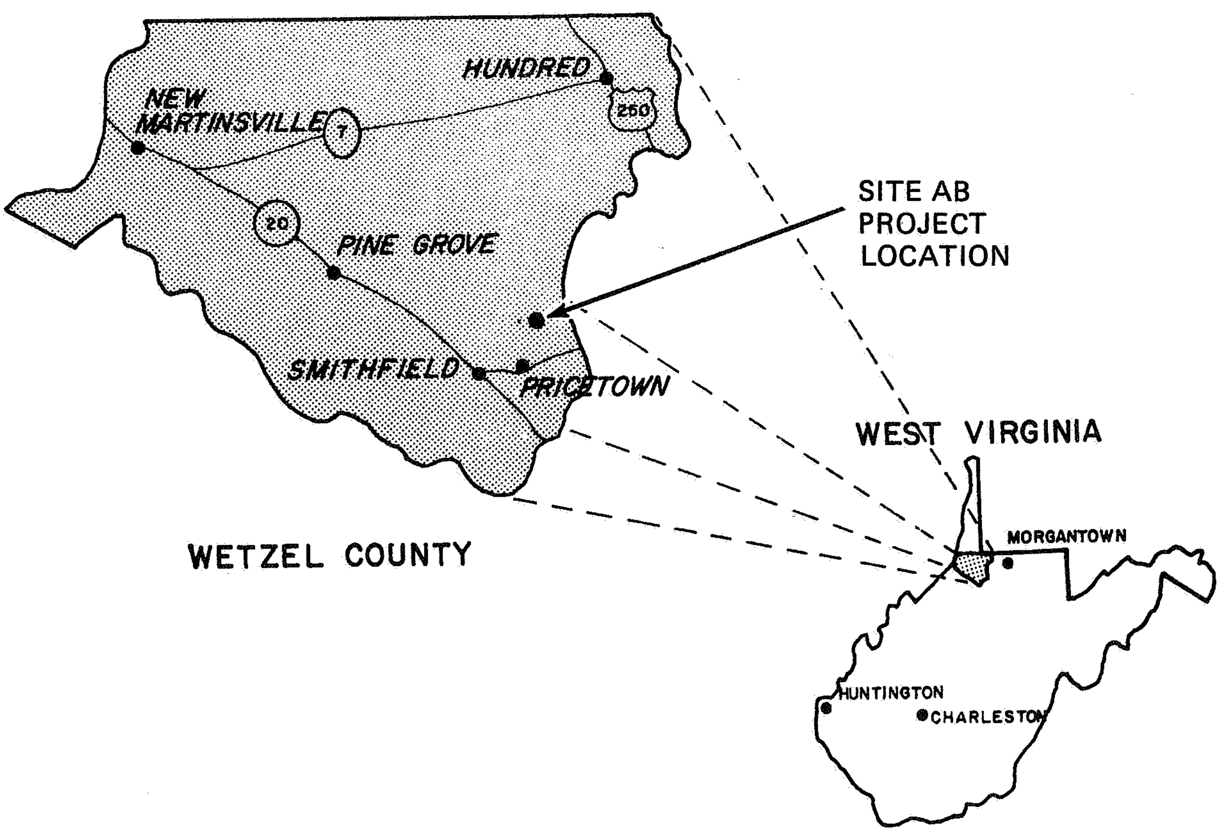
Investigating Group:
Morgantown Energy Technology Center
Morgantown, West Virginia

Status: Active

Field Work Performance Period: January—December, 1978
Principal Investigator: D. W. Gillmore

OBJECTIVE

To determine the methane content and reservoir properties of the Pittsburg coal within the Northern Appalachian Basin as part of an effort to delineate the potential for production from this resource area.



SCOPE OF WORK

The Morgantown Energy Technology Center (METC/DOE) is conducting an underground coal gasification (UCG) experiment in Wetzel County, near Pricetown, West Virginia. This site was selected on the basis of geographical, geological, environmental and other technical factors which were favorable to in situ gasification of the Pittsburgh coal seam, particularly for a proposed scheme involving directional wells drilled from the surface horizontally into the coal seam.

During the course of preparations for the UCG project, an old gas well (Snodgrass No. 2 well) was uncovered on the site. This well was initially proposed for use as a monitor well in the UCG program. However, during the implementation of the UCG project, the Snodgrass No. 2 well became available for testing in the DOE/METC methane drainage program.

The test plan for the well was designed to obtain baseline data prior to any treatments, and to measure the same parameters after perforating and hydraulic fracturing. The test procedures included measurement of water and gas production rates, and water injection rates at 100 and 200 psig. The size of the stimulation treatments were limited because of the proximity of Snodgrass No. 2 to a directional well in the coal seam (approximately 600 feet), and to the Pricetown I UCG site (approximately 800 feet).

SUMMARY OF PROGRESS

Pressure tests indicate that the coal seam is a tight low permeability matrix, approximately 0.01 md. Desorption data from coal cores at Pricetown I indicate that the methane content of the Pittsburgh coal at Pricetown is 50 - 100 cf/ton.

A small water frac treatment was designed and conducted on the coal seam (3,700 gal water and 1,500 lb sand). The permeability of the coal seam was improved to 6.2 md; however, injection tests indicated only short fracture lengths (estimated fracture length of 12 ft). Following the pressure injection tests a pump was placed in the well and the water pumped off. The gas production rate stabilized at approximately 400 cfd methane and the water production at 1 bpd.

From these data it appears that vertical wells in the Pittsburgh coal seam at the Pricetown site are not likely to produce commercial gas in the near future. If the coal were given a large volume stimulation, creating a 750-foot hydraulic fracture, the resultant initial flows of around 4000 cfd would still not be considered commercially recoverable quantities of gas. The behavior of the Pittsburgh coalbed methane resource in this area is considered anomalous as the pressure and specific gas content are very low considering the depth of the coal.

2.2.13 PICEANCE BASIN (COLORADO)

Coals in the Piceance Basin are found within the sandstones and shales of the Mesaverde group of Late Cretaceous age. There are approximately 18 seams in the Mesaverde with an aggregate thickness of 30 to 80 feet. The individual seams may be lenticular and discontinuous, to thick and continuous with lateral extent in excess of 2,000 square miles. The coal resource is estimated at about 60 billion tons. Individual beds range from a few feet to 20 feet thick, but average about 10 feet thick. The coal is of sub-bituminous to anthracite rank. Mine emission data indicate that 13 seams have methane production potential. The coal is found in a geologic basin with steep dips at the margin and nearly horizontal beds in the center. Depth to coal exceeds 3,000 feet a very short distance from the outcrop. The coal has been observed in oil tests at depths of about 6,700 feet.

The initial target area of interest within the Piceance Basin is shown in Figure 2-7. As of the end of the reporting period, four sites had been investigated in the Piceance Basin. Gas content is to be estimated via desorption studies performed subsequent to sampling.

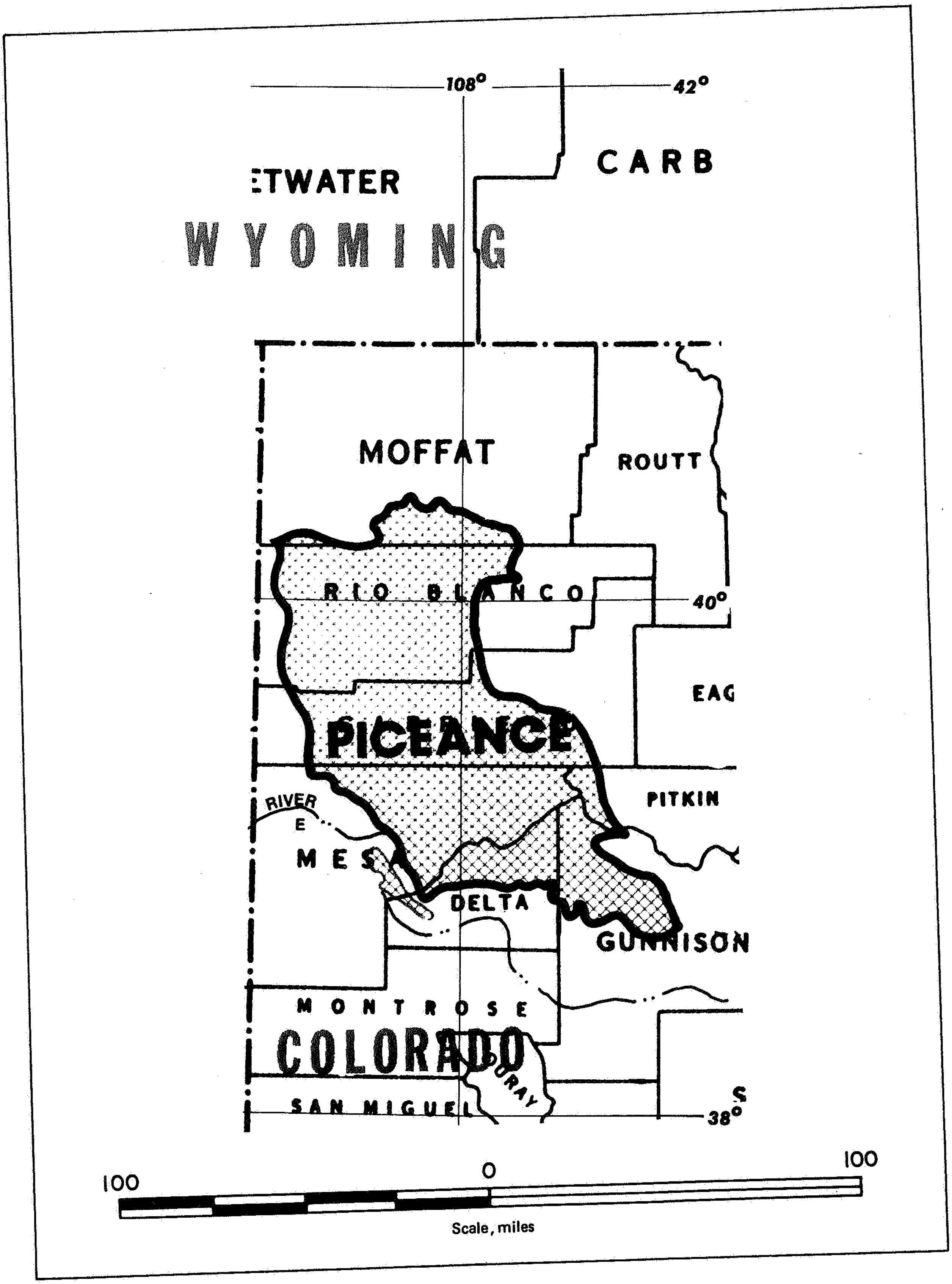


Figure 2-7. Piceance Basin Target Area

PICEANCE BASIN, SITE AA
RIO BLANCO COUNTY, COLORADO

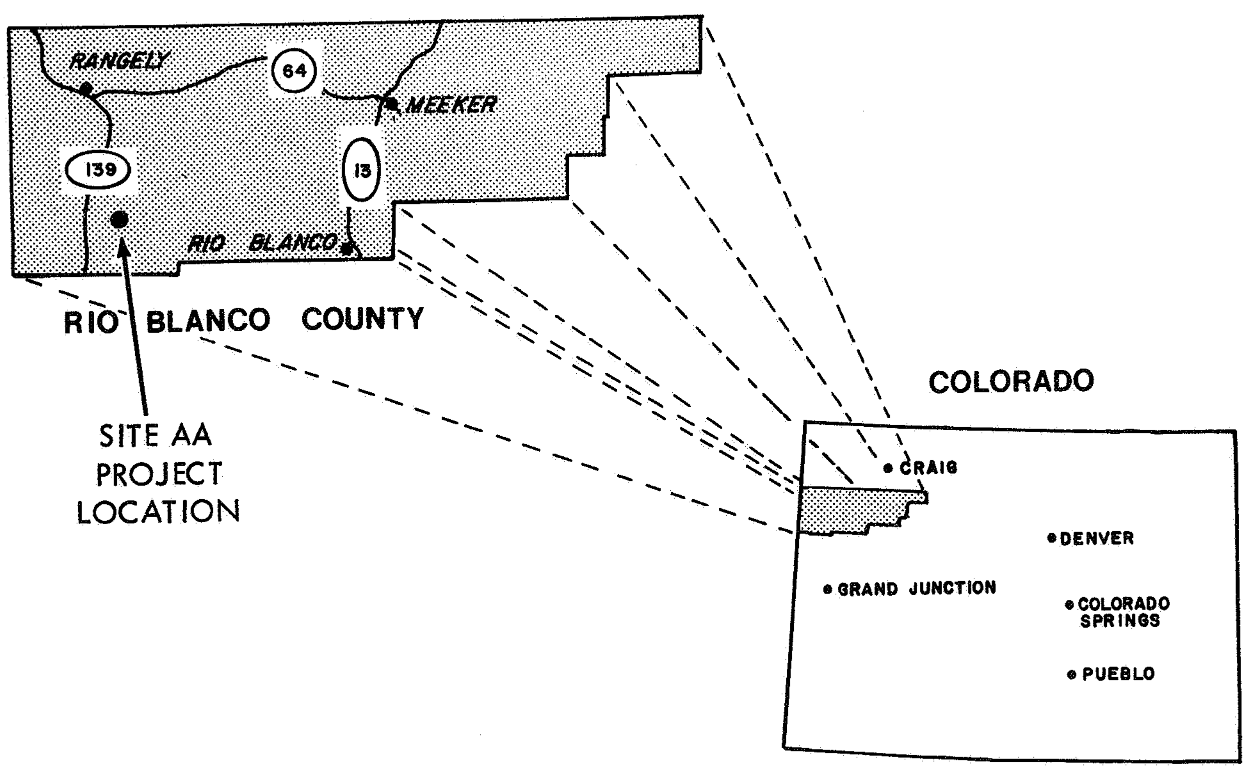
Cooperating Company:
Fuel Resources Development Company
Denver, Colorado

Status: Active

Field Work Performance Period: September 9–10, 1978
Principal Investigator: A. A. Lee (TRW)
DOE Technical Project Officer: R. L. Wise

OBJECTIVE

To determine the methane content and reservoir properties of coal seams within the Lower Mesaverde Group sediments in the Piceance Basin as part of an effort to delineate the potential for production from this resource area.



SCOPE OF WORK

This contract provides for coring of approximately 120 feet of coal-bearing Lower Mesaverde Group sediments in the Douglas Creek Arch area of the Piceance Basin. Gas content is to be estimated via desorption studies performed subsequent to sampling.

SUMMARY OF PROGRESS

- The Fuelco well, 0-28-3-101-A, Section 28, T3S, R101W, Rio Blanco County, Colorado was cored on September 9 and 10, 1978. Because of unexpected structural complexities, the primary objective coals were not encountered in coring. Less than five feet of coal was cored between 1,582 and 1,623 feet. Two coal samples were collected for desorption studies. The two samples came from depths of 1,584 to 1,586 feet and 1,603 to 1,604 feet.

- Desorption data from conventional cores are as follows:

Sample Depth (ft)	Total Gas (cc)	Sample Weight	Total Gas per unit Weight cc	Total Gas per unit Weight ft^3/ton
1585	898	1584	0.56	17.9
1603	364	144	2.5	80.9

PICEANCE BASIN, SITE AB
RIO BLANCO COUNTY, COLORADO

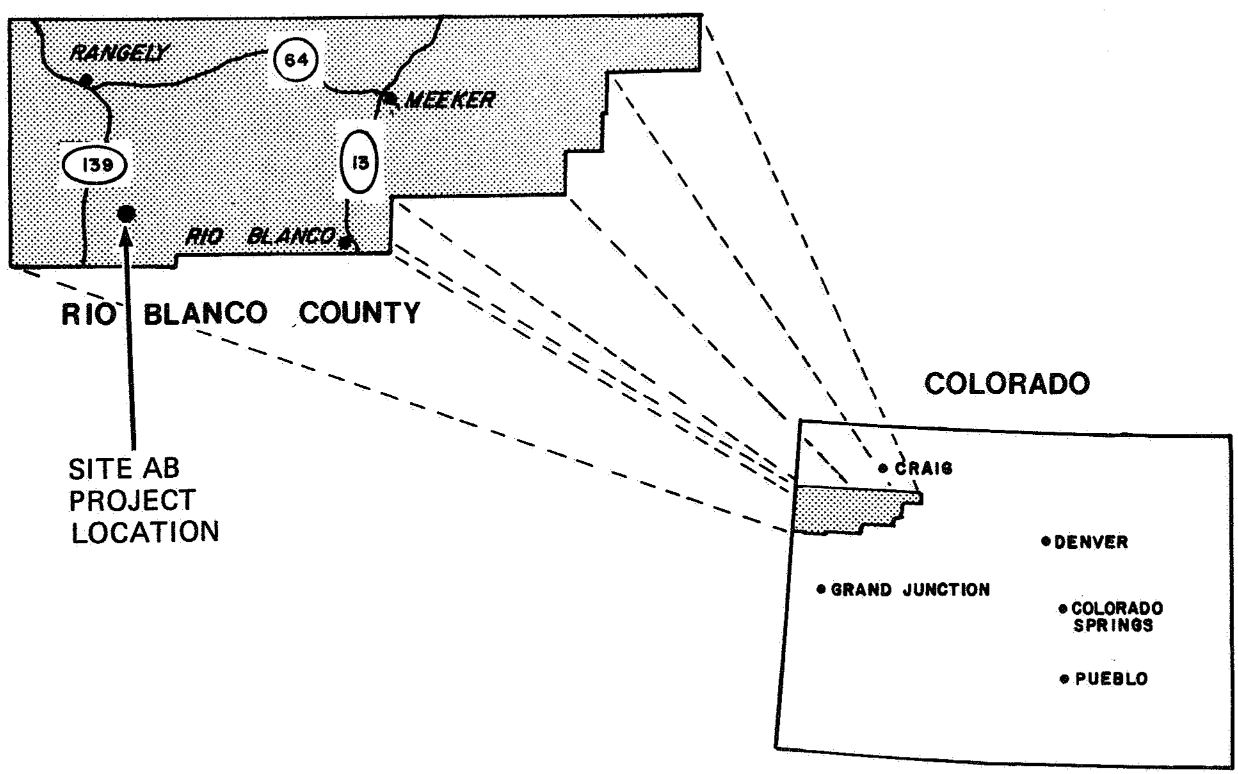
Status: Complete

Cooperating Company:
Twin Arrow Drilling Company
Rangely, Colorado

Field Work Performance Period: October, 1978
Principal Investigator: A. A. Lee (TRW)
DOE Technical Project Officer: R. L. Wise

OBJECTIVE

To determine the gas permeability, flow rate, and producibility of several coal seams of the Mesaverde Formation in the Piceance Basin as part of an effort to delineate the potential for production from this resource area.



SCOPE OF WORK

This work consists of a well test in Rio Blanco County, Colorado, to be accomplished in four phases. Phase I consists of placing a plug at 1,050 feet in the well (below the present horizon of interest), swabbing out the well, and installing an orifice flow meter on the surface to measure any flow from casing perforations near the coal bearing zones. Phase II consists of cementing behind the casing from the present top of cement to meet Federal lease requirements in the event one or more of the coal seams is fraced. Phase III consists of perforating and flow testing the sections shown as coal on Twin Arrow logs. Phase IV consists of fracturing and flow testing appropriate intervals.

SUMMARY OF PROGRESS

- Twin Arrow well C&K #1-13, located in Section 13, Township 3S, Range 101W, Rio Blanco County, Colorado (Piceance Basin) was pressure and flow tested, cemented, perforated, acid treated and again flow tested.

  - The following intervals were tested:

    573-581 ft.
    627-633 ft.
    661-665 ft.
    726-736 ft.
    801-810 ft.

  - Initial pressure and flow testing indicated zero pressure and zero flow.

  - After cementing, the target intervals were jet perforated (1 shot/ft). They were then individually acid treated (7.5% HF), swabbed and pressure and flow tested. A zero psi shut-in reading was obtained for all five zones and no flow could be observed or felt through a 1/8 inch orifice.

- No further activity is planned due to the absence of gas.

PICEANCE BASIN, SITE AC
RIO BLANCO COUNTY, COLORADO

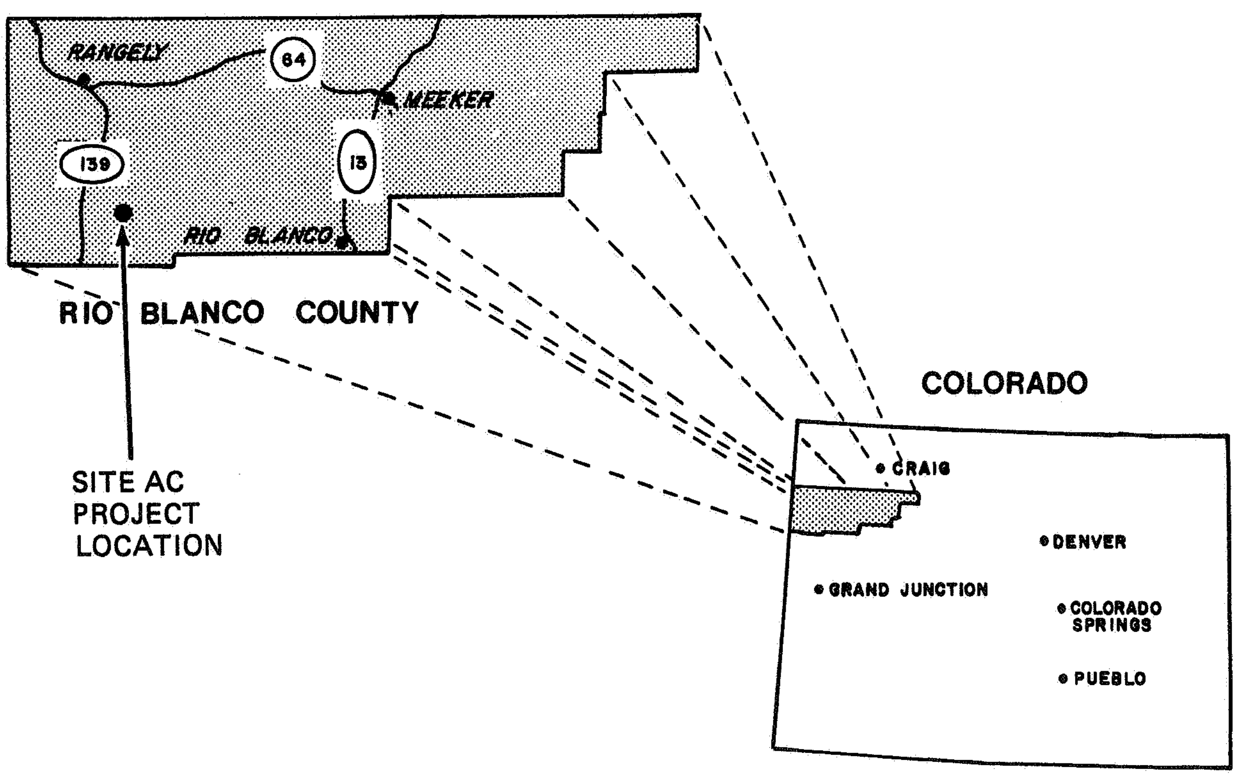
Status: Active

Cooperating Company:
Twin Arrow Drilling Company
Rangley, Colorado

Field Work Performance Period: November—December 1978
Principal Investigator: A. A. Lee (TRW)
DOE Technical Project Officer: R. L. Wise

OBJECTIVE

To determine the methane content and reservoir properties of multiple coal seams of the Piceance Basin as part of an effort to delineate the potential from this resource area.



SCOPE OF WORK

This cooperative agreement provides for the coring and testing of several coal seams of the Mesaverde Formation of the Piceance Basin. Determination of gas content will be through desorption testing of core samples.

SUMMARY OF PROGRESS

- Twin Arrow well C&K #4-14, located in Section 14, Township 3S, Range 101W, Rio Blanco County, Colorado (Piceance Basin) was cored between November 29 and December 1, 1978. In addition, it was planned that open-hole pressure and flow testing would be accomplished. However, a combination of no gas shows during drilling and poor weather prevented this part of the testing.

- Preliminary desorption data are as follows:

Depth of Sample (ft.)	Lithology	Sample Weight	Gas Content cc	Gas Content $ft.^3$/ton
685.2-685.6	Coal	355	3.08	98.8
698.1-698.45	Carb. shale/coal	410	4.1	130.3
772.3-772.6 773.3-773.6	Carb. siltstone	420	1.7	54.0
770.9-771.6	Carb. shale w/coal	605	1.03	33.1
759.2-760.0	Coal	445	2.8	88.5
809.3-809.7	Coal	186	4.6	146.9
801.9-802.6	Coal	366	3.4	107.7
804.5-805.0	Carb. shale	697	1.75	56.1
986.5-987.3	Coal	718	1.43	45.9

- No well testing was performed because the hole was lost.

- Reservoir simulation was performed resulting in a gas-in-place estimate of 157 MMcf per 640 acre section and a deliverability estimate of zero because of lack of flow in the Twin Arrow #1 Test. See section 2.2.3 for a discussion of Ø.

2.2.14 SAN JUAN BASIN (COLORADO AND NEW MEXICO)

Coal in the San Juan Basin is found in sandstones and shales of the Mesaverde group and the Fruitland formation of Upper Cretaceous age and the Dakota sandstone of Lower Cretaceous age. The total coal thickness generally varies from 15 to 25 feet. Total coal resources in the basin are in excess of 150 billion tons. Individual seams are lenticular and discontinuous in the Upper Cretaceous and thin and discontinuous in the Dakota. Individual seams average 3 to 6 feet of high volatile bituminous coal where mined. The Mesaverde group coals have shown the presence of gas. The beds are gently dipping to horizontal in the west to steeply dipping in the east with some local faulting.

The initial target area of interest within the San Juan Basin is shown in Figure 2-8. As of the end of the reporting period, one site had been investigated in the San Juan Basin. Results for this field test are summarized in the following paragraphs.

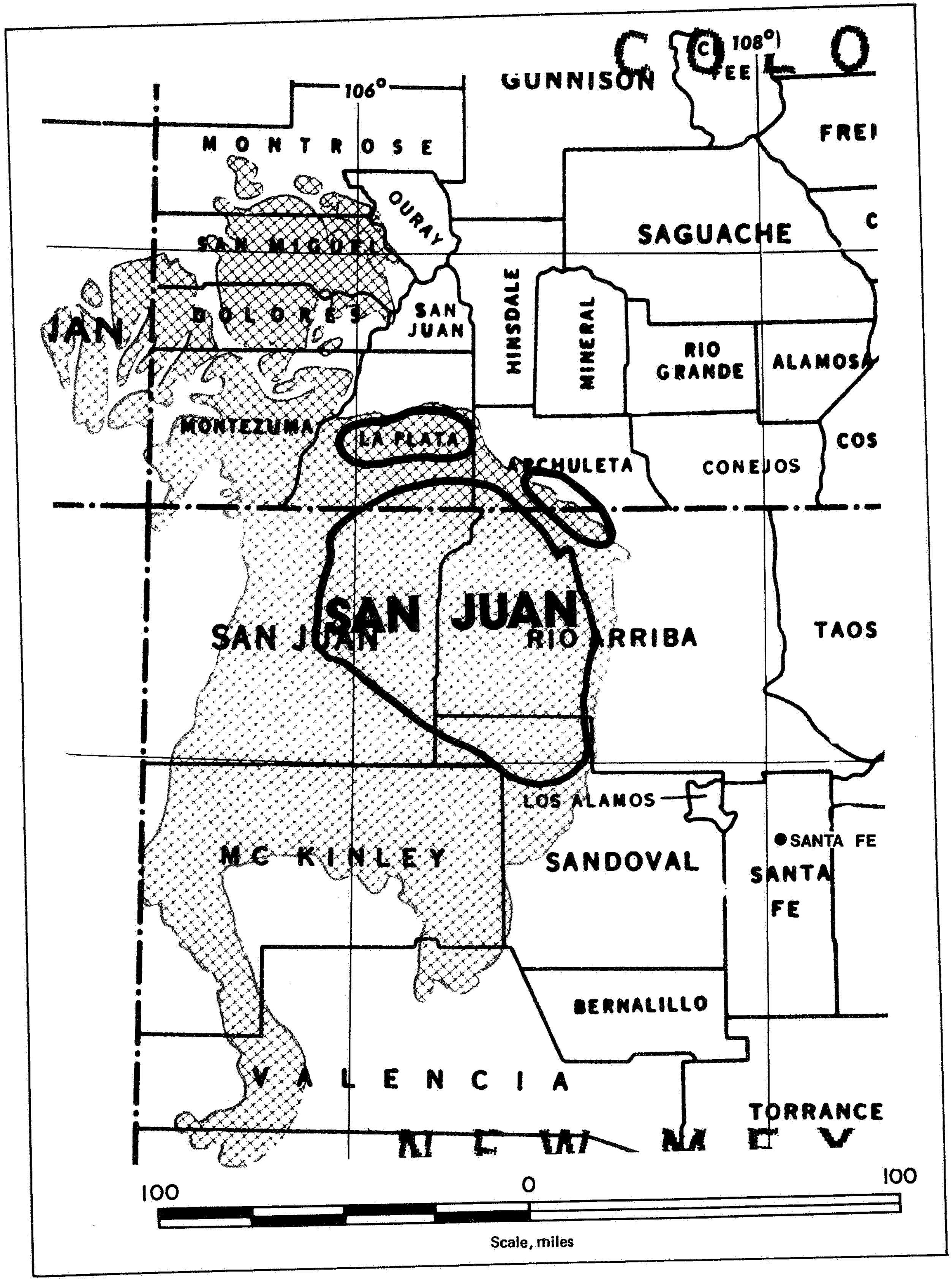


Figure 2-8. San Juan Basin Target Area

SAN JUAN BASIN, SITE AA
SAN JUAN COUNTY, NEW MEXICO

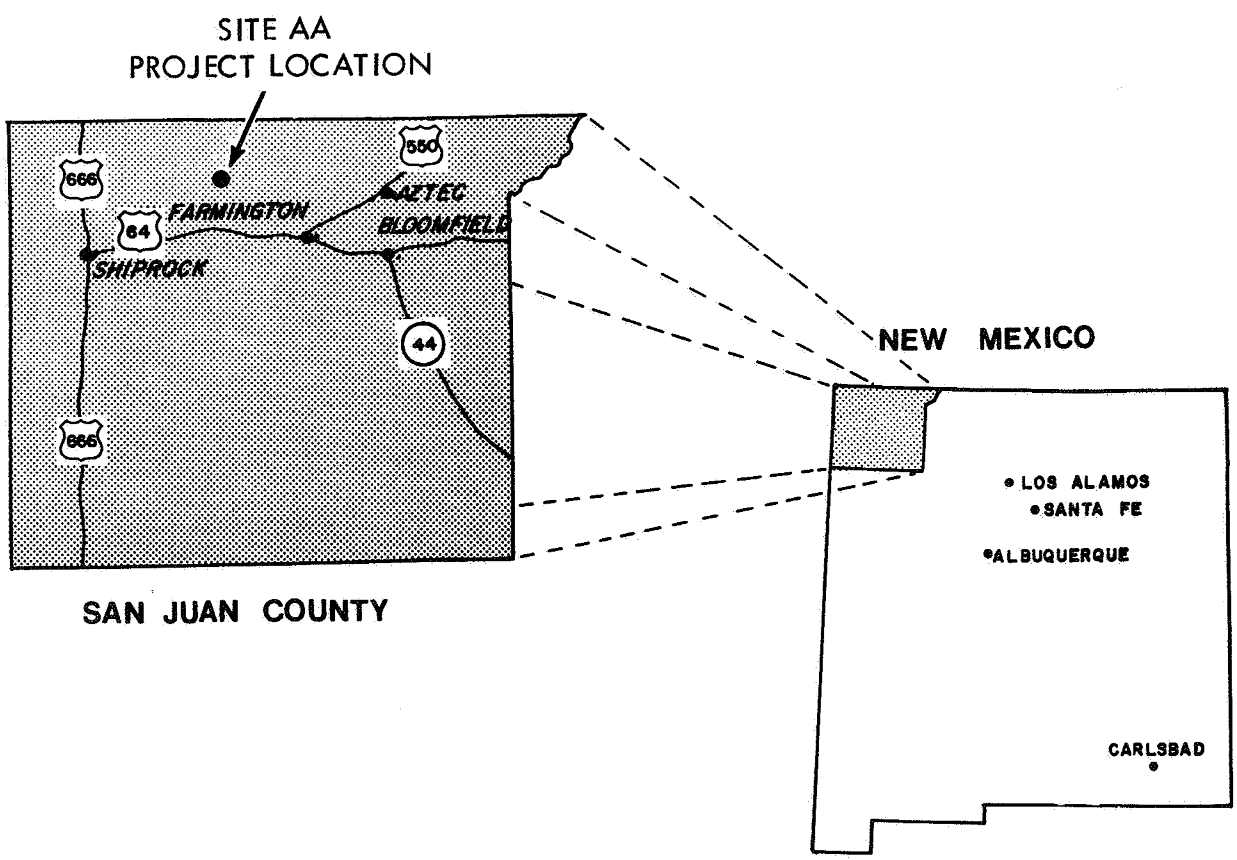
Cooperating Company:
Western Coal Company
Albuquerque, New Mexico

Status: Active

Field Work Performance Period: June 16, 1978
Principal Investigator: A. A. Lee (TRW)
DOE Technical Project Officer: R. L. Wise

OBJECTIVE

To determine the methane content and reservoir properties of coal seams within the Fruitland Formation in the San Juan Basin as part of an effort to delineate the potential for production from this resource area.



SCOPE OF WORK

This cooperative agreement provides for coring operations to obtain coal samples in the outcrop area of the Upper Fruitland Formation, or Lower Kirtland Shale, on the western flank of the San Juan Basin: SE 1/4 Section 22, T30N, R15W. Gas content is to be measured via desorption studies subsequent to collection of samples.

SUMMARY OF PROGRESS

Coring was initiated and completed on June 16, 1978. Two coal samples were collected from an approximately 12-foot thick seam penetrated at a depth of 393.5 feet. The two coal samples were collected from depths of 398.2 to 398.9 feet (sample #1) and 398.85 to 399.45 feet (sample #2). Initial desorption measurements were completed in August, 1978, with 640 cc of gas being desorbed from sample #1 and 163 cc of gas being desorbed from sample #2. These amounts are equivalent to 1.39 cc (or 44.5 cubic ft/ton) and 0.32 cc (or 10.26 cubic ft/ton) of coal respectively.

The coal samples were submitted to the U.S. Bureau of Mines for proximate, ultimate, and residual gas analysis. Final interpretation of the data from this effort awaits completion of USBM laboratory analyses. Initial results from desorption measurements indicate that at this location the gas content of the Fruitland seam appears low in comparison to virgin Eastern coalbeds. This low gas content might possibly be due to the shallow depth at which the Fruitland seam was sampled.

2.3 RESEARCH & DEVELOPMENT

2.3.1 GENERAL

The MRCP Research and Development (R&D) effort is being directed at development of improved, more cost effective methods and systems for methane extraction and utilization from coalbeds. As of the end of the reporting period, two R&D projects were underway: manufacture of a 5-3/8" Turbodrill by Maurer Engineering, Inc. and evaluation of the feasibility of explosive fracturing of coal to increase permeability, by Physics International Company. Firm planning was executed for two additional R&D projects: an investigation of water jet drilling for methane drainage by Sandia Laboratories and a study of fracture mechanics of coal by West Virginia University. Scopes of work and progress to date are summarized for the four projects in Sections 2.3.2 through 2.3.5.

2.3.2 TURBODRILL

Maurer Engineering, Inc.
Houston, Texas

Status: Active

Contract:	DE-AC21-78MCO8380
Contract Date:	September 15, 1978
Anticpated Completion Date:	October 1, 1979
Principal Investigator:	Ralph L. Coates
DOE Technical Project Officer:	H.D. Shoemaker

OBJECTIVE

To develop and test a turobdrill downhole motor for use in directional drilling applications in the extraction of methane from coal seams.

SCOPE OF WORK

This contract provides for the development and testing of a turbodrill downhole motor for use in directional drilling applications in the extraction of methane from coal seams. The development aspect involves a complete design and construction of the turbodrill. The testing aspect is to focus on three areas: (1) a horizontal, above-ground bench test mode to generate baseline performance data; (2) a controlled, straight-hole field test drilling into well-known formations with a drilling rig; and (3) a directional field test drilling a well from vertical at the surface to horizontal in a coal seam.

A schematic drawing of the turbodrill is presented in Figure 2-9. The motor consists of a turbine section and a bearing package. The driving fluid is drilling mud or water. All blades and vanes are contained in the turbine pack, and all bearings (thrust and radial) and seals are in the bearing pack. The turbine pack contains 50 stages of blades and vanes. The bearing package comes in two versions: the sealed bearing pack for use in drilling with mud through abrasive formations and the flow-through pack for use with less abrasive muds and water (in softer formations). The sealed bearing pack has application for directional and straight-hole drilling in conventional oil and gas fields. The flow-through bearing pack is designed for use with water in geothermal applications and in relatively shallow coal seam methane drainage directional drilling.

The floating piston assembly in the sealed bearing pack pressurizes the oil reservoir (containing a synthetic bearing lubricant) and prevents the intrusion of drilling mud into the roller bearings. (Refer to Figure 2-9).

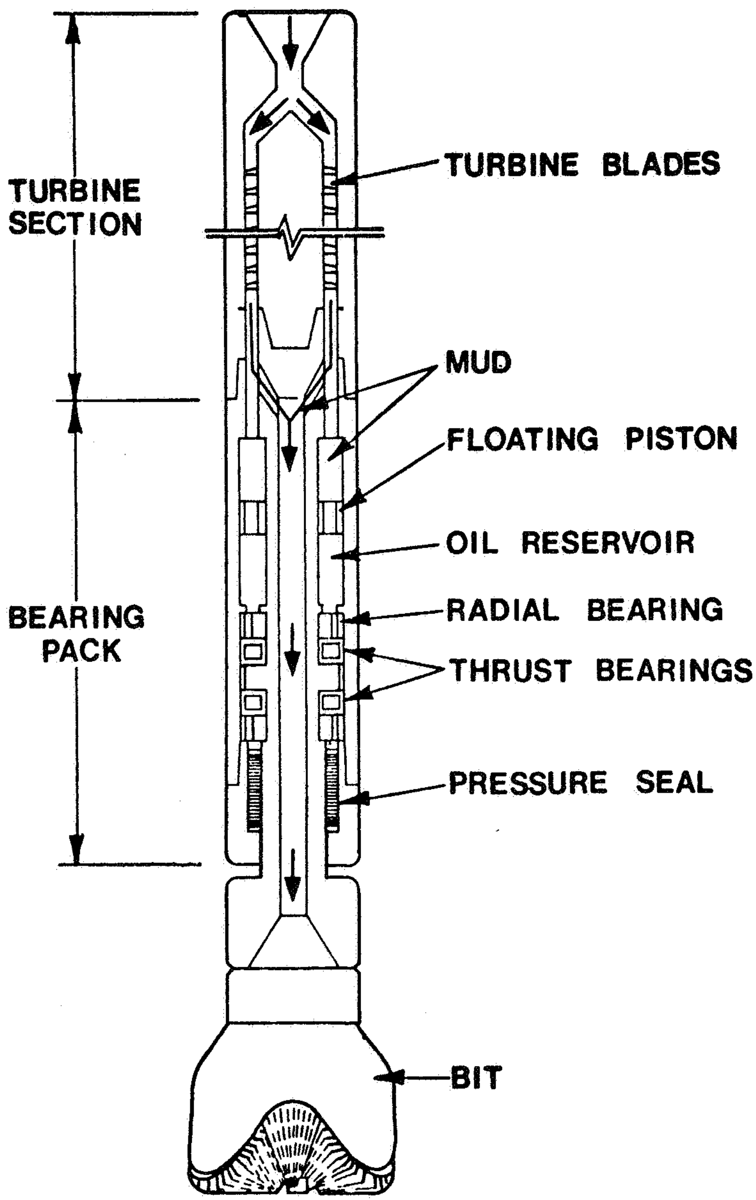


Figure 2-9. Schematic of Maurer Turbodrill

There are two significant pressure drops in the turbodrill: across the stage assembly of blades and vanes in the turbine section and across the pressure-seal assembly at the front-end of the bearing package. The bit pressure drop (up to 1000 psi), which strongly influences penetration rates, is supported by the pressure seal assembly. Weight-on-bit or downward thrust force is transmitted to the bearings via the rotor shaft and axial compression spacer rings mounted on the shaft. There are a total of seven such spacers, three sets of radial roller bearings, and two sets of roller thrust bearings. Proper alignment of all these elements with the rotor shaft is important.

The bearing pack is designed to maintain a thrust bearing preload to take advantage of the hydraulic downthrust in counteracting the upward bit reaction force on the bearings. The net effect is that considerably greater weight can be applied to the bit to increase penetration rate while drilling. The preload also serves to eliminate roller bearing "chatter" when temporarily operating under low-load or no-load conditions, for example, at startup. All bearings and seals are commercial, off-the-shelf items.

Performance profiles that characterize turbodrill operation are presented in Figure 2-10. These curves represent theoretical response. The output torque increases linearly from zero at runaway speed (under no load conditions) to maximum value at zero rotary speed. Maximum power output and efficiency occur theoretically at exactly one-half the runaway speed (as shown in Figure 2-10).

SUMMARY OF PROGRESS

Five short-duration shakedown tests of the Turbodrill have been performed. Baseline no-load performance data were obtained. Teardown and inspection of the drill motor has indicated a problem area in the pressure seal in the bearing package. Maurer Engineering instituted design modifications to the floating piston seal assembly in preparation for subsequent formal Phase I testing at TRW Mission Manufacturing. The option was exercised to proceed into a modified testing project using the flow-through version of the bearing pack. The flow-through bearing pack will be used in Phase I and Phase II. When an adequate pressure seal is obtained, an abbreviated Phase I test may be run. At that point, the project may proceed directly into Phase III testing in a rugged field environment.

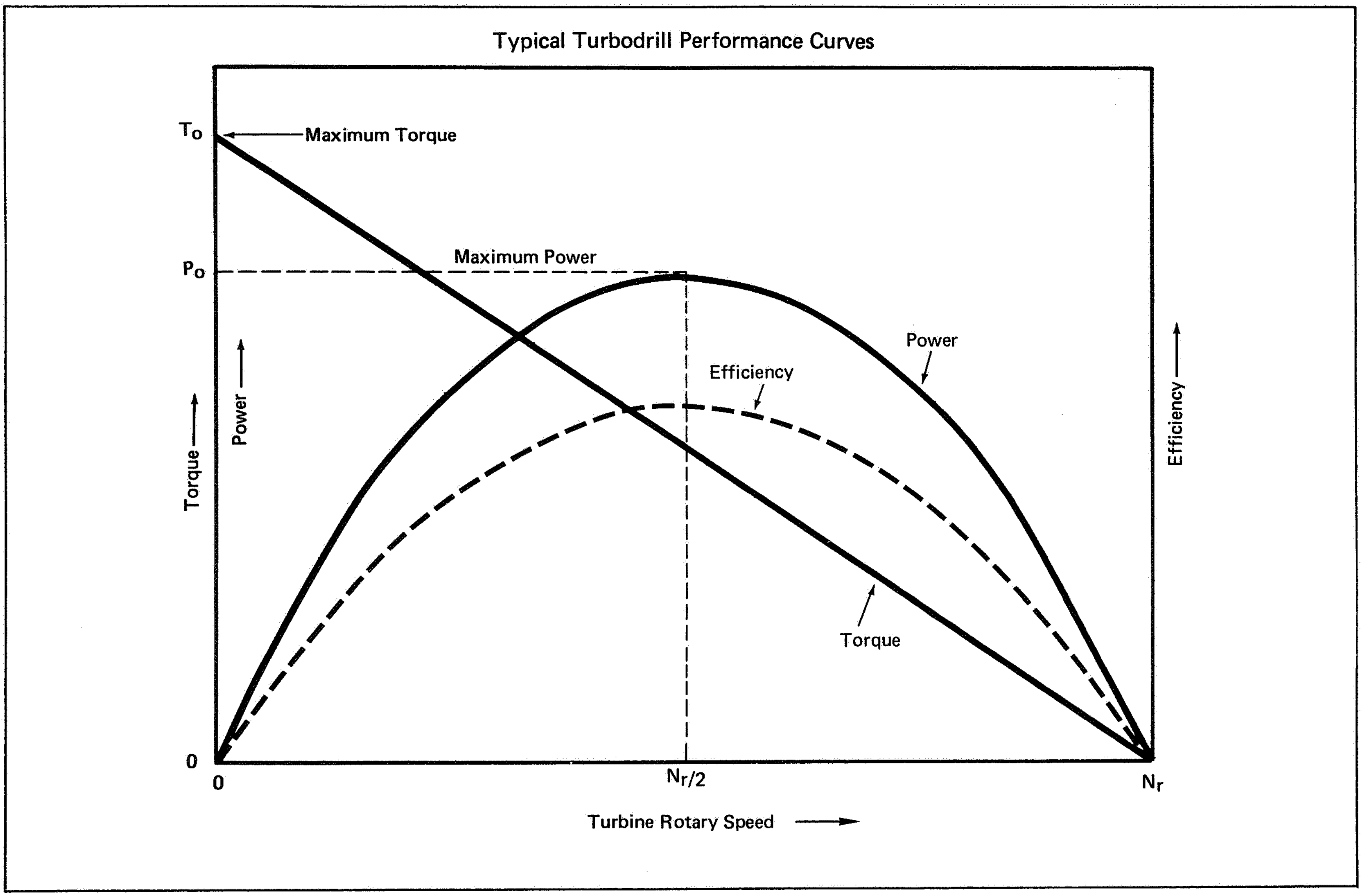


Figure 2-10. Turbodrill Performance Characteristics

2.3.3 COALFRAC

Status: Active

Physics International Company
San Leandro, California

Contract: DE-AC21-79M10642
Contract Date: March 22, 1979
Anticipated Completion Date: September 22, 1979

Principal Investigator: Bob Flagg
DOE Technical Project Officer: H.D. Shoemaker

OBJECTIVE

To evaluate the feasibility of increasing the permeability of coal by the ignition of an explosive gas mixture that is injected into a fracture system of the coal.

SCOPE OF WORK

The objective of this work is to evaluate the feasibility of increasing the permeability of coal by the ignition of an explosive gas mixture that is injected into a fracture system of the coal. The activities which will be conducted include the following:

A. Modification of an existing test chamber for use in: (1) determining the permeability of coal samples before detonable gases are injected into the coal, (2) detonating the gas over a range of pressure, and (3) determining the permeability of the coal after the gas has been ignited, without introducing apparatus effects.

B. Performance of up to 20 tests to determine the effects of igniting a detonatable or combustible gas mixture that has been injected into large diameter cores of coal, and specifically determine the effect of initial pressure, gas composition, mixture, and multiple shots.

SUMMARY OF PROGRESS

This work was initiated near the end of the reporting interval. Results will be presented in subsequent semi-annual reports.

2.3.4 WATER JET DRILLING

Sandia Laboratories
Albuquerque, New Mexico

Status: Awaiting Startup

Contract:	MR-11098
Contract Date:	April 1, 1979
Anticipated Completion Date:	November 1, 1979
Principal Investigator:	K.M. Timmerman
DOE Technical Project Officer:	H.D. Shoemaker

OBJECTIVE

To develop required technology for deep horizontal penetration of coal seams using water jet drilling techniques.

SCOPE OF WORK

Work is planned to develop the required technology for deep horizontal penetration of coal seams using water jet drilling techniques. More specifically, it is desired to complete multiple horizontal holes in the coal seam from a single vertical borehole. This project will be a phased effort involving a comprehensive program in the investigation and application of water jet drilling to the problem of economical methane drainage. Phase I consists of various tasks for the program initiation and development of the water jet drilling system design. Phase II consists of tasks involving the actual construction of a prototype water jet drilling system and, following a specific site selection, field evaluating the drilling system.

The planned activities for this work are as follows:

Phase I -- Program Initiation and Development

a. Program Definition

Determine the elements necessary to achieve a working water jet drilling system applicable to the methane drainage of coal seams.

b. Mechanical Systems Study

Design a simple reliable mechanical system for controlling the small radius corner for the water jet drilling system. Investigate/design a means for propelling and steering a water jet drill head to horizontal distances to 1,000 feet. In implementing this task, all state-of-the-art existing systems will be evaluated, and the feasibility of new concepts will be critically determined.

c. Locating Sensor Study

Investigate the possibility of utilizing several rock-coal interface sensors such as gamma ray, resistivity, and acoustic as a real-time sensor package in determining the location of the water jet drill head.

Phase II -- Recommendation, Fabrication, and Field Demonstration

a. System Recommendation

Conduct a system review and submit recommendations for a totally integrated water jet drilling system based on the Phase I studies.

b. Final Design

Complete the design and final drawings for the fabrication of a water jet drill.

c. Fabrication

Fabricate a prototype water jet drilling system for use in the field demonstration.

d. Field Demonstration

Conduct a field demonstration to evaluate the water jet system based on a site most likely in the thicker western coal seams.

SUMMARY OF PROGRESS

Results of this work will be presented in subsequent semi-annual reports.

2.3.5 FRACTURE MECHANICS

West Virginia University Morgantown, West Virginia	Status: Under Negotiation
Contract:	To be determined
Contract Date:	To be determined
Anticipated Completion Date:	To be determined
Principal Investigator:	W.R. Powell
DOE Technical Project Officer:	H.D. Shoemaker

OBJECTIVE

To acquire fundamental knowledge of the mechanisms controlling fracture initiation and growth in coal.

SCOPE OF WORK

Work is planned to acquire more fundamental knowledge of the mechanisms controlling fracture initiation and growth in coal. This knowledge will lead to improved predictions, and perhaps control, of fracture patterns developed and understanding of when fractures will cross stratigraphic sections such as bedding planes, fault cleats and other fractures.

This work will include the following activities:

1. Quantifying the fracture toughness of coal and shale.
2. Identifying directions of natural weakness in these materials (e.g., butt cleats, face cleats) and determining their relative strengths.
3. Experimentally measuring the interactions of stresses, directions of weakness and fracture orientation.
4. Determining the influence of liquid flow rates, viscosity and simulated tectonic stresses on the propagation of hydraulically induced fractures.
5. Developing models for the mechanical behavior of coal which can be used to predict fracture patterns in the field.

6. Experimentally examining the ability, under various stress states, of cracks in these materials to propagate across joints, other fractures and across boundaries into surrounding rocks.

Activities supplemental to the basic work include:

7. Comparison of fracture properties of coal with those of the more thoroughly studied limestone and Berea Sandstone.

8. Comparison of fracture properties of coal to those of the western gas sands.

9. Interpreting data from field tests in terms of the models developed.

SUMMARY OF PROGRESS

Results of the above-described work will be presented in subsequent semi-annual reports.

2.4 TECHNOLOGY SYSTEMS TESTS

2.4.1 GENERAL

Four Technology Systems Tests were underway at the close of the reporting period:

- Westinghouse Electric Contract DE-AC21-77MC08098 for utilization of methane from coalbeds for on-site power generation (Cambria County, Pennsylvania)

- Westinghouse Electric Contract DE-AC21-78MC08332 for methane extraction from virgin coal and space heating/fuel cell application (Westmoreland County, Pennsylvania)

- Mountain Fuel Supply Company Contract DE-AC21-78MC10734 for methane recovery from unminable coal and pipeline utilization

- Intercomp, Inc./COSEKA Contract DE-AC21-78MC08384 for methane recovery from unminable coal and pipeline utilization

- United States Steel Corporation Contract ET-75-C-01-9027 for demonstration of degasification of a portion of the Mary Lee coal group

Negotiations were underway for three additional projects:

- Pennsylvania Energy Resources, Inc. contract for an anthracite coal drainage test project (Luzerne County, Pennsylvania)

- Waynesburg College contract for a multiple completion test project (Greene County, Pennsylvania)

- Occidental Research Corporation/Island Creek Coal Company contract for a long horizontal holes active mine test project (Buchanan County, Virginia)

Additional information pertaining to these projects is presented in Sections 2.4.2 through 2.4.9.

2.4.2 ON-SITE POWER GENERATION

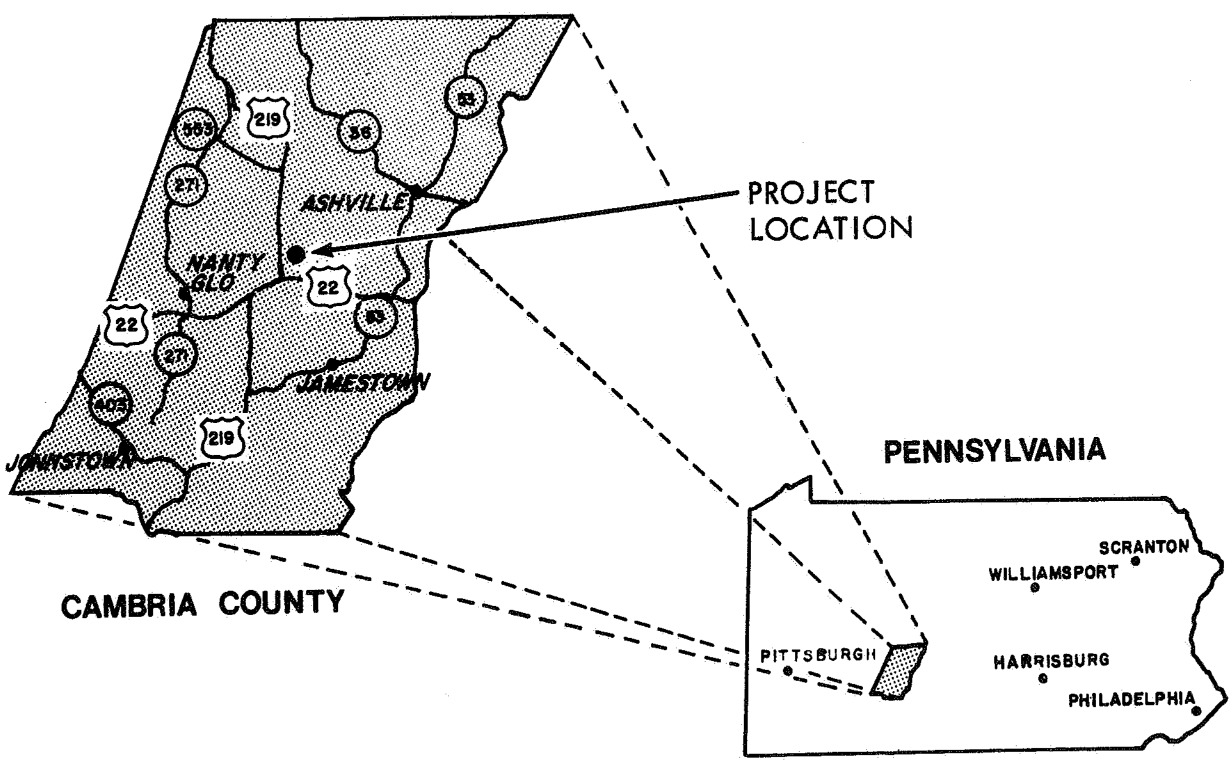
Westinghouse Electric Corporation
Pittsburgh, Pennsylvania

Status: Active

Contract:	DE–AC21–77MC08098
Contract Date:	September 1, 1977
Anticipated Completion Date:	October 30, 1979
Principal Investigator:	C. L. Sturgill (Westinghouse)
DOE Technical Project Officer:	G. E. Rennick

OBJECTIVE

To develop capability for using coalbed gas for power generation.



SCOPE OF WORK

This contract, which involves DOE, Westinghouse, and the Commonwealth of Pennsylvania, consists of a project near Ebensburg, Pennsylvania in cooperation with the Bethlehem Mines Corporation which owns the site property lease rights. A specific objective of this project is to demonstrate the operation of a gas turbine using coalbed methane as the fuel source. The original intent was to utilize an existing gob gas well (Well No. 32-10) to demonstrate gob gas recovery and utilization. However, due to a mine fire two-and-a-half years ago along with subsequent mine flooding, Well 32-10 production became too erratic for consideration. As an alternative, a gas source for the turbine will be provided via predrainage of virgin coal through a vertical well until mining progresses and makes sufficient gob gas available. A goal of this project is to provide wells with production rates sufficient to sustain operation of a turbine which could supply power directly to the local mine power grid. The new vertical well (Well No. 32-13) will be drilled to 900 feet in virgin coal and stimulated by Bethlehem in five 10-foot horizons with hydraulic fracture treatments designed by Intercomp. The design flow rate to be achieved is 300 Mcfd which would drive the turbine at its rated net power output of 625 kW (five percent of the total mine power requirement). However, the turbine can be run at lower output in the event well production is less than intended.

This contract is implemented in three sequential phases:

- Phase I - Fuel analysis, well selection, and interface equipment design.
- Phase II - Fuel availability, interface equipment installation, and turbine installation.
- Phase III - Turbine operation, data collection and analysis.

SUMMARY OF PROGRESS

The status of the Ebensburg work is as follows:

- The degasification Revloc #32-13 well was drilled in the virgin coal area through the seams of the Bethlehem Mines Corporation, Ebensburg Division lease to just above the "A" seam at 825 feet. Six coal seams are present: Upper Freeport, 4 feet; Lower Freeport, 4 feet; Upper Kitanning, 2 feet; unknown seam, 3 feet; Middle Kitanning, 4 feet; and Lower Kitanning, 6 feet.
- No testing was performed on this well. Data from adjacent wells and other cores is being sought.

2.4.3 SPACE HEATING/FUEL CELL

Westinghouse Electric Corporation
Pittsburgh, Pennsylvania

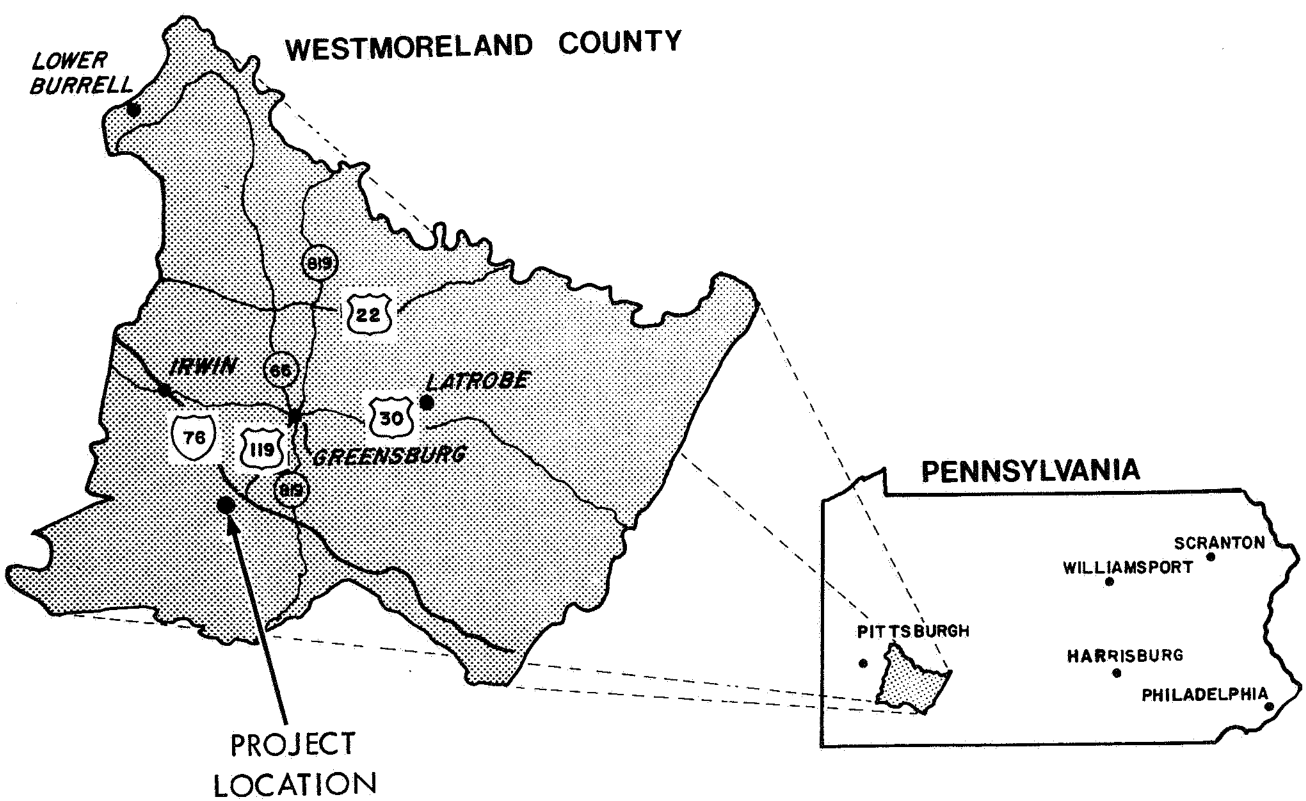
Status: Active

Contract: DE–AC21–78MC08332
Contract Date: May 12, 1978
Anticipated Completion Date: July 12, 1981

Principal Investigator: C. L. Sturgill (Westinghouse)
DOE Technical Project Officer: G. E. Rennick

OBJECTIVE

To develop techniques for extraction of methane from coalbeds and to determine the suitability of the gas for process heat generation.



SCOPE OF WORK

This contract, a cooperative agreement between DOE and Westinghouse, consists of a methane drainage utilization project at the Westinghouse Waltz Mill site in Westmoreland County, Pennsylvania. The project objective is to determine and demonstrate effective extraction and stimulation techniques for drainage of methane from 850 acres of virgin coal and utilize the methane for process heat generation (steam, hot water and space heating). This data will be used to assist in determining optimum well spacing for methane drainage operations. Drainage will be accomplished with vertically drilled wells penetrating 11 coal seams of the Allegheny and Pottsville Groups, at depths between approximately 190 and 350 feet. Stimulation will be accomplished by multiple hydraulic fracturing treatments in four zones. This project is implemented in three sequential phases:

Phase I - System Preliminary Design, Development, and Analysis

Phase II - Detailed Design and Analysis

Phase III - Site Preparation and Operation

During Phase I, two wells will be drilled - a production well and an observation well; Phase II consists of evaluation of the work performed during Phase I and planning for Phase III; and Phase III will consist of drilling and stimulating a sufficient number of production wells to drain the entire 850-acre tract.

Phases I and II are each planned to be of six-month duration. Phase III (not yet contracted) is planned to run 26 months. The stimulation treatment (four zones) for the Phase I production well (#4) has been designed by Intercomp. That well will be cored and logged both before and after casing. The observation well (#5) will be used to monitor water and pressure levels once gas production begins in well #4. It will be cored (full depth) but not logged.

SUMMARY OF PROGRESS

The status of the Phase I work consists of the following:

- The #4 well was completed in December in four zones using a Kiel frac. An electric downhole pump was used to dewater the well. The frac water has been recovered, but the well is making 6,500 gpd. The water has an acceptable pH but the salt concentration is unacceptable and is being hauled away for disposal. The water is suspected to be ground water and not from the coal seams, indicating some interconnection between aquifers. Water is being analyzed to attempt to discover the source. No well testing for cement integrity was conducted.

- The free flow (flared) over four or five days was 32-33 Mcfd. The shut-in pressure ranged from 12 to 25 psi.

- Cost/benefit analyses assuming a 25 Mcfd flow, 850 total acres, and 10 wells show 13 years to amortize costs. Investment costs are estimated at $1.21/MMBtu and O&M at $0.14/MMBtu/year; with 30 Mcfd, amortization period drops to 7 years.

- Due to low gas content, a 3-well coring program at the northwest, southwest, and north boundaries is under consideration.

2.4.4 BOOK CLIFFS COAL FIELD PRODUCTION TEST

Mountain Fuel Supply Company
Salt Lake City, Utah

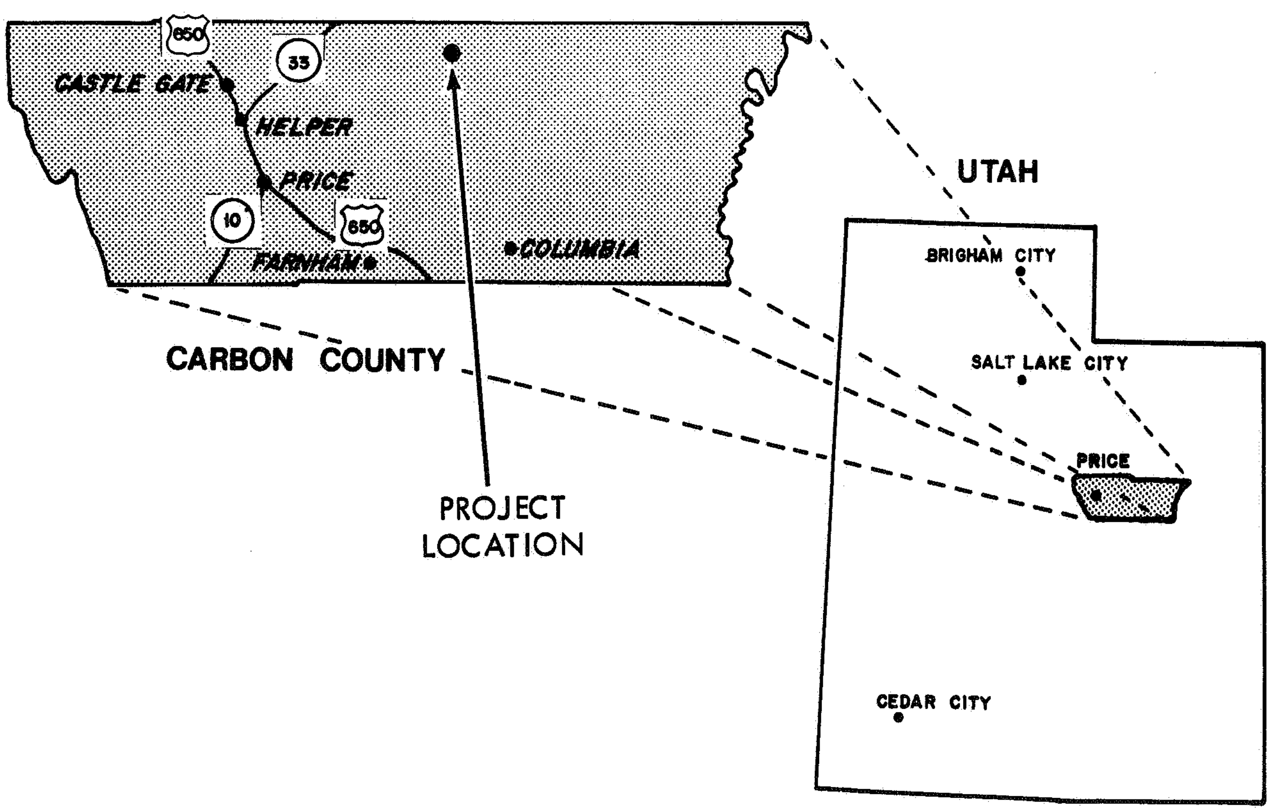
Status: Active

Contract: DE–AC21–78MC10734
Contract Date: January 11, 1979
Completion Date: April 11, 1982

Principal Investigator: R. L. Coates (Mountain Fuel)
DOE Technical Project Officer: H. D. Shoemaker

OBJECTIVE

To determine effective extraction techniques for ultimate recovery and utilization of coalbed methane from deep horizons.



SCOPE OF WORK

The Mountain Fuel Supply Company (MFSC) contract with the DOE consists of a project to demonstrate methane production from deep coal seams of the Book Cliffs Coal Field in central Utah. The purpose of the project is to determine effective extraction techniques leading to gas recovery for pipeline injection into an interstate facility owned by MFSC. The project will consist of three sequential phases:

Phase I - System Preliminary Design, Development and Analysis (3 months)

Phase II - Detailed Design and Analysis (6 months)

Phase III - Site Preparation and Operation (27 months)

A tentative demonstration program is planned in which three vertical boreholes will be drilled. The boreholes will be completed using fracture techniques similar to those which have been successfully employed by USBM in shallower Eastern coals. One or more seams will be stimulated in each borehole depending on drilling and coring test data. Following an initial production test period of up to three months during which the coalbed will be dewatered, facilities will be installed to gather, compress, dehydrate, and inject the gas into a nearby transmission line; an extended production demonstration period of up to 15 months would then be conducted. The entire project will be completed over a 36-month interval (Phases I, II and III).

SUMMARY OF PROGRESS

Results of activities during the reporting period are summarized as follows:

- Pertinent core data available from the Utah Geological and Mineral Survey were evaluated. Fourteen samples had gas contents between 101 and 200 cf/ton coal.
- Three recovery well site locations were selected based on favorable coal depth, high methane content of the coal, access for drilling, proximity to an existing natural gas pipeline, and favorable coal, oil and gas lease ownerships. The sites are all located in areas expected to have high gas content coal. Wells No. 1 and No. 2 will be located in the Whitmore Park area of the Book Cliffs region (NE and SW, Sec. 34, T.12S., R.12E., Carbon County, Utah). Well No. 3 will be located in the Castle Gate area of the Book Cliffs region (SW, Sec. 15., T.12S., R.10E., Carbon County, Utah) about 12 miles west of Wells No. 1 and No. 2.
- A tentative drilling and completion plan was developed and is outlined in Table 2-8.
- A preliminary environmental assessment has been made of the three demonstration well locations. Final assessments will be made and approval will be obtained during Phase II of the project.

Table 2-8. *Proposed Methane Drilling/Completion Plan*

PROCEDURE/TASK ITEM	WELL NO. 1	WELL NO. 2	WELL NO. 3
WELL LOCATION	Whitmore Park Carbon County, Utah T.12S., R.12E., Sec. 34	Whitmore Park Carbon County, Utah T.12S., R.12E., Sec. 34	Castle Gate Carbon County, Utah T.12S., R.10E., Sec. 22
DRILLING (Drill All Wells at Same Time Depending on Contractor Availability)	Drill to approximate top of upper coal seam with 7-7/8" hole (depth ~2500') using prescribed drilling procedures.	Same as No. 1. Depth to coal – 2325'.	Same as No. 1. Depth to coal – 2240'.
CORING (Collect Samples)	Core through all coal seams to a depth 100' below lowest coal seam (Gilson) with 7-7/8" diamond core bit. Total Depth: 2950'.	Same as No. 1. Total Depth: 2775'.	Same as No. 1. Total Depth: 2700'. Lowest coal seam known is the Kenilworth.
LOGGING	Run a full series of logs to determine characteristics of coal and surrounding formations above and below coal seams.	Same as No. 1.	Same as No. 1.
SET CASING	Set specified 4-1/2" casing to the top of the large Gilson coal seam (coal interval – 18-20'). Use a guide shoe with one-way portals on the bottom of the casing.	Set specified 4-1/2" casing to total depth below Gilson coal using guide shoe in bottom of casing.	Same as No. 1 setting casing to top of Kenilworth coal.
CEMENT CASING	Cement casing and well above Gilson coalbed with enough cement to fill 1000' above bottom of casing. Drill out guide shoe and cement in bottom of casing. (Casing and cementing procedures may vary depending on results of logging.)	Cement bottom joint of casing and fill casing with a cement plug. Do not drill out plug.	Same as No. 1.
PERFORATIONS (Variations May Occur Depending on Coal Thickness Encountered)	No perforations required at this time. Later decision may be made to perforate upper seams.	Perforate three major coal seams (Sunnyside, Rock Canyon, Gilson) using jet-slotting technique. Slot one foot of casing per 3 feet of coal interval.	Perforate major coal seams based on core data with jet shots. Run 8 shots per foot into specified coal seams.
PRODUCTION TESTING	Use air from drilling rig to blow water out of well. Release rig and monitor production and pressure if gas flow results.	Same as No. 1 or run DST dependent on results of No. 1 experience.	Dependent on results of No. 1 and No. 2 wells.
WATER INJECTION TEST FOR PERMEABILITY	Set packer at bottom of tubing above open hole. Inject water down tubing into formation at constant rate. Monitor rate and pressure at surface. (May vary depending on production test results.)	Same as No. 1 with packer set above highest perforation.	Same as No. 2.
DEWATERING	Install oversized sucker rod pumps (~240 gph) and dewater well.	Install production tubing and sucker rod pump. Use air to remove water if dewatering is too slow.	Same as No. 2.
PRE-STIMULATION PRODUCTION TESTING	Install gas and water production monitoring equipment and record data over a 4-week period followed by a 2-week shut-in period.	Same as No. 1, extended over a 3-month period.	Same as No. 1, extended over a 4- to 5-month period.
STIMULATION (Type and Size Stimulation Pending Further Analysis)	Probable stimulation method: N_2/foam (based on logging and prior formation testing). Preliminary design based on eastern methane drainage experience. Western coal assumed to be similar.	Same as No. 1. Changes will be based on experience from No. 1 stimulation.	To be determined based on results of Wells No. 1 and 2.
CLEANUP	Use a sand pump boiler to clean out well if necessary. Install sucker rod pump.	Same as No. 1.	Same as No. 1.
POST-STIMULATION PRODUCTION TESTING	Monitor gas and water production and pressures.	Same as No. 1.	Same as No. 1.
INSTALL SURFACE PRODUCTION EQUIPMENT	Install if justified after production from Wells No. 1 and 2 is known.	Same as No. 1.	Produced gas will be vented.

- A simulator was used to predict water and gas production with inputs which reflect current estimated coal seam parameters. Preliminary conclusions are as follows:

  (1) The current assumptions for economic analysis may well be appropriate. Well decline rates will be very dependent on well spacing.

  (2) Actual gas-to-water ratio in the target coal seams may be much better than values assumed for the simulation. Higher than predicted gas production may result if this is the case.

  (3) Proper core analysis and field testing is essential prior to hydraulic stimulation. A better understanding of porosity, water saturation, and relative permeabilities is needed.

  (4) Additional computer simulation runs should be conducted to understand key production variables.

  (5) Well spacing will affect water production rate. Water from a single well will be higher than from a well located near other wells.

- Cost of service analysis was performed for base case assumptions (Table 2-9) as well as for the effect of variations in production parameters. The gas production cost, using base case assumptions, was calculated to be $3.31/Mcf. This compares with the calculated average FERC regulated price of gas over the same five-year period of $3.27/Mcf. The variations in such parameters as well productivity, decline rate, well life, capital costs, escalation, cost of debt, and return on equity resulted in production costs ranging from $2.50/Mcf to $5.73/Mcf, with most costs being around $3.45/Mcf. The gas production cost is most sensitive to variations in the assumed initial production rates. Variations in the decline rate and capital costs also affect the gas production cost, but not to as great a degree as the initial production rate. Variations in the actual decline rate or actual capital expenditures are not considered as likely to occur as a variation in the initial production rate.

Table 2-9.

Cost Evaluation Basis and Assumptions for Base Case Analysis

Capital Investment Costs

Drainage wells - It is assumed that 55 methane drainage wells are drilled, completed, and placed on production.

Capital cost estimates are based on actual gas production well costs drilled by MFS at Lower Horse Draw (escalation for inflation), recent suppliers' estimates, and cost comparisons with similar methane drainage projects.

Production equipment is sized for 5.5 MMcfd flow with compression required from 20 psig to 660 psig.

Capital Expenses

Depreciation - Straight-line depreciation is taken on the plant investment. Well investment is depreciated with units of production.

Working capital - cash is 45 days of annual operating and maintenance expenses.

Working capital - materials and supplies is 2.7% of total capital investment.

Financing is assumed to be 50% debt, 50% equity.

Interest on debt is 10% of rate base debt.

Return on equity is 13.25% of rate base equity.

Tax rate for combined federal and state income taxes is assumed to be 47.67%.

Operating and Maintenance Expenses

Labor costs are based on the assumption of one operator per 18 wells and one mechanic per 55 wells. The present wage rate is $8.92/manhour for an operator and $10.45/manhour for a mechanic. Wages are assumed to escalate at 7% per year. Labor overhead is 89.78%.

Repair materials costs are 5% of capital equipment costs per year for compressors and dehydration units and 2% for production lines.

Fuel requirements were calculated to be 7.5% of gas produced.

Royalties are based on the escalating FERC regulated price of new gas. Federal royalties are 12.5% of the regulated value, and Utah state and county taxes are 8.5% of the regulated value.

Total Production Cost

Total gas production is assumed to decline 10% per year with a well life of five years.

2.4.5 PICEANCE BASIN PRODUCTION TEST

Status: Active

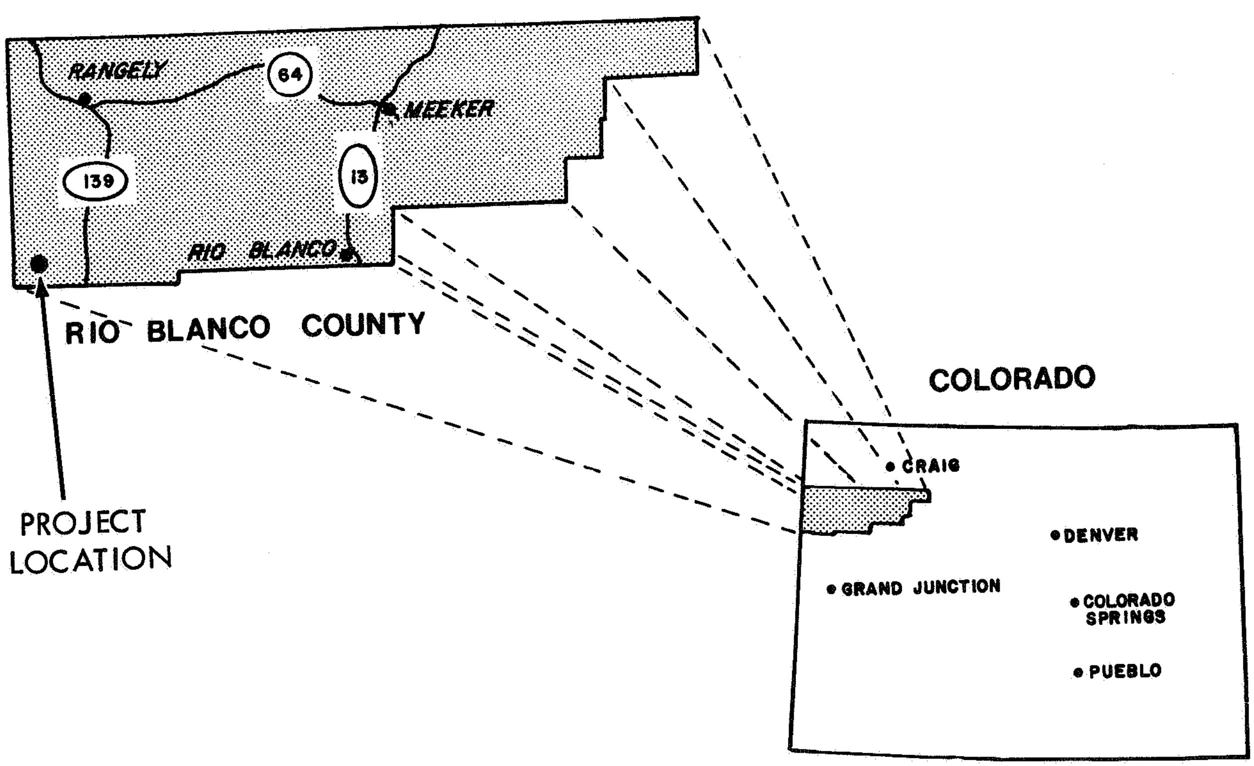
Intercomp, Inc.
Houston, Texas

Contract:	DE–AC21–78MC08384
Contract Date:	September 29, 1978
Completion Date:	May 31, 1980

Principal Investigator:	K. L. Ancell (Intercomp)
DOE Technical Project Officer:	H. D. Shoemaker

OBJECTIVE

To demonstrate effective extraction technology for ultimate recovery and utilization of methane from coalbeds located in Rio Blanco County, Colorado.



SCOPE OF WORK

This contract, a cooperative agreement between DOE and Intercomp/COSEKA, consists of a project at a COSEKA site in Rio Blanco County, Colorado involving an existing COSEKA well, Federal 1-16, which has demonstrated 100 Mcfd production. The project objective is to determine effective extraction techniques leading to methane production from coalbeds underlying the COSEKA site for injection into an 80 psi pipeline located nearby. Methane extraction will be accomplished by vertically drilled wells involving multiple hydraulic fracture treatments. The project consists of three sequential phases:

Phase I - System Preliminary Design, Development and Analysis (6 months)

Phase II - Detailed Design and Analysis (3 months)

Phase III - Site Preparation and Operation (9 months)

Phase I will consist of a multi-well program involving the current COSEKA Federal 1-16 well for observation and at least one other offset production well which will be drilled, cored, logged, stimulated and thoroughly tested. The production well will be drilled 2,000 feet north of the Federal 1-16 well to a depth of 1,500 feet; both water and gas production will be monitored, and samples collected and analyzed. Four to 12 weeks of production data will be collected. Data collected from the various well tests will be analyzed mathematically using the Intercomp reservoir model. Model results will be used in the design of appropriate hydraulic fracture treatments. Once the stimulation work is complete, a complete evaluation of well performance will be made.

Phase II will use the Phase I results for detailed design and analysis of the methane production system for Phase III. Phase III will consist of the implementation of a pilot-scale methane production system including wells, gas gathering system, compressor station, etc. Arrangements will be made for prerelease and sales agreements prior to introduction of the gas into the pipeline system.

SUMMARY OF PROGRESS

No field activities were completed during the reporting period due to adverse weather. Results will be presented in subsequent semi-annual reports.

2.4.6 LONG HORIZONTAL HOLES, ACTIVE MINE TEST PROJECT BUCHANAN COUNTY, VIRGINIA

Occidental Research Corp.
Irvine, California

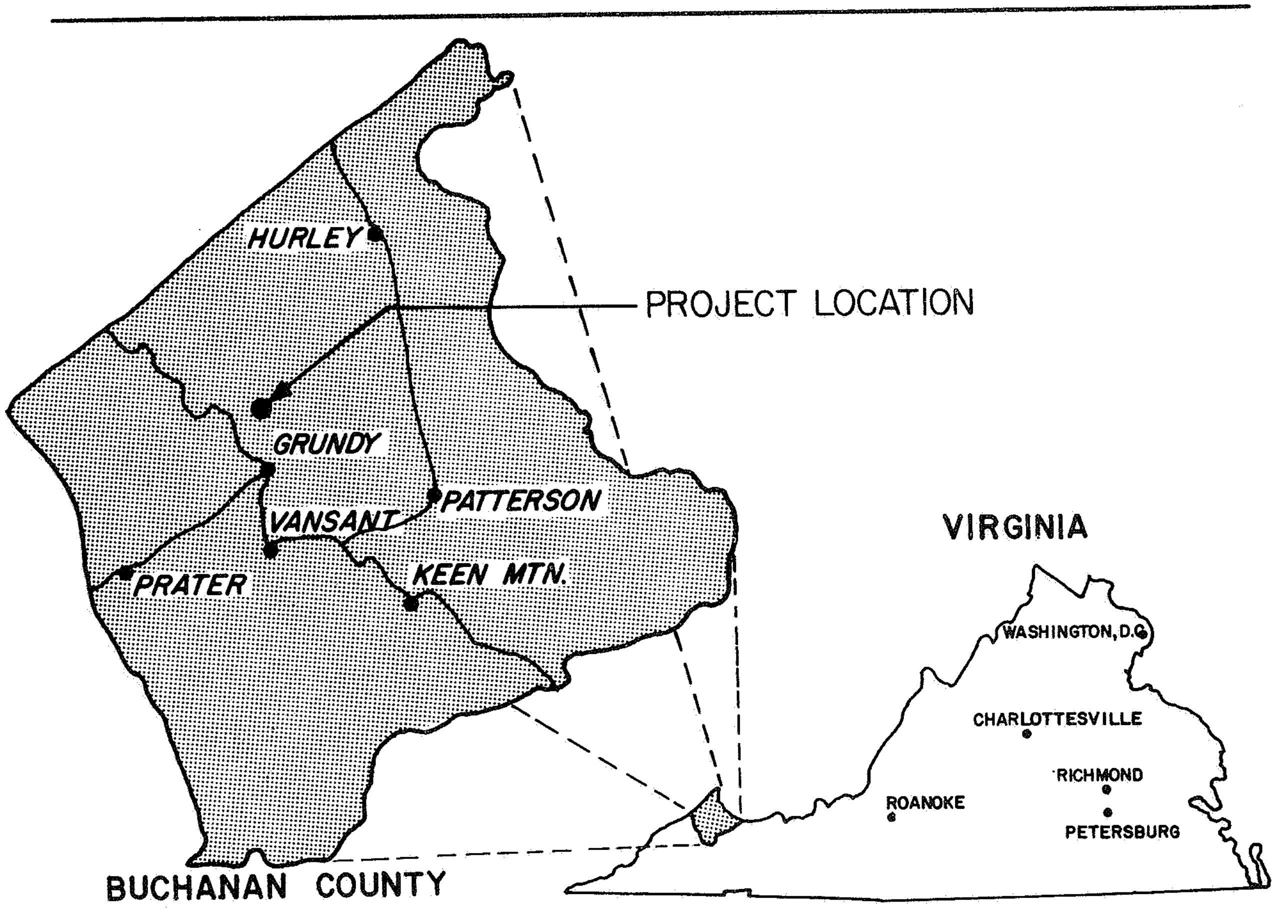
Status: In negotiation

Contract: DE–AC21–78MC08089
Contract Date: To be determined (estimated July 1979)
Completion Date: July 1, 1981

Principal Investigator: A. Gillies (TRW)
DOE Technical Project Officer: R. L. Wise

OBJECTIVE

To develop a technique for recovery of methane from long horizontal holes drilled from within the mine and use the gas to produce LNG; or a similar application.



SCOPE OF WORK

This planned project is a methane drainage project using multiple horizontal boreholes in a mine under development. The site selected for this technology test project is the Virginia Pocahontas No. 5 Mine of the Island Creek Coal Company and is located in Buchanan County in the western part of Virginia.

A predrainage technique for longwall mining is desirable for reducing drilling costs and avoiding adverse surface ownership problems. The project selected to develop this technique was proposed by the team of Occidental Research Corporation (ORC) and Island Creek. This project includes several technology developments including the development of a drilling technique for long boreholes (greater than 2000 feet) to drain the entire length of a longwall panel. Included in this project is the development of a bit guidance technique to keep the borehole within the coal seam to ease control problems at the drill location.

The test project also includes the development of an in-mine piping system with an integrated safety system using plastic pipe to reduce costs. During the design and design validation effort, a small vertical vent to the surface will be used for testing. Assuming success, a large vent shaft will be installed in advance of its need for mining to provide a passageway for the mine-to-surface piping. The gas drained by this project in the design validation phase will be utilized to produce LNG in a unit under development by a separate venture of Island Creek Coal. This unit, located at an adjacent mine, is being developed to operate at low gas feed volumes. Options to use the gas in multiple small LNG units, in a large LNG plant, or in other systems will be evaluated during the design and validation phase.

SUMMARY OF PROGRESS

Results of the above-described activities will be presented in subsequent semi-annual reports.

2.4.7 MULTIPLE COMPLETION DEVELOPMENT TEST PROJECT GREENE COUNTY, PENNSYLVANIA

Waynesburg College,
Waynesburg, Pennsylvania

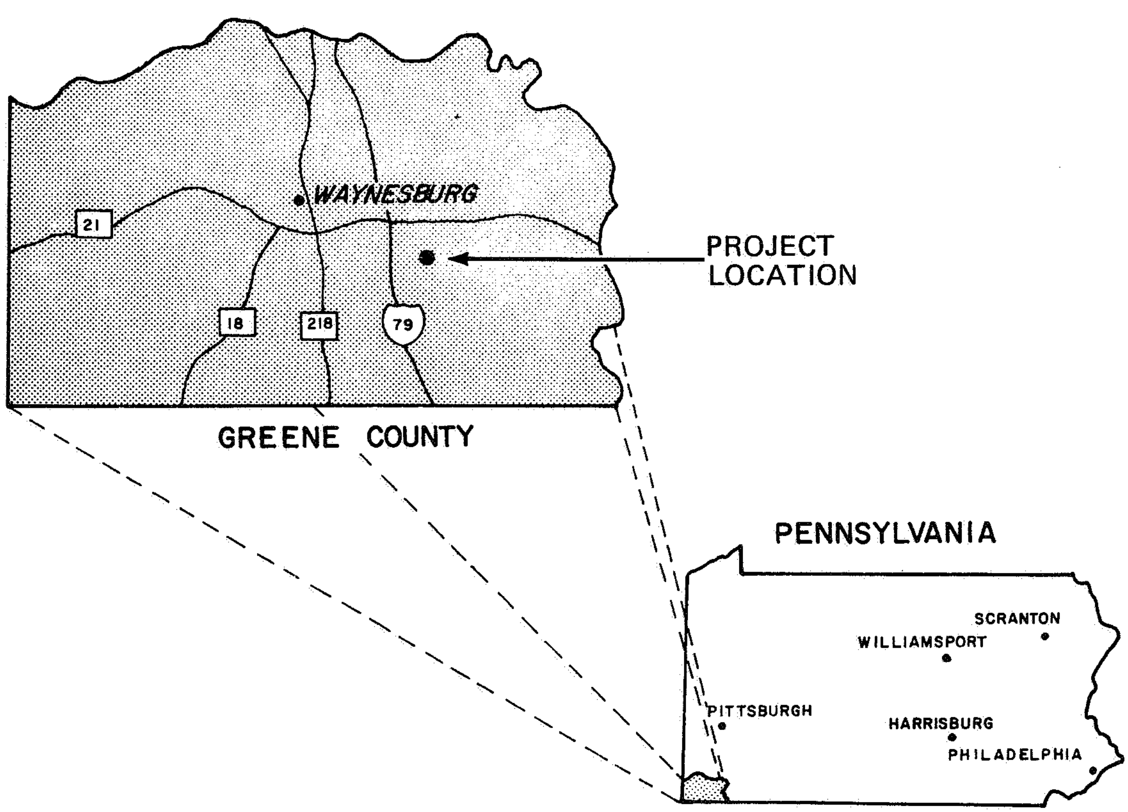
Status: Awaiting approval

Contract: DE–AC21 78MC08089
Contract Date: To be determined (estimated July 1979)
Completion Date: March 31, 1980

Principal Investigator: A. Gillies (TRW)
DOE Technical Project Officer: R. L. Wise

OBJECTIVE

To develop and demonstrate a multiple completion technique system considering a variable need for dewatering each zone and utilizing the recovered methane in a local distribution pipeline.



SCOPE OF WORK

The development of multiple methane production zones in a single well is the objective of this planned project. The coal is not being mined since it underlies extensively developed surface areas. The site selected for this project is on land owned by Waynesburg College, the Purman Run tract on the campus of the college in Waynesburg, Pennsylvania. The proposed utilization of the gas is to supplement the college's natural gas supply.

A method will be developed to perform multiple completions in a single well considering the requirements to isolate the production zones and de-water the production intervals as required. The development of a multiple completion technique will increase the cost of an individual well but will lower the overall cost of recovering gas from multiple coal seams. The major issue is to develop a technique which will isolate the methane production intervals, as in standard oil field practice, but still provide for the removal of water which is produced in methane drainage.

SUMMARY OF PROGRESS

The results of the above-described activities will be presented in subsequent semi-annual reports.

2.4.8 ANTHRACITE COAL DRAINAGE TEST PROJECT LUZERNE COUNTY, PENNSYLVANIA

Pennsylvania Energy Resources, Inc. (PERI)
Wilkes–Barre, Pennsylvania

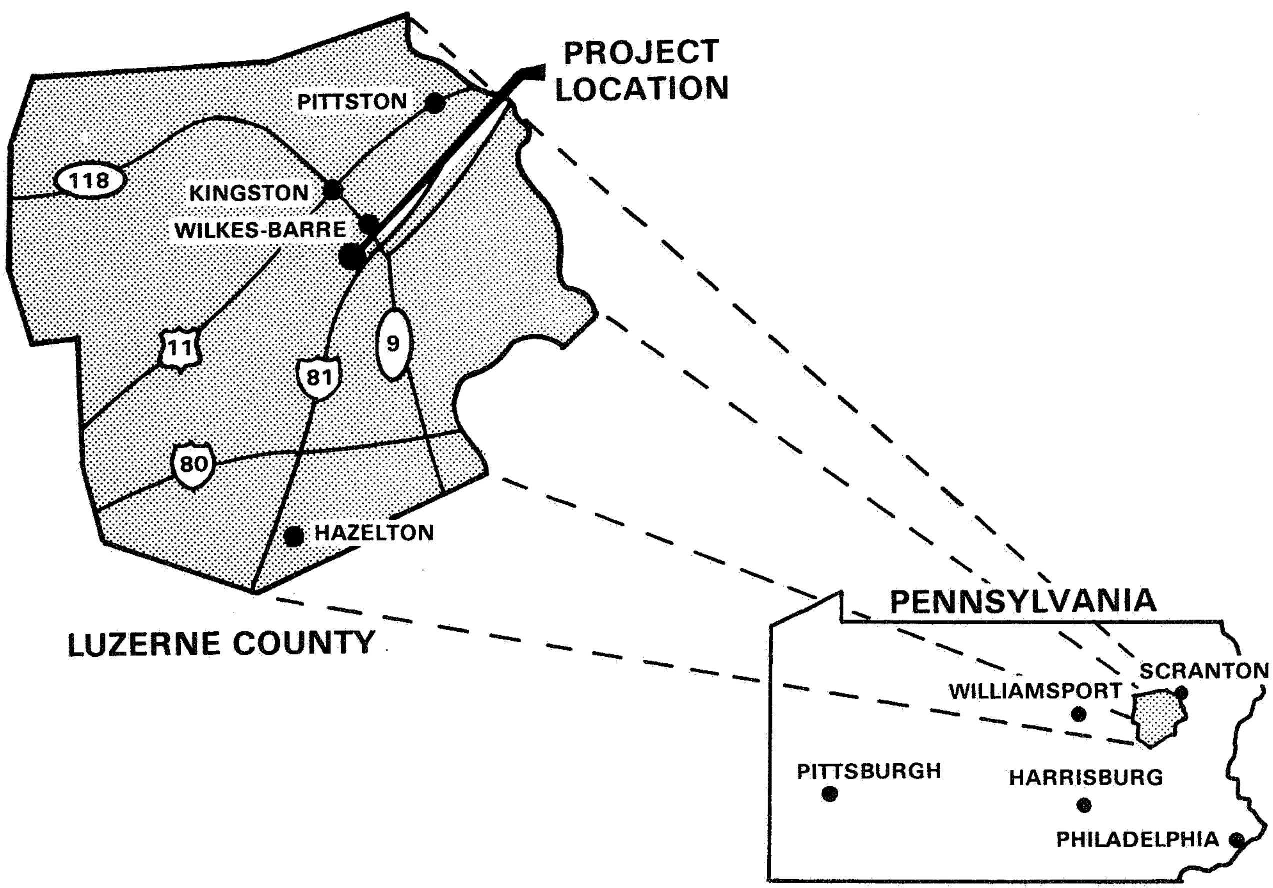
Status: In negotiation

Contract:	DE–AC21–78MC08089
Contract Date:	To be determined (estimated July 1979)
Completion Date:	December 31, 1980

Principal Investigator:	A. Gillies (TRW)
DOE Technical Project Officer:	R. L. Wise

OBJECTIVE

To develop and demonstrate a system for the recovery of methane from anthracite coal using multiple stimulated wells, and utilizing the gas by injection into a local pipeline.



SCOPE OF WORK

This project is planned to develop methane drainage technology for anthracite coal. The coal seams to be drained are in an area not considered suitable for mining due to extensive water intrusion from a nearby large river. The project includes the development of multiple completions and stimulation techniques for the production zones. The site selected is located on a 3400-acre lease owned by Pennsylvania Energy Resources, Inc. (PERI) in Hanover Township, Luzerne County, Pennsylvania, in the lower half of the Northern Anthracite Field.

The proposed effort was conceived by PERI to develop a technique for economically producing methane from the red ash veins in the area northwest of Wilkes-Barre. The coal is in an area where deep mining was halted due to flooding after a major cave-in. The veins are under zones containing water which are probably connected to the nearby Susquehanna River. Surface or pit mining is not deemed to be practical due to the depth of the coal (2000 feet). The concept provides for the geological characterization of the test area, the development of a completion technique and the drilling of three production wells. The proposed utilization is to tie the wells into a local pipeline owned by the Pennsylvania Gas and Water Company, a company associated with PERI.

SUMMARY OF PROGRESS

Results of the above-described activities will be presented in subsequent semi-annual reports.

2.4.9 DEMONSTRATION OF DEGASIFICATION OF A PORTION OF THE MARY LEE GOAL GROUP

United States Steel Corporation | | **Status: Active**

Contract:	**ET-75-C-01-9027**
Contract Date:	**June, 1975**
Completion Date:	**June, 1980**
Principal Investigator:	**J.A. Wallace (U.S. Steel)**
DOE Technical Project Officer:	**S.W. Lambert**

OBJECTIVE

To develop the capability of removing coalbed gas using a pattern of vertical boreholes and to demonstrate this method's compatibility with the process of mining coal.

SCOPE OF WORK

This contract is a cost-reimbursement/cost-sharing agreement between the DOE and U.S. Steel Corporation to test twenty-eight vertical boreholes near U.S. Steel's Oak Grove Mine, Jefferson County, Alabama. Twenty-three of these boreholes are to be placed on a grid pattern located approximately five years ahead of active mining while the remaining five boreholes will be placed less than a 1000 feet from the underground mine operations. All twenty-eight boreholes will be completed into the Mary Lee coalbed, stimulated, produced, and mined through. The goal of this project is to provide increased coal output, and decreased mine ventilation costs using large-scale application of vertical borehole methane drainage techniques designed to be minimumly disruptive to the coal mining process.

SUMMARY OF PROGRESS

A total of twenty-one boreholes have been fully completed at Oak Grove. Four of these were placed near the mine and have since been mined through. Detailed studies of these near-mine tests, published in late 1978 and early 1979 (USBM RI No. 8295 and DOE RI-PMTC-3(79), support the following conclusions.

1. Rotary drilling using roller bit and foam is an effective technique to avoid extensive wellbore and/or coalbed damage.

2. A lightweight, low-fluid-loss cement mixture can reduce cement infiltration into the floor, coal, and roof rock.

3. Density logs may be used to identify zones within coalbeds which may have a substantial influence on the geometry of hydraulically induced channels. Density logs may also be used to identify successfully slotted portions of casing.

4. The hydraulic forces used to stimulate coal may be diverted several times, resulting in numerous short channels rather than one or two continuous long channels. Horizontal channels may be propagated when injection pressure exceeds effective overburden pressure, but because of the relative softness of coal, the principal mechanism leading to horizontal channel development is compression rather than flexing and lifting of the overburden.

5. Underground fracture studies indicate a direct correlation between propagated vertical channel directions and the joint and cleat orientations. There is also a direct relationship between surface and underground fractures which can be used to determine the vertical induced channel direction before stimulation.

6. Gel may not break down sufficiently near the wellbore, because of low temperatures or adverse chemical reaction with casing materials.

7. Highly variable gas flow rates may be attributed to downhole water pump malfunction and/or to the positioning of production openings (slots or perforations) below the productive coal zone.

8. The favorable results obtained using foam stimulation far exceed those obtained from gel stimulation designs. The most notable of these results is the much higher drainage rates obtained with subsequent reduction of mine methane emissions. Other advantages of foam include lesser onsite logistical requirements and considerably less treatment fluid clean-up time.

9. The Mary Lee coalbed possesses reservoir characteristics which provide relatively high daily flow rates from properly completed vertical boreholes placed near active mine workings. These same favorable reservoir conditions may be created anywhere in the coalbed by establishing "interference" between at least two drainage points (producing wells).

10. Producing wells create very favorable conditions for gas release and migration within areas of the coalbed affected by drainage. If mining intersects these drainage areas before the coalbed gas reservoir has been sufficiently depleted, conditions become very favorable for methane to flow into active mine workings. The potential problem can be avoided by resaturating the areas with water prior to interception.

11. It is possible to extend fractures outside the coalbed using injection pressures below those necessary to "break" the surrounding rock material. The probability for this to occur is thought to depend heavily on the existence of incipient rock fractures and on the type of fluids and material used to induce and fill fractures.

12. The geologic history of the Mary Lee coalbed and associated rock strata does not allow meaningful prediction of the effects of stimulation on roof stability. However, since these effects appear to be minimal and the potential gas problem severe, the decision to employ stimulation is considered truly justifiable at this time.

13. Total methane gas emission can be reduced by over 40% in mine sections containing vertical gas drainage holes given one year of pre-drainage activity.

Seventeen boreholes have been completed in the test area located five years ahead of mining. These boreholes are placed on a 3 by 5 grid pattern of 21.5 acre spacings with two adjacent but outlying boreholes.

The number of actively producing wells on the grid pattern fluctuates greatly because of mechanical difficulties caused by heretofore unprecedented high and sudden coalbed gas flows. Despite these problems, approximately twelve boreholes were draining gas on a regular basis by October 1978. Total gas flow from the pattern at that time averaged about 600 mcf daily. Gas flows from the pattern did not change much until the beginning of March 1979 when a total of sixteen boreholes were put into production. On March 16, total gas flow rose to approximately 1.2 million cubic feet with individual borehole gas flows ranging from 6 mcf to 200 mcf daily. The entire pattern of boreholes removes about 400 barrels of water daily.

The outstanding production resulting from the degasification effort has prompted DOE to encourage the owner of the gas, U.S. Steel, to initiate a program designed to capture this gas for utilization at a nearby U.S. Steel facility, such as the mine, or pipe it directly into an existing commercial gas pipeline.

Information regarding all aspects of the Oak Grove degasification tests will soon be made available through regular DOE reports. Borehole specifications and drilling, completion, and stimulation designs used during the course of this project, although not as yet in report form, are available for inspection. All of the production data have been computerized and are updated each month. Borehole fluid analyses, coalbed gas content, results of reservoir tests, and borehole installation and maintenance costs may also be examined directly until a formal report is issued.

2.5 PROJECT INTEGRATION

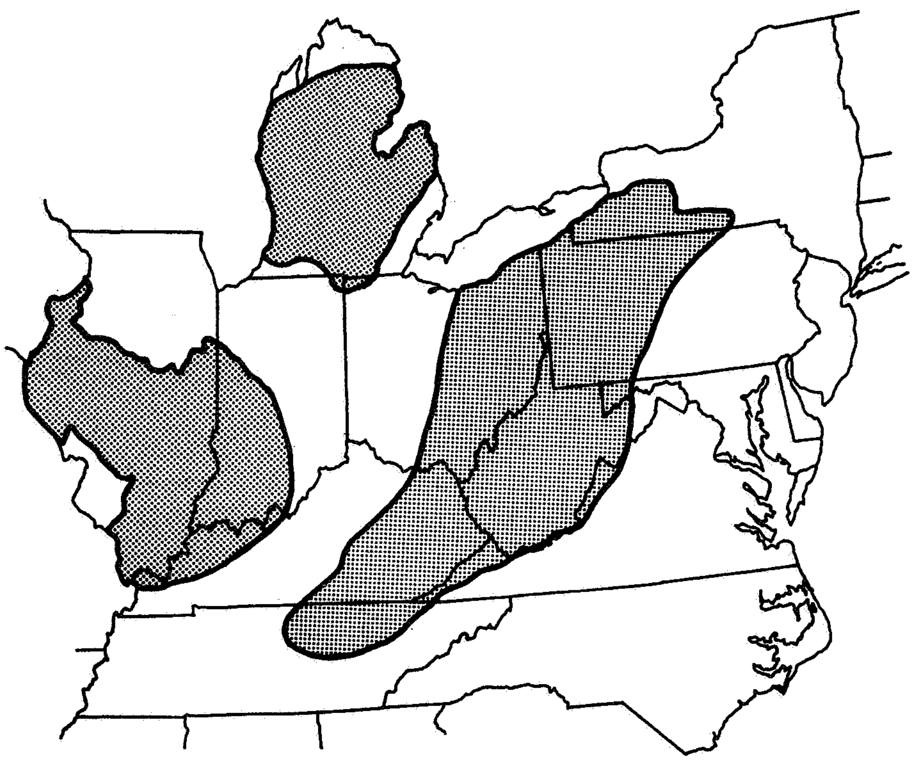
2.5.1 GENERAL

In addition to coordination of the Resource Engineering, Research and Development, and Technology Systems Tests efforts, the MRCP Project Plan Document (PPD) was prepared. The PPD provides information for implementation and field management of the MRCP by the Morgantown Energy Technology Center (METC), U. S. Department of Energy (DOE). The document is a project-oriented plan for achievement of the goals and objectives of tactical implementation planning for coalbed methane recovery. The PPD is intended to be sufficiently comprehensive to permit detailed planning, conducting and monitoring of project level activities. Provision is made to support coalbed methane program level requirements of DOE headquarters. The PPD presents the project objectives and strategy and describes the project elements, project activity flow, and project management planning.

2.5.2 TECHNOLOGY TRANSFER

A Methane Recovery from Coalbeds Symposium was planned to be held April 18-20, 1979 in Pittsburgh, Pennsylvania. Additional details of papers and their authors will be presented in the semi-annual report for the period ending September 30, 1979.

3. EASTERN GAS SHALES



3. EASTERN GAS SHALES

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3.1 INTRODUCTION

3.1.1 BACKGROUND

Eastern Gas Shales are shale formations of Mississippian and middle and late Devonian age. These formations underlie much of the Appalachian, Michigan and Illinois Basins. Shale deposits in the Appalachian Basin, and to a lesser degree those of the Michigan and Illinois Basins, have been known to produce gas since the nineteenth century. The attractiveness of this resource is enhanced by its proximity to natural gas markets in the populous East and industrial Midwest (Figure 3-1).

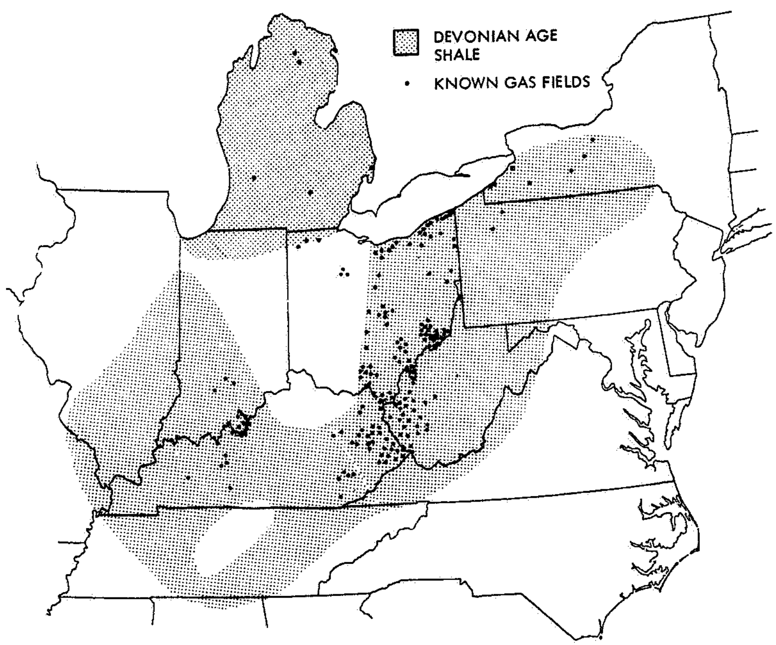


Figure 3-1. Distribution of Eastern Devonian Shale Gas Fields

To a great extent, recent attention has been focused on the western portion of the Appalachian Basin. Of the approximately 160,000 square miles underlying the western Appalachian Basin, about 40 percent is underlain by Devonian black and brown shale deposits at depths of less than 4,000 feet, 50 percent at depths between 4,000 and 8,000 feet and the remainder at depths below 8,000 feet. The depth at which the resource occurs is important because at depths of less than 1,500 feet much of the gas may have escaped to the surface, and at depths greater than 8,000 feet thermal maturation processes may have driven the gas from the shale.

Studies indicate that gas is produced from natural fracture systems within the Devonian Shales. The fractures serve as reservoirs and also as channels of high permeability for movement of the gas to the wellbore. Because the gas production rates associated with conventionally emplaced wells have generally been too low to be economically attractive, efforts have been directed toward developing fracture stimulation and drilling techniques to connect more gas-containing natural and induced fractures to the wellbore. However, development of this resource by the private sector has been slow because little was known about the shale's fracture systems and about how reservoir stimulation technology should be applied. The high variability in the geologic setting of the shales adds to the uncertainties facing potential developers. The result is that, in the past, gas production has been unpredictable and the economics marginal.

Estimates of the size of the resource and the economics of recovery vary considerably. Certain basic data on this resource are available from approximately 9,600 producing wells in the Appalachian region today, but a lack of geologic information on most of the Appalachian Basin makes accurate resource and reserve estimates difficult. The gas produced from this resource to date has been limited to an estimated 2.5 trillion cubic ft. (Tcf). Industry estimates of gas-in-place range up to 900 Tcf.

3.1.2 EASTERN GAS SHALES PROJECT

The Eastern Gas Shales Project is one of several unconventional gas resource projects currently being funded by the Department of Energy (DOE) to enhance the nation's natural gas supply posture. When U.S. natural gas reserves began declining in 1968, the Bureau of Mines initiated a program to examine marginal gas resources to determine what methods would be required to extract the vast amounts of gas trapped in the Devonian Shales in the Appalachian states. Although private companies were interested in this resource, it was clear that technical uncertainties and marginal economics were causing them to develop it slowly. Gas shortages of the early 1970s increased the need for additional domestic gas sources, so that in early 1976 the Department of Energy (then ERDA) formally initiated the EGSP at the Morgantown Energy Technology Center (METC). Full-scale implementation started in Fiscal Year 1977 with about 30 contractors initiating the first phases of selected long-term research activities required to achieve project goals.

EGSP efforts during the first three years of the eight-year project have been directed at determining the geologic character and magnitude of the Devonian Shale gas resource and toward increasing production of the natural gas from this resource base. Some of the early accomplishments of the project include the development and standardization of procedures for gathering data and testing samples. A significant amount of the coring required to update the resource knowledge base has been completed (over 15,300 feet of core) with emphasis on coordinating coring and logging activities to ensure that project objectives for resource characterization and inventory can be achieved with the material collected. Most of the geologic evaluation of the states covering the Appalachian and Illinois Basins will be completed by the end of FY79. Means have been established for providing geological and test data for interested parties.

EGSP research has begun to reveal the nature of containment of the producible gas in the micro- and macrofractures of the shale. Knowledge of these fractures is enabling the development and testing of more effective stimulation methods. In the first three years, more than 40 field experiments were performed to investigate the application of five types of fracture stimulation techniques. The results of these experiments are undergoing systematic evaluation to permit refinement of R&D objectives. Initial economic analyses of Devonian Shale drilling ventures involving fracture stimulation have been encouraging, indicating shale gas production should be technically and economically viable.

The EGSP activities are organized into the following four functional categories, or project elements:

- Resource Characterization and Inventory
- Extraction Technology Research and Development
- Technology Testing and Verification
- Project Integration

Each element organizes all functions with similar objectives. The advantage in organizing the project in this manner lies in standardizing and correlating results from area to area and in an overall economy of management. Figure 3.2 shows the relationship of the project elements in highly simplified form. The three central elements provide for resource data acquisition, and development and testing of techniques for improving gas recovery. The fourth element, Project Integration, provides for project coordination, definition of the requirements for the other three elements, and integration of the outputs from them. The following summaries define each element's objectives and discuss the type of work to be performed.

RESOURCE CHARACTERIZATION AND INVENTORY

Although numerous data exist on the nature of the Devonian Shale hydrocarbon resource, additional data must yet be acquired and all of these data must be analyzed to make definitive estimates of gas-in-place and economically recoverable resources. In order to determine the potential of this energy source more exactly, the extent as well as the composition and properties of these deposits must be ascertained.

The technical goals of this element are to determine the geologic, physical and geochemical characteristics of the Devonian Shales in order to develop methods of quantifying the amount of available gas, and to develop methods to locate high potential areas of gas production.

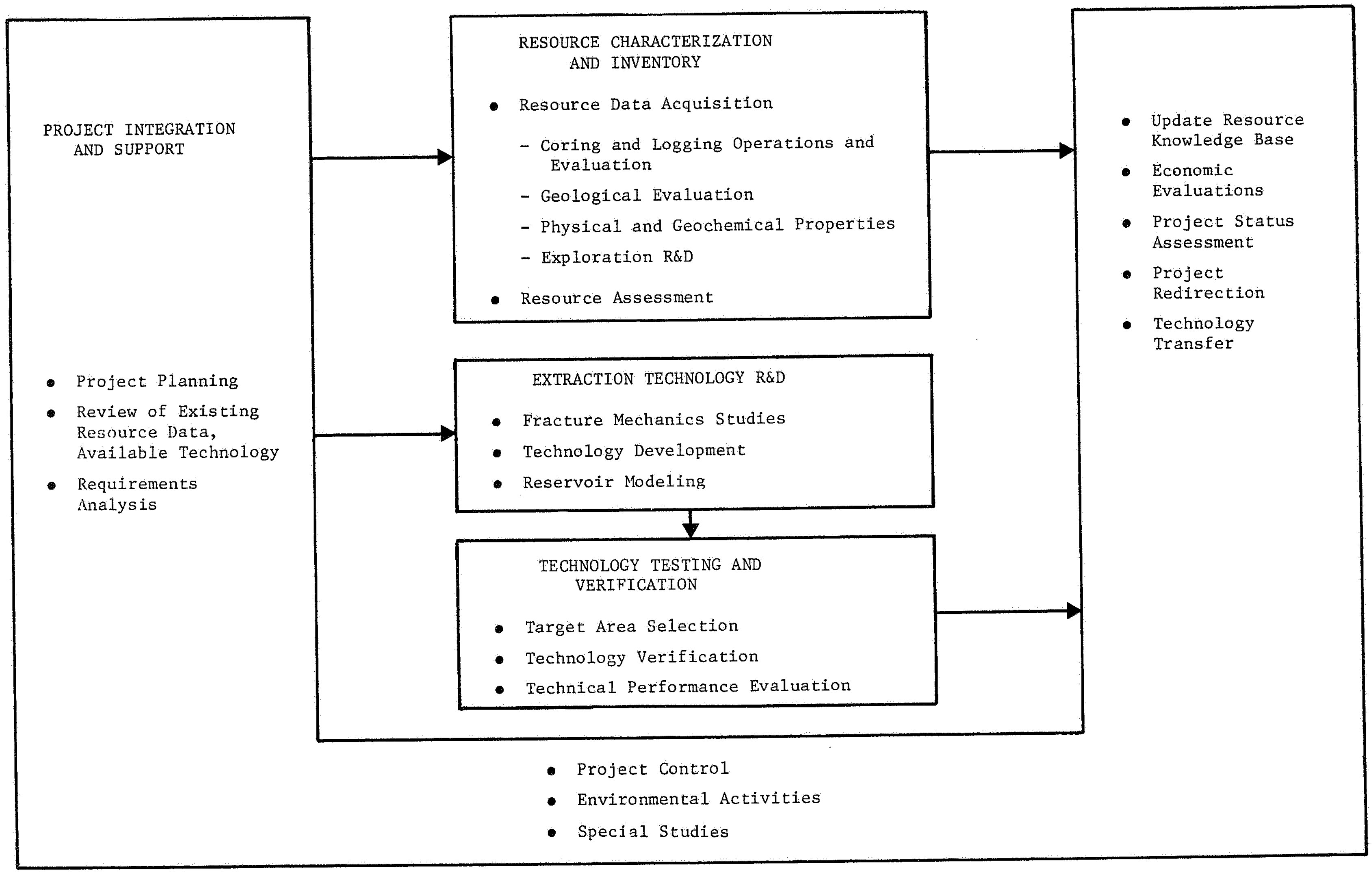


Figure 3-2. Eastern Gas Shales Project Description

The objectives are to:

- Generate stratigraphic, structural, and sedimentological data in order to characterize the geologic setting of the Devonian Shale in the Appalachian, Illinois, and Michigan Basins.

- Physically and chemically characterize rocks of Devonian age within their geologic framework.

- Estimate the total gas resource and producible reserves of the Devonian Shale.

- Identify analogs to known fracture systems and production areas and to utilize geological, geophysical and geochemical methods to locate fracture systems in the Devonian Shale.

Achievement of these first three objectives will provide needed information on the size of the resource. Achievement of the last objective will define productive Devonian Shale gas regions, support the resource potential assessment, and support the research and development of exploration rationales and extraction techniques.

To meet these objectives, the following activities are being conducted:

- Collection of cores, geophysical logs, and other pertinent shale data needed to support shale characterization activities and to assist in correlating shale reservoir characteristics with the relative effectiveness of the various shale stimulation techniques.

- Identification of subsurface geologic relationships and analysis of known areas of gas production.

- Determination of the basic physical and geochemical properties of shale samples.

- Computation of the total gas-in-place and that fraction of the resource which is economically recoverable.

- Development of exploration rationales, and techniques for locating gas filled, fractured reservoirs.

EXTRACTION TECHNOLOGY RESEARCH AND DEVELOPMENT

The technical goals of this element are to: undertake laboratory, theoretical and/or field-based R&D studies aimed at identifying promising ways to recover substantial amounts of new gas from the Devonian Shale reservoirs that have been located by particular exploration rationales.

The objectives are to:

- Understand and predict the effects of stimulation treatments.

- Understand and predict production flow.

- Develop cost-effective recovery methods.

To meet these objectives, the following activities are being conducted:

- Development of appropriate reservoir and stimulation models needed to assist in the development and evaluation of extraction techniques.
- Special studies on core material to determine the effects of drilling and stimulation fluids and practices on the producing characteristics of the shale.
- Investigation of the various potential methods of modifying the shale matrix to alter and improve the rate of evolution and production of gas.
- Testing under design conditions of specific extraction methods.

Conceptual reservoir models are developed from a knowledge of the relevant properties of the shale reservoirs. Models provide not only an understanding of the amount of gas available in the fractures, pores, and interstices of the reservoir, but also the factors determining the rate of gas flow into the wellbore. Using existing knowledge of stimulation techniques in conjunction with the reservoir models, it is possible to develop a theory describing the operation of the techniques. From this base it should be possible to improve existing techniques and develop new ones. Laboratory testing and development is part of the process, and will usually result in refining the models and theory. When a stimulation technique has been adequately developed in theory, it will be tested in the field under design conditions. Techniques successfully tested will be further studied in the Technology Testing and Verification element to determine the technique's range of applicability.

TECHNOLOGY TESTING AND VERIFICATION

The technical goals are to test, evaluate, and document exploration techniques used to locate natural fracture systems in the Devonian Shale; to verify and document various extraction techniques used to maximize the recovery of natural gas; to establish feasible economic options for various exploration, drilling, completion, and stimulation techniques in view of current and projected exploration and extraction technologies.

The objectives are to:

- Utilize various exploration techniques to locate target wells and to perform subsequent well stimulation, well testing, and reservoir evaluation to verify these techniques.
- Verify by field testing, various drilling and completion techniques developed through the Extraction Technology R&D element.
- Demonstrate the cost-effectiveness of the various exploration and exploitation techniques tested.

The principal activities consist of selecting favorable test sites, conducting field tests, and evaluating the performance of the extraction techniques.

Candidate well sites will be carefully analyzed to match their geologic properties with the appropriate extraction techniques, for unless the site properties match those defined for the extraction technique, it will be difficult to determine the success or failure of the technique. The actual field work will consist of drilling, logging, coring, and stimulating wells. Finally, the production will be monitored and the performance evaluated.

PROJECT INTEGRATION

The wide diversity of effort requires considerable coordination to maintain a coherent project. The Project Integration element provides for that function.

The objectives of this element are to:

- Plan, coordinate, and evaluate the project.
- Establish the technical requirements for the other project elements and determine if they are met.
- Establish economic options for gas production based on current and projected drilling, completion, and stimulation technologies.
- Identify and coordinate all project environmental activities.
- Implement transfer to the private sector of the technology developed and utilized in the EGSP.

The Project Integration functions interact closely with the three other elements, both in terms of planning their activities and in integrating their outputs. This activity includes definition of goals, milestones, and implementation strategy. This element also provides for requirements analyses to establish criteria and standards for the planned work. As the project proceeds, the element provides for program monitoring and evaluation.

For a stimulation technique to be widely accepted it must be shown to be capable of producing gas at competitive costs. Economic evaluation of data taken during field tests will establish the cost of these techniques relative to the production benefits derived. Economic analyses will also provide the basis for developing utilization options for gas from the Devonian Shales. This work will involve market studies, technology forecasting, and institutional and regulatory barrier analysis.

Environmental activities include analysis of potential environmental problems, preparation of environmental impact assessments of field tests, and analysis of environmental data developed during field tests. This element will also serve to transfer technology to the private sector by establishing workshops and symposia and by publishing reports, professional papers, and technical notes. Technology transfer is a continuous process, and an open-file system will make current data available to interested parties as quickly as possible.

3.1.3 CONTRACTORS

During the reporting interval, 35 contractors performed work for the EGSP on 42 contracts. Contractors and the work areas in which they are engaged are shown in Table 3-1.

Table 3-1. EGSP Contractors/Work Packages

EGSP CONTRACTORS	RESOURCE CHARACTERIZATION AND INVENTORY					EXTRACTION TECHNOLOGY R&D			TECHNOLOGY TESTING AND VERIFICATION	
	Core & Log Acquisition and Evaluation	Geological Evaluation	Physical and Geochemical Characterization	Exploration R&D	Resource Assessment	Fracture Mechanics	Production Enhancement	Reservoir Performance	Exploration Rationale	Exploitation Rationale
Ashland Exploration, Inc.	x						x			
Battelle Columbus Laboratories	x		x							
Cliff Minerals, Inc.	x		x							
Columbia Gas System Ser. Corp. (3)	x	x		x		x	x	x		x
Consolidated Gas	x	x		x			x			
Department of Energy (METC-1)	x			x			x			
Donohue, Anstey & Morrill	x			x			x		x	
ERIM*		x		x						
Gruy Federal, Inc. (2)	x						x	x		
Illinois Geological Survey (2)	x	x	x	x						
Indiana Geological Survey		x	x	x						
Intercomp	x							x		
Juniata College			x					x		
Lawrence Livermore Laboratory				x		x				
Los Alamos Scientific Laboratory						x				
Minard Run Oil Co.	x						x			
Mitchell Energy Corporation	x		x	x			x		x	
Mound Facility			x	x		x				
New York Geological Survey		x		x						
Ohio Geological Survey		x	x	x						
Pennsylvania Geological Survey		x		x						
Combustion Engineering, Inc.	x						x			
Petroleum Technology Corp. (3)	x	x		x			x			
Rector & Stone Drilling Co.	x									
Sandia Laboratories				x		x				
Science Applications, Inc.	x		x	x	x	x		x		
Tennessee Geological Survey	x			x						
Tetra Tech, Inc.	x						x			
United States Geological Survey	X	x	x	x	x					
University of Cincinnati		x	x							
University of Kentucky RF (2)	x	x	x	x						
University of North Carolina		x	x	x						
Thurlow Weed & Associates	x	x		x			x			x
West Virginia Geological Survey		x	x							
West Virginia University		x		x						

* Environmental Research Institute of Michigan

3.2 RESOURCE CHARACTERIZATION AND INVENTORY

3.2.1 APPALACHIAN BASIN

3.2.1.1 General

To date, approximately 14,126 feet of Devonian Shale core have been collected for physical and geochemical analysis and stratigraphic interpretations-seven WV cores, seven TN cores, three KY cores, two OH cores, one PA core, one NY core and one VA core. Initial efforts have been completed to define the well logging suite which will yield optimum formation evaluation data at a minimum cost. Basic geologic mapping is 75% complete. Six regional cross sections covering the Appalachian Basin have been completed and are available from the UGR file. Iospach mapping will be completed by the end of the fiscal year. Approximately 12 analytical tests have been identified as providing the most useful data to measure the gas resource. The mean gas content of Appalachian Basin Devonian Shale samples has been determined to be 0.52 cu ft gas/cu ft shale.

3.2.1.2 COLLECTION, DESCRIPTION, AND LOGGING OF EGSP DEVONIAN SHALE CORES

Status: Active

Cliff Minerals, Inc.
Granville, West Virginia

Contract:	DE-AC21-78MC08199
Contract Date:	August 16, 1978
Anticipated Completion Date:	November 30, 1981
Principal Investigator:	H.J. Leach
DOE Technical Project Officer:	J. Byrer

OBJECTIVE

To collect, describe lithology, and log oriented Devonian Shale core for all EGSP core wells.

SCOPE OF WORK

The scope of the Cliff Minerals Contract is to provide the following for each EGSP coring and logging operation:

- A detailed lithologic description and fracture description (frequency and location) and notations of significant gas shows; A lithologic strip log annotated with the location of the various canned samples to be collected for EGSP contractors working on core analyses.
- An approximate footage of oriented core to be retrieved.
- A wet-hole and a dry-hole suite of logs, to be run upon completion of drilling/coring operations.

SUMMARY OF PROGRESS

The contractor has coordinated and assisted in the extraction of approximately 4952 feet of Devonian Shale core from seven EGSP core wells. Detailed lithology and fracture descriptions were logged for each core and the appropriate number of samples were collected for physical and geochemical analyses.

In addition to the lithologic and fracture descriptions, a full set of photographs is being made of the cores as they are laid out in the field. These photos will be a part of the core record maintained at the core laboratory.

The core laboratory in Granville, WV has been renovated and equipped for core testing and storage. The laboratory is open, upon request, to interested persons for the inspection of a large amount of Devonian Shale core.

Arrangements were finalized with Michigan Technological University to perform directional tensile strength and point load tests on the EGSP cores.

3.2.1.3 ORGANIZATION AND COLLECTION OF DATA FROM EGSP DRILLING, CORING, AND LOGGING OPERATIONS

Gruy Federal, Inc.
Houston, Texas

Status: Active

Contract:	DE-AC05-78MC08382
Contract Date:	April 1, 1979
Anticipated Completion Date:	April, 1981
Principal Investigator:	A. Louse
DOE Technical Project Officer:	C.W Byrer

OBJECTIVE

To plan, organize, and manage a program for the collection, consolidation, and delivery of core material, logging data, and limited stimulation data from the Devonian Shales of the Appalachian, Illinois and Michigan Basins.

SCOPE OF WORK

Under this new two year contract, Gruy Federal will contract, collect, consolidate, organize, and prepare for delivery to DOE core material and data extracted from the 22 new wells located as shown on Figure 3-3 and as indicated in Table 3-2. All field activities connected with the coring, logging, completion, and testing of the EGSP core wells will be reported.

Gruy will also be responsible, under this contract, for monitoring, collecting, and assimilating all the data generated from the analyses or cores, geophysical logs, well completions, and the well testing of the 22 wells.

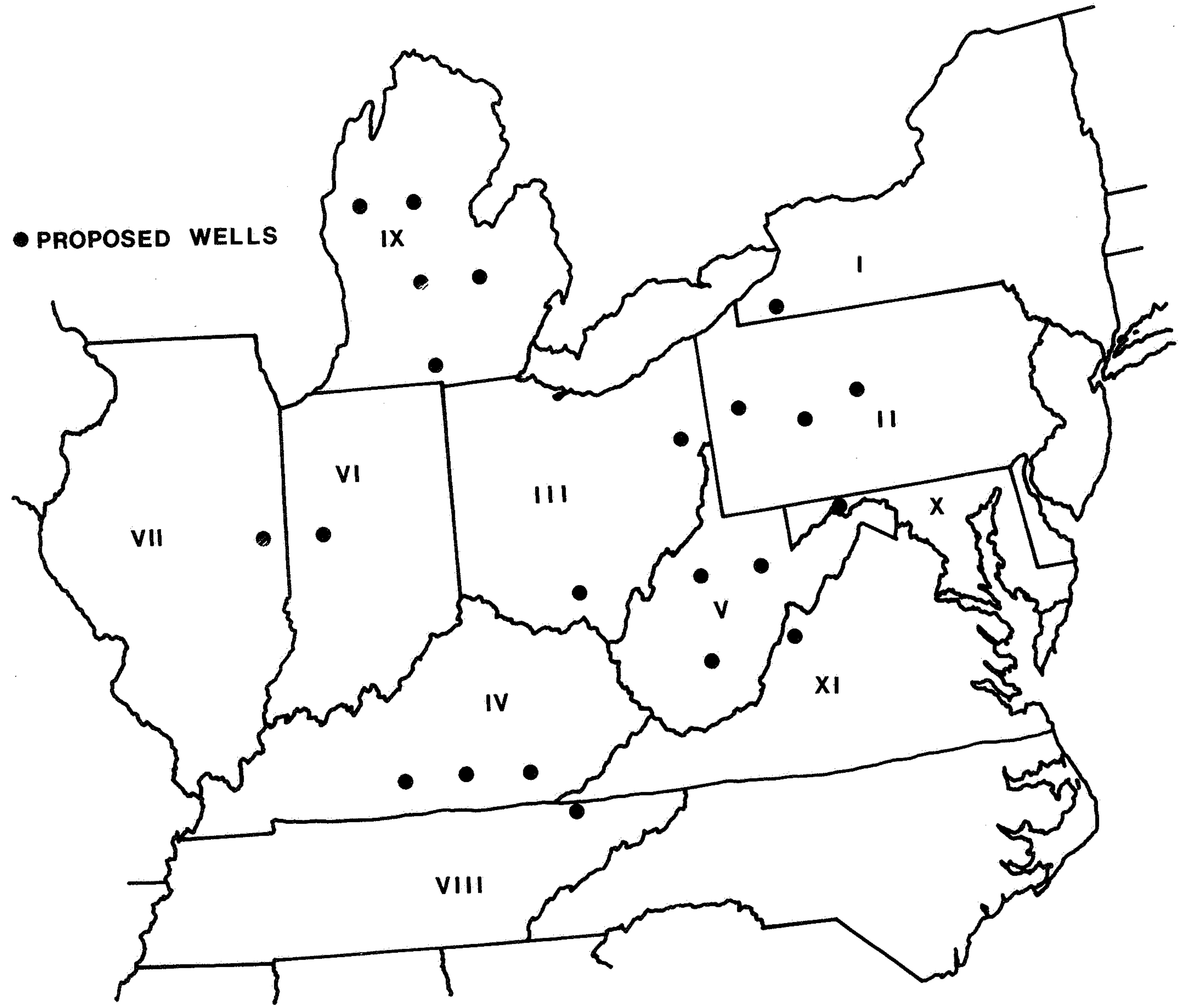


Figure 3-3. EGSP Proposed Well Locations

Table 3-2. Location of Proposed EGSP Core Wells

STATE NUMBER	STATE	NUMBER OF WELLS	COUNTIES
I	New York	1	Chautauqua
II	Pennsylvania	3	Indiana-Clearfield Clinton-Centre Lawrence-Butler
III	Ohio	2	Richland-Ashland Pike-Scioto
IV	Kentucky	3	Laurel-Clay Barren-Warren Wayne-Adair
V	West Virginia	3	Gilmer-Calhoun Barbour-Randolph-Upshur Raleigh-Fayette
VI	Indiana	1	Putnam-Morgan
VII	Illinois	1	Douglas-Champlain
VIII	Tennessee	1	Hawkins-Green
IX	Michigan	5	Branch-Hillsdale Clinton-Eaton Clare-Isabella Mason-Lane Oakland-Genessee
X	Maryland	1	Allegany
XI	Virginia	1	Highland-Beth

3.2.1.4 EVALUATION OF THE CHATTANOOGA SHALE IN THE TENNESSEE VALLEY AND RIDGE FOR NATURAL GAS AND URANIUM

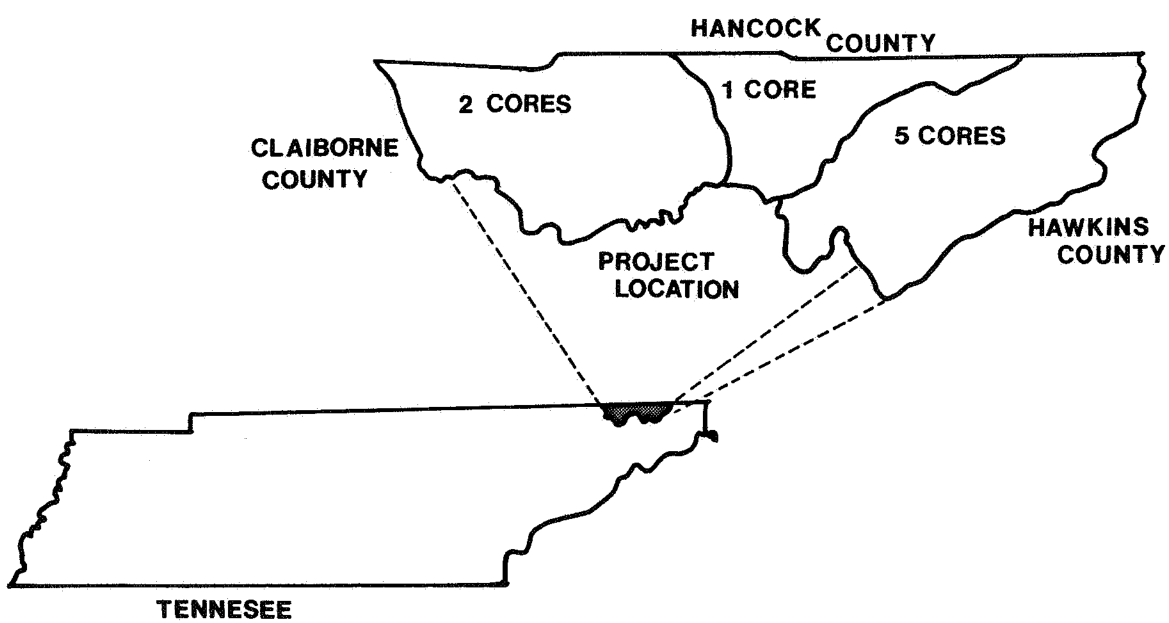
Tennessee Department of Conservation
Nashville, Tennessee

Status: Active

Contract:	EY-76-C-05-5196
Contract Date:	October 1, 1977
Anticipated Completion Date:	October 31, 1979
Principal Investigator:	C. Ferguson
DOE Technical Project Officer:	C.S. Dean

OBJECTIVE

To obtain and evaluate seismic profiles in eastern Tennessee and to core drill the Chattanooga Shale along its outcrop and use the core for stratigraphic, mineralogic and fracture studies.



SCOPE OF WORK

Specific tasks included in the Tennessee contract are:

- To subcontract wireline coring of eight stratigraphic exploration wells in the Chattanooga Shale adjacent to Clinch Mountain and Newman Ridge in eastern Tennessee.
- To use the core data to document the regional stratigraphy and structure in the Tennessee Valley and Ridge and to locate the Chattanooga Members which contain high hydrocarbon values.
- To subcontract a regional seismic survey in order to identify by seismic profiles the location of tectonically fractured Chattanooga Shale formations.

SUMMARY OF PROGRESS

Core drilling of the Chattanooga Shale along Clinch Mountain continued during the reporting period. Core holes 4 and 6 were completed. Hole number 5 was drilled to 175 feet and bottomed in black shale of the upper member of the Chattanooga Shale. Hole 5 will be re-entered and deepened near the end of the project. Core hole number 7 reached the base of the Chattanooga Shale at 826 feet. The core was logged and some samples canned on site were sent to the USGS laboratory in Denver for geochemical analysis. Lithologic description of all core material is being made by the USGS.

The final report of the seismic interpretation is nearing completion.

The eighth and final core is scheduled to be recovered in May or June, 1979.

3.2.1.5 CHARACTERIZATION AND HYDROCARBON RESOURCE APPRAISAL OF MIDDLE AND UPPER DEVONIAN SHALES IN NEW YORK

New York State Geological Survey
Albany, New York

Status: Active

Contract:	EY-76-C-05-5206
Contract Date:	July 1, 1976
Anticipated Completion Date:	September 30, 1979
Principal Investigators:	A.M. Van Tyne L.V. Rickard
DOE Technical Project Officer:	P.Y. Williams

OBJECTIVE

To perform major stratigraphic and structural geological investigations using well cuttings, core data, production data, geophysical logs, aerial photogrpahy, and geochemical data in order to construct maps and cross sections which define the extent and productive capacity of the potentially gas-productive Devonian age shales of New York.

SCOPE OF WORK

The New York contract provides for the following specific tasks:

- To characterize the stratigraphic and lithologic framework and extent of the Middle and Upper Devonian Black Shales of New York and to correlate this information with the stratigraphic network of surrounding states.
- To assemble data from previously drilled wells and to correlate wireline and sample log data.
- To determine the detailed lithology, geochemistry, and mineralogy of the shales in this area.
- To determine the extent of lineaments in areas thought to be the most promising for shale gas production.
- To prepare subsurface structure, isopach, and lithofacies maps showing the entire 3-dimensional aspect of these shale bodies.
- To identify and prepare final maps showing the geographic areas most promising for exploitation of the gas resource in these shales.

SUMMARY OF PROGRESS

Lithologic logs were prepared for approximately 50,000 feet of cuttings from wells penetrating the Devonian Shale in New York. The microscopic examination of approximately 60,000 feet of well cuttings from wells penetrating the Devonian Shale was completed.

The extensive work in sample and core examination and description is being used for the interpretation of the relationship between the gamma ray log curve response to the actual lithology of the Devonian Black Shales. When concluded, the results of this study will be useful for generating lithofacies maps using the gamma ray log. If the gamma ray log can be used to distinguish the silt from the clay components of the shale as opposed to sample and core descriptions only, the time required to generate these maps should be reduced.

3.2.1.6 EASTERN GAS SHALES PROJECT STUDY OF THE UPPER DEVONIAN SHALE IN OHIO

Ohio Department of Natural Resources
Division of Geological Survey
Columbus, Ohio

Status: Active

Contract:	DE-AS05-76MCO5200
Contract Date:	April 15, 1977
Anticipated Completion Date:	September 30, 1979
Principal Investigator:	R.A. Struble
DOE Technical Project Officer:	R.J. Watts

OBJECTIVE

To determine the magnitude of potential gas reserves, characterize the shale, and improve the current stimulation technology for Devonian Shales in Ohio.

SCOPE OF WORK

The geological evaluation work in Ohio performed under this contract includes advising DOE in the selection of drilling sites and coring intervals, construction of a well data file and construction of a computer data base. Stratigraphic work includes construction of interlocking cross sections, isopach and lithofacies maps. Structural work includes both regional and detailed structural mapping and lineament analysis.

Mineralogic and petrographic characterization includes analysis of EGSP cores, OHGS cores, and drill cuttings. Gas detectors will be used to monitor gas shows encountered in the drilling of wells which will be correlated with samples, core, and by data.

SUMMARY OF PROGRESS

The identification, correlation, and shale thickness determinations of selected Devonian Shale units have been completed for 34 of the 49 counties in the study. Initial contouring of the isopach maps is underway in these counties. Datums for the Berea Sandstone and Packer Shell have been determined in Noble County. Datums have been determined for the Berea Sandstone, Packer Shell, and Knox Dolomite in Morgan and Mahoning Counties. Datums for the regional structure maps were obtained and posted for 22 counties during the reporting period.

Structural mapping was completed for the top of the Onondaga Limestone (base of the Devonian Shale) in Trumbull, Huron, Portage, and Lawrence

Counties. Structure contouring was updated on the Packer Shell in Ashtabula, Portage, Trumbull, Mahoning, Noble, and Geauga Counties. Structure contouring was updated on the Berea in Washington County.

The plotting of linear features using 1:80,000 aerial photography has been completed for Ohio (1:24,000 used for Hocking County).

The Ohio Geological Survey is using cores from the Survey files to augment the EGSP cores. Mineralogical and geochemical analysis is underway on cores from the Barberton Limestone Mine, International Salt Company, and the Erie Nuclear Plant. Cuttings have been examined from a well in Muskingham County.

Work has been initiated on OHGS cores from seven counties.

Gas shows were monitored on seventeen wells during the reporting period, bringing the total to twenty-seven. Gas show profiles are currently being plotted against geophysical logs and sample descriptions for these wells.

3.2.1.7 STRATIGRAPHIC FRAMEWORK FOR THE MIDDLE AND UPPER DEVONIAN BLACK SHALES AND RELATED ROCKS OF WESTERN AND CENTRAL PENNSYLVANIA

Pennsylvania Division of Topographic and Geologic Survey
Pittsburgh, Pennsylvania

Status: Active

Contract:	**DE-AS21-76MC05198**
Contract Date:	**July 1, 1976**
Anticipated Completion Date:	**September 30, 1979**
Principal Investigator:	**R.G. Piotrowski**
DOE Technical Project Officer:	**P.Y. Williams**

OBJECTIVE

To provide a detailed stratigraphic and structural framework for the "Canadaway Group," Java Formation, and the included black shale units in western and northwestern Pennsylvania.

SCOPE OF WORK

Specific tasks include the following:

- To provide detailed stratigraphic sections of the "Canadaway Group" and the Java Formation in order to give a thorough picture of their regional relationships with associated lithologies.
- To define and map the radioactive black shale facies and related rocks within these units in order to understand their sedimentological history and in order to help in predicting and evaluating potential gas resources in the "Canadaway Group" and Java Formation.
- To generate detailed structure contour maps and lithofacies maps of the above mentioned units and related rocks in Pennsylvania.
- To generate a detailed isopach map of the Java Formation.
- To maintain a storage site for data and cores obtained in Pennsylvania for the EGSP.

SUMMARY OF PROGRESS

The Pennsylvania Geological Survey completed all the isopach, structure contour, and lithofacies maps and cross sections that are required to provide an overall stratigraphic and structural framework for the Devonian Shales of western Pennsylvania. The information obtained from the maps and cross sections has been used to identify three areas in western and northwestern Pennsylvania that should be drilled and cored to evaluate the gas potential of the Devonian Shales in the State. The most likely targets for exploration among the Devonian Shales are the Rhinestreet and Dunkirk Shale facies.

3.2.1.8 ENERGY RESOURCES OF THE DEVONIAN SHALE IN THE APPALACHIAN BASIN

Status: Active

University of Cincinnati
Cincinnati, Ohio

Contract:	EY-76-C-05-5201
Contract Date:	July 1, 1976
Anticipated Completion Date:	September 30, 1979
Principal Investigators:	P.E. Potter J.B. Maynard W.A. Pryor
DOE Technical Project Officer:	C.S. Dean

OBJECTIVE

To provide special geochemical and petrologic studies of the Devonian Shale in the Appalachian Basin and to prepare a depositional model for the entire Basin.

SCOPE OF WORK

The original major task of this project was to construct a depositional model of the Appalachian Basin. Completion of this task will not be possible within the initial time frame and the task has been altered to achieve the maximum amount of interpretation from the available data. The altered task consists of a series of block diagrams constructed from stratigraphic cross sections and incorporating data from the paleocurrent study. The University of Cincinnati is also performing geologic and geochemical studies in several areas of interest to the Eastern Gas Shales Project.

SUMMARY OF PROGRESS

The final report of the paleocurrent study for the Appalachian Basin has been submitted. The study indicates that a homogeneous sediment source, located to the east, provided most of the Devonian Shale sediment.

The study of the Middleboro Syncline has almost been completed. The base isopach, structure contour and isotope maps have been completed. Thin section analysis work has also been completed.

The study of the Brailler Formation stratigraphy, petrology, and geochemistry has also been completed. Shale horizons that can be used as stratigraphic markers have been identified.

The Pine Mountain overthrust study is still underway. Thin section analysis has been completed for Virginia and is well advanced in Kentucky.

A chromatographic technique has been developed for the separation of the phenolic aldehydes of the organic fraction of the shale. C^{13}/C^{12} analysis continues and 50 additional samples were analyzed during the reporting period.

3.2.1.9 BLACK SHALE STUDY IN KENTUCKY

University of Kentucky Research Foundation
University of Kentucky
Lexington, Kentucky

Status: Active

Contract: DE-AC21-76MC05202
Contract Date: July 1, 1976
Anticipated Completion Date: September 30, 1979

Principal Investigators: W.F. Dennen
F.R. Ettensohn
E.N. Wilson
D.C. Haney

DOE Technical Project Officer: C.W. Byrer

OBJECTIVE:

To collect, compile and analyze all available drill hole and outcrop data on Devonian Shales of eastern Kentucky; to study the sedimentary history and stratigraphic framework of the Devonian Shale in eastern Kentucky; to provide detailed lithologic and geochemical analyses of core material; to provide a data bank of geologic and reservoir data; and to archive core taken by DOE contract from wells in Kentucky.

SCOPE OF WORK

This program is designed to provide geologic data on the Mississippian-Devonian black shales of eastern Kentucky and is divided into the following four major tasks:

- To determine the internal lithostratigraphy, biostratigraphy, and radiostratigraphy of the sequence; to perform a basin analysis and paleoenvironmental interpretation; to generate isopach maps; to perform detailed lithologic logging of cores by routine methods and thin-section study.

- To provide subsurface characterization of black shales using records, cores, and wireline logs in order to correlate gas productivity with geologic parameters; to enter geologic and reservoir data into computer storage for record and computer manipulation.

- To manipulate the geochemical data acquired; to examine the relationships between marine and terrestrial kerogen, uranium content and gas productivity; to examine geochemical and clay mineral trends in the black shale depositional basin.

- To provide an archive of cored materials produced under the EGSP.

SUMMARY OF PROGRESS

The Devonian-Mississippian organic shales and associated rocks, as deposited, are affected mainly by contemporary tectonism. Relative to the basin itself, the Cincinnati Arch was mildly positive and the sediment source to the east and northeast was strongly emergent, producing a thick prism of rocks difficult to correlate. Within the Basin, differential movement recurred along regional longitudinal faults (probably related to the Rome Trough) before, after, and possibly during the depositional episode. Subsequent crustal shortening along the Valley-and-Ridge longitudinal faults acting as overthrusts produced the present geography on the southeast side of the Basin.

Data obtained from the study of both whole-rock and separated kerogen have indicated that both are acceptable materials for geochemical study of the kerogen precursors and general stratigraphic applications but that, not unexpectedly, kerogen isolated from a rock sample provides more sharply defined information. The separation of kerogen has been mainly accomplished by dissolution of the rock matrix with hydrofluoric acid, etc. which is apt to strip adsorbed ions from the kerogen. The results obtained, however, have been generally consistent with other measures of partition obtained using a laser microprobe to compare the composition of carbonaceous fossil fragments and their kerogenous matrix, separations utilizing boric acid fluxing followed by treatment with acids, and comparisons of whole-rock and ashed samples.

3.2.1.10 SUMMARY OF TIOGA BENTONITE MARKER HORIZON IN APPALACHIAN BASIN DEVONIAN SHALES

University of North Carolina
Chapel Hill, North Carolina

Status: Active

Contract:	EY-76-C-05-5195
Contract Date:	July 1, 1976
Anticipated Completion Date:	September 30, 1979
Principal Investigator:	J. Dennison
DOE Technical Project Officer:	C.S. Dean

OBJECTIVE

To geographically and geologically characterize the Tioga Bentonite.

SCOPE OF WORK

The scope of this contract includes two major tasks: to compile geologic outcrop and subsurface data which will be representative of the entire Tioga Bentonite throughout the Appalachian Basin; and to prepare a series of stratigraphic cross sections, columnar sections, and maps which together with a report will show the areal extent and interrelationships between the Tioga Bentonite and stratigraphic units within the Devonian Shale interval.

SUMMARY OF PROGRESS

The wind distribution patterns of the Tioga volcanic ash are being studied in order to see how they differ from the currents which distributed the Devonian sea bottom sediments. Detailed cross sections of the Tioga Bentonite are being prepared for the final report.

3.2.1.11 CHARACTERIZATION AND EVALUATION OF THE DEVONIAN SHALES IN WEST VIRGINIA

West Virginia Geological and Economic Survey
Morgantown, West Virginia

Status: Active

Contract:	EY-76-C-05-5199
Contract Date:	July 1, 1976
Anticipated Completion Date:	June 30, 1979
Principal Investigators:	L. Woodfork D. Patchen M. Behling J. Renton
DOE Technical Project Officer:	C.S. Dean

OBJECTIVE

To conduct a detailed and comprehensive stratigraphic, petrologic, and geochemical study of the Devonian Shales in West Virginia to result in a comprehensive appraisal of the total energy resource potential of these shales.

SCOPE OF WORK

The West Virginia Geological and Economic Survey contract includes the following major tasks:

- To collect, compile and analyze all available drill hole and outcrop data on the Devonian Shales of West Virginia, including additional geological and geochemical data provided from a number of full section, oriented cores of the Devonian Shale sequence obtained by DOE/METC through contractual agreements with oil and gas operators or core drilling contractors.

- To conduct a comprehensive study of the sedimentary history and stratigraphic framework of the Devonian Shales and closely associated lithologic units above, below and laterally equivalent to the shale interval in order to delineate the geologic relationships between the various units and how these relationships bear upon the occurrence of gas.

- To perform detailed lithologic and geochemical analyses of the core material in order to enable project investigators to delineate target areas where commercial volumes of natural gas are likely to be present and where specific stimulation techniques would be most likely to succeed.

SUMMARY OF PROGRESS

The following isopach maps were completed for southwest West Virginia: α and β beds of the Java Formation; α and β beds of the Angola Shale Member of the West Falls Formation; the Rhinestreet Shale Member of the West Falls Formation; α and β beds of the Cashaqua Shale Member of the Sonyea Formation; Middlesex Shale Member of the Sonyea; West River Shale Member of the Genessee Formation; Geneseo Shale Member of the Genesee; and the Marcellus Shale. All USGS-requested isopach maps for the Appalachian Basin resource assessment were completed.

Four preliminary cross sections were completed: E-W from Lewis to Mason County; E-W from Wetzel to Pleasants County; N-S from Pleasants to Putnam County; and N-S from Wood to Putnam County.

Field work was accomplished near Elkins and Petersburg, WV. Sections of the Chemung, Harrell and Mahantango Formations were measured and a gamma ray survey of the outcrops was recorded.

Petrologic characterization and strip logs of critical mineralogic, petrologic and density data from Well #20403, Lincoln County, WV were completed.

A total of 1595 XRF and 1326 XRD analyses have been completed on Devonian Shale samples. Data analysis will begin in May, 1979.

Research was initiated to study the insoluble residue of concretions by x-ray diffraction and SEM.

The stratigraphic codes for Silurian units in the WVGES data base were revised. All data from shale gas producers in southern WV have been coded. A stratigraphic and gas producing data base for all shale gas-producing counties in WV was completed.

3.2.1.12 CHEMICAL AND PHYSICAL ANALYSIS OF EASTERN SHALE

Battelle Columbus Laboratory
Columbus, Ohio

Status: Active

Contract:	DE-AC21-76MCO5205
Contract Date:	July 1, 1976
Anticipated Completion Date:	September 30, 1979
Principal Investigator:	J. Snyder
DOE Technical Project Officer:	S. Bialobok

OBJECTIVE

To determine the relationship between shale characteristics, hydrocarbon gas content, and well location to provide a sound basis for defining the productive capacity of the Eastern Devonian Shale deposits.

SCOPE OF WORK

Approximately 600 core samples of gas-bearing Eastern Devonian Shale will be examined in the program. After the characterization data for individual wells have been compiled, a regression-type analysis for pattern recognition will be performed. This analysis will establish the interrelationship between the shale characteristics, the hydrocarbon gas content, and the well locations from which the samples were obtained.

The work for this contract period comprises six tasks:

- Core sampling
- Gas content and gas release kinetics
- Chemical characterization of shale
- Physical characterization of shale
- Lithology of shale
- Data interpretation and correlation

SUMMARY OF PROGRESS

Prior to this reporting period, Battelle Columbus Laboratories had collected 499 samples of core encapsulated at the well sites. During this reporting period, the following samples were collected:

Location	EGSP Well No.	No. of Samples
Allegany County, NY	NY-1	165
Wetzel County, WV	WV-7	46
Johnson County, KY	KY-4	60
McKean County, PA	PA-1	36
Allegheny County, PA	PA-2	24
Hardin County, IL	IL-4	19

All analytical work has been completed on the samples from Allegany County, NY and Wetzel County, WV. This completes analytical work for 14 cores in the Appalachian and Illinois Basins. These 14 cores total 710 encapsulated samples that have been analyzed for gas volume and composition, C/H/N/S, density, porosity, surface area, color, and fracture description. Selected samples were analyzed for permeability, trace elements, mineralogy, and pore size distribution.

In addition to the characterization analysis, Battelle Columbus Laboratories is determining rates of gas release on samples from Mason County, WV and Allegany County, NY. This work has indicated that significant amounts of gas are released after the initial equilibration period.

3.2.1.13 INTERACTION BETWEEN GASES AND SHALE OF THE EASTERN U.S.

Juniata College
Huntingdon, Pennsylvania

Status: Active

Contract:	DE-AS05-76MCO5197
Contract Date:	July 1, 1976
Anticipated Completion Date:	September 30, 1979
Principal Investigator:	P. Schettler
DOE Technical Project Officer:	S. Bialobok

OBJECTIVE

To measure the amount and composition of shale gas as a function of the presence of foreign gases; to determine gas diffusion constants, total adsorptive capacity and permeability of shale samples; and to evaluate these data as a function of particle size and various degassed states of each sample as induced by elevated temperatures.

SCOPE OF WORK

This contract provides for an experimental program to determine the amount of gas a volume of rock holds as a function of pressure and to determine how fast that gas can be desorbed from the rock.

A second area of activity is to link explicitly the important isotherm/ diffusion parameters to a basic knowledge of sorption and gas transport within the rock.

A third area of work is concerned with the interpretation of the data-gathering program in terms of its implication for well productivity.

SUMMARY OF PROGRESS

Ninety-two isotherm and 85 degasibility analyses were completed at low pressures.

A temperature effects study (-15 to +37°C) was initiated on previously run samples. Three samples have each been run at seven different temperatures. He and CH_4 degasibility data have been collected at each temperature.

The high pressure isotherm apparatus was completed, but leaky valve assemblies have resulted in a delay in initiating the analyses. New valves have been ordered.

3.2.1.14 PHYSICAL AND CHEMICAL CHARACTERIZATION OF DEVONIAN SHALE GAS

Mound Facility
Miamisburg, Ohio

Status: Active

Contract:	DE-ACO4-DP00053
Contract Date:	February 15, 1977
Anticipated Completion Date:	September 30, 1979
Principal Investigator:	R.E. Zielinski
DOE Technical Project Officer:	A.E. Hunt

OBJECTIVE

To determine the fuel yield and the chemical characterization of fuel from shale; to perform detailed characterization of kerogen material within the shale; to determine the relationship of hydrocarbon release to mechanical loading of shale samples in the laboratory; and to perform spectroscopic and microscopic physiochemical characterization of organic species in shale.

SCOPE OF WORK

Mound Facility performs detailed analysis and interpretation of EGSP cores. Analytical work includes gas volume and composition, C/H/N/S, material balance assay, vitrinite reflectance, elemental analysis, bulk and clay mineralogy, detailed analysis of heavy hydrocarbons, Shore hardness, and tensile strength. Mound also provides lithologic descriptions and biostratigraphic analysis of the cores. The program includes statistical analysis of all data and interpretation of regional and stratigraphic variation of the different component variables.

SUMMARY OF PROGRESS

During this reporting period, samples from the following wells were analyzed:

Location	EGSP Well No.
Martin County, KY..........................	KY-3
Wise County, VA............................	VA-1
Henderson County, IL.......................	IL-2
Mason County, WV...........................	WV-5
Monongalia County, WV......................	WV-6

The shale fabric and depositional facies of high and low permeability samples from the WV-5 well were compared to determine the significant factor controlling sample permeability, other than fracturing. The results indicated that the permeability of these unfractured shales was not consistently controlled by a specific variable.

The preliminary interpretation has been made of the results of the thermal maturation analysis of Appalachian and Illinois Basin Upper Devonian Shales. The thermal maturation has a significant effect on the hydrocarbon producing potential of these shales. Subtle differences in the thermal diagenesis are significant. It is also apparent that burial history has a significant role in the generation of hydrocarbons and a significant effect on the maturation indices.

Interpretations were also made concerning the relationship between Upper Devonian Shale organic carbon content and uranium, thorium and potassium concentrations as well as the ratio of uranium to thorium. The interpretations suggest that a gamma spectral logging might be a more accurate method for the in situ determination of shale organic content than total gamma logging.

The mineralogical composition and fabric of WV-6 shales were determined from shale core and drill cuttings. The results continue to indicate illite as the dominant clay mineral. The degree of orientation parallel to bedding of clay and organic material is generally good or excellent.

The methane permeability of five shale samples from the WV-5 well was determined. Permeability parallel to the bedding planes ranged from 5×10^{-5} to 2×10^{-11} darcys. A measurement of permeability perpendicular to the bedding planes indicated K to be 6.6×10^{-9} darcys and the slope of the line describing the Klinkenberg effect (correction for slip flow) to be 1.6×10^{-7} darcys per atmosphere.

Preliminary results were obtained from the study to determine the adsorption-desorption characteristics of Devonian shales. Four KY-3 shale samples with varying organic carbon contents were selected for analysis. The results are tentative but suggest that adsorption of methane occurs in several phases.

Studies were continued to determine the relationship between splitting tensile strength and Shore hardness for a shale from a given depositional environment. The results of select shales from the Illinois and Appalachian Basin indicate splitting tensile strength increases with hardness for marine and restricted marine shales. The restricted marine shales had the highest mean values for splitting tensile strength and Shore hardness.

Kerogen analysis and vitrinite relfectance analysis have been completed for well WV-6. The visual kerogen analysis indicates that the nature of the organic material in the WV-6 samples is similar to that found in the VA-1 well samples. The organic material in WV-6 is composed primarily of woody and coaly substances; however, these are zones of predominantly algal, amorphous, and herbaceous material.

Detailed kerogen analyses indicated that the atomic H/C values ranged from 0.45 to 1.22, and the atomic O/C values ranged from 0.10 to 0.18. The weight percent of ash varies from 8.42 to 52.78. Vitrinite reflectance values ranged from 1.13 to 3.47.

Correlation studies of organic carbon with minor and trace elements have continued. Aside from minor variations, good agreement holds for KY-3, WV-5, IL-2 and VA-1 data. Elements that correlate positively with organic carbon have the highest absolute value of correlation. An examination of the scatter diagrams shows that in the negative correlation cases stratification or clustering lowers the absolute value of correlation. Analysis of the structure indicated in the scatter diagrams for the negative correlation cases has been initiated.

Biostratigraphic analysis has been completed for the WV-6 well, Monongalia County, WV. The shales from this well were deposited primarily in a non-marine environment with two restricted marine intervals identified on the basis of severely altered Tasmanites.

Material balance assays are currently being performed on samples from well WV-5, Mason County, WV. The results to date confirm the pyrolysis-gas chromatography data previously reported for the WV-5 well. Oil yields vary from approximately 5 gallons/ton to less than 0.5 gallons/ton. Hydrocarbon gas yields vary from 84 to less than 3 ft^3/ton.

3.2.1.15 REMOTE SENSING APPLIED TO THE INCREASE OF NATURAL GAS RESERVES IN MISSISSIPPIAN-DEVONIAN SHALES, COTTAGEVILLE FIELD, WEST VIRGINIA

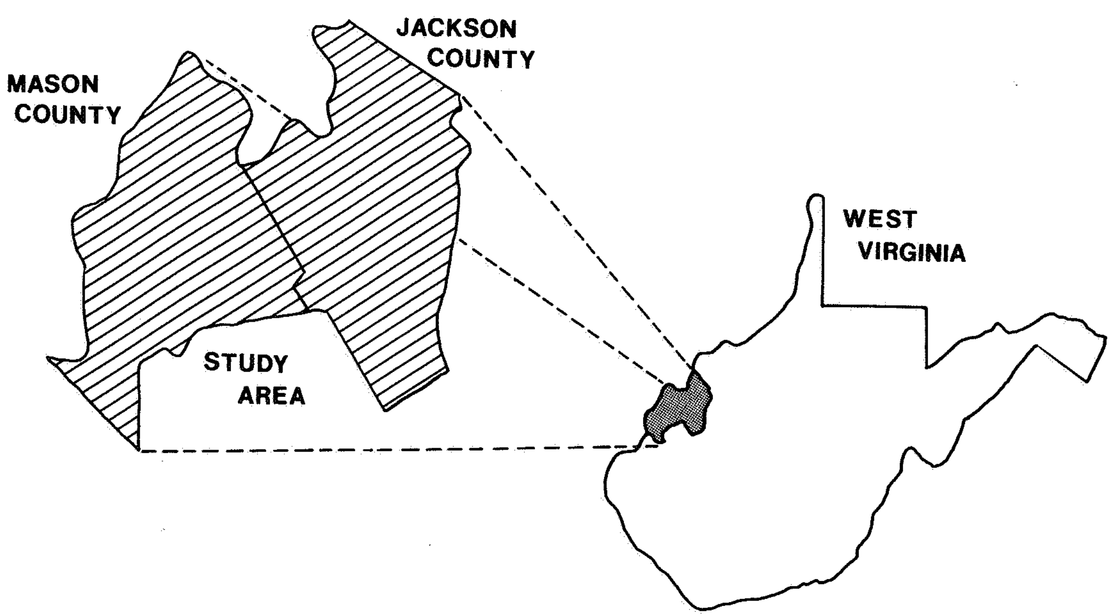
Status: Active

Environmental Research Institute of Michigan
Ann Arbor, Michigan

Contract:	DE-AC05-77ET12137
Contract Date:	August 14, 1977
Anticipated Completion Date:	February 15, 1979
Principal Investigator:	P.L. Jackson
Technical Project Officer:	C.S. Dean

OBJECTIVE

To collect high resolution synthetic aperture radar and multispectral scanning (MSS) imagery of an area in West Virginia which includes the Cottageville gas field; and to analyze the imagery by optical and digital analysis techniques in order to develop a remote sensing system capable of locating (or aiding in locating) areas in which the eastern shales have a high potential for gas production.



SCOPE OF WORK

The four major tasks to be performed under this contract include data gathering, data analysis, technique appraisal, and recommendations.

More specifically, the ERIM contract provides for the following tasks:

- To collect and analyze geological, geophysical, and high resolution remote sensing data.
- To evaluate the various modern optical and digital image processing techniques and establish their value in enhancing the identification of geologic features.
- To identify the advantages of optically and digitally machine aided image analysis over conventional visual image analysis.
- To correlate and integrate available geophysical and geological data with remote sensing data.
- To develop an efficient and effective remote sensing method for use as a first step in exploration for fractured shale gas reservoirs.

SUMMARY OF PROGRESS

All analysis work and the final report were completed during the reporting period.

Due to the lack of surface expression of subsurface features in the Cottageville area, imagery analysis did not result in the elucidation of lineament vs gas production relationships.

The LANDSAT ratios 4/5, 5/7, and 6/7 have been made. These are produced by first performing dark-object subtraction and ratioing individual pixels. Three ratios were used to make one color composite, and, because one ratio (6/7) was rather flat, the remaining two ratios were made into another color composite. Although interesting features were revealed in the ratioing, no interpretation or evaluation could be made.

LANDSAT images of the region about the Cottageville test site were filtered with both Fourier transforms in coherent light and Ronchi-gratings. The images were filtered at 10° intervals. Subsequently, Fourier transforms of the two sets of filtered images were made for comparison. A photographic film method was used to obtain detailed contours of the energy levels in a Fourier transform of a LANDSAT image.

Interactive work at the MDAS terminal at ERIM was performed on LANDSAT data of the test site. Three-color displays of level-slicing, contrast-stretched false color, ratioing, and training sets of Euclidean distance were employed. Although some subtle lineaments appeared under some presentations to be more obvious, no definitive stage was attained. A training set taken on the Cottageville field showed no difference between the field and similar terrain elsewhere within the region.

The concepts and techniques developed during the Cottageville study will be applied to an area in western Kentucky where abundant surface tectonic features are known to exist in proximity to shale gas production.

This one-year study should be initiated in the summer of 1979 and will be directed to locating areas of gas-filled, fractured Devonian Shale formations.

3.2.1.16 ANALYSIS OF STRUCTURAL GEOLOGICAL PARAMETERS THAT INFLUENCE GAS PRODUCTION FROM THE DEVONIAN SHALE OF THE APPALACHIAN BASIN

Status: Active

West Virginia University
Morgantown, West Virginia

Contract:	DE-AC21-76MCO5194
Contract Date:	July 1, 1976
Anticipated Completion Date:	November 30, 1979
Principal Investigator:	R.C. Shumaker
Technical Project Officer:	C.S. Dean

OBJECTIVE

To analyze regional and local geologic structures to determine how they affect Devonian Shale gas production within eastern Kentucky and West Virginia; and to develop, along with other EGSP contractors, techniques and rationales for enhanced gas recovery and exploration.

SCOPE OF WORK

The scope of this contract includes the following activities:

- The compilation of regional structure data to ascertain its effect on the limits of gas production from the Devonian Shale within eastern Kentucky and West Virginia.
- The compilation of surface and subsurface fracture data, largely joints, to determine if they can be used to predict the trends of Devonian Shale fractures and shale gas production.
- The study of selected producing areas where detailed data are available to isolate those parameters which affect gas production.
- The study of surface structure, largely cross-strike structural discontinuities (CSD's) to determine if they are zones of more intense fracturing and to determine if they are prospective for gas production.
- To investigate the relationship between water well yield and water well quality data to proximity to photolineaments and highly productive shale gas wells.
- To develop inexpensive geophysical instruments and techniques that can delineate shallow fracture zones.

SUMMARY OF PROGRESS

A preliminary analysis of LANDSAT lineament density and gas well yields (initial open-flow at Midway-Extra) shows that the gas well yield is probably related to photolineament density, with the highest-producing wells being located in areas of concentrated photolineaments. This relationship also appears to hold true for nearby water well yields. This suggests that the fracturing of the sediments from which gas is produced extends upward into the shallow water-bearing sediments.

Statistical tests show that water well yields increase as the centers of short photolineaments are approached. Maximum permeability is along the center line of the lineament and the surface zone of enhanced permeability is approximately 400 feet wide.

A study of initial open-flow gas data from 4,750 wells in eastern Kentucky gas fields relates Devonian Shale gas production to geologic factors including structural/stratigraphic sections, lithology, and geochemistry.

Trend analyses of initial open-flow data are interpreted as zones of more intense fracturing and show four preferred directional trends.

A series of structural cross sections were completed through the Cottageville Gas field. "Bench-like" structural features are apparent along these sections These features may be indications of basement faulting in the Rome Trough. Thickening of sediments towards the center of the Rome Trough suggests movement of the basement during deposition. Post-depositional faulting is indicated, and this faulting may have produced fracture systems for gas migration and accumulation.

Preliminary results of a fracture study along the Parsons Lineament, Tucker County, WV, indicate that: (a) there is generally no variation in joint orientations across the Lineament, (b) dominant joint sets trend N45° W and prominent sets trend N85° W and N35° E, and (c) rocks within the Lineament are more intensely fractured.

Surface structural studies of bedding orientations were conducted in the Middle Devonian black shales exposed in the Middle Mountain Syncline, Pendleton County, WV where this structure is intersected by the Parsons cross strike structural discontinuity. These studies have revealed that: (a) a zone exists within which these organic rich shales have undergone more intense flowage and faulting, (b) this zone is co-linear with the Parsons Structural Lineament, and (c) the more intense deformation therein is associated with changes in structural level and fold terminations occurring across this Lineament.

3.2.1.17 GEOLOGICAL, GEOCHEMICAL, AND GEOPHYSICAL APPRAISAL OF ENERGY RESOURCES OF THE DEVONIAN BLACK SHALE IN THE APPALACHIAN BASIN

Status: Active

United States Geological Survey
Reston, Virginia

Contract:	EX-76-C-01-2287
Contract Date:	January 1, 1976
Anticipated Completion Date:	September 30, 1979
Principal Investigator:	W. de Witt, Jr.
DOE Technical Project Officer:	A.E. Hunt

OBJECTIVE

To conduct a characterization study of the Devonian Black Shale in the Appalachian Basin and to make a detailed appraisal of the resource potential of the shale sequence, with particular emphasis on the natural gas resource.

SCOPE OF WORK

Major tasks to be performed under this interagency agreement by the United States Geological Survey include the following:

- To characterize the gas-productive and potentially gas-productive black and brown carbonaceous shales and related rocks of Middle and Late Devonian age in the Appalachian Basin using data developed on the stratigraphy, structure, mineralogy, geochemistry, geophysics, paleontology and hydrocarbon productivity of these rocks.
- To develop a comprehensive paleogeographic model of the basin of accumulation and the environment of deposition for the Devonian black shales.
- To monitor and coordinate the efforts of other EGSP contractors in their stratigraphic studies.
- To develop a data system capable of storing for retrieval the data generated by EGSP contractors in the Appalachian Basin.
- To make a resource appraisal of the energy potential of the black shale and dark brown Devonian Shales of the Appalachian Basin.

SUMMARY OF PROGRESS

To date, seven small diameter cores (NX) have been cut in eastern Tennessee. The core data is used by the USGS for geochemical, mineralogic, and paleontologic analysis. The data is being used in conjunction with the Tennessee Geological Survey - USGS - DOE seismic investigations in eastern Tennessee. Based on the analysis of the TDG/DOE core well #3, the presence of a metabentonite in the upper part of the Dowelltown Member of the Chattanooga shale has been confirmed. This ashfall bed appears to be the Center Hill metabentonite. It lies about 30 feet below the base of the Gassaway Member and in the gray shale part of the Dowelltown.

Based on conodont identifications made from samples recovered from cores in Lincoln County, WV, all but the basal few feet of black shale above the Onondaga Limestone in Lincoln County are Late Devonian in age and probably are the Rhinestreet Member of the West Falls Formation. The absence of a fauna in the basal rich shale beds precludes their identification and assignment to a specific stratigraphic interval.

A structural analysis of the Eastern Interior Aulacogen in Pennsylvania and south-central New York has determined that an old gas field in the Marcellus Shale at Watkins Glen, NY may be associated with faulting along the west side of Seneca Lake.

The integration of some of the selected radioactive shale isopach and structure maps supplied by other EGSP contractors has been initiated. These maps will be compiled into basin-wide maps and will be utilized in the resource appraisal for the Appalachian Basin.

3.2.2 ILLINOIS BASIN

3.2.2.1 General

To date, approximately 1186 feet of Devonian Shale core have been collected for physical and geochemical analysis and stratigraphic interpretations - one KY core, two IN cores and four IL cores. Basic geologic mapping is 75% complete. The mean gas content of Devonian Shale samples has been determined to be 0.42 cu ft gas/cu ft shale. The IL basin core samples have a higher organic content, but a lower degree of thermal maturity than Appalachian Basin samples resulting in a lower gas content. The ILGS has identified a 19-county area in southeastern Illinois as the only area in the state which has potential for economical shale gas production. A core will be taken in the area in late FY79 - early FY80.

3.2.2.2 CORING AND LOGGING IN HARDIN COUNTY, ILLINOIS

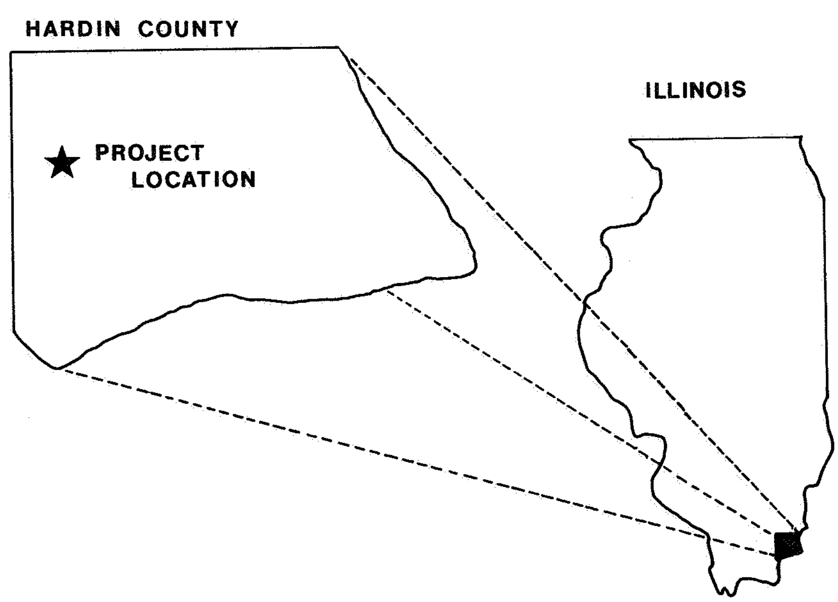
Rector & Stone Drilling Co.
Carmi, Illinois

Status: Completed

Contract:	DE-AC21-78MCO8467
Contract Date:	September 20, 1978
Anticipated Completion Date:	March, 1979
Principal Investigator:	S. Stone
DOE Technical Project Officer	C.W. Bryer

OBJECTIVE

To drill, core and log a gas well in the Devonian Shale in Hardin County, Illinois.



SCOPE OF WORK

The scope of work for this contract includes the drilling, logging, and coring of approximately 420 feet of Devonian Shale core from a well in Hardin County, IL. A detailed suite of geophysical wet-hole and dry-hole logs will be run upon completion of drilling and coring operations.

SUMMARY OF PROGRESS

The well in Hardin County, Illinois was drilled, logged, and cored in October, 1978. 237 feet of oriented core were retrieved and a suite of wet-hole and dry-hole logs was run. This completes activities under this contract.

3.2.2.3 GEOLOGIC AND GEOCHEMICAL STUDIES OF THE NEW ALBANY GROUP (DEVONIAN BLACK SHALE) IN ILLINOIS TO EVALUATE ITS CHARACTERISTICS AS A SOURCE OF HYDROCARBONS

Illinois State Geological Survey
Urbana, Illinois

Status: Active

Contract:	**DE-AC21-76MCO5203**
Contract Date:	**June 1, 1976**
Anticipated Completion Date:	**September 30, 1979**
Principal Investigators:	**N. Shimp** **R. Bergstrom**
DOE Technical Project Officer	**C.W. Byrer**

OBJECTIVE

To conduct a geologic and geochemical study of the new Albany Group (Devonian Black Shale) in Illinois to discover its potential as a hydrocarbon source, particularly natural gas.

SCOPE OF WORK

The Illinois State Geological Survey contract provides for the following characterization, evaluation, and analysis activities in the Illinois Basin:

- Geological evaluation: a detailed analysis of the lithology, stratigraphy and structure of the New Albany Group to determine those characteristics most relevant to the occurrence of hydrocarbons.

- Mineralogic and petrographic characterization: a detailed study of the New Albany Shale including quantitative and qualitative characterization by optical and x-ray techniques, of the inorganic mineral constituents, the dispersed organic matter, and the fabric of the shale.

- Physical characterization: a study of the index properties, directiona properties, and strength of oriented Devonian Shale core.

- Geochemical characterization: the determination of major, minor, and trace elements including organic and mineral carbon, total hydrogen, total sulfur, and other elements observed during normal routine analysis.

- Trace element distribution: the development of chemical and/or physical methods for the separation of the organic and inorganic phases of the shale and the determination of the trace elements associated with each phase.

- Isotopic analysis: the determination of the carbon isotopic composition of methane in off-gases from core samples.

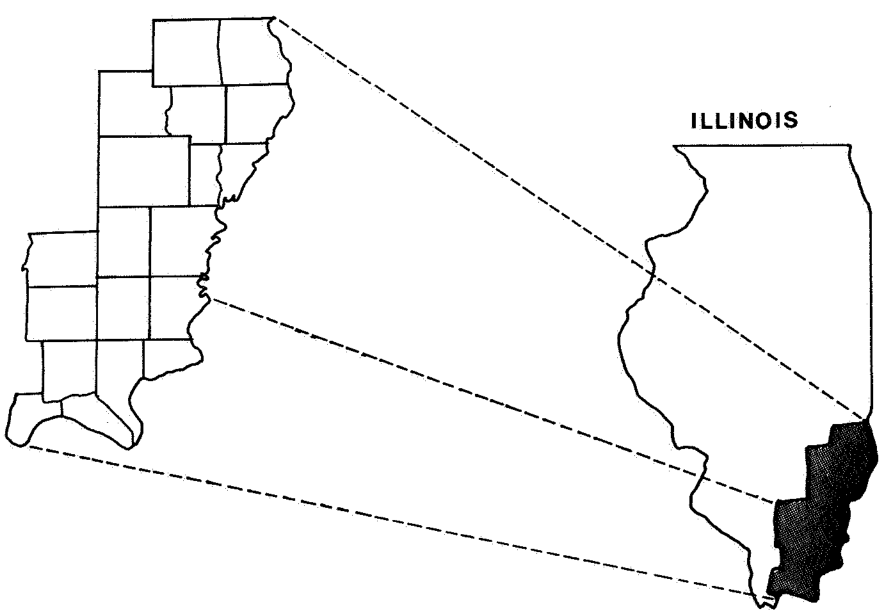
- Adsorption/desorption studies: the measurement, with nitrogen and carbon dioxide, of internal surface area on shale core samples.

- Mode of occurrence and relative distribution: the determination of the character of off-gases from approximate 10-foot intervals in cores; the determination of the relative distribution of hydrocarbons in ten specially prepared core samples; and the analysis of these special cores for evolved gases, highly volatile liquids, medium-volatile hydrocarbons, and solvent-extracted low volatile hydrocarbons.

SUMMARY OF PROGRESS

The Illinois State Geological Survey has concluded that most of the New Albany Shale in Illinois has a neglible gas resource. However, a nineteen county area in southern Illinois has been identified as a possible area with significant gas resources. This area was delineated by depositional facies, shale thickness, maturation, presence of faulting, and gas shows (see Figure 3-4).

Figure 3-4. Potential Gas Resource in Southern Illinois



Alternative methods of determining directional acoustic velocities in the shale are being tested in order to obtain greater accuracy in velocity measurements. A reflection method of determining acoustic velocities in cubic shale samples cut from core 01KY, Christian County, KY has been attempted. A transducer epoxied to one side of the cube transmits a pulse and receives the same signal after it has been reflected off the opposite side of the cube. However, tests with this method have shown that a consistently sharp signal is not received. The nature of the shale apparently attenuates the transmitted pulse. These results have discouraged further testing by this method.

The structure map on the base of the Devonian Shale in Illinois was updated and revised. A preliminary isopach map of the New Albany Shale in Illinois has been completed. Structure and isopach maps of the New Albany Shale in Illinois have been integrated with maps from Indiana. The fit is generally good although there is some disagreement over stratigraphic boundaries within the shale.

Samples from ten wells in the Illinois Basin were described and correlated to the geophysical logs. Lithologic descriptions for the Christian County, KY and Sangamon County, IL wells were revised.

Directional properties testing was completed on the Tazewell County, IL core and showed a preferred strength direction trending NW-SE and dominant point load fractures trending NE-SW. Cores previously tested in the Illinois Basin showed no directional trends.

Drill cutting samples are being used to supplement well samples. Cuttings from 13 oil wells were examined. The New Albany Group was described in detail and samples for vitrinite reflectance studies were removed from the cuttings. The lithology determined from the cuttings was compared to geophysical logs from the wells to verify lithologic determinations made from the logs. These wells were used in revising existing cross sections and in constructing new cross sections used in reports being readied for publication and oral presentation.

3.2.2.4 COORDINATION OF STUDY OF THE DEVONIAN BLACK SHALE IN THE ILLINOIS BASIN

Status: Active

Illinois State Geological Survey
Urbana, Illinois

Contract:	EW-78-S-21-8214
Contract Date:	December 1, 1977
Anticipated Completion Date:	March 1, 1980
Principal Investigator:	J.A. Lineback
DOE Technical Project Officer:	C.W. Byrer

OBJECTIVE

To coordinate EGSP studies in the Illinois Basin and develop a basin wide data base that can be used to integrate analytical results with structure, stratigraphy and production/show information.

SCOPE OF WORK

This project is designed to systematically collect and summarize data being generated by each of the contractors in the Illinois Basin in the following areas: stratigraphy and structure, physical characterization, and geochemical and mineralogical characterization. The results will be used to prepare resource and reserve estimates. Major tasks covered by this coordination activity include the following:

- To conduct a survey of current data accumulation activities to determine necessary new or expanded tasks to fill voids.
- To maintain a continuing liason with Illinois Basin contractors to ensure consistent nomenclature and comparable procedures.
- To extend the computer mapping system (ILLIMAP) to include Indiana (FY78) and Kentucky (FY79) portions of the Basin.
- To correlate geophysical log marker beds and extend cross sections across the Illinois Basin.
- To construct various types of maps of representative units of the Basin to help define the shale.
- To insure integration of core data in stratigraphic, lithologic, and structural contexts.

- To summarize all Illinois Basin data in a central computer data bank.

SUMMARY OF PROGRESS

Digitization of topographic maps needed to extend ILLIMAP into the Illinois Basin portion of Indiana has been completed.

A report on the resource potential of the Illinois Basin portion of the Devonian Black Shale has been completed and will appear in a future report.

Stratigraphic studies in the Illinois Basin part of Kentucky have been completed.

The Illinois G.S. is expected to end active data acquisition in all but some geochemical studies by the end of 1979. They propose to use the period from 12/1/79 to 3/31/80 for data analysis and synthesis and preparation of final reports.

3.2.2.5 EASTERN GAS SHALES PROJECT STUDY OF THE NEW ALBANY SHALE IN INDIANA

Status: Active

Indiana Geological Survey
Department of Natural Resources
Bloomington, Indiana

Contract:	EY-76-C-05-5204
Contract Date:	September 21, 1976
Anticipated Completed Date:	November 30, 1979
Principal Investigators:	J.B. Patton D.D. Carr R.K. Leininger G. Carpenter
DOE Technical Project Officer:	R.J. Watts

OBJECTIVE

To determine the magnitude of potential gas reserves and to characterize the New Albany Shale in Indiana.

SCOPE OF WORK

The Indiana contract provides for the following specific tasks:

- To collect, compile and analyze all available drill hole and out-crop data for the New Albany Group in Indiana. A number of full section, oriented cores of the New Albany Group will provide geological and geochemical data.

- To study the stratigraphic and structural framework of the New Albany Group and associated lithologic units above, below, and laterally equivalent to the shale interval. Series of detailed stratigraphic cross sections, isopach maps, lithofacies maps, regional structure maps, and data maps will be constructed.

- To perform detailed physical, mineral, and chemical analyses of the core material including bulk mineralogy, clay mineralogy, organic geochemistry, presence of trace elements, and physical and geophysical properties.

- To delineate target areas where commercial volumes of natural gas are likely to be present and specific production stimulation techniques are most likely to succeed.

SUMMARY OF PROGRESS

Correlation was initiated of units recognized on INGS cross sections of northern Indiana with those units recognized on cross sections of the shale interval in southern Michigan prepared by the Michigan GS. The units recognized in the shale interval are similar; however, the calcareous, medium-gray shale that lies between the base of the black shale and the top of the Traverse Formation is not recognized as part of the Antrim Shale by Michigan stratigraphers. In Indiana this calcareous shale interval is included in the Antrim. Examination of lithologic strip logs and geophysical logs shows that this gray shale, which is not present in western LaPorte County, thickens to over 40 feet in Steuben County. In several wells in LaPorte County, where the shale is absent, a thin sandstone is present at the base of the Antrim.

Thirty cores of the basal part of the New Albany Shale (Blocher Member) were examined and the core descriptions used to aid in construction of isopach maps of the Blocher. The top of the Blocher Member as recognized in southeastern Indiana commonly is marked by a fine-grained pyritic, quartzose sandstone bed that reaches a maximum thickness of about two feet in Jackson County south to the Ohio River. A thin sandy zone also was present in the Phegley core from Sullivan County. Mapping of the Blocher Member now is continuing in light of the newly collected data concerning the sandstone.

The INGS isopach map and the structure contour maps on the top and base of the New Albany Shale in Indiana were compared with recently published isopach and structure maps of the shale in western and central Kentucky. Additional data from northern Kentucky made possible a better interpretation of the structure and thickness of the New Albany in southern and southwestern Indiana where wells are sparse. The isopach and structure maps for this region have been revised and replotted at a scale of 1:500,000. Copies of these maps will be sent to EGSP participants at the Kentucky and Illinois Geological Surveys.

INGS staff collected samples from the Rockford Limestone and the upper part of the New Albany Shale from four outcrops near Henryville in Clark County, IN. These samples will be analyzed and the analyses compared with those of the New Albany core from Clark County, IN (EGSP IND-2).

A field description of the Survey Drill Hole (SDH) 291 core was completed. Forty-three samples of the Clark County core were taken to the Bureau of Mines Laboratory in Minneapolis for some physical testing procedures. In order to measure the travel time of sonic energy in the samples, ten readings in each of seven directions on each sample were made for a total of 3010 readings. Fifteen point load and Brazil split samples were also prepared.

Ninety-two samples of the Clark County, IN core were tested for scleroscope hardness.

C/H/N determinations were completed for 305 samples.

Analytical work was completed on 14 selected samples from the Phegley core. The work included quantitative alkane plus olefins and aromatic and polar compounds of retort oil, and the quantification of the components in the retort gases.

Determination of major elements in SDH 275 (Marion County) and determination of trace elements in 18 of the samples were completed by the ICP-OES method. In addition, silver was determined in the two reference samples from SDH 273 (Marion County) by atomic absorption.

Forty-four shale samples from SDH 185A (Clark County) and 11 samples from SDH 199 (Putnam County) IN were analyzed for 20 trace elements.

3.2.2.6 EASTERN GAS SHALES PROJECT NEW ALBANY BLACK SHALE STUDY OF WESTERN KENTUCKY

University of Kentucky Research Foundation
Henderson, Kentucky

Status: Active

Contract:	EW-78-S-21-8215
Contract Date:	December 1, 1977
Anticipated Completion Date:	September 30, 1979
Principal Investigator:	J. Beard
DOE Technical Project Officer:	C.W. Byrer

OBJECTIVE

To collect, interpret, and report geological and geochemical information about the New Albany Shale of western Kentucky.

SCOPE OF WORK

This contract provides for the characterization of the New Albany shale in the western Kentucky portion of the Illinois Basin. Close contact will be maintained with the Indiana and Illinois Geological Surveys. The Illinois Geological Survey (contract #8214) is responsible for overall coordination of the Illinois Basin studies.

Specific tasks included under this contract are:

- To map the occurrence of the New Albany Shale in the subsurface through the construction of cross sections, isopach maps, and structure maps.
- To extend the subsurface study to the surface exposures and near surface areas of the New Albany Shale.
- To describe lithologies from outcrop and shallow cores and to correlate these data with the subsurface data.
- To identify, plot and interpret joint and fracture system, petrologic, x-ray diffraction, and geochemical data.
- To prepare a map of wells with shows of gas and to tabulate well data for gas production, gas analysis, and drill stem tests of New Albany wells.

SUMMARY OF PROGRESS

All isopach maps and cross sections generated under this contract have been reviewed and are awaiting publication.

The final report for FY78 is in preparation. An appendix to the report will include the reported gas shows and known producing wells in the Devonian Shale of western Kentucky.

Stratigraphic information has been compiled from available well logs and forwarded to the Illinois GS, for inclusion in the overall Illinois Basin study.

Three Devonian Shale cores have been recovered from the outcrop belt in the western Kentucky portion of the Illinois Basin. The cores have been described and samples taken for petrographic and geochemical analysis. Two or three additional cores will be recovered in the Spring of 1979.

3.2.3 MICHIGAN BASIN

3.2.3.1 General

Dow Chemical Company, Midland, Michigan is responsible for the geological, lithological, physical, and geochemical characterization of the Antrim Shale in the Michigan Basin under a separate Department of Energy contract. The emphasis of the Dow program is in situ processing of the shale for oil and gas extraction. Efforts are currently underway through the EGSP to assess the shale characterization being performed in the Michigan Basin and how it relates to EGSP goals and objectives. Preliminary results indicate that the geologic, physical, and lithologic analyses and products being generated in the Basin are compatible with the information needed by the EGSP. Additional core sites and EGSP geochemical analytical tests on these cores are required before the gas resource potential of the Devonian Shale in the Michigan Basin can be determined.

3.3 SUPPORTING RESEARCH AND DEVELOPMENT

3.3.1 GENERAL

Except for the Technical and Management Support contract (see Section 3.3.4), all contracts included in this section are part of the Extraction Technology R&D element of the Eastern Gas Shales Project.

This effort includes work specific to the EGSP, as well as relevant aspects of work performed as part of the Unconventional Gas Recovery Program. The former category consists of the development of reservoir models and well testing procedures for Devonian Shale. The latter includes work performed by three national laboratories relating to rock mechanics properties, and the propagation and geometry of induced fractures.

3.3.2 GAS WELL TESTING AND ANALYSIS SERVICE IN THE DEVONIAN SHALE

Gruy Federal, Inc.
Houston, Texas

Status: Active

Contract:	EW-78-C-21-8096
Contract Date:	April 17, 1978
Anticipated Completion Date:	October 1, 1979
Principal Investigator:	J. Hartsock
DOE Technical Project Officer:	K-H. Frohne

OBJECTIVE

To develop and conduct a program of uniform gas well testing procedures and to analyze the test results in support of the Eastern Gas Shales Project (EGSP).

SCOPE OF WORK

This testing program is divided into two phases. Phase I consists of a six month program to test five wells in order to develop an orderly procedure by which Devonian Shale wells can be tested and the transient pressure analyzed. Phase II applies the technology developed in Phase I to test approximately twenty wells on an "as needed" basis. The well tests and analyses are intended to permit evaluation of the effectiveness of various hydraulic and explosive stimulation techniques conducted under the EGSP.

SUMMARY OF PROGRESS

Phase I of the program was completed during this reporting period. The number of wells tested was reduced to three.

The Pacific States Gas and Oil Co., L. Bonnett No. 1 well in Gilmer County, WV, treated with a cryogenic stimulation between 6377 feet and 6501 feet was tested. The test data was history matched using a three dimensional single-phase gas simulator which solves the flow equations in terms of the real gas pseudo-potential. The model also includes wellbore storage, finite capacity fractures and turbulence. The best history match is shown in Figure 3-5. The properties used in the history match were:

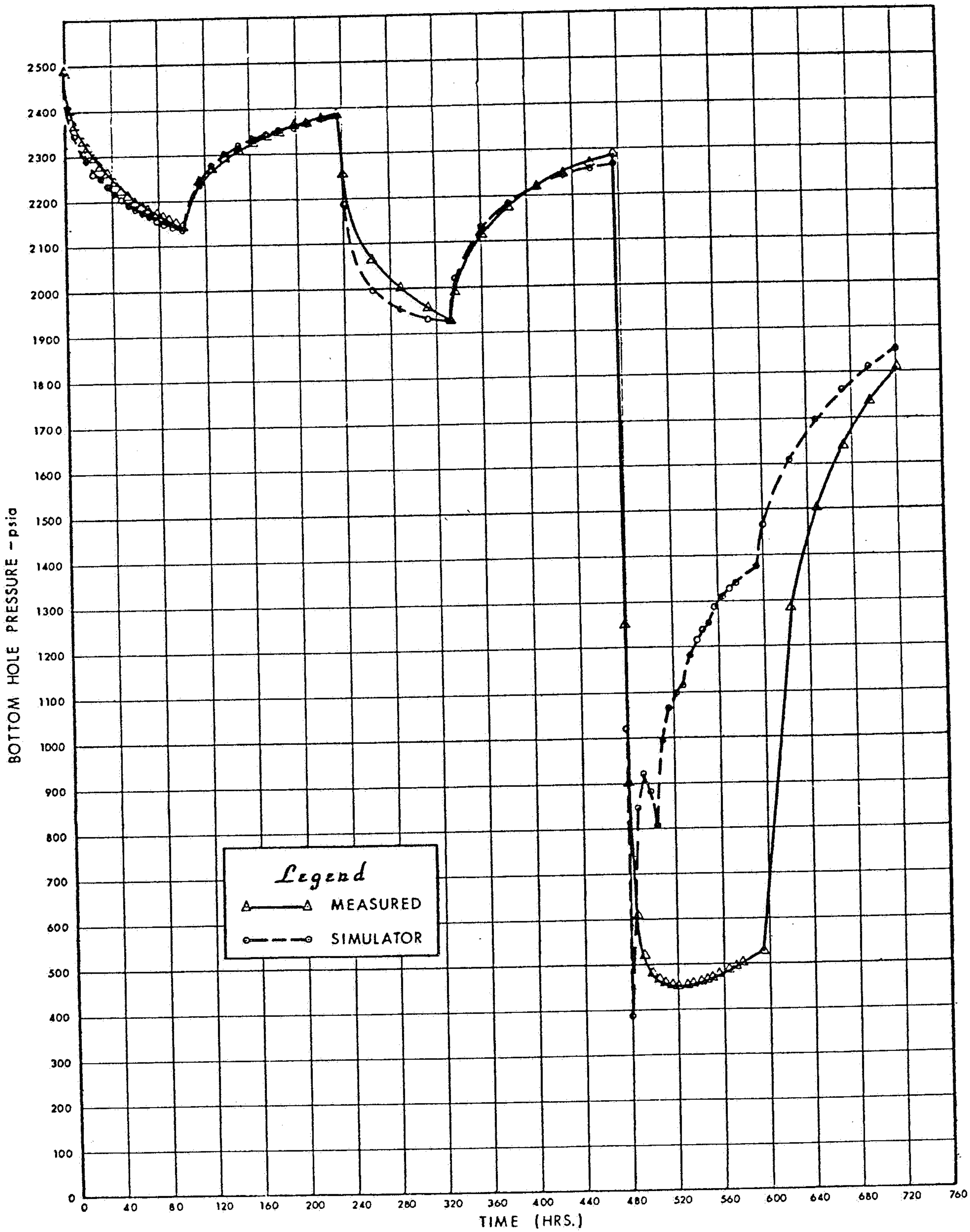


Figure 3-5. History Match for Pacific States Gas and Oil Company, L. Bonnett No. 1 Well

RESERVOIR

Effective porosity	- 0.8%
Effective permeability	- 0.002 md
Turbulence coefficient	
formation	- 12.236×10^{15} ft.$^{-1}$
fracture	- 950 ft.$^{-1}$

FRACTURE

Half fracture length	- 195 feet
Total fracture porosity	- 33%
Effective fracture permeability	- 125 md - 650 md*
Fracture height	- 124 feet

*At the highest flow rate the frac water flowed from the fracture to the wellbore, which increased the gas saturation in the fracture and thus increased the effective permeability to gas.

An estimation of matrix permeability from an analysis of drawdown and build-up follows.

	DRAWDOWN PERMEABILITY (md)	BUILDUP PERMEABILITY (md)
First Period	.005	.00011
Second Period	.0026	.0015
Third Period	.0066	.002
Fourth Period	.0019	.0014
Arithmetic Mean	.00403	.00125
Log-Mean	.00357	.00082
Overall Arithmetic Mean	.00264	
Overall Log-Mean	.00171	

Analysis of the transient test data on the Pacific States Gas and Oil Company, L. Bonnett No. 1 well led to the following conclusions:

- The cryogenic frac treatment created a fracture whose half-length is approximately 195 feet. In the vertical direction the fracture was probably confined to the perforated interval.
- The presence of water in the well increased the back pressure on the formation and created a high water saturation in the fracture, resulting in a low effective permeability to gas. Rerunning the siphon string might reduce this water volume and increase deliverability.
- The wellbore storage effect was never detected during the early time transient test.

- It must be realized that the reservoir properties obtained from the history match using the reservoir simulator are not unique and that other combinations will give similar history matches. These properties were selected on the basis of their consistency with the other analyses.

The Columbia Gas well 20336, located in Martin County, KY was treated with a cryogenic stimulation in the intervals between 2666 feet to 2712 feet and 2968 feet to 3122 feet. Post fracture well test analysis was performed on this well. Reservoir properties used in history matching well test data were as follows and a plot of these data is presented in Figure 3-6.

RESERVOIR

Effective Porosity	1.275%
Effective Permeability	0.015 md
Turbulence Coefficient	0.0272×10^{15} ft $^{-1}$
Total Reservoir Thickness	456 ft.

FRACTURE

Half Fracture Length (Top Zone)	636 ft.
Half Fracture Length (Bottom Zone)	173 ft.
Fracture Porosity	33%
Effective Fracture Permeability	500,000 md
Fracture Height (Top Zone)	46 ft.
Fracture Height (Bottom Zone)	154 ft.
Turbulence Coefficient	10,744 ft $^{-1}$
Fracture Width	0.2 in.

An estimation of matrix permeability from pressure drawdown and buildup analysis is as follows:

	Permeability (md)
First Drawdown	0.0831
Second Drawdown	0.186
Buildup	0.07185
Arithmetic Mean	0.1137
Log-Mean	0.1036

Analysis of the transient test data on the Columbia Gas Corp. Well No. 20336 led to the following conclusions:

- The cryogenic fluid treatment created fractures in the top and bottom zones with half-lengths of approximately 635 feet and 173 feet, respectively. In the vertical direction the fractures were probably confined to the perforated intervals only.

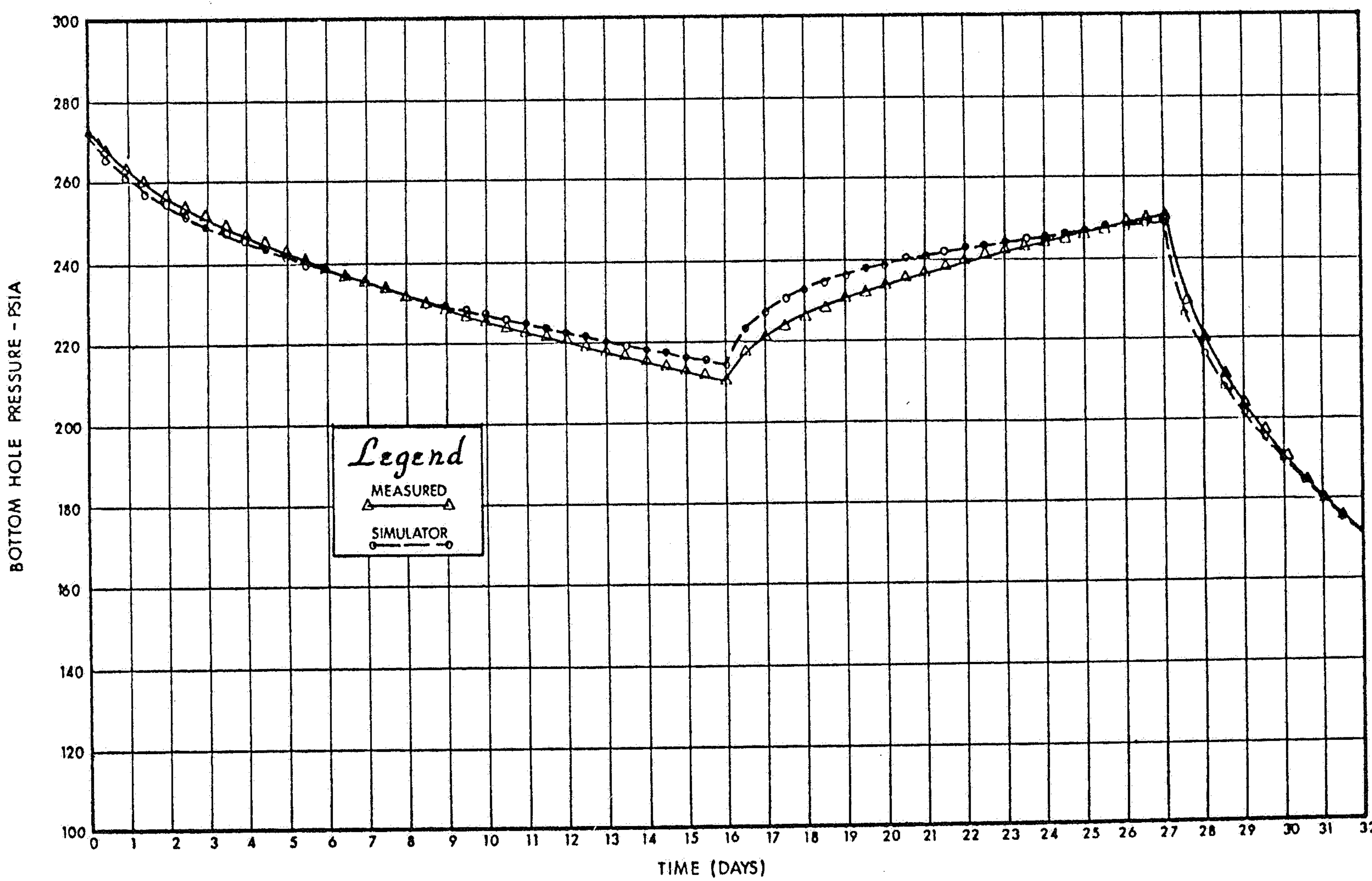


Figure 3-6. History Match for Columbia Gas Transmission Corp. Well No. 20336

- It must be realized that the reservoir properties obtained from the history match using the reservoir simulator may not be unique, but they are consistent with the results of the other analyses. However, other combinations might give similar history matches. These properties were selected on the basis of their consistency with the other analyses.

A history match for Kentucky-West Virginia Gas Company Well No. 1627 appears in Figure 3-7. Reservoir properties and conclusions resulting from the analysis of the transient test data will be discussed in a subsequent report.

These three wells conclude Phase I of the program and Phase II is presently in progress.

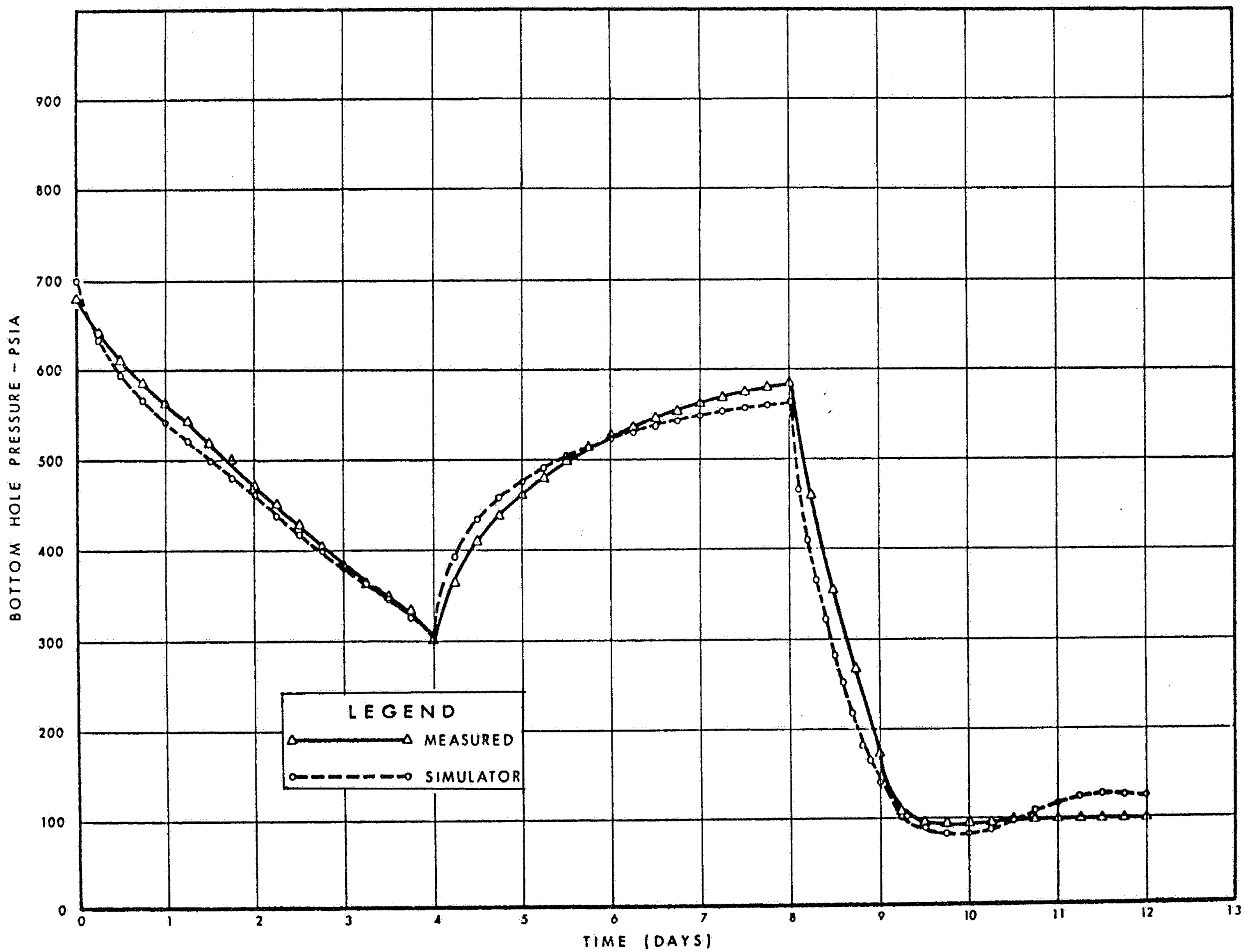


Figure 3-7. History Match for Kentucky-West Virginia Gas Company Well No. 1627

3.3.3 ANALYSIS OF GAS PRODUCTION FROM EASTERN GAS SHALES

Intercomp Resource Development and
Engineering, Inc.
Houston, Texas

Status: Active

Contract: EW-78-C-21-8485
Contract Date: October 1, 1978
Anticipated Completion Date: March 31, 1979

Principal Investigator: H. Price
DOE Technical Project Officer: C.A. Komar

OBJECTIVE

To analyze and determine performance parameters critical to the productivity and future recovery of gas from the Devonian Shales.

SCOPE OF WORK

The major tasks under this contract include the following:

- To analyze the sensitivity of parameters that affect the deliverability and recovery of gas from shales including well stimulation processes.
- To design field tests, well logging and coring programs, log analysis procedures and well test interpretation techniques and to recommend laboratory measurements for the determination of those parameters critical to the productivity and timely recovery of gas from the Devonian Shales.
- To analyze pressure transient data from producing shale gas wells and pre- and post-fracture stimulation treatments on such wells in order to determine critical performance parameters and to project future deliverabilities and recovery.
- To develop and apply petrophysical techniques for shale resource description.

SUMMARY OF PROGRESS

The usefulness of a possible three-well field test was studied using the validated model of a portion of the Cottageville Field from the first contract phase. The results showed that such a test would not indicate the existence of an adsorbed gas phase, that is, the projected production from each well and the central well showed no unusual characteristic that could be attributed to the adsorption/desorption mechanism.

Sensitivity analyses indicated the parameters having greatest effect on production and recovery were matrix permeability and fracture length.

3.3.4 TECHNICAL AND MANAGEMENT SUPPORT SERVICES

Status: Active

Science Applications, Inc.
Morgantown, West Virginia

Contract:	DE-AT21-78MCO8216
Contract Date:	August 1, 1978
Anticipated Completion Date:	July 31, 1979
Principal Investigator:	W.G. McGlade
DOE Technical Project Officer:	R.L. Wise

OBJECTIVE

To provide technical and management support services for a program to increase natural gas production from marginal gas resources of the United States.

SCOPE OF WORK

The technical and management support consists of planning assistance, analytical studies, technical fact finding and evaluation, engineering services, and technical and management analyses and investigations.

SUMMARY OF PROGRESS

Significant technical results during the last six months included:

a. A draft report "Hydraulic Fracture Containment as it Relates to Eastern Devonian Shales" was prepared.

b. Various explosive stimulation techniques are being evaluated for use in the EGSP. Tailored-pulse-loading has been shown to be a promising technique.

c. A health and safety feasibility study for *in situ* test experiments in Devonian Shales was performed, and indicated that no unusual hazards are likely to be encountered.

d. A study comparing well logs with core analysis data concluded that the most practical and economical suite of logs that will provide sufficient data for the analysis of the shales consists of: gamma ray, compensated bulk density, induction, temperature and sibilation.

e. Analytical solutions for simplified and idealized Devonian Shale reservoirs were developed. This model indicated that the diffusion coefficient, adsorption isotherm, initial concentration of gas in the matrix, and size of the matrix strongly affect production.

f. A report including compilation and evaluation of all outgassing data collected to date was produced.

In addition, support was provided to METC in activities related to the Project Integration element of the EGSP.

3.3.5 NATIONAL LABORATORIES

Ongoing work at the National Laboratories relating to the EGSP is for the most part an ancillary part of a larger program of activities directed to solving general fossil energy exploration and exploitation problems.

LOS ALAMOS SCIENTIFIC LABORATORY

The Los Alamos work related to the EGSP is primarily concerned with questions of production enhancement through new technology that can model and control the flow of fluids. Specifically, the following are being undertaken:

- Technical studies of heat and mass transport in reservoir rocks.
- Consideration of fluid/formation damage interactions.
- Development of a fracture model.
- Computer generation of geological and reservoir maps.
- Establishment of an NMR focused logging capability.
- Consideration of the dynamic aspects of an explosive event in well stimulation.

The latter activity involves lab and field studies based on rock mechanics and fluid flow understanding. Specifically, attention is given to topics such as natural flow, explosive behavior, stress wave propagation, material response, late time effects, and altered flow. The aim is to understand stress wave propagation, fracture containment and related problems.

LASL also is involved in the following activities:

- Downhole instrumentation development (NMR logging, epithermal neutron logging, methane-detector logging).
- Fracture/flow correlations (e.g. geological/production), correlations via Monte Carlo, and stochastic modeling).
- Dynamic rock mechanics (e.g. jet penetrators, dynamic fracture modeling, field tests).
- Dynamic map transfer (permeability/porosity measurements, simulated in situ studies, flow mechanism studies)
- Geochemistry (laserpyrolysis, core analysis, kerogen and maturation studies).

Of special interest is the modeling work to describe the situation at Cottageville, WV. An evaluation and integration of all geological, geophysical and gas production data is being done. These data will then be considered in a way that accounts for historical production. By using a single-phase Darcy-flow simulator together with a data base management code, selecting, ranking, rotating, mapping, meshing and plotting of various attributes of wells in the field will be achieved. Individual well flow data also are interpolated onto the grid together with stratigraphic information. Contingency tables then are employed to study the degree of correlation achieved.

The advantages of the Nuclear Magnetic Logging (NMR) tool include the short duration ("dead time") and the absence of elaborate (costly) drilling procedures in the tests. The tool is focused, and through a Fourier Transform spectral analysis an identification of hydrocarbon perhaps will be possible. In any event, the tool is capable of yielding total fluid saturation, free fluid index, calculations of porosity and permeability, and the like.

With respect to explosive characterization, LASL is dealing with explosives such as PBX 9407, ANFO, ANFO/AL, DBA-1 water gel, TNT, Amatex/40, Stratablast C, and Talley TAL-1005-E. Performance is studied in terms of detonation velocity, detonation pressure and energy release. The techniques employed involve aquarium tests and air-shock experiments.

LAWRENCE LIVERMORE LABORATORY

The Lawrence Livermore Laboratory work also deals with the fracture containment problem, especially with respect to the effect of friction at lithologic boundaries. Also being dealt with are topics such as proppant crushing, and formation damage due to frac fluid.

One conclusion reached is that simplistic theories of fracture generation and propagation fail in most cases to predict true fracture orientation, size and shape. Because of this conclusion, LLL has focused on questions dealing with the geometry of created fractures, and controlling factors. Their position appears to be that with respect to hydraulic fracturing little is really known about what actually occurs in field tests.

Their study program contains both theoretical and experimental facets including:

- Two and three dimensional modeling of hydraulic fracturing.
- Laboratory experiment modeling.
- Rock mechanics measurements.
- Reservoir analysis.
- Conventional log evaluation.
- Dry hole sonic log development and application.
- Environmental reports.

SANDIA LABORATORIES

Sandia is intensively involved in stimulation, fracturing, logging, and drilling research. They are providing instrumentation for, and designing and analyzing test results at the Nevada Test Site mineback facility. Among other things, this work relates to developing a better understanding of the tailored pulse loading concept. In logging, Sandia is reconsidering the subject at the very basic level of applying the Maxwell relations. The aim is to develop a capability to measure rock properties such as porosity and fracture density.

Specific items of interest include:

- Crack 'R Frac approach. The objectives are: to determine if dynamic effects (i.e. pump rate) can affect fracture containment at an interface; to confirm in situ stress data at particular locations; and to examine the merits of small scale tests.

- The high energy gas frac approach. The concept is to tailor the pressure-time behavior of the deflagration of a suitable propellant to create multiple radial fractures. The requirements are to achieve a rapid loading rate, peak pressures considerably above the in situ stresses (but below the flow stresses of the rock), contained gas generation, and self propping.

- In situ testing of well shooting concepts. Attention will be given to Dynafrac, augmented Dynafrac (with propellant pusher), Kinefrac (small diameter pressure insensitive propellant), and multiple Kinefrac, and gas frac (well bore filled with pressure sensitive propellant).

Sandia is also working on the development of borehole hydrophone systems in order to gain information about aspects such as fracture geometry and formation (acoustic) velocity. In their advanced logging program attention is being given to the dispersive electrical parameters (conductivity, permittivity and permeability), and to the ancillary relations that connect electrical and production parameters.

3.4 FIELD TESTS AND DEMONSTRATIONS

3.4.1 GENERAL

The contracts in this section include all the work under the Technology Testing and Verification element of the Eastern Gas Shales Project, (contracts 3.4.3, 3.4.5, 3.4.8, 3.4.10, and 3.4.15) as well as part of the Extraction Technology R&D element.

Field tests and demonstrations are required to verify the exploration and exploitation rationales developed in the project. The work reported here includes tests of explosive and hydraulic fracturing methods, dual completion and deviated drilling techniques, and also tests of several proposed exploration rationales.

3.4.2 HYDRAULIC FRACTURING EXPERIMENT IN JOHNSON COUNTY, KENTUCKY

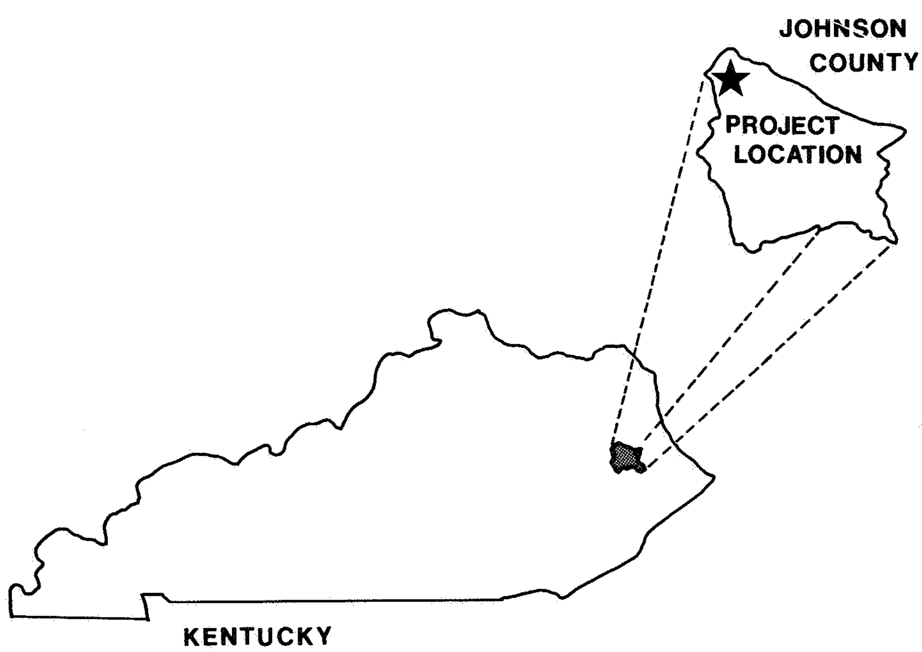
Ashland Exploration, Inc.
Ashland, Kentucky

Status: Completed

Contract:	DE-AC21-78MCOO8444
Contract Date:	September 26, 1978
Anticipated Completion Date:	March, 1979
Principal Investigator:	J. Avila
DOE Technical Project Officer	C.W. Byrer

OBJECTIVE

To drill, log, core, stimulate, and test a gas well in the Devonian Shale in Johnson County, Kentucky.



SCOPE OF WORK

Specific tasks include the following:

- To drill, core, log and case a well into the Devonian Shale in Johnson County, KY. Approximately 500 feet of core are to be retrieved. Following the coring operation, a comprehensive suite of geophysical wet-hole and dry-hole well logs will be run.

- To hydraulically fracture the well. The shale is to be stimulated in two separate sections utilizing two different types of hydraulic treatments. Complete records of the frac job will be kept and when the well is adequately "cleaned-up", a suite of post-frac logs will be run.

- To perform post-frac testing and long range monitoring of production history and to report production history on a monthly basis for five years.

SUMMARY OF PROGRESS

The well in Johnson County, Kentucky was drilled, logged, and cored in October, 1978. 543 feet of oriented core were retrieved and suites of wet-hole and dry-hole well logs were run.

Two zones were stimulated using foam with nitrogen. The Lower Brown Shale Zone between 1294-1382 feet was fractured using 318 bbls of water and 60,000 lbs of sand. The final flow of gas was measured at 28 Mcfd. The lower zone was isolated and the upper Brown Shale between 1010-1120 feet was stimulated using 260 bbls water w/nitrogen and 60,000 lbs of sand. After clean-up of both zones a 16 hour open flow test was made and gas was measured at 57.7 Mcfd. After 110 hours the stabilized gas flow rate was 43 Mcfd.

3.4.3 PROJECT GASDEVEL—GAS PRODUCTION STIMULATION BY MASSIVE HYDRAULIC FRACTURING

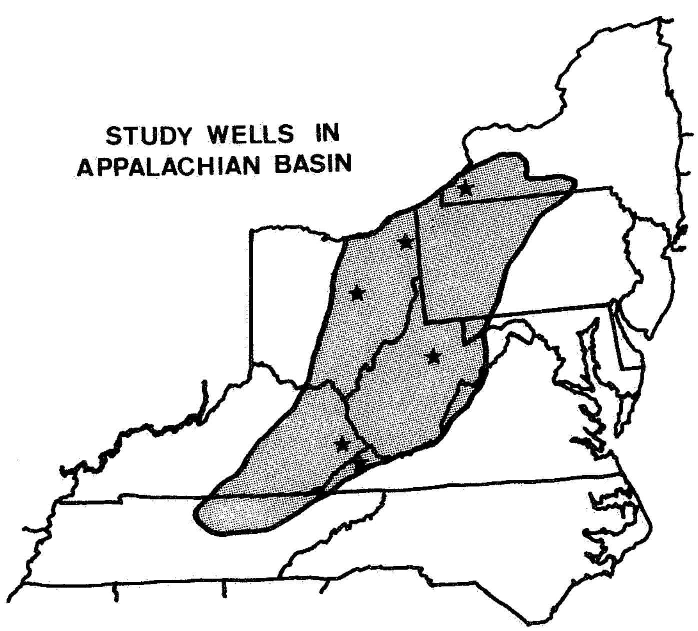
Columbia Gas System Service Corporation
Columbus, Ohio

Status: Completed

Contract:	EY-76-C-05-5303
Contract Date:	July 1, 1976
Anticipated Completion Date:	December, 1978
Principal Investigator:	W.F. Morse
DOE Technical Project Officer:	K-H. Frohne

OBJECTIVE

To demonstrate the technical and economic feasibility of using massive hydraulic fracturing technology for increasing gas deliverability from the marginal gas resources of the Appalachian Basin.



STUDY WELLS IN APPALACHIAN BASIN

SCOPE OF WORK

The scope of this field project is to demonstrate the technical and economic feasibility of massive hydraulic fracturing (MHF) as an effective technique for increasing gas deliverability from the marginal gas reservoirs of the Appalachian Basin. The fracturing work is to be conducted as a seven phase program involving 13 wells and 14 fracturing treatments in five different producing formations in several Appalachian states in order to determine: (a) if present production on presently producing formations could be increased, and (b) if presently uneconomical formations and new areas could be made economical production areas. Project activities include the investigation of four dendritic-type stimulation treatments, four cryogenic treatments (including one dual completion) and six other MHF treatments.

SUMMARY OF PROGRESS

This program was designed to stimulate and test thirteen wells scattered throughout the Appalachian Basin. The project activities have been completed and the final report is being prepared. A total of eighteen stimulation treatments were performed on thirteen wells. The breakdown of these treatments by type, and formation treated is as follows:

Type of Treatment	Formation and Wells Treated									
	Devonian Shales		Clinton Sandstone		Berea Sandstone		Medina Sandstone		Benson Sandstone	
	Wells (No.)	Treat-ments	Wells (No.)	Treat-ments	Wells (No.)	Treat-ments	Wells (No.)	Treat-ments	Wells (No.)	Treat-ments
Cryogenic	4	8	-	-	-	-	-	-	-	-
Dendritic (Kiel)	-	-	1	1	1	1	1	1	1	1
MHF	-	-	3	3	1	1	-	-	-	-
MHF Foam	-	-	-	-	-	-	1	1	1	1
TOTALS	4*	8*	4*	4*	2	2	2	2	2	2

*Includes one dual completion well

Long-term production testing is required before absolute conclusions can be made. However, the following initial conclusions have been made:

- The effectiveness of remote sensing in increasing productivity appears to be localized.
- Hydraulic stimulation is more economical than stimulation by shooting with gelled nitroglycerine. The optimum size has not been determined.
- Massive treatments in Appalachian sandstone had mixed results. Thus, it appears unlikely that MHF treatments will provide a universal improvement although there may be some potential application.
- Dendritic fracturing tests were successful when nitrogen or carbon dioxide was used to provide energy assist.
- Adding nitrogen or carbon dioxide as an energy assist mechanism improved well cleanup in all cases.
- Reservoir testing is more costly and time consuming than originally expected when large quantities of fluids have been introduced into the wells. Large cleanup periods are required.

3.4.4 MASSIVE HYDRAULIC FRACTURING IN THE DEVONIAN SHALE

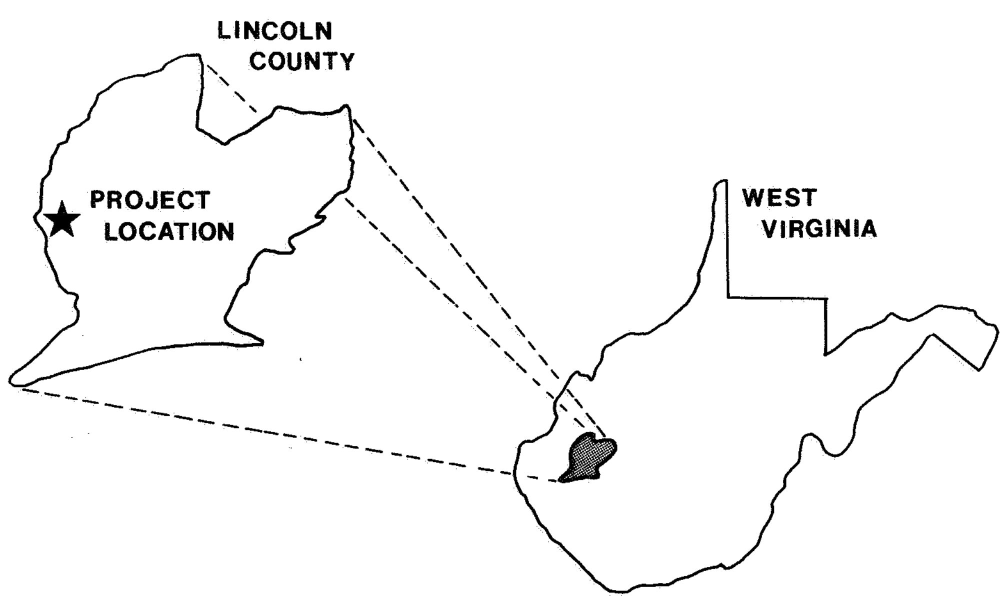
Columbia Gas System Service Corporation
Columbus, Ohio

Status: Completed

Contract:	EF-76-C-05-8014
Contract Date:	June 18, 1975
Anticipated Completion Date:	September, 1978
Principal Investigator:	W.F. Morse
DOE Technical Project Officer:	K-H. Frohne

OBJECTIVE

To assess the technical and economic effectiveness of massive hydraulic fracturing for the development of the marginal gas resource known as the Devonian Shale.



SCOPE OF WORK

The scope of this contract includes three distinct phases as follows:

- Phase I: To drill, retrieve oriented core, log, and case three wells in an established, naturally fractured, gas producing area of the Devonian Shale in preparation for stimulation by massive hydraulic fracturing. In Well No. 1, to design and execute four stages of formation stimulation; and to conduct reservoir tests after each completed stage.

- Phase II: To hydraulically fracture up to four zones in Well No. 2 in order to determine the effectiveness of fracture extension from relatively thin zones in the wellbore; and to conduct reservoir tests after completion of each stage.

- Phase III: To stimulate well No. 3 utilizing the knowledge gained from Phase I and Phase II in order to optimize the target zone; and to make recommendations for application of the results of this program to the development of shale gas production.

SUMMARY OF PROGRESS

The program consisted of drilling three wells in Lincoln County, WV, which were stimulated with a total of ten varied massive hydraulic fracturing treatments. Additionally, special logging, coring, and other types of analyses were performed.

All activities defined in the scope of work have been completed. Based on the studies and tests performed in the program, the following conclusions have been reached.

Shale Characterization

- Mobile gas is in the black or dark brown organic-rich zones high in kerogen and uranium, and to a lesser extent near these zones where fractures are present.

- Gamma ray and density logs can adequately locate the black Devonian Shales in the western Appalachian Basin which contain high kerogen and uranium concentrations.

- Drilling and fracturing fluids do not affect the organic-rich black Devonian Shale; however, they do affect some gray shales.

- Rock properties show that the black shales fracture more easily than gray shales.

- Based upon well production, log, and core data, the amount of potentially recoverable Devonian Shale gas estimated by various methods ranges from 200 to 900 trillion cubic feet.

- The bulk of the recoverable shale gas is adsorbed on the kerogen within the shale matrix. Diffusion rates, desorption rates, natural fracture density and interconnectedness control gas volumes and production rates.

- The lower brown shales (Marcellus and Rhinestreet Formations) contain significant producible gas.

Shale Stimulation

- Hydraulically fractured wells will produce considerably more gas than wells stimulated with 80% gelled nitroglycerine. Based on the production data available from one of the wells treated, it should produce about 800 MMcf over 30 years in spite of the fact that the area is partially depleted. This compares with 525 to 605 MMcf from nearby shot wells.

- Energy assist treatments such as foam (with nitrogen) are more effective than gelled water treatments due to faster cleanup.

- A single, limited entry treatment in selected intervals with an energy assist fluid is the preferred stimulation approach.

- Large treatment sizes do not necessarily increase production proportionally and may cause extensive cleanup problems.

- Optimization of treatment design has not yet been achieved.

Well Testing

- Cumulative production curves on a log-log plot provide the most reliable index of a well's ultimate potential, if based on at least six months' production data.

- Normal reservoir pressure tests provide little useful data on hydraulically fractured wells due to the protracted presence of fracturing fluid and a slow response causing increased time and cost.

- Excessive shut-in times required for testing could be detrimental if production is from fractures in the gray shales.

3.4.5 ASSESSMENT OF THE ECONOMIC POTENTIAL OF DEVONIAN SHALE GAS PRODUCTION

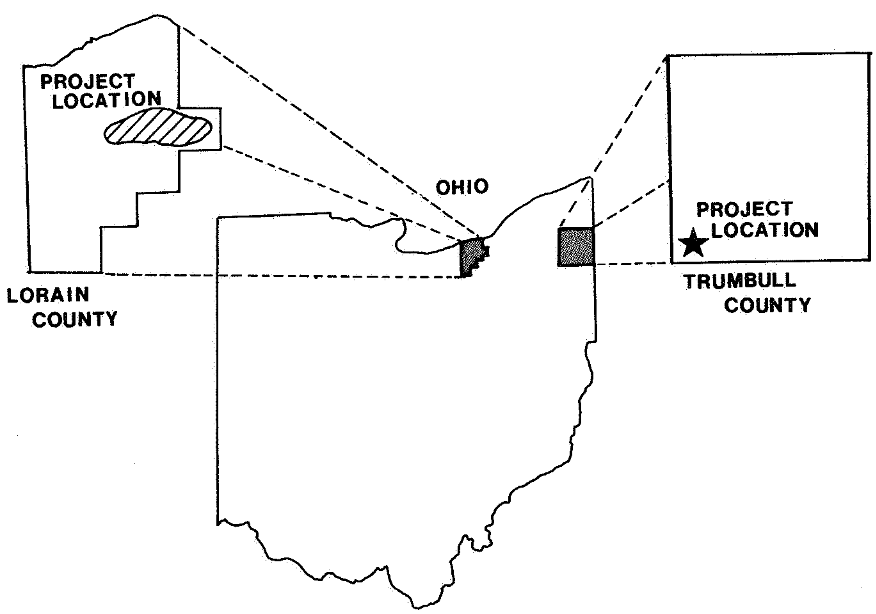
Columbia Gas System Service Corporation
Columbus, Ohio

Status: Active

Contract:	EW-78-C-21-8385
Contract Date:	September 27, 1978
Anticipated Completion Date:	September, 1980
Principal Investigator:	W.F. Morse
DOE Technical Project Officer:	C.A. Komar

OBJECTIVE

To demonstrate the gas producing potential of the Devonian Shale over a wide area in the Appalachian Basin, and to demonstrate state-of-the-art logging and stimulation techniques in relation to geologic and stress conditions of regional provinces in the Basin.



SCOPE OF WORK

The major tasks to be performed under this contract are to drill, log, and stimulate ten wells (two regions with five wells per region) in Trumbull and Lorain Counties, OH. One well in each region will be cored. Selection of stimulation technology will be made in light of geological conditions in the area. After site selections, drilling, logging, coring, and stimulations are completed, an evaluation of the results will be made including a determination of the reserves, economics, and the most efficient program for the development of Devonian Shale gas in the areas of the study.

SUMMARY OF PROGRESS

Columbia Gas System and DOE finalized the contract on March 20, 1979. Tentative proposed locations of well sites on the target areas have been made and EIA's have been completed showing the sites to be environmentally acceptable. Drilling is expected to begin during mid-summer, 1979.

3.4.6 HYDRAULIC FRACTURING EXPERIMENT IN ALLEGHENY COUNTY, PENNSYLVANIA

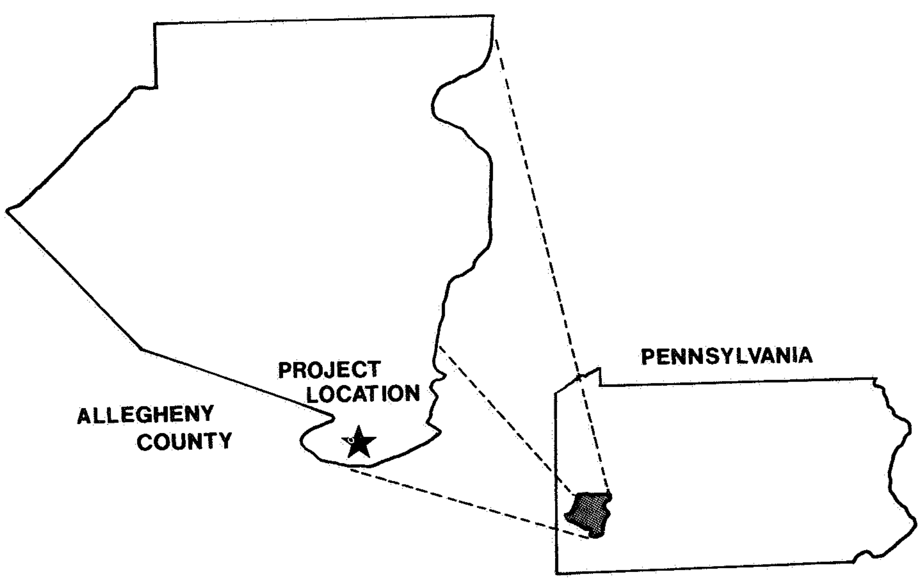
Status: Active

Combustion Engineering, Inc.
Windsor, Connecticut

Contract:	DE-AC21-79MC10374
Contract Date:	February 12, 1979
Anticipated Completion Date:	June, 1979
Principal Investigator:	P. Murphy
DOE Technical Project Officer:	K-H. Frohne

OBJECTIVE

To drill, log, core, stimulate, and test a gas well in the Devonian Shale in Allegheny County, Pennsylvania.



SCOPE OF WORK

Specific tasks include the following:

- To drill, core, log and case a well into the Devonian Shale in Allegheny County, PA. Approximately 800 feet of core are to be retrieved. Following the coring operation, a comprehensive suite of geophysical wet-hole and dry-hole well logs will be run.
- To hydraulically fracture the well. Complete records of the frac job will be kept and when the well is adequately "cleaned-up", a suite of post-frac logs will be run.
- To perform post-frac testing and long range monitoring of production history and to report production history on a monthly basis for five years.

SUMMARY OF PROGRESS

The well in Allegheny County, Pennsylvania was drilled, logged, and cored in March, 1979. 570 feet of oriented core were retrieved and suites of wet-hole and dry-hole well logs were run. The well is presently shut-in and is scheduled for stimulation in the Marcellus and Burket zones during the next reporting period.

3.4.7 DIRECTIONALLY DRILLED WELL IN THE DEVONIAN SHALE

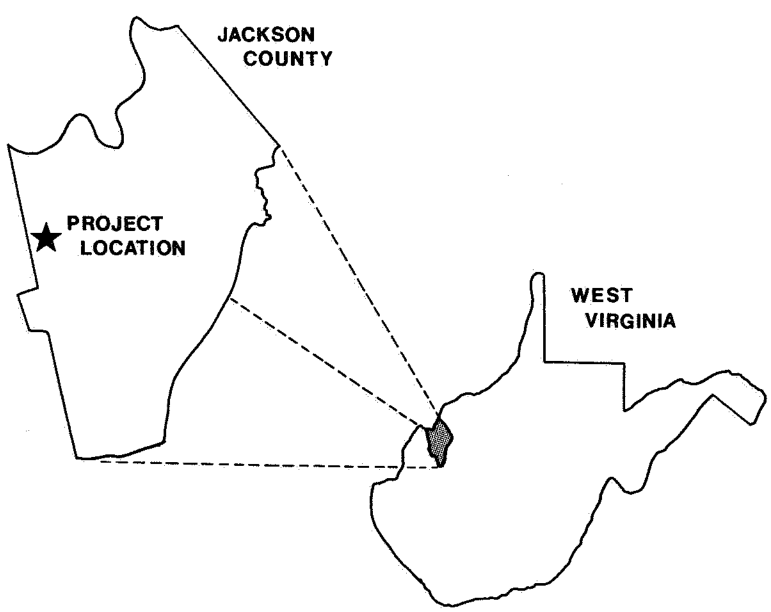
Status: Completed

Consolidated Gas Supply Corporation
Clarksburg, West Virginia

Contract:	EY-76-C-21-8047
Contract Date:	September 30, 1976
Anticipated Completion Date:	December 31, 1978
Principal Investigator:	T.A. Kuhn
DOE Technical Project Officer	A.B. Yost II

OBJECTIVE

To test the concept that a deviated gas well will intercept more of the natural fracture system than vertical wellbores, and will therefore, produce more gas.



SCOPE OF WORK

This project is to be conducted as a three phase operation as follows:

- Phase I: To conduct geophysical investigations; to study and analyze remotely sensed imagery of the Cottageville area, near-surface measurements of the earth's stress field, the orientations of surface joints in rocks in the Cottageville area, fracture density and fracture orientation data; and using all the information thus gathered to locate and design a directionally controlled deviated well in an area of the Devonian Shale expected to have the highest fracture density.

- Phase II: To drill a wellbore through the Devonian Shale according to the design arrived at in Phase I; to conduct a wireline logging program, to run and cement production casing; and to evaluate the results of the logging program and to apply these results to the design of a multiple stage hydraulic fracture treatment.

- Phase III: To hydraulically fracture the Devonian Shale in several intervals; to conduct well tests in order to evaluate the stimulation treatments; and to put the well "on line" if it is producing a sufficient amount of natural gas, and to monitor and report its production for a period of five years.

SUMMARY OF PROGRESS

Drilling was initiated on the deviated well project on July 31, 1978. The well was drilled to a total depth of 4736 feet and 4 1/2 inch casing was set at a depth of 4635 feet.

Following completion of the drilling operations, the well was perforated at three intervals in Zone II of the Brown Shale prior to performing a mud acid breakdown test. The well immediately began making formation water. Bridge plugs were set within the perforations in Brown Shale Zone II and the water production was isolated in the middle set of perforations in Brown Shale Zone II. The interval 4280 ft. to 4320 ft. was treated with 1000 gallons of mud acid and stimulated. Formation water was again encountered and Zone II was abandoned as a potential producing horizon.

After setting an additional bridge plug to isolate this zone of water production, Zone III which is 276 feet above, was given a foam treatment during the latter part of December. Following the foam fracturing treatment, a final open flow of 12 Mcfd was obtained on January 9, 1979. Since then the well has been shut-in to determine final well head pressure. The last pressure taken was 870 psig.

All activities under this contract have been completed with the exception of submission of the final report.

3.4.8 NEW EXPLORATION CONCEPT FOR LOCATING FRACTURE ZONES IN THE DEVONIAN SHALE

Status: Active

Donohue, Anstey and Morrill
Boston, Massachusetts

Contract:	DE-AC21-78MCO8339
Contract Date:	February 23, 1979
Anticipated Completion Date:	March, 1980
Principal Investigator:	D.A. Donohue
DOE Technical Project Officer:	C.A. Komar

OBJECTIVE

To test a new exploration technique using surface measurements of seismic velocity to locate zones of natural fractures in Devonian Shale in Ohio.

SCOPE OF WORK

This contract calls for the drilling of three wells through the Devonian Shale in Ohio to test the exploration technique that zones of natural fracture intensity in the shale can be identified through measurement of seismic velocity. The velocity analysis technique will be used in the siting of the three wells, which will then be drilled, logged, and stimulated. Standard sonic logging techniques will be supplemented by check shooting for seismic velocity before and after stimulation in all three wells.

SUMMARY OF PROGRESS

Initial contract work began in the last weeks of the reporting period. The velocity analysis processing of the data has been initiated.

3.4.9 HYDRAULIC FRACTURING EXPERIMENT IN MCKEAN COUNTY, PENNSYLVANIA

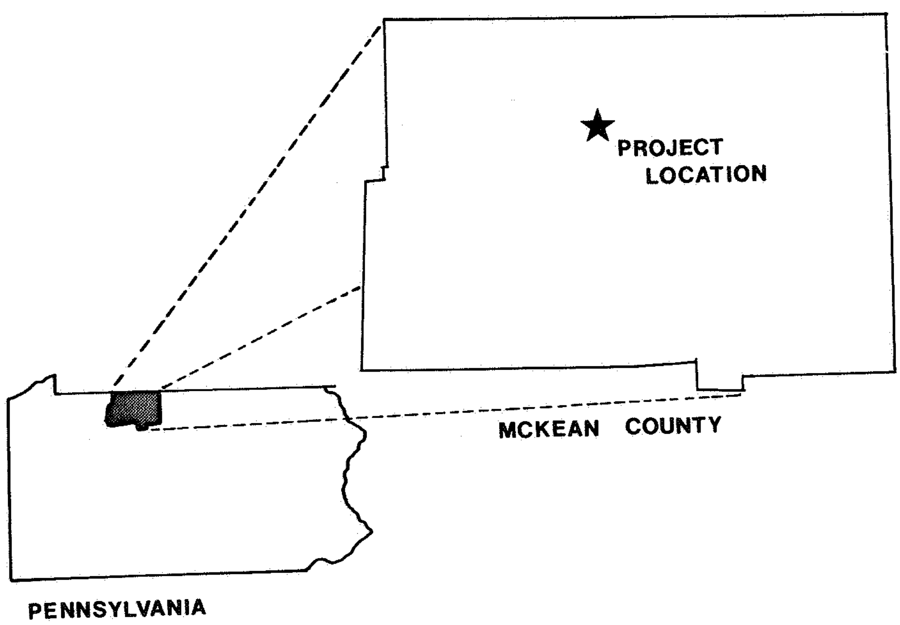
Status: Active

Minard Run Exploration Co., Inc.
Bradford, Pennsylvania

Contract:	EW-78-C-21-8483
Contract Date:	September 24, 1978
Anticipated Completion Date:	June, 1979
Principal Investigator:	R.T. Wolfe
DOE Technical Project Officer	C.W. Byrer

OBJECTIVE

To drill, log, core, stimulate, and test a gas well in the Devonian Shale in McKean County, Pennsylvania.



SCOPE OF WORK

Specific tasks include the following:

- To drill, core, log and case a well into the Devonian Shale in McKean County, PA. Approximately 800 feet of core are to be retrieved. Following the coring operation, a comprehensive suite of geophysical wet-hole and dry-hole well logs will be run.

- To hydraulically fracture the well. Complete records of the frac job will be kept and when the well is adequately "cleaned-up" a suite of post-frac logs will be run.

- To perform post-frac testing and long range monitoring of production history and to report production history on a monthly basis for five years.

SUMMARY OF PROGRESS

The well in McKean County, Pennsylvania was drilled, logged and cored in March, 1979. 725 feet of oriented core were retrieved and suites of wet-hole and dry-hole well logs were run.

An open hole stage fracturing technique with five stages per 100 feet was planned. An attempt was made to stimulate the well in multiple stages using compression packers to isolate zones. The zones could not be isolated and presently the technique is being evaluated.

3.4.10 SUPPORT DEVELOPMENT OF AN UNCONVENTIONAL EXPLORATION TECHNIQUE TO SELECTIVELY LOCATE NATURAL FRACTURE SYSTEMS IN THE DEVONIAN-OHIO SHALE

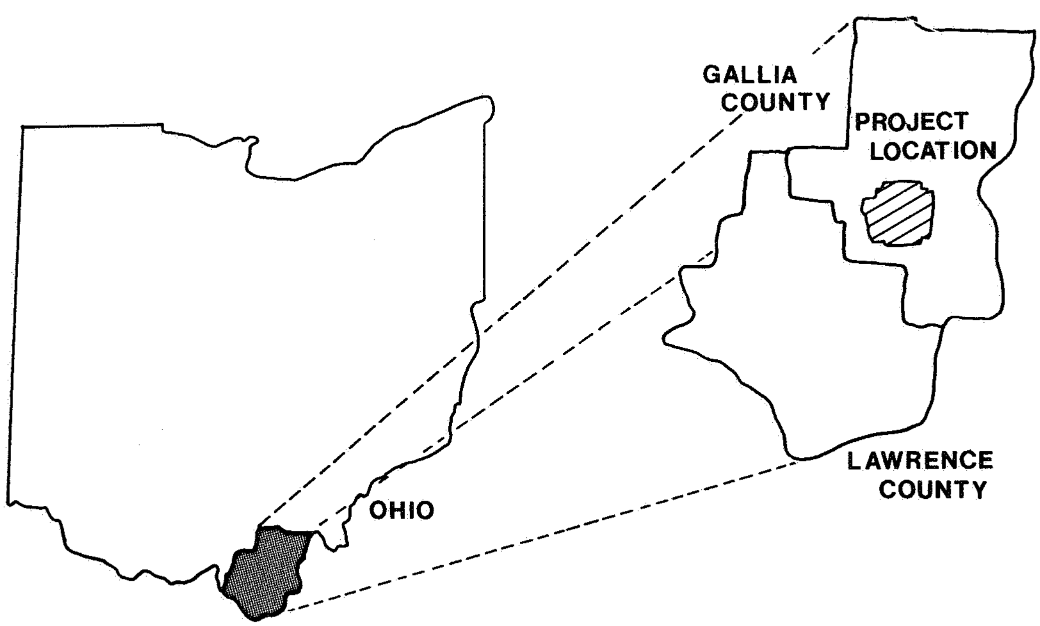
Mitchell Energy Corporation
Houston, Texas
Columbia Gas System Service Corp.
Columbus, Ohio

Status: Active

Contract:	EW-78-C-21-8387
Contract Date:	September, 1978
Anticipated Completion Date:	September, 1980
Principal Investigator:	W.M. Hennington
DOE Technical Project Officer:	C.A. Komar

OBJECTIVE

To establish: An unconventional technique to selectively locate naturally fractured shale reservoirs; the presence and orientation of naturally fractured reservoirs; and the relationship of hydrocarbon distribution to depositional environment.



SCOPE OF WORK

This project is designed to test the theory that the development of natural fracture systems is related to the structure at the time of deposition.

The tasks involved aim at determining the depositional structure by interrelating subsurface structure, porosity, and production information. The focus of this is to remove from the present day structure the distortion which has occurred from the time of deposition to the present. Specific tasks include the following:

- To drill, selectively core, and log five wells in order to evaluate the concept through standard and experimental analyses (Phase I).
- To select specific reservoir intervals for stimulation.
- To verify Phase I results by drilling, logging, and stimulating six additional wells and comparing results (Phase II).
- To prepare a final analysis which recommends a program for large scale, economical development of the Ohio Devonian Shale reserves.

SUMMARY OF PROGRESS

Initial contract work began during this reporting period.

A favorable environmental impact study of the area has been completed. A 60-point "Spot Correlation" seismic survey has been initiated. Preliminary well locations have been selected. Final determination of the locations will be made after seismic and field study data have been interpreted.

3.4.11 DEVONIAN SHALE CHEMICAL EXPLOSIVE FRACTURING TEST PROGRAM

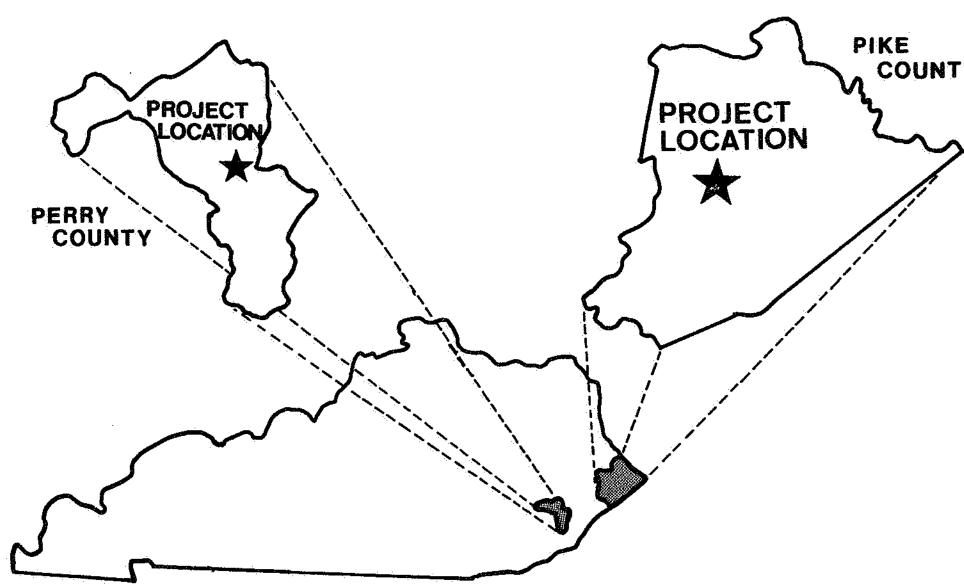
Status: Active

Petroleum Technology Corporation/
Kentucky-West Virginia Gas Company
Redmond, Washington

Contract:	EY-76-C-08-0685
Contract Date:	July 1, 1976
Anticipated Completion Date:	June, 1979
Principal Investigator:	S.J. LaRocca
DOE Technical Project Officer:	C.A. Komar

OBJECTIVE

To demonstrate the technical and economic feasibility of chemical explosive fracturing (CEF) technology as an effective stimulation technique for increasing gas deliverability from the Devonian Shale.



SCOPE OF WORK

CEF field test stimulation of three wells in Kentucky will be conducted in order to determine the technical and economic feasibility of this technique. Two new wells will be drilled, completed, and stimulated with CEF liquids and one existing well will be recompleted and stimulated.

Technical feasibility will be based on production tests and temperature, gamma ray, caliper, formation density, resistivity, Keroband, and sibilation log surveys. Economic feasibility will be determined from monthly production figures before and after treatment. Each treatment will use up to 30,000 pounds of PTC-4 explosive and the contractor will perform pressure buildup and drawdown tests as well as long-term productivity tests.

SUMMARY OF PROGRESS

This program includes stimulation of three wells in Kentucky. Two wells were drilled and completed in Pike County, KY. Both wells were stimulated with chemical explosive fracturing liquids. Each treatment emplaced approximately 30,000 lbs of liquid explosives in the boreholes. The wells are presently shut-in and waiting for the rubble to be cleaned from the wellbore.

The third well in the program was an existing well. This well was drilled and stimulated with borehole explosives twelve years ago. The original open flow potential was 60 Mcfd and prior to remedial work was down to 9 Mcfd. After cleaning out it has an average daily gas production between 7.9 and 20 Mcfd. This well has not yet been stimulated with a CEF.

3.4.12 CHEMICAL EXPLOSIVE FRACTURING DEMONSTRATION, LINCOLN COUNTY, WV

Petroleum Technology Corporation
Columbia Gas Transmission Corporation
Redmond, Washington

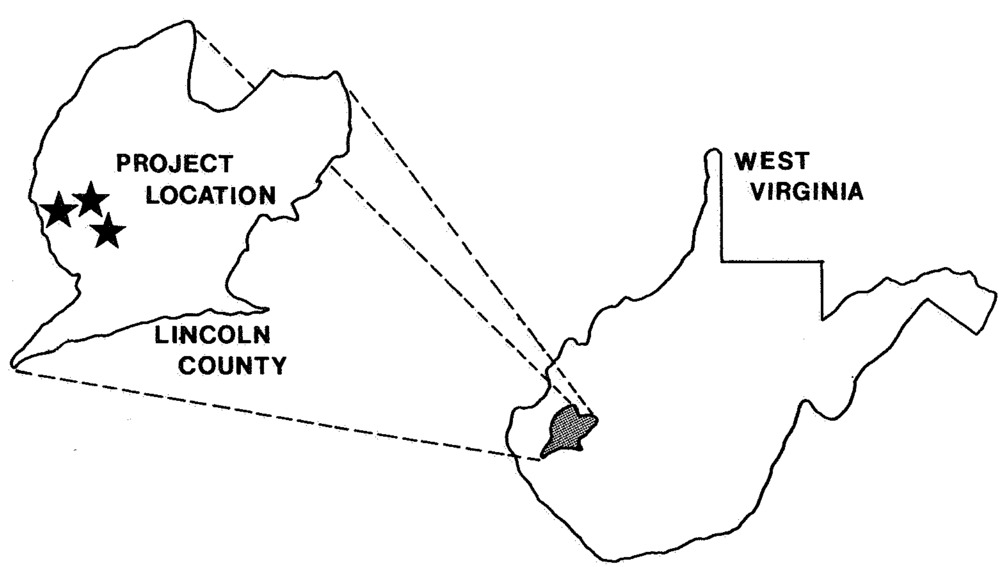
Status: Active

Contract: EY-76-C-08-0686
Contract Date: July 1, 1976
Anticipated Completion Date: September, 1979

Principal Investigator: S.J. LaRocca
DOE Technical Project Officer: C.A. Komar

OBJECTIVE

To demonstrate the technical and economic feasibility of chemical explosive fracturing (CEF) technology as an effective stimulation technique for increasing gas deliverability from the Devonian Shale.



SCOPE OF WORK

Three wells in Lincoln County, West Virginia will be drilled, logged and stimulated with chemical explosives. The selection of intervals within the formation will be identified as gas bearing from the temperature, gamma ray, formation density, resistivity, Keroband and sibilation log surveys. Pressure and productivity tests will provide information for a technical evaluation. Economic assessment of the proposed method of stimulation will be based on monthly production figures over a period of six months.

SUMMARY OF PROGRESS

All three wells in the contract have been drilled, logged, and stimulated with chemical explosives during the last reporting period.

Daily production on all three test wells has continued to be monitored. At the end of a six month production period the program will be evaluated. Initial production figures indicate low well productivity. The last reported production was as follows:

686-1	-	18.6 Mcfd
686-2	-	25.4 Mcfd
686-3	-	67.0 Mcfd

These wells were producing against a line pressure of 40 psi.

All field activities associated with this project are now concluded. A final report from the contractor is now due.

3.4.13 CANYON SAND EXPLOSIVE FRACTURING TEST PROJECT

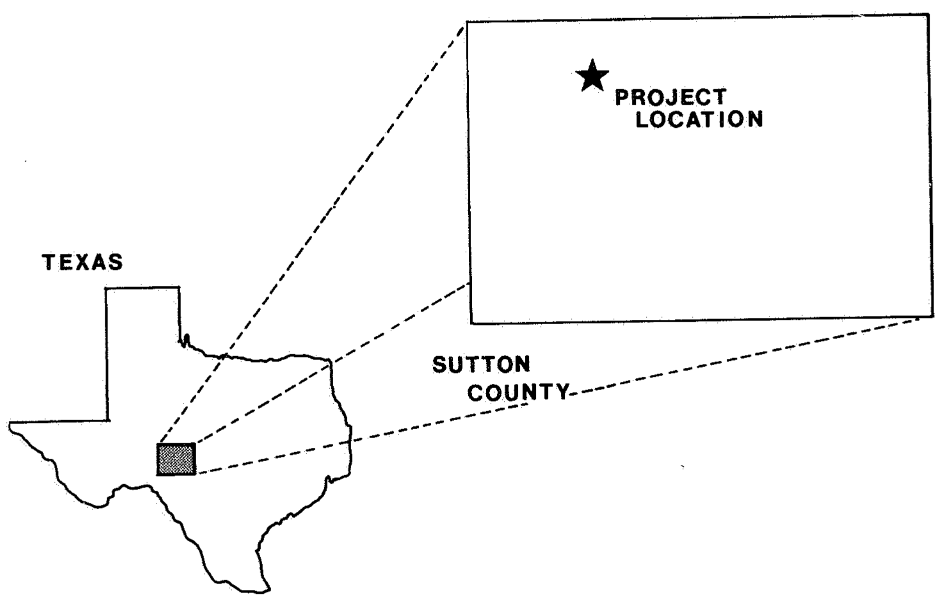
Petroleum Technology Corporation/
Union Oil Corporation
Redmond, Washington

Status: Active

Contract:	EY-76-C-08-0687
Contract Date:	July 1, 1976
Anticipated Completion Date:	March, 1979
Principal Investigator:	S.J. LaRocca
DOE Technical Project Officer:	C.A. Komar

OBJECTIVE

To demonstrate the technical and economic feasibility of chemical explosive fracturing (CEF) technology as an effective means of stimulating gas production from lenticular tight sands.



SCOPE OF WORK

Two wells in the Canyon Sands of the Val Verde-Kerr Basin in Sutton County, Texas will be tested to evaluate the effectiveness of a staged CEF treatment and to compare the results of a simple borehole treatment where essentially all potential producible lenses are treated to the results obtained in the two-stage job in the first phase. The wells will be drilled, dry-logged, and then tested based on production and extended pressure buildup tests to assess the productive capacity of the formation. The bottom 500 feet of Canyon Sands will be stimulated with up to 30,000 pounds of explosives.

SUMMARY OF PROGRESS

A new detonation system coupled with a specially designed thicker-wall fiberglass string of tubing was fabricated, assembled, tested, and evaluated as field-worthy for the planned explosive frac test of the Canyon Sand. The well scheduled for stimulation has already been drilled, dry logged, and tested via production and extended pressure build-up tests to assess the productive capacity of the formation.

Plans for this period were to stimulate the bottom 500 feet of Canyon Sands with up to 30,000 pounds of explosives. However, problems associated with the packer unit in the wellbore have caused delays on the work planned. Efforts to clean up the well are continuing.

3.4.14 ASSESSMENT OF SHALE PRODUCTION IN DUAL COMPLETED WELLS

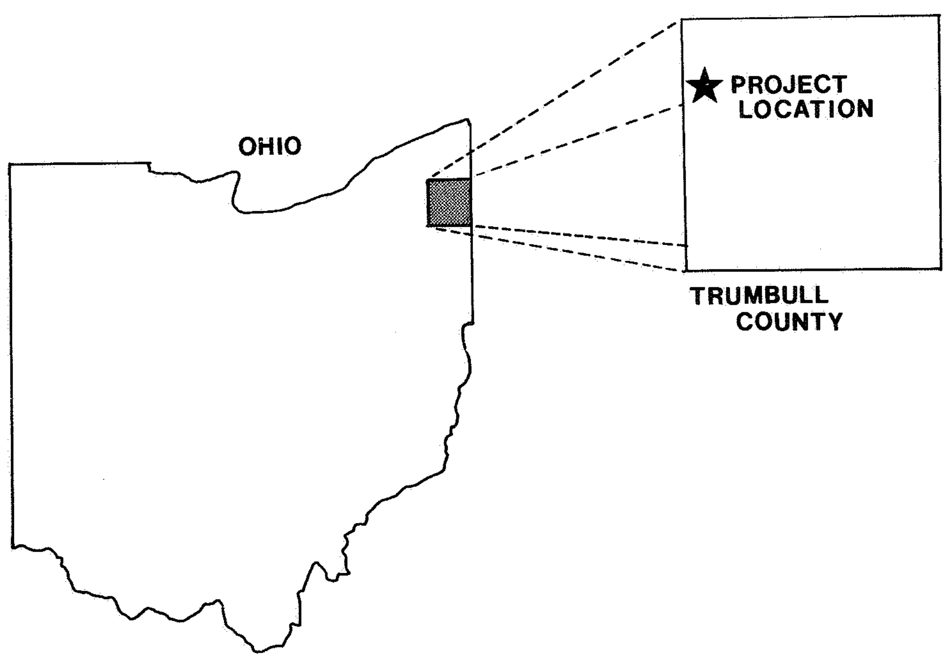
Tetra Tech, Inc.
Houston, Texas

Status: Active

Contract:	DE-AC21-78MC10389
Contract Date:	February 5, 1979
Anticipated Completion Date:	August, 1979
Principal Investigator:	J.P. Trunz
DOE Technical Project Officer:	C.A. Komar

OBJECTIVE

To test the feasibility of producing from two horizons simultaneously (Devonian Shale and Clinton Sand) as an effective means of exploiting the unconventional Devonian Shale gas resource.



SCOPE OF WORK

The five major tasks included in this program are: resource evaluation, site selection and preparation, drilling and logging, stimulation and completion, and production testing. Five wells are scheduled for this logging, stimulation, and evaluation in an area of Farmington Township, Trumbull County, OH. Both the Clinton Sand and the Devonian Shale will be drilled, logged, completed, and tested in order to determine the production potential of each and in order to demonstrate the cost effectiveness of producing them simultaneously. Individually metered production from both zones in each of the five wells will be reported to DOE/METC on an annual basis for five years. Economics of the dual completion system will be performed using cost benefit analysis and industry payout criteria.

SUMMARY OF PROGRESS

Tetra Tech, Inc. acquired a 511 acre farm-out from East Ohio Gas to drill five wells in Farmington Township, Trumbull County, OH.

Drilling of well #1 (Berg #1) was initiated on February 6, 1979. It was drilled to a total depth of 4,144 feet. The well was drilled with mud to 370 feet and with air from 370 feet to total depth. The interval between 200 to 370 feet had gas shows during drilling. The well was logged and logs indicated gas shows between 457 to 548 feet. Results from the logging program indicated the Clinton to be potentially productive and no prospective producing zones in the Devonian Shales. The well has been cased and cemented.

Drilling of well #2 (Shaffer) was initiated on February 24, 1979. Drilling was continuing at 2,234 feet at the end of this reporting period. Gamma ray and sibilation logs were run from 2,234 feet to 353 feet and showed no indication of gas.

3.4.15 TESTING PROGRAM FOR SHALE GAS PRODUCTION POTENTIAL

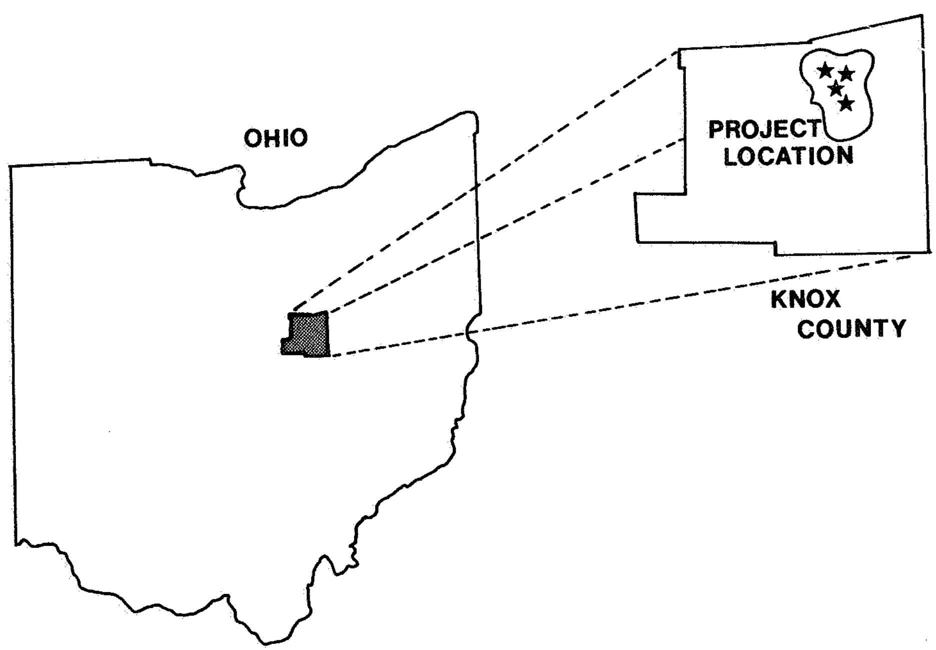
Status: Active

Thurlow Weed and Associates, Inc.
Mount Vernon, Ohio

Contract:	EW-78-C-21-8386
Contract Date:	September, 1978
Anticipated Completion Date:	September, 1979
Principal Investigator:	T. Weed
DOE Technical Project Officer:	C.A. Komar

OBJECTIVE

To acquire data on the commercial potential of various stimulation techniques, to evaluate methods of determing stimulation selection, and to provide information on technology developments that can have an impact on marginal operations in the Devonian Shale formation of Ohio.



SCOPE OF WORK

The scope of this contract includes the drilling and coring of one new well in Knox County, OH; logging of four existing wells in Ohio; and performing stimulation treatments on three existing wells and the newly drilled well in Ohio. The stimulation treatments will be designed for site-specific geologic conditions. Characteristics of existing wells plus characteristics of the new test well will be studied in light of resulting production.

SUMMARY OF PROGRESS

Activities on the project were initiated during this reporting period. The existing wells were logged with a series of dry-hole logs. Environmental and archaeological impact studies were completed. Eleven drill sites were proposed (see Figure 3-8) in the target area from which one test hole is expected to be sited. These sites will be established based on the potential for Devonian Shale fractures on the intersections of lineaments. This is based on the exploration rationale that natural, geomorphic lineaments observed at high altitudes represent significant fractured, jointed and/or faulted bedrock zones. The well is expected to be drilled, cored, and stimulated during the next reporting period.

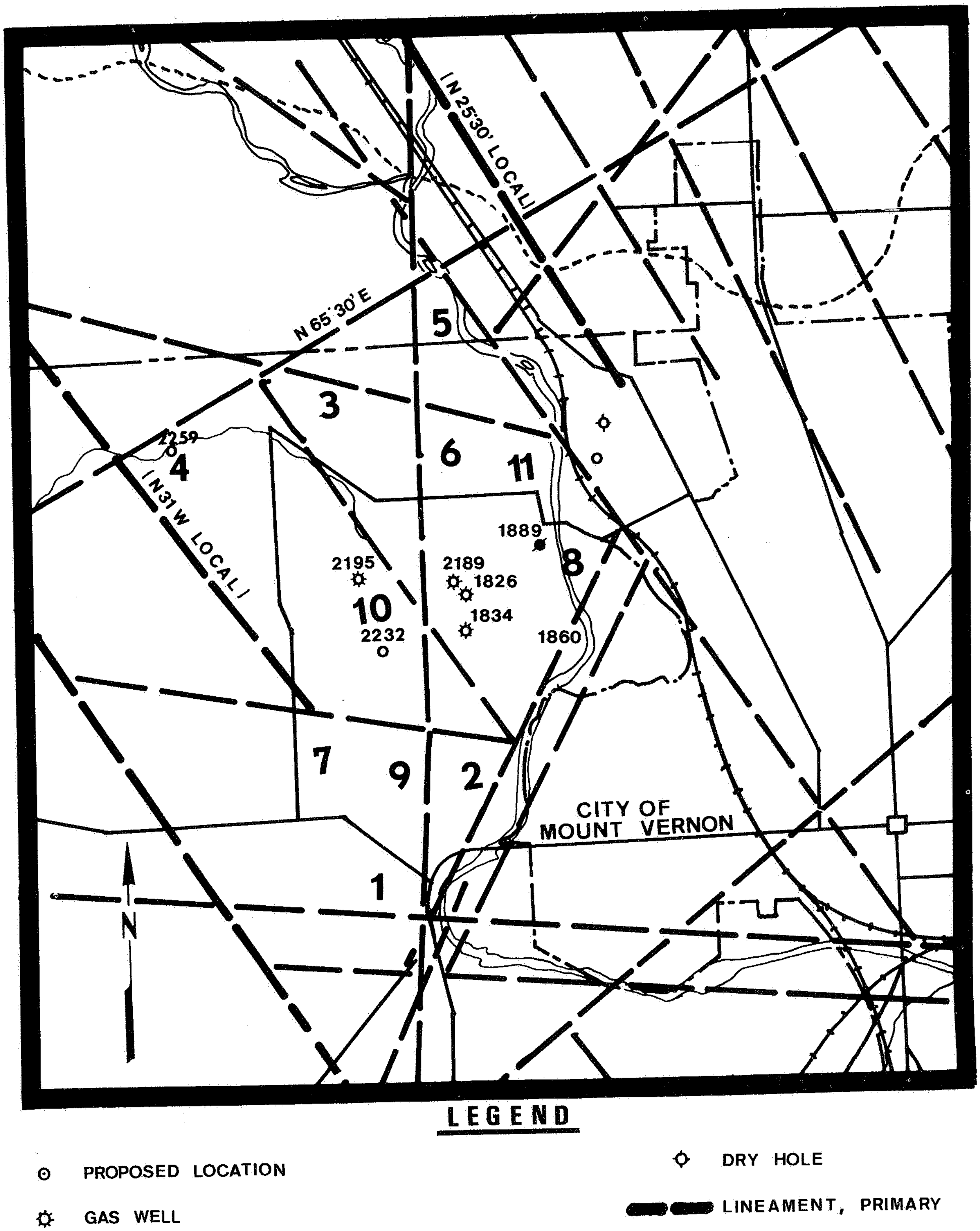


Figure 3-8. Lineament Map Indicating Proposed Drill Sites

3.4.16 DEEP DEVONIAN SHALE GAS TEST IN NORTHERN WEST VIRGINIA

U.S. Department of Energy
Morgantown, West Virginia

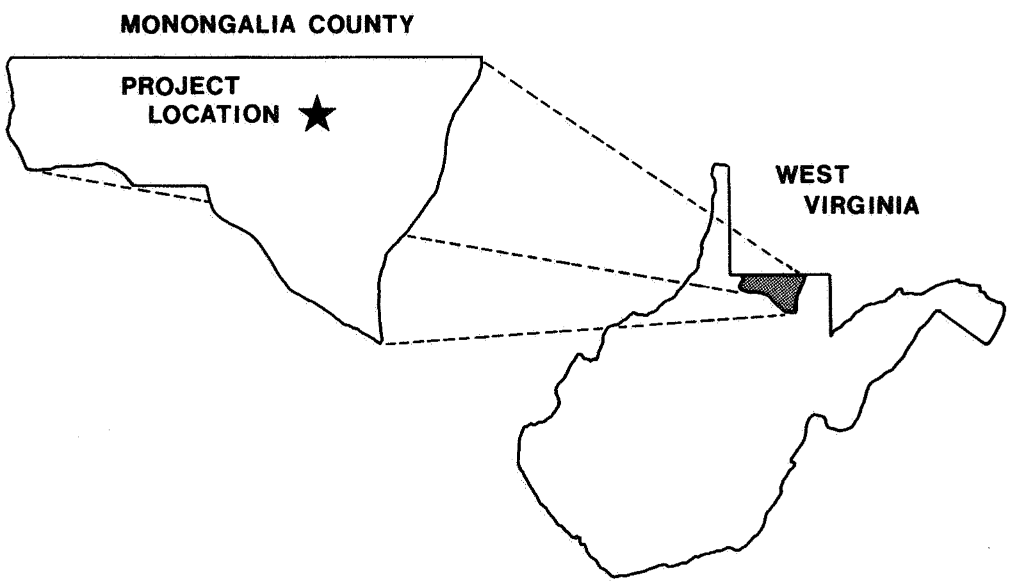
Status: Active

Field Work Performance Period: Spring, 1978

Principal Investigator: K-H. Frohne

OBJECTIVE

To drill, core, and stimulate in more than one zone a well into the Devonian Shale in order to provide stratigraphic information and in order to test and evaluate gas production potential of the Devonian Shale in northern West Virginia.



SCOPE OF WORK

The scope of work for this project includes the following tasks:

- To site and drill a well into the Devonian Shale on the METC property in Morgantown, West Virginia.
- To core the lower Devonian Shales in order to characterize these formations for gas resource potential.
- To run an extensive suite of wet-hole and dry-hole geophysical well logs designed to fully evaluate the formations for lithology, hydrocarbon and organic content, borehole gas entry, natural fracturing, porosity, and Devonian Shale characteristics and mechanical properties.
- To perform a special formation breakdown test to understand the mechanical strength of Devonian Shale at great depth.
- To stimulate the shale in more than one zone, and when the well is adequately "cleaned-up", to perform post-frac testing and long range monitoring of production history.

SUMMARY OF PROGRESS

The research well "MERC 1" was drilled on the Morgantown Energy Technology Center property in Morgantown, WV. The well was drilled with air to the top of the Tully Lime and then cored through the Mahantango and Marcellus Shales to a total depth of 7520 ft in the top of the Onondaga Lime. A total of 348 feet of oriented core was recovered. A field evaluation of core and log analyses showed both the Burkett Member of the Harrell Shale and the Marcellus Shale to have a relatively high organic content, but the effective porosity from native jointing and fracturing was limited. No noticeable gas shows were encountered during drilling and coring of the Devonian Shales in this location.

A formation breakdown test was run on the Mahantango interval and it indicated a minimum horizontal rock stress of 6350 to 6600 psi. The Marcellus/Mahantango interval was fractured first between 7320 and 7490 ft, with a cryogenic stimulation. After 87,000 gallons of water and 28,000 gallons of CO_2 with 228,500 lbs of sand (75 percent of design) were injected, the treatment was stopped due to sand screen-out problems. Additional mechanical problems caused abandonment of the interval.

The Burkett Member between 7107 and 7157 ft was stimulated next with a cryogenic treatment. A total of 62,450 gallons of gel, 12,980 gallons of CO_2, and 120,000 lbs of sand were injected before this well was again screened-out. This treatment injected 88 percent of the fluids and 75 percent of the sand of the original design. The final flow from this zone was tested at 27 Mcfd.

The well has since been shut-in and no additional work was done during this reporting period.

3.5 PROJECT INTEGRATION AND SUPPORT

3.5.1 GENERAL

Review meetings were periodically convened to assess and evaluate project status and progress. Re-direction of some contracts was considered necessary, and appropriate changes were reflected in the modification of certain existing contracts and in new contract procurements.

In addition to routine planning and control functions, certain technical tasks under Element 1 (Resource Characterization and Inventory) and Element 2 (Extraction Technology, R&D) were performed.

3.5.2 PROJECT DATA BANK

A Data Base Management System (DBMS-System 2000) is currently being implemented through a cooperative effort involving DOE/METC, Petroleum Information (a subcontractor to USGS), and MRI.

As an intermediate step, the data base will provide for the retrieval of EGSP data, keyed by API number, state code, county code, contractor/laboratory code, sample number and card class. Future refinements will depend on further system development.

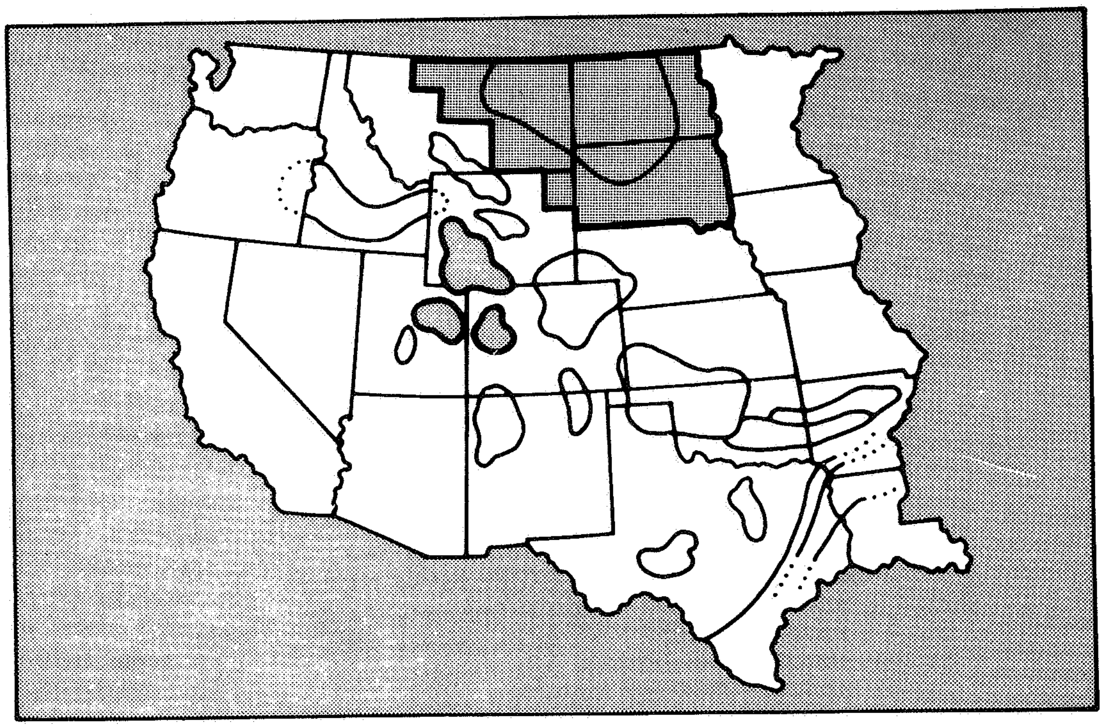
3.5.3 TECHNOLOGY TRANSFER

The Second Eastern Gas Shales Symposium was held in Morgantown, West Virginia on October 16, 17, and 18, 1978. Fifty papers covering work funded by the EGSP were presented. The symposium proceedings are published in Special Publication MERC/SP-78/6, available from the National Technical Information Service (NTIS).

All documents produced as part of the EGSP are available for inspection in the UGR Program Information File (formerly called the EGSP Open File). The file contains over 150 documents, 19 logs and 68 maps. Any published documents in the file can be obtained from NTIS, while copies of unpublished documents and maps are available from METC.

The other main activity in technology transfer has been the preparation and distribution of eight Technological Information Letters to a mailing list of over 1000, including oil and gas associations, the Gas Research Institute, AGA, and gas producers and operators.

4. WESTERN GAS SANDS



4. WESTERN GAS SANDS

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4.1 INTRODUCTION

4.1.1 BACKGROUND

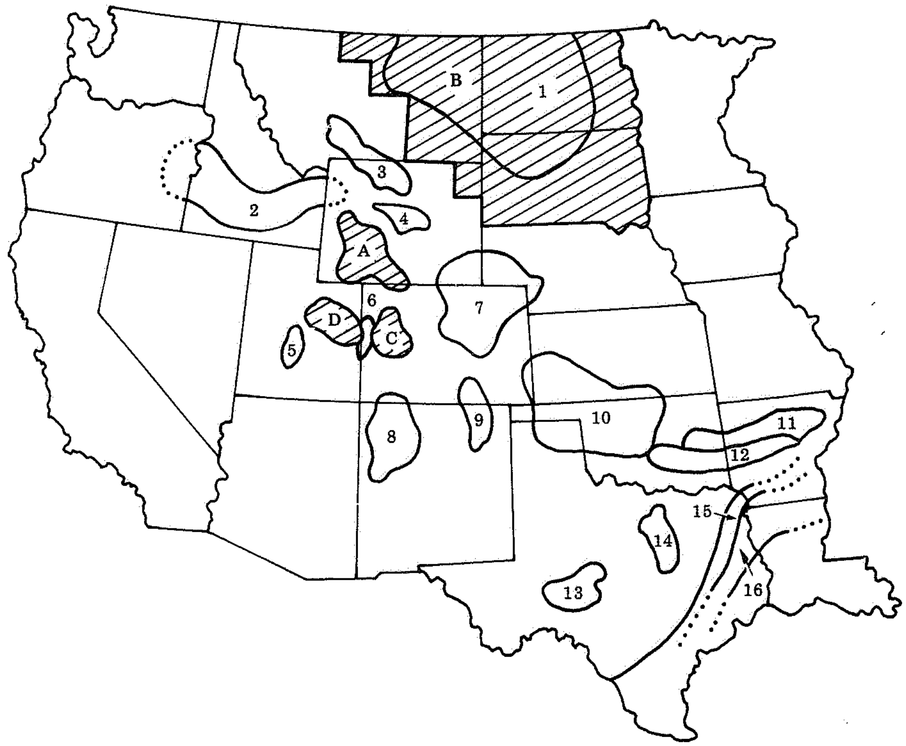
Geologic studies indicate that an immense resource of natural gas exists in the reservoirs in a number of geologic basins scattered throughout the western United States (Figure 4-1). The low permeability gas sands contained in these basins are interbedded with shale throughout intervals thousands of feet thick. The potentially gas productive sands within these intervals might number a hundred or more and may range in thickness from a few feet to more than 100 feet. In addition, the lateral extent of these sands is quite variable, and they may either be "blanket" type deposits of large areal extent, or be lenticular of limited but unknown size.

Studies by the Federal Power Commission (FPC) in 1973, supplemented by the United States Geological Survey (USGS), and by Lewin & Associates in 1978 have identified four areas which are large in areal extent, contain a large fraction of known low permeability reservoirs, and have a sizable existing data base (Table 4-1). The Lewin study also evaluated nine other basins which were estimated to contain an additional 190 trillion cubic feet of gas in low permeability reservoirs.

Table 4-1. Principal Study Areas and Resource Base Estimates

		ESTIMATED RESOURCE (TCF)*	
AREA	STATE	FPC & USGS EST.	LEWIN & ASSOC. INC.**
Greater Green River Basin	WY	240	91
Northern Great Plains Province	MT,WY, SD,ND	130	53
Piceance Basin	CO	210	36
Uinta Basin	UT	150	50
	TOTALS	730	230

*Trillion Cubic Feet
**Does not include presently commercial or "speculative" areas



PRIMARY STUDY AREAS

A. Greater Green River Basin
B. Northern Great Plains Province
C. Piceance Basin
D. Uinta Basin

Additional Low Permeability Sandstone Areas

1. Williston Basin
2. Snake River Downwarp
3. Big Horn Basin
4. Wind River Basin
5. Wasatch Plateau
6. Douglas Creek Arch
7. Denver Basin
8. San Juan Basin
9. Raton Basin
10. Anadarko Basin
11. Arkoma Basin
12. Quachita Mountains Province
13. Sonora Basin
14. Fort Worth Basin
15. Western Gulf Basin
16. Cotton Valley Trend

Figure 4-1 Map of Western United States, Showing Areas of Interest (Refer to this figure for the location of WGSP Study Areas)

4.1.2 WESTERN GAS SANDS PROJECT

The Western Gas Sands Project (WGSP) is part of a U.S. Department of Energy program to accelerate the development of domestic energy resources. It is directed toward the development of new and improved techniques for recovering gas from low-permeability reservoirs that currently cannot be economically produced. The purpose of the project is to encourage and supplement industrial efforts in developing technology and demonstrating the feasibility of economically producing natural gas from these reservoirs.

The project objectives are:

- To accurately define the resource base.
- To develop and implement techniques for determining physical and chemical properties of the reservoirs.
- To determine appropriate stimulation technology.
- To assess potential gas reserves and demonstrate economic productivity to encourage industrial development of the resource.

Achieving these objectives will require:

- Utilization of updated drilling and geological information to determine optimum drilling sites for resource confirmation and production research activities.
- Cost-sharing field tests with industry to characterize the reservoirs and to test and refine production stimulation technologies, particularly massive hydraulic fracturing.
- Maintaining an effective research program in government, industry and academic institution laboratories oriented toward improving diagnostic tools and methods and increasing the effectiveness of gas stimulation techniques.
- Incorporating and building upon the R&D results.
- Economic analyses and technology transfer.

Figure 4-2 shows a breakdown of the project by elements. Figure 4-3 identifies activities that will be accomplished concurrently and sequentially. Some field tests are dependent upon the outcome of resource assessment as well as laboratory evaluations, while others can be conducted immediately.

RESOURCE ASSESSMENT

Resource assessment includes geological and geophysical studies to better understand the target resource base. Continued effort in general and detailed mapping in particular are needed to improve the understanding of the gas-bearing formations and trapping mechanisms. This work leads to selection of sites where subsurface information is needed from cores,

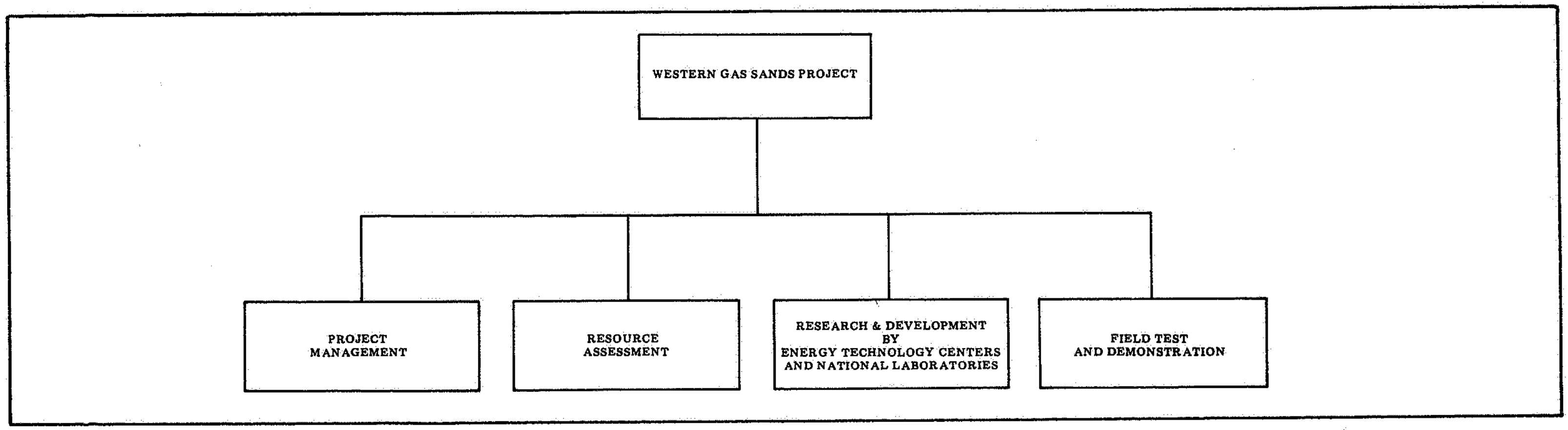


Figure 4-2 Elements of Western Gas Sands Project

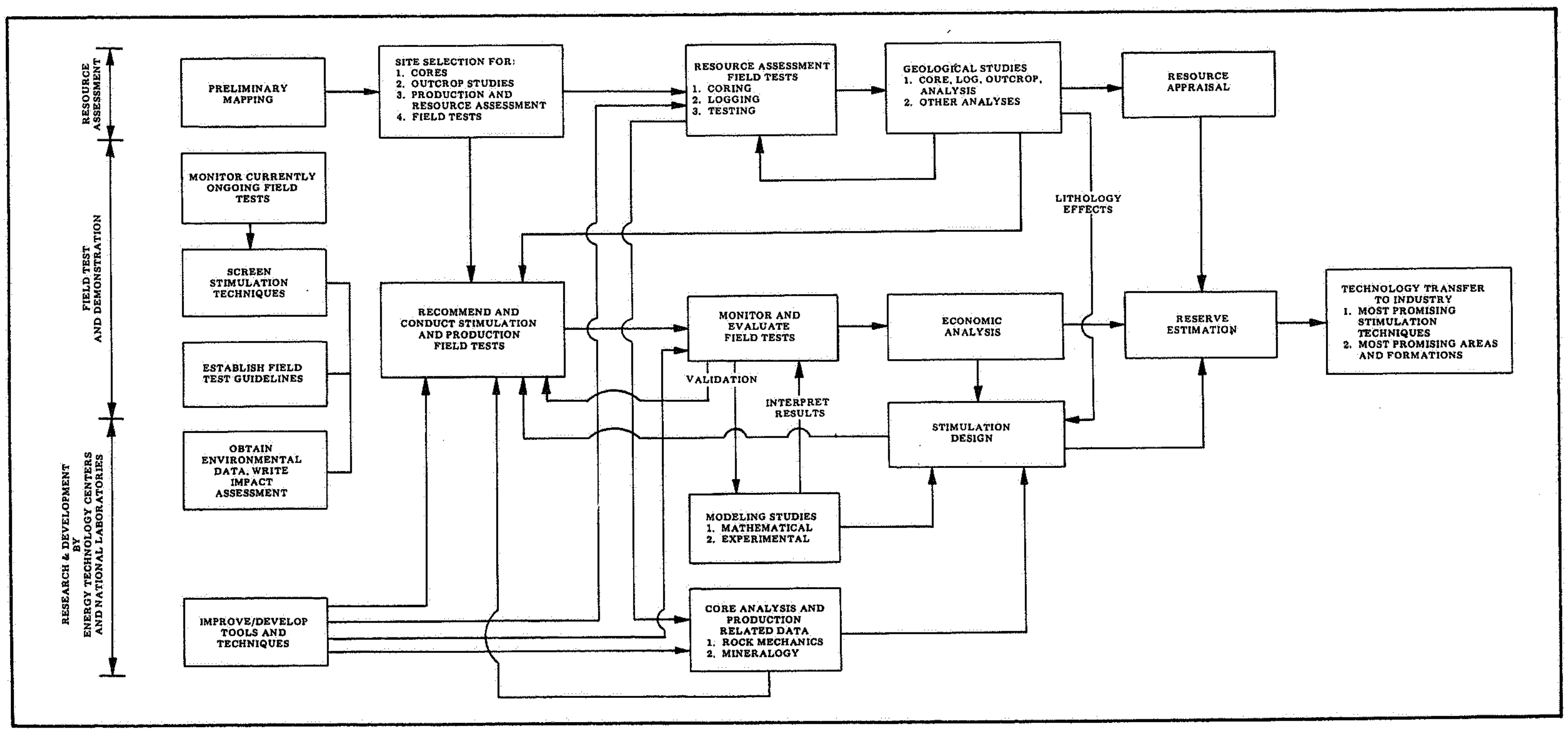


Figure 4-3 Principal Project Activities and Their Interrelationships

geophysical logs, and gas-production tests. Some of these sites will become the locations for field tests; and when sufficient information is accumulated, estimation of resource and reserve will be possible. The appraisals will delineate and characterize the reservoirs in areas that are promising for economic development.

The major portion of the resource assessment activity, as well as basic geological work, is being performed by the United States Geological Survey. There are, however, other activities providing input data and support to USGS work, primarily in the area of field tests, obtaining core samples and special core tests.

The USGS effort is being carried out in two phases. Phase One, now completed, involved a one-year (FY78) reconnaissance of geological, geophysical and engineering properties currently known about the tight gas sands of the principal western sedimentary basins. Phase Two, FY79 and on, involves a four-year comprehensive program to define the resource base and to better characterize the mechanical and chemical properties of these reservoirs.

RESEARCH AND DEVELOPMENT BY ENERGY TECHNOLOGY CENTERS AND NATIONAL LABORATORIES

Research and development effort is continuing in conjunction with field tests, with the principal effort directed toward developing equipment and techniques required for accurate resource evaluation and effective stimulation technology. This includes development and refinement of techniques for recovering cores at reservoir conditions, improving logging instrumentation and interpretation, and improving production testing techniques. Equipment and techniques will be developed to better estimate induced fracture geometry and orientation. Other laboratory support includes reservoir simulation and computer use to provide a basis for conducting statistical, parametric and prediction analyses. Test data will be used to validate the models which, in turn, may be used in the interpretation of subsequent test results.

Innovative stimulation technology will be evaluated. Core samples will be analyzed to obtain rock mechanics data and other formation properties needed to improve stimulation technology.

Energy Technology Centers and National Laboratories participating are the Bartlesville Energy Technology Center, Lawrence Livermore Laboratory, Sandia Laboratories, and Los Alamos Scientific Laboratory.

The Bartlesville Energy Technology Center is handling R&D tasks associated with logging research, rock-fluid interactions, instrument development (such as new coring and logging tools) and will provide various other support as the project develops. Lawrence Livermore Laboratory primarily is pursuing modeling and computer applications associated with fracturing processes and rock mechanics studies applicable to fracturing. Sandia is developing instrumentation systems to determine fracture orientation and geometry, and new coring tools to obtain pressurized cores. Sandia also is evaluating fracturing by mining through induced fractures in formations at the Nevada Test Site. Los Alamos is developing a logging tool using nuclear magnetic resonance to measure porosity, fluid saturations, and permeability.

FIELD TESTS AND DEMONSTRATIONS

Field tests and demonstrations comprise an essential part of the WGSP. The selection of future test sites and promising new technical approaches will utilize the experience gained from prior laboratory and field tests. There will be a continuing effort to improve the effectiveness of stimulation treatments. Data will be taken before and during field tests for analysis of the potential environmental impact of large-scale commercial development.

PROJECT MANAGEMENT

The Western Gas Sands Project is a multi-year effort involving federal agencies, national laboratories, state organizations, universities and industry. The project is managed through a project office consisting of a project manager and selected consultants, with contractual support from the DOE Nevada Operations office, Bartlesville Energy Technology Center, and Morgantown Energy Technology Center.

The roles and responsibilities of the project participants are summarized in Table 4-2. The roles and responsibilities are traditional with the exception of the project office, which must operate as the interface between DOE and contractors. During the year the project office monitors project activities and performs reviews on technical adequacy, technique and results.

Routine monthly status reports, required from all participants, are summarized by the project manager and submitted to the appropriate DOE offices and participants. The reports are available to the public from the Technical Information Center (TIC). Cost data and activity schedule information are reported in a separate document for internal use.

In addition, use of technical forums, symposia and workshops, publications in technical journals, and other means of disseminating information ensure technology transfer to industry.

As cost and production data become available, the economic viability of commercial development can be calculated, based on both prevailing and projected price structures.

Table 4-2 Roles and Responsibilities of Western Gas Sands Project Participants

HEADQUARTERS	Develops and defines division budget requests Formulates policies encompassing project content, goals and objectives Approves project plans
MORGANTOWN ENERGY TECHNOLOGY CENTER	Provides overall guidance for the Unconventional Gas Recovery Program, which includes the WGSP. Monitors project progress, evaluates results, initiates project reviews and modifies project direction as appropriate.
BARTLESVILLE ENERGY TECHNOLOGY CENTER	Provides project manager (resident at NV) to staff project office and supports the project with in-house and contracted R&D
PROJECT OFFICE	Executes technical direction to contractors and agencies participating in the project within the guidance originated by headquarters Participates in the planning, review, evaluation and overall guidance of the project Assists in contract work statement preparation, proposal evaluations and technical negotiations Is responsible for contract technical performance Certifies contractor expense vouchers for NV payment
NEVADA OPERATIONS OFFICE (NV)	Prepares and negotiates contracts, performs related contractual administrative activities, and makes necessary payment to contractors Fowards financial plan documents originated by headquarters to project office
CONTRACTORS AND AGENCIES	Execute contract work Maintain proper interface with project office and its representatives on technical matters Interface with NV on financial, legal and contract administrative matters
NATIONAL LABORATORIES	Perform and direct research and development in various areas of expertise

4.2 RESOURCE ASSESSMENT

4.2.1 GREATER GREEN RIVER BASIN

SUMMARY OF PROGRESS, USGS ACTIVITIES

A well penetration map of the Great Divide Basin was completed and is ready for review.

A tentative agreement was made with Champlin Oil & Gas Company to conduct a geochemical profile on a well in the vicinity of Moxa Arch in the western portion of the basin.

Ten samples from the Green River Basin were submitted for palynological examination, and samples from Forest Oil's Federal 31-1 well (section 31, T22N, R106W) and Rainbow Resources' Pacific Creek Federal 1-34 well (section 34, T27N, R106W) were submitted for organic analysis in March, 1979.

A cross section (open file report 79-357) through the northern Washakie Basin has been completed, and other cross sections are in preparation. Further work in the Washakie Basin includes a continuing lineament study, and a petrographic study of the Tierney wells.

Work on the Superior No. 1 Pacific Creek Federal well in the northeast Green River Basin included petrographic analysis of core samples, a thermal alteration index study of organic extract from core, temperature versus depth and reservoir pressure versus depth plots, organic maturation studies, x-ray diffraction analysis of samples and integration of analytical data results.

Heavy-mineral analysis of samples collected during the 1978 field season in the Hogback Basin was begun. Other work in progress includes a lineament study of the Great Divide Basin and a well penetration map of the Great Divide Basin which is being reviewed.

An overall stratigraphic analysis of the Greater Green River Basin is continuing.

CORING AND LOGGING

To assess the resource potential within the Greater Green River Basin the USGS recommended core acquisition in the following areas (Figure 4-4):

- Area 1

  The crest of the Wamsutter Arch in Sweetwater and Carbon Counties, the northern edge of which borders on the Red Desert Basin and the southern edge which occupies part of the Washakie Basin. The section below the commercial Almond and Ericson (Mesaverde) is of primary interest in this area.

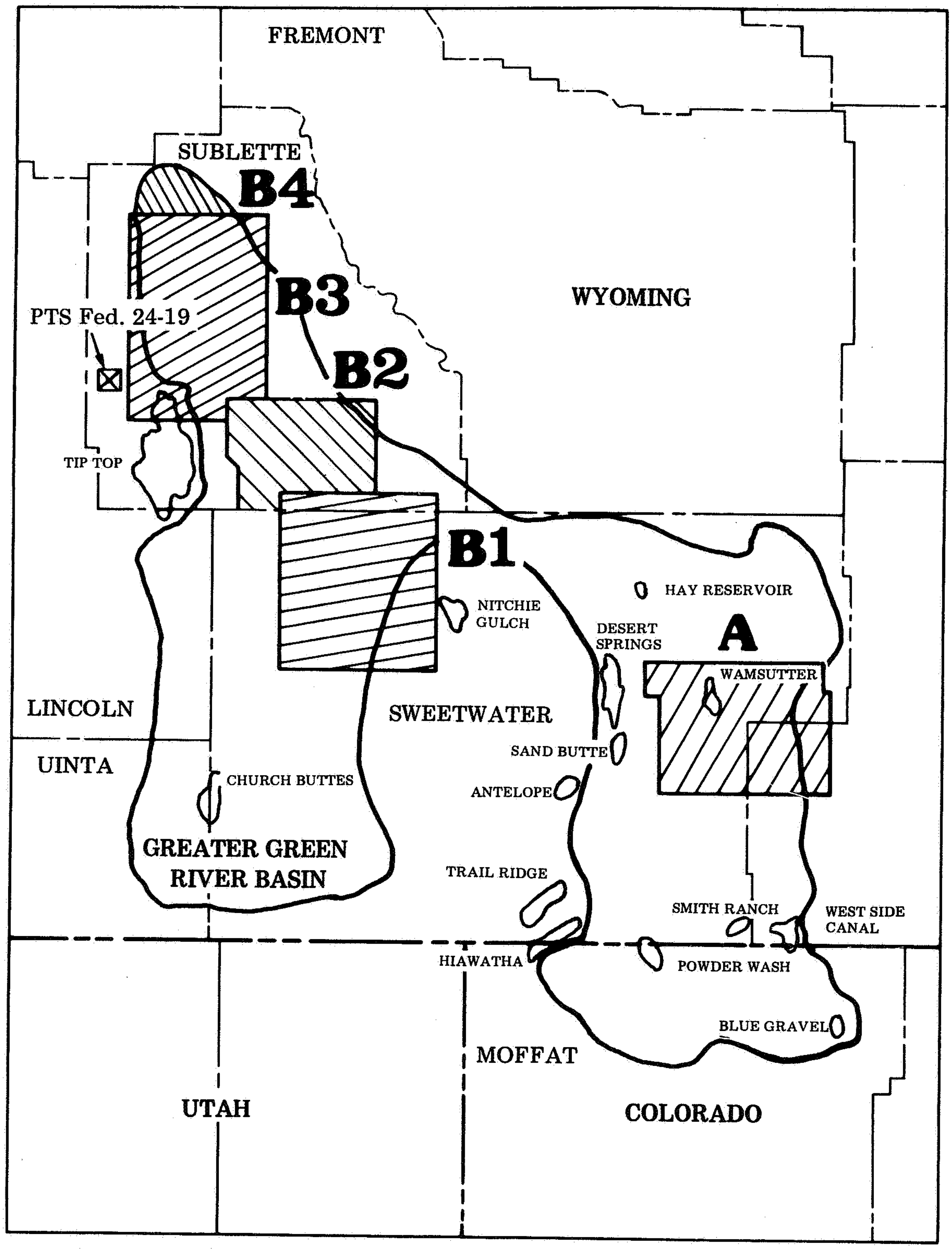


Figure 4-4 USGS Designated Core Areas and PTS 24-19 cored well location, Greater Green River Basin

- Area 2

  The area east of the Big Piney/LaBarge Field in Sweetwater and Sublette Counties, running north and south through the Pinedale area and to the northern edge of the Green River Basin. These areas skirt the edge of the Wind River Range. Production here is primarily Frontier, with some Mesaverde and Fort Union tests.

  Area 2 was divided into four subdivisions, illustrated in Figure 4-4.

The core sites contain thick sections of tight, but generally untested gas sands with "tight gas sand" potential in Upper Cretaceous and Tertiary formations. Figure 4-5 presents a generalized stratigraphic correlation chart for this area. Operators active in these areas are being contacted concerning possible participation in DOE's Core Program.

Many operators were active in core area 1; however, most were drilling to the commercial Almond and Ericson Formations of the Mesaverde Group (9,200 to 11,000 ft) which are not of primary interest to the WGSP.

During the six-month period October 1, 1978 through March 31, 1979, two wells were cored for the WGSP core program. Information on these two wells follows:

- Pacific Transmission Supply (PTS, Federal No. 24-19 (section 19, T33N, R114W), Sublette County, Wyoming. This well is just outside the specific core areas designated in Figure 4-4, but cores from this well will be useful in the overall study. The well is located at the eastern edge of the Wyoming overthrust belt near the western edge of the Green River Basin. About 220 ft of oriented 4-inch core was shipped to Core Laboratories for analysis. About 20 ft of this core was seal-peeled for study by LASL, LLL, and BETC. The core was probably taken in upper Mesaverde rocks, which lie below the thrust fault. Operations at the well have been shut down for the winter. When operations resume, the following logs will be run:

  - Dual Induction Laterolog with SP
  - Bore hole Compensated Sonic with Gamma Ray and Hole Caliper
  - Compensated Neutron-Formation Density with Gamma Ray and Hole Caliper
  - Dipmeter with Directional Survey
  - Proximity-Minilog or Microlaterolog
  - Field Taping with Computer Processed Sandstone Analysis
  - Spectral Gamma Ray

- Smokey Oil, 3-18 Bluewater Federal (section 18, T15N, R99W), Sweetwater County, Wyoming is scheduled for a 13,500 ft Mesaverde test. Core personnel were on hand when operations to obtain Mesaverde core began in March, 1979. The lower part of the coring apparatus was twisted off in the hole and after extensive fishing operations, the operator decided against further attempts to core the well. No core was obtained, and the logging program for this well has been dropped.

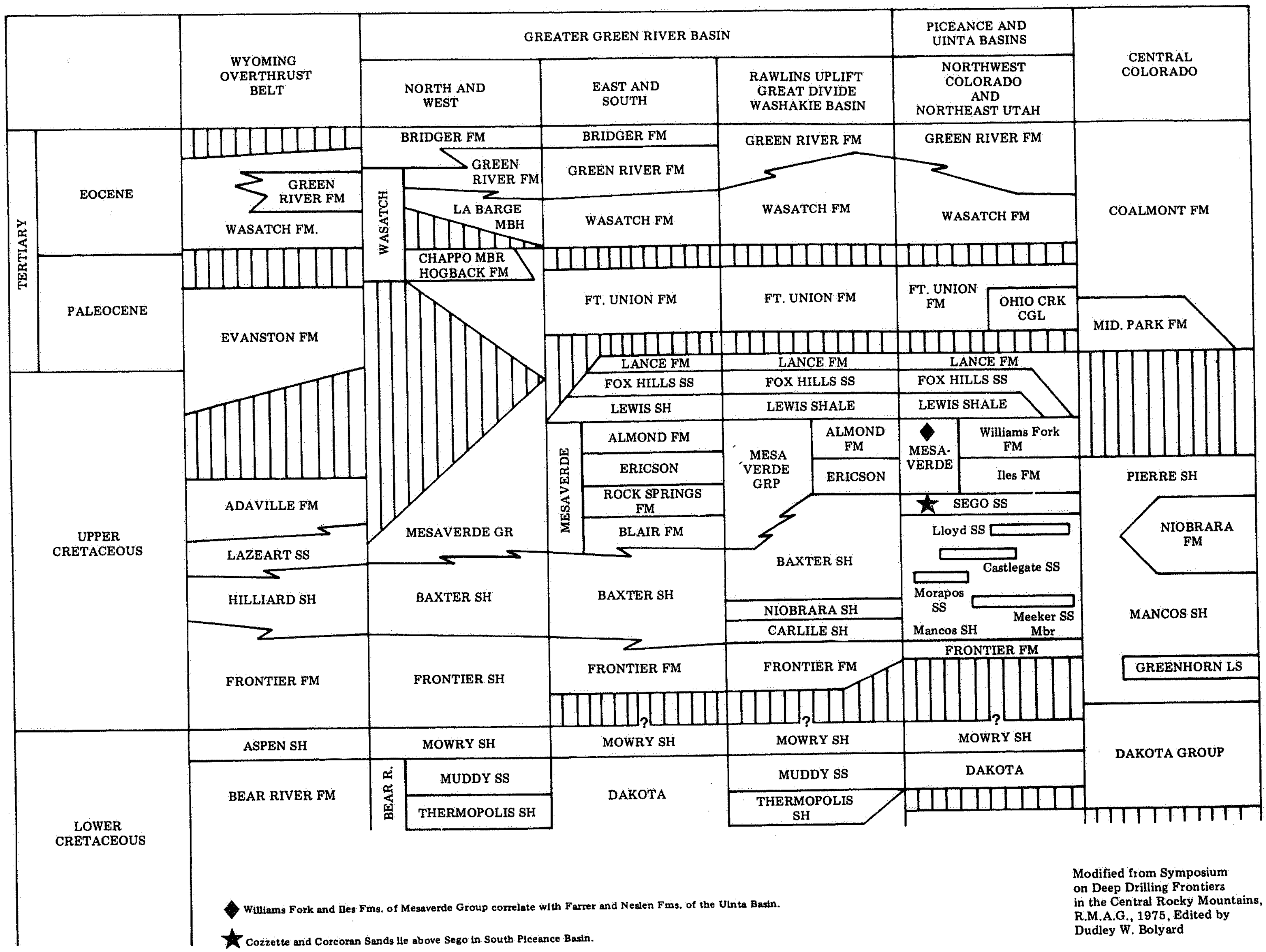


Figure 4-5 Stratigraphic Correlation Chart of Greater Green River, Piceance and Uinta Basins

Operators contacted for possible participation in the WGSP coring program over the six-month period were:

True Oil Company
Michigan-Wisconsin Pipeline Company
Pacific Transmission Supply
Davis Oil Company
Southland Royalty

4.2.2 NORTHERN GREAT PLAINS PROVINCE

SUMMARY OF PROGRESS, USGS ACTIVITIES

A change in the boundaries of the Northern Great Plains Province was made effective October 1, 1978 to include the entire states of North and South Dakota (Figure 4-6). The expansion opens new areas which should be tested, including Upper Cretaceous chalks (Greenhorn, Carlile, and Niobrara Formations (Figure 4-7), which are potential tight reservoirs. Late Cretaceous shelf sandstones which are developed throughout central and eastern South Dakota are identical to those developed in Montana and are considered to be potential tight, gas-bearing reservoirs. There is also gas producing potential to be tested in the Pierre Shale and associated units in South Dakota.

Although drilling activity relevant to the WGSP is limited in North and South Dakota at this time, six or seven wells are expected to be drilled in the West Short Pines Hills Field (Harding County, South Dakota) next year and Unichem International is evaluating the Niobrara Sand in south-central North Dakota. A stratigraphic study is being done on the Niobrara Formation in the eastern Dakotas and gas well data has been collected.

Core taken by the Water Resources Division of the USGS was sampled from the Pierre Shale in central South Dakota for mineralogical studies to evaluate the potential of producing gas from a naturally fractured shale sequence.

CORING AND LOGGING

USGS designated core areas for the Northern Great Plains Province are illustrated in Figure 4-6.

Operators contacted over this period about possible participation in the WGSP program include:

Odessa Natural Corporation
Midlands Gas Company
Erico Resources of Denver
Joseph J.C. Paine & Associates
Kansas-Nebraska Natural Gas Company
Universal Gas Company

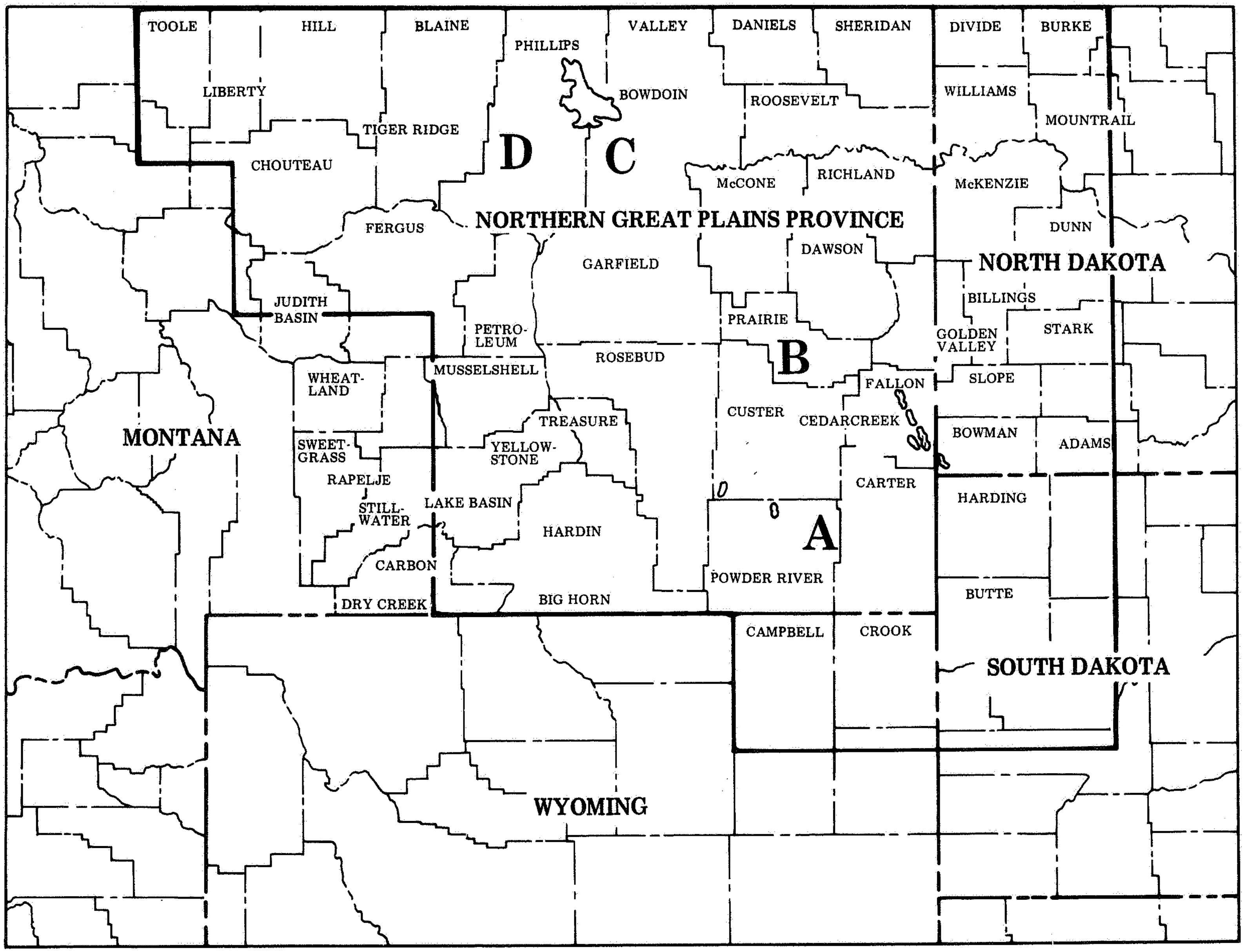


Figure 4-6 Northern Great Plains Province Showing USGS Designated Core Areas A, B, C and D

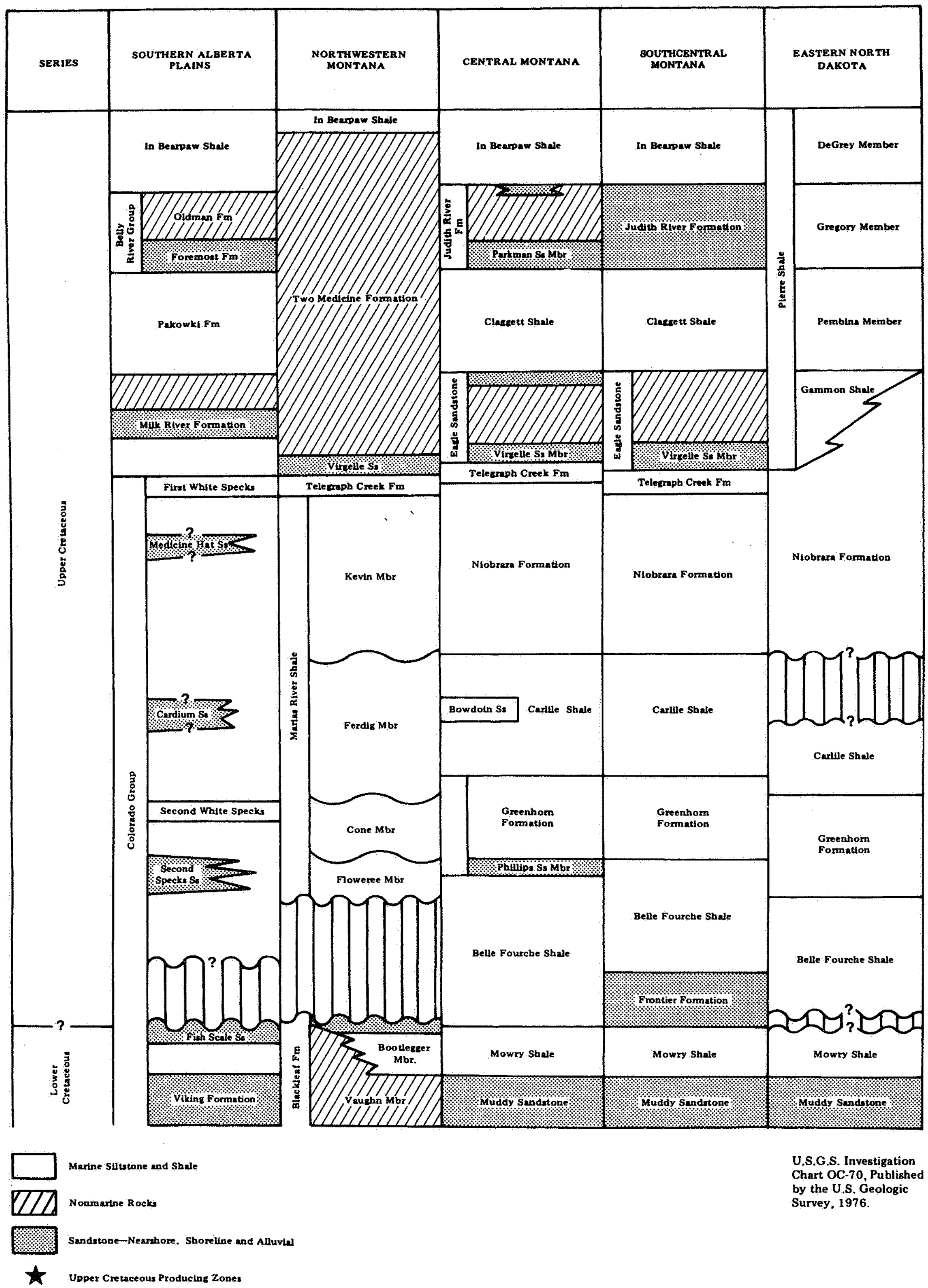


Figure 4-7 Correlation Chart of Cretaceous Rocks of the Northern Great Plains Province

4.2.3 PICEANCE BASIN

SUMMARY OF PROGRESS, USGS ACTIVITIES

Three cross-sections of Upper Cretaceous and Tertiary rocks in the southern and northern Piceance Basin have been prepared as USGS oil and gas charts and are being reviewed. A manuscript discussing the cross-sections is being prepared.

Porosity and permeability analyses on core samples of Tertiary and Cretaceous age sandstone beds from the Rio Blanco area were initiated in December, 1978.

In the area of the Piceance Creek Dome, rock types have been related to depositional environments.

CORING AND LOGGING

The USGS designated core areas in the Piceance Basin are illustrated in Figure 4-8.

DOE representatives were on site during the first half of December, 1978 to core the Twin Arrow C&K 4-14 well in section 14, T3S, R101W, Rio Blanco County, Colorado (Figure 4-8). The complete cored interval was from lenticular sands and shales of the continental Williams Fork Formation (Mesaverde Group). The well was cored to recover sections from low permeability gas sandstones and coal stringers for on-site gas desorption (degassing) measurements. There were nine core runs with a 60 ft core barrel. A total of 359 ft of 2-inch core was recovered and described on site. A core point began at 636 ft (drilling depth) and ended at 824 ft. An additional core point began at 983 ft (drilling depth) and continued to 1,210 ft. Hole problems prevented recovery of core from a deeper objective. This operation experienced a very good overall total core recovery.

The well was drilled to approximately 1,600 ft, where the drill pipe twisted off. An unsuccessful fishing operation resulted in losing the hole. Twin Arrow management later elected to skid the rig over about 75 ft and drill the C&K 4-14X well. After completing this hole through the equivalent cored interval, the well was logged with a comprehensive suite of geophysical well logs. This suite included:

- Dual Induction Laterolog/Gamma Ray
- Dual Laterolog/Gamma Ray
- Sonic/Gamma Ray
- Neutron
- Density/Gamma Ray
- Microlaterolog
- Diplog
- Spectralog

Although the well was cored with air mist, the hole was logged with a salt based mud to minimize clay swelling in the formation.

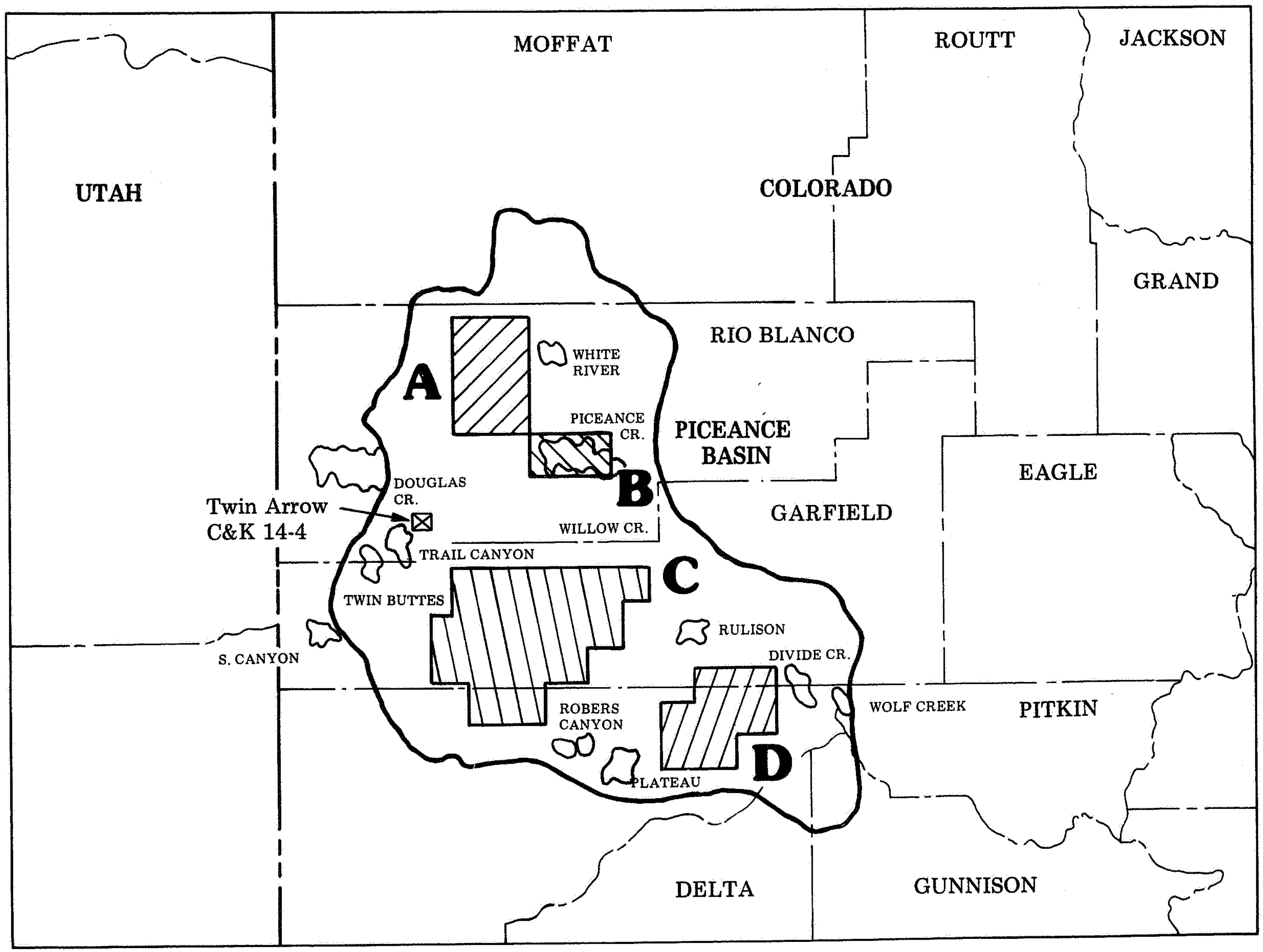


Figure 4-8 *USGS Designated Core Areas and C&K 4-14 cored well location, Piceance Basin*

Selected intervals of core were seal-peeled and sent to BETC and LLL. LASL also received some core placed in cannisters. The balance of the core was sent to Core Laboratories for whole core analysis. These commercial lab tests included porosity, permeability, and grain density measurements over selected intervals, and a core gamma analysis over the entire core. Special analysis included cation exchange capacity, resistivity index-formation factor and acoustic velocity measurements.

Companies contacted over the six-month period for possible participation in the WGSP coring program were:

Fuel Resources Development Company
Cities Service Gas Exploration Company
Teton Energy
Chandler & Associates
Northwest Exploration
Adolph Coors
Koch Exploration
Dome Petroleum

4.2.4 UINTA BASIN

SUMMARY OF PROGRESS, USGS ACTIVITIES

A report on Carbonate Cements in Low-Permeability Eocene Sandstones in the southeast Uinta Basin was completed in October, 1978 and is due for release in an SPE Volume during spring, 1979.

In November, analysis of microfossils from potential reservoir units at Southman Canyon was completed and a brief report on the production of natural gas from Upper Cretaceous Mesaverde Group sandstones was released. Porosity and permeability studies on rock plugs from the Mesaverde Group (Natural Buttes area) have been in progress since November with some preliminary results having been released during January, 1979.

Core samples of Tertiary age reservoir rocks were obtained from Shell Oil Company Southman Canyon gas wells.

Progress was reported on preparation of the detailed cross section extending from the Wasatch Plateau to the Island gas field.

Additional projects in progress over the last six months include preparation of a manuscript for a future SPE volume on the Mesaverde Group reservoirs at Southman Canyon gas field and compilation of a rock inventory for Upper Cretaceous, Paleocene and Eocene Formations at Price River Canyon.

CORING AND LOGGING

The USGS designated core areas for the Uinta Basin are illustrated in Figure 4-9.

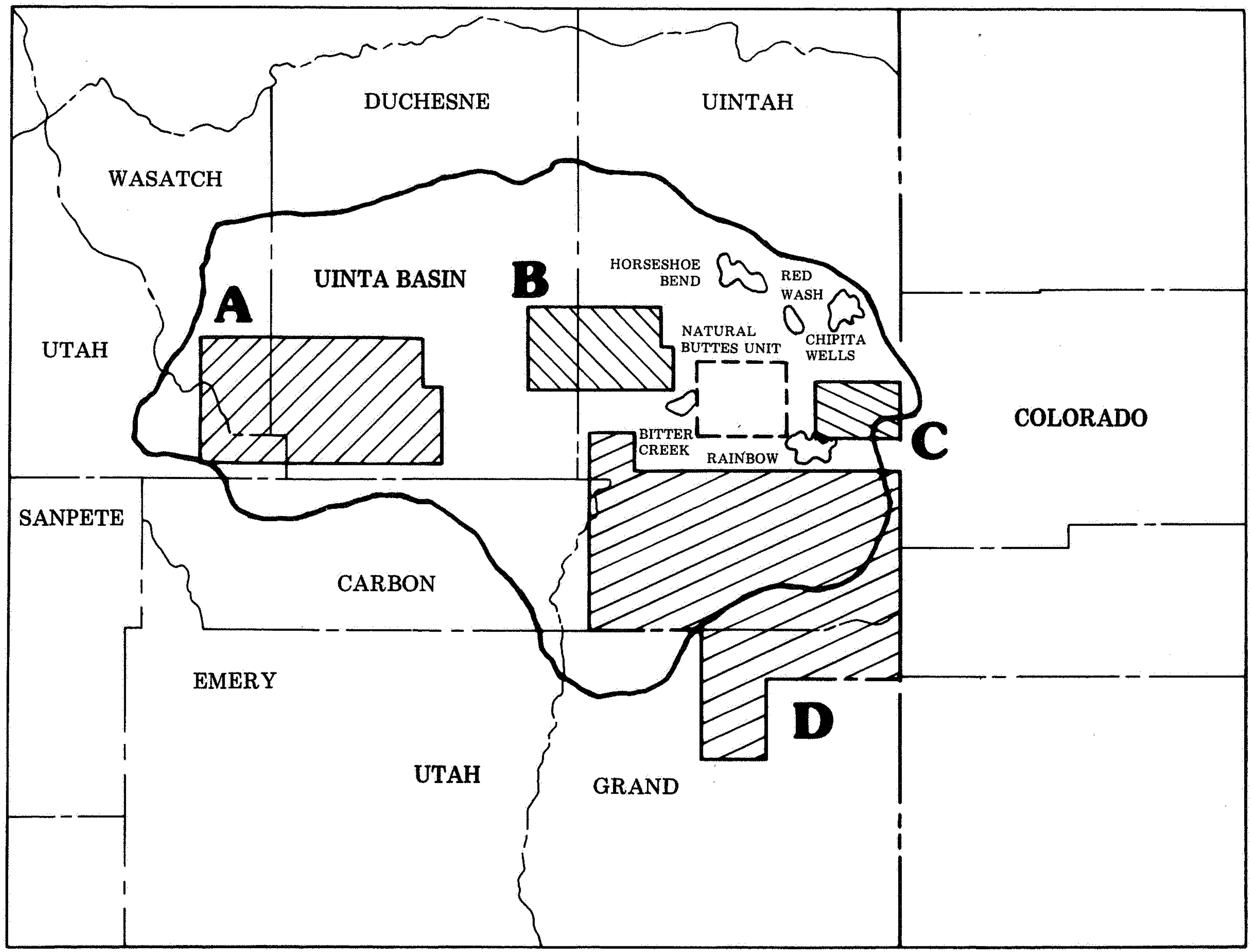


Figure 4-9   USGS Designated Core Areas, Uinta Basin

Contacts for possible participation in the WGSP core program were made throughout the six-month period with operators as follows:

- Odessa Natural Corporation
- Coseka Resources
- Ensearch Exploration
- Pacific Transmission Supply

4.3 RESEARCH AND DEVELOPMENT BY ENERGY TECHNOLOGY CENTERS AND NATIONAL LABORATORIES

4.3.1 BARTLESVILLE ENERGY TECHNOLOGY CENTER

IMPROVED PRESSURE CORING SYSTEM

The design phase of the pressure coring system has been completed. Work is proceding on fabrication and testing of an improved system.

Core Retriever Design

Design drawings of the pressure core barrel were completed and the drawings were reviewed resulting in identification of a number of areas where design modifications were necessary. Proposals were solicited, based on the Maurer design, for a joint industry and DOE cost-sharing development program to fabricate and field test the improved pressure coring system. An industry partner has been identified and a contract is being negotiated. Modifying the existing core barrels to use the Sandia two-piece bits and the low invasion coring fluid will be provided for in this contract. Use of an existing barrel circumvents most of the design flaws identified in the sub-contracted engineering design.

Core Fluid Tests

Based on tests of oil-base and water-base fluids, the water-base "Sanheal" was initially recommended for use with the new pressure coring system. Subsequently, Brinadd "Sanheal" and IMCO "Polysafe", were subjected to a number of tests. These materials are both hydroxyethyl cellulose polymers (HEC); the Sanheal has lignosulfonate compounds and calcium carbonate bridging materials in addition to the HEC.

A core freezing experiment was performed using 100 lb/bbl of Sanheal in 30 percent $CaCl_2$ brine. Testing revealed that the Sanheal froze at -55°F and was very soft and slick at -53°F. This shows that a core could easily be removed from a core barrel at -50°F or lower, depending upon how fast the outside film of mud could be melted.

The same mixture of Sanheal was tested in a high pressure/high temperature filter press to study the filtrate loss as a function of temperature. The results using 100 lb/bbl of Sanheal are as follows:

Test	Temperature, °F	Pressures, psig	Time, min	Filtrate Loss per 7.1 in.^{2}, c.c.
1	75	500/0	10	0.0
		1,000/0	50	2.0
2*	78	100/0	30	0.4
3	150	500/0	5	0.2
			30	2.2
4	250	600/0	5	0.6
			30	2.4
5*	300	600/100	5	2.2
			30	4.6

*Standard API filtrate tests

The Sanheal was quite viscous and a sample was subsequently analyzed to obtain pseudo-plastic viscosity data from -50°F to 250°F. Although this fluid appears to meet the requirements of a low invasion coring fluid, further work is needed to optimize the amount of polymer and bridging material required to reduce the dynamic invasion to a mimimum.

A similar series of static filtrate tests were run for the coring fluid recommended by IMCO, a 20 lb/bbl Polysafe (hydroxy ethyl cellulose) mixed with 20 lb/bbl Wate™ (1 to 60 micron $CaCO_3$ bridging particles). The mud was again mixed using 30 percent $CaCl_2$ brine because of its low freezing point and its favorable clay stabilizing and filter loss properties. After running filtrate tests using only 20 lb/bbl of bridging material, another Polysafe mix was tested. The only difference was the use of 50 lb/bbl Wate™ and 50 lb/bbl Safe Seal (0.5 to 200 micron $CaCO_3$ bridging material) instead of just 20 lb/bbl Wate™. The results are presented in the table on the following page.

In test No. 2, which is representative of anticipated downhole conditions, there was an obvious improvement in filtrate loss control by using more bridging material. Although additional experimental work needs to be done, it appears that particle bridging is a more important mechanism in static filtration control than is high viscosity, since the Sanheal was much thicker than the last Polysafe mixture, but had a higher fluid loss.

Test	Temperature, °F	Pressure, psig	Time, min.	Filtrate Loss per 7.1 in.^{2}, c.c.
1a	70	500/0	30	2.0
1b	250	600/100	30	faulty O-Ring
1c	250	600/100	5 30	1.0 5.4
1d	250	600/100	5	faulty O-Ring
2a	65	500/0	30	0.8
2b	250	600/100	5 30	0.2 1.6

Plastic viscosity measurements made for the Sanheal as a function of temperature from -44°F to 196°F showed the fluid to be highly shear-thinning with the viscosity well within design limits at the anticipated shear rates in the core barrel. There has been some question about the maximum pseudoplastic fluid viscosity which can be used without causing excessive pressure increases in the core barrel, and a study of the pseudo-plastic flow properties of non-Newtonian power-law fluids in the core/core barrel annulus was completed. Experimental data from the Brinadd polymer system Sanheal showed the fluid properties to be highly non-Newtonian and a strong function of temperature and shear rate. In order to calculate the pressure buildup during coring for this type of fluid, the necessary power-law equations were developed and solved numerically using a computer.

The Hassler cell core holder and associated equipment ordered from Core Laboratories was received. This equipment has been assembled and tested, and experimental procedures are being developed. Cores have been drilled from the Brown sandstone and Indiana limestone; permeability tests have been run on both rock types.

Bit Design and Fabrication

Drawings of the full bit body (8-1/2 in.) were completed. A computer program was completed for fabrication of the bits on a numerically controlled five axis machine, and the first bits were fabricated, inspected and cleaned.

Stratapax™ cutters were brazed to the first pressure core barrel pilot bit body. Fabrication errors made it necessary to redesign the tooling for ultrasonic tacking of Stratapax™ cutters to steel studs.

A 6-1/2 in. main bit and a 2-1/2 in. pilot bit are also being designed and fabricated for use with existing core barrels for an early field test. This will provide the earliest possible introduction of the improved coring system.

INTERFACE CONDUCTIVITY EFFECTS ON ELECTRIC LOGGING

Resistivity measurements on core plugs from the Mesaverde Group continued, although repeated oil leaks into the cores required equipment modification to eliminate the problem. An apparatus for determining the cation exchange capacity (CEC) of clay-containing core samples was assembled. CEC determinations were subsequently made for a number of core samples. Porosity, permeability and conductivity measurements were made for cores from eight well depths from the Natural Buttes No. 21 well in Uintah County, Utah.

LOGGING TECHNIQUES AND INTERPRETATIONS

Study of the Sonic, Neutron and Density logs of the cored intervals of the Paine well, along with accompanying core data, showed that, with two exceptions, the core data agreed with the porosity determined from the Sonic log.

In December, 48 plugs were cut from the Natural Buttes No. 21 cores. Bulk volume of the cores was determined and porosity was calculated based on matrix volume measurements made with a helium porosimeter. Porosity will also be determined using a second method, an extension of the Modified Barnes Method.

RESERVOIR SIMULATION STUDIES

Parametric Analysis of MHF Test Data; An Engineering Study of Western Gas Sands - Intercomp, Inc.

Mobil's well F31-13G was chosen as a starting point. The well has nine perforated and tested zones and six MHF treatments. Zone 1, from 10,549 - 10,680 ft, has several sands perforated. Build-up data is available for the pre-frac and post-frac periods. Classical transient testing techniques were applied to the pre- and post-frac build-up data. The pre-frac kh (permeability-thickness) value obtained was reported at 0.3 md-ft. The post-frac value was 1.1 md-ft.

A three-dimensional, cylindrical coordinate, dry gas simulator is being used to simulate well behavior under the conditions of the tests. The simulator has been modified to account for the presence of a fracture. The third dimension, the z direction, is used to simulate the effect of various sands that may be open to the wellbore.

Several runs were attempted with the kh values specified by build-up analysis. The wellbore boundary condition was fixed at 100 psi specified at the surface outlet of the tubing string. The gas flow rate from the well was computed by the simulator. Using the kh values computed by the build-up analysis, the well would not produce the observed rate for the pre-frac draw-down period. A value of 1.45 for kh was used and the computed rate and bottom-hole pressure corresponded to the observed values. This method is valid if the well has not been fractured and the skin value is zero.

A type curve for the pre-frac build-up of zone 1, given in Figure 4-10, shows a constant slope of 0.2 after an initial wellbore storage period. This behavior is not typical of type curves found when the reservoir properties are affecting the build-up. Also shown on Figure 4-10 are the simulated results for the pre-frac case, given kh = 1.45, h = 60 ft, ϕ = 0.04 and a wellbore storage volume of 1,988 cf. The storage volume is computed for the wellbore using a 7 in. casing and 2-3/8 in. tubing without a packer.

It can be seen, on Figure 4-11, that the observed storage is smaller than expected during the initial shut in. This could be due to two storage periods: the first for the 2-3/8 in. tubing followed by storage in the annulus.

Figure 4-12 is a Horner plot of the observed and simulated results for the pre-frac case. The kh value analyzed from the simulated data is 0.9 with a skin value of -2.6. This analysis is incorrect since storage is still affecting the solution.

The post-frac period was simulated using reservoir properties determined from pre-frac draw-down simulations. Several fracture half-lengths (X_f) were used. The simulation run which gave the best results is shown on Figure 4-13 and Figure 4-14 along with the observed data. The fracture half-length used in this simulation is 35 ft., which is much smaller than the design. A fracture half-length of 100 ft. shows a definite slope of 0.5 on a type curve plot seen on Figure 4-14. Since no slope of 0.5 can be seen on the type curve for the observed data, Figure 4-12, the fracture must be smaller than the X_f of 100 ft.

The kh values determined from the slope of the Horner plot, Figure 4-13, are close to the kh calculated from the observed data of 1.1 md - ft. The effect of after flow for these tight gas sands must not be neglected; the kh value determined from build-up analysis is smaller than actual when analyzed using classical transient testing techniques.

Test data from various zones in the Mobil well F31-13G show total buildup time longer than flow time. This, together with long periods of wellbore storage, causes errors in results from type curve match analysis of the build-up data. Available type curves give drawdown solutions and may be used for the analysis of buildup data if the flow time preceding the buildup is much larger than the buildup time. A set of buildup type curves that take flow time into account has been developed to help in the analysis of data.

Herber Cinco-L. and Fernando Samaniego-V. presented a paper titled "Transient Pressure Analysis for Fractured Well" at the fall meeting of the SPE in Houston, 1978. Four flow periods were defined. The first is linear flow from the fracture only. The second is bilinear flow. The third is for linear flow from the matrix alone and the fourth is for radial flow from the matrix.

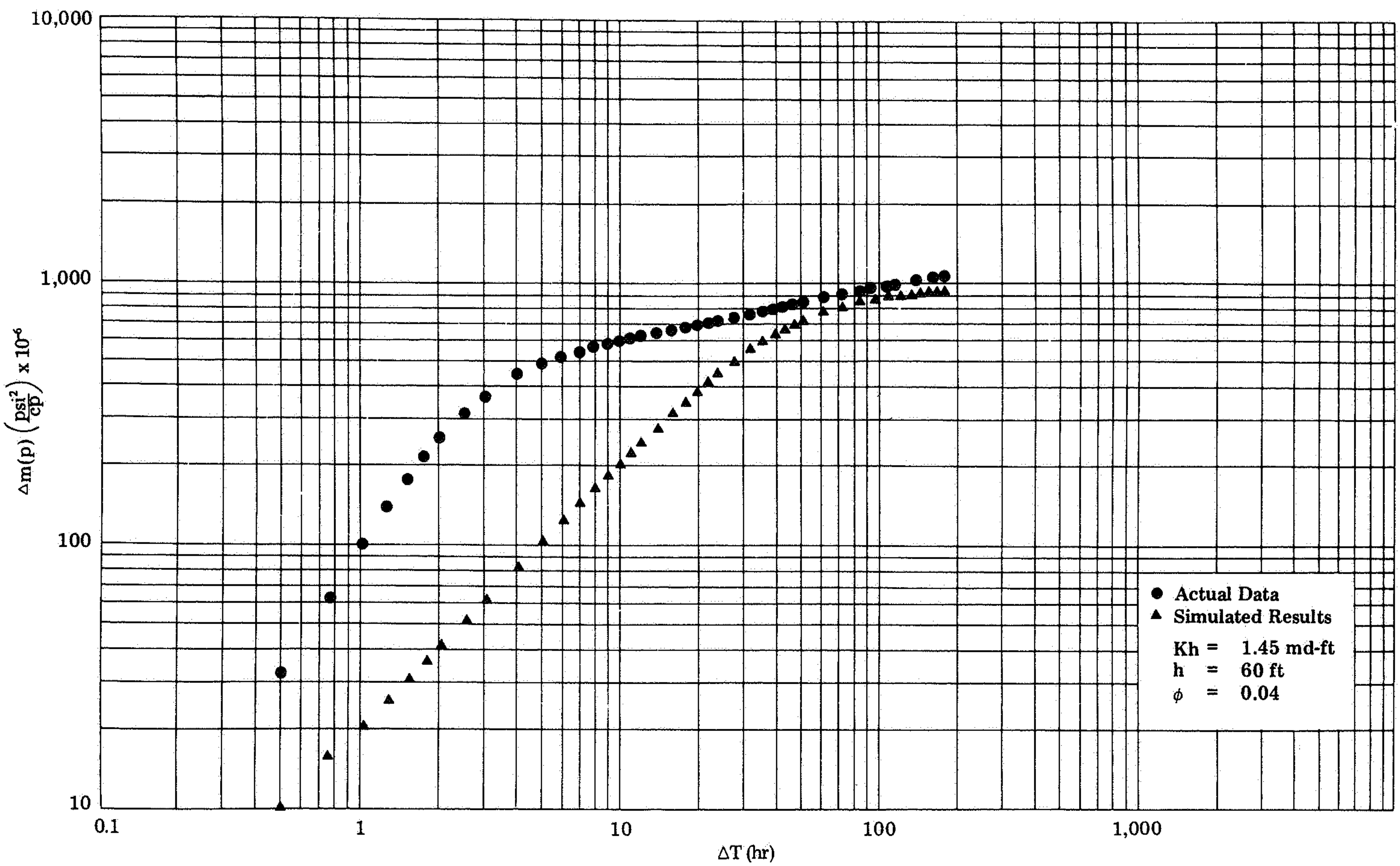


Figure 4-10 Type Curve for Pre-Frac Buildup of Zone 1, Mobil Well F31-13G

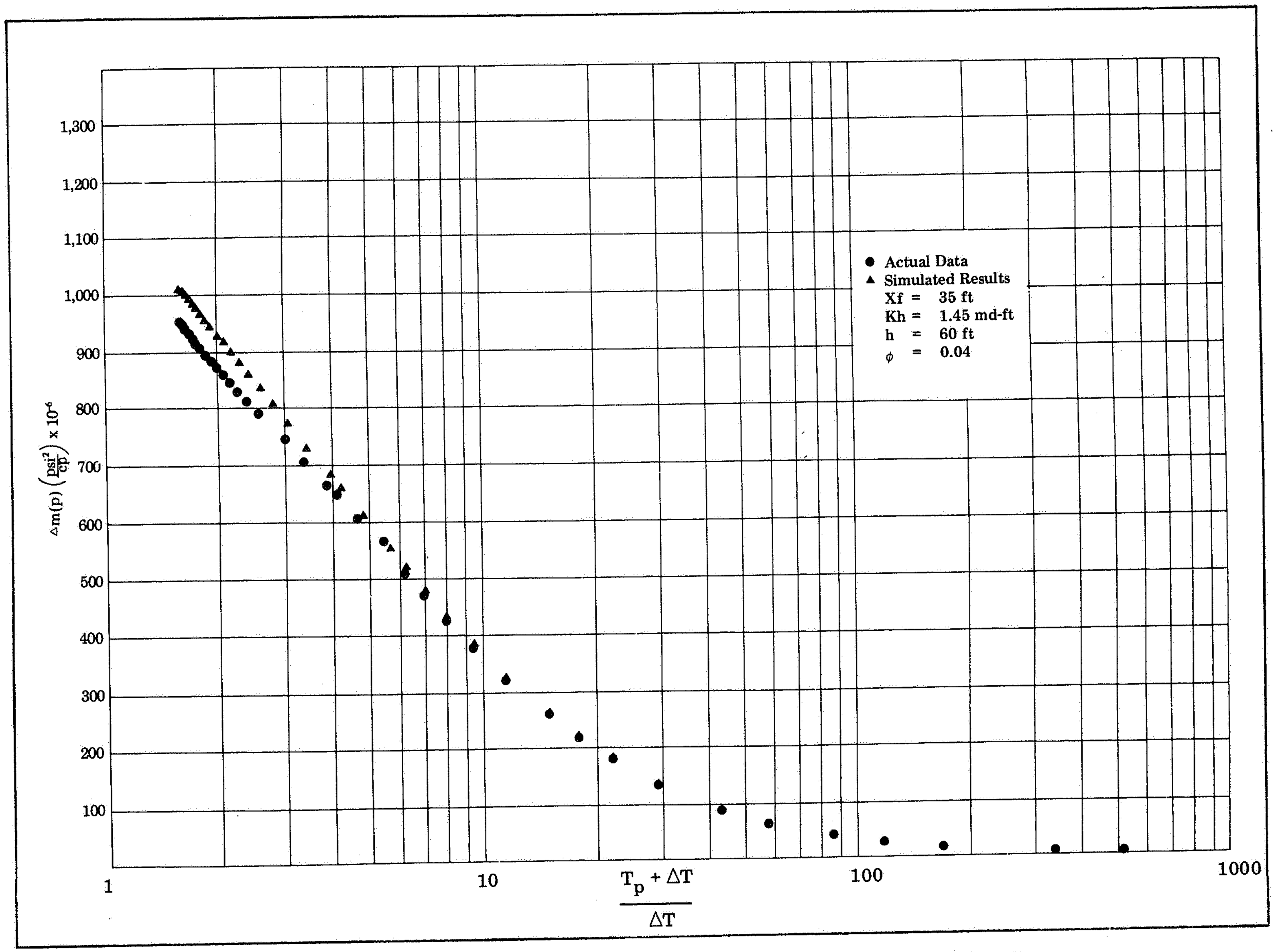


Figure 4-11 Observed Storage during Initial Zone 1 Shut in, Mobil F31-13G

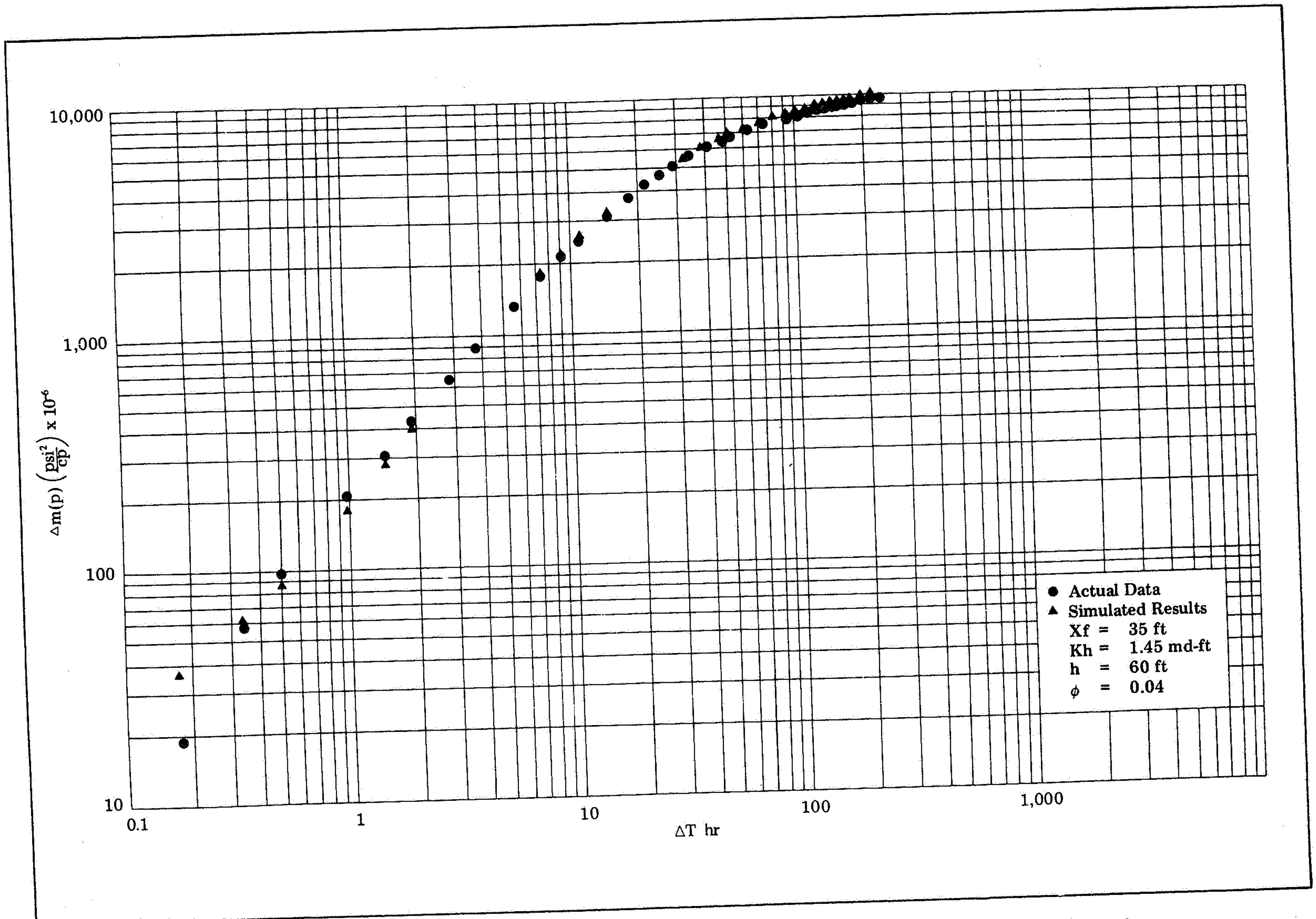


Figure 4-12 *Horner Plot of Observed and Simulated Results for Pre-Frac Case, Zone 1, Mobil Well F31-13G*

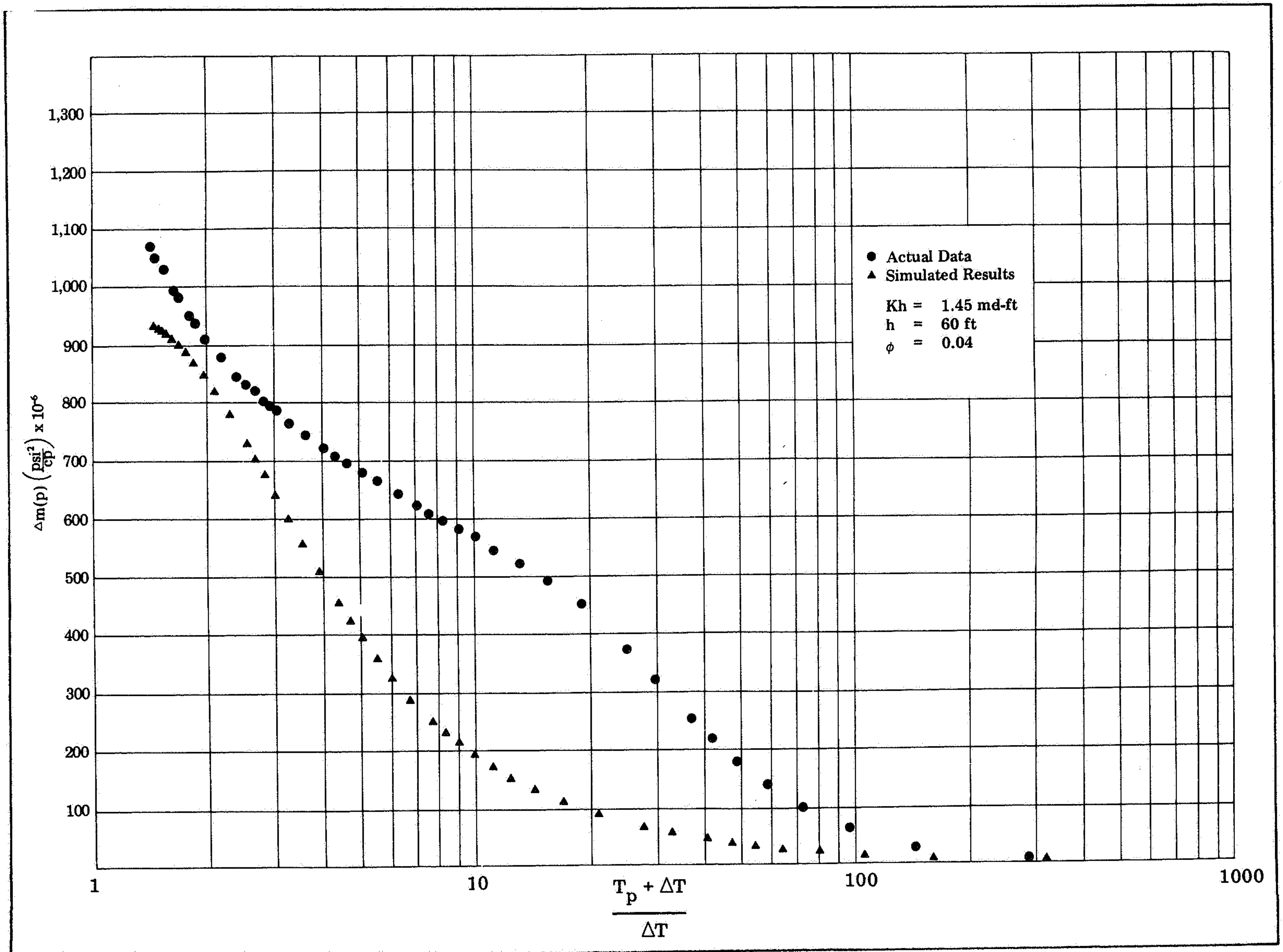


Figure 4-13 Zone 1, Post-Frac Period Simulation using Reservoir Properties Determined from Pre-Frac Draw-down Simulations

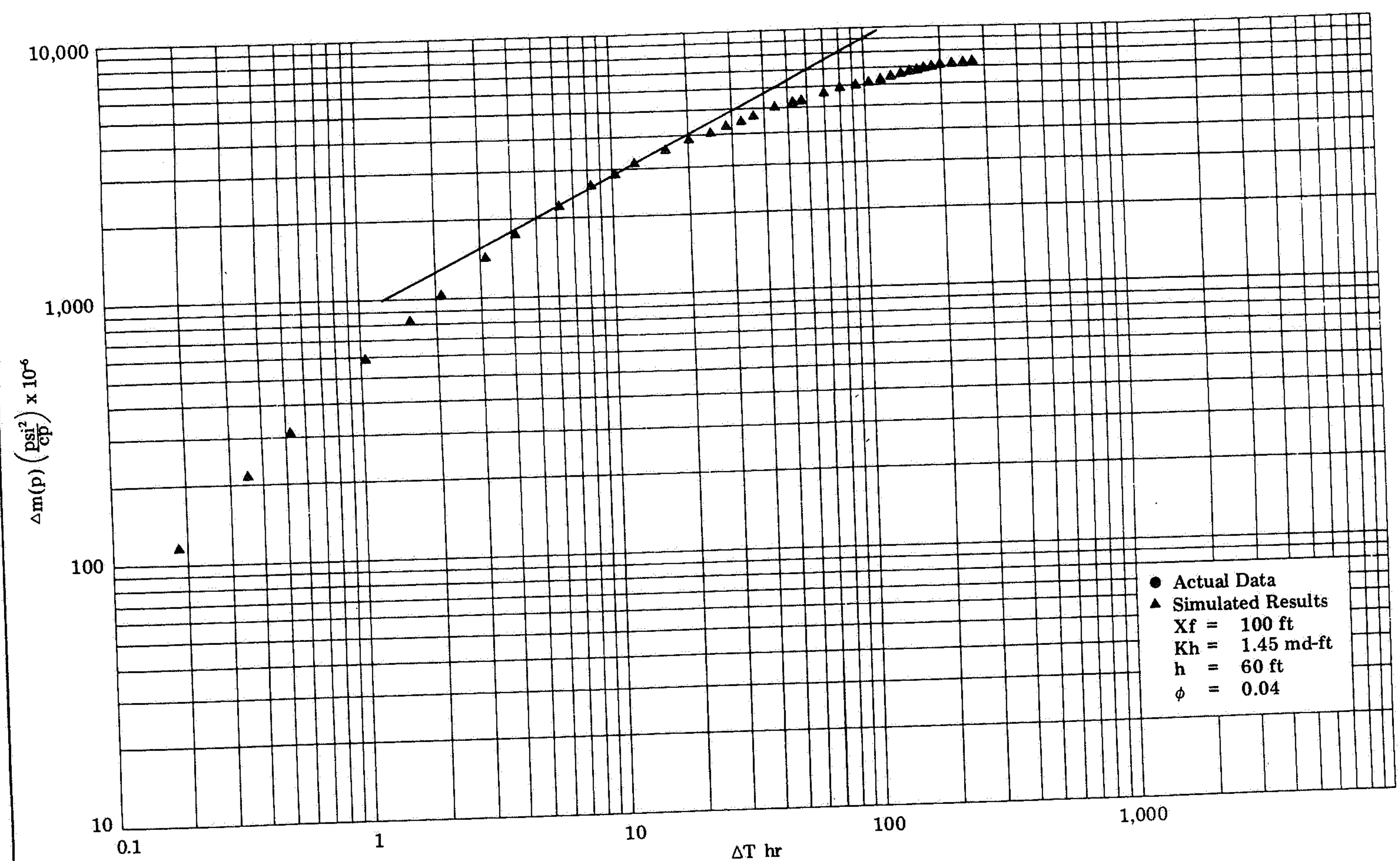


Figure 4-14 Zone 1, Post-Frac Period Simulation using Reservoir Properties Determined from Pre-Frac Draw-down Simulation

The slope during the first flow period should be a straight line on a log ΔP versus Δt or type curve plot with a value of 0.5. The second period should be a straight line of a slope of 0.25 on a type curve plot. The third flow period should have a slope of 0.5 on a type curve plot and the fourth should bend over.

The various flow periods may be present on any test or may be non-existent on any one test depending on the parameters of the reservoir. The first flow period may be masked by storage effects, etc. The buildup tests for zone 1 and zone 3 of the Mobil well F31-13G show a slope of about 0.25 for the pre-frac tests. This slope was previously recognized and noted but the reason was unknown. It appears that zones 1 and 3 of the F31-13G well have natural fractures or that they were created during drilling or completion operations. Figure 4-15 is the type curve for zone 3 pre-frac build-up. It appears that the first two flow periods may be present. Seen on Figure 4-16, the first slope, notation 1, is a 0.5 slope and the second slope, notation 2, is a 0.27 slope. It appears that the third slope is not present. Cinco et al states that this is true if $k_f w/(kx_f)$ is <1.6. The nomenclature above is:

k_f = fracture permeability, md
w = fracture width, ft
k = formation permeability, md
x_f = fracture half-length, ft

Previous work was performed assuming that the reservoir was not fractured prior during the pre-frac tests.

Pre-fracture pressure buildup data taken on zone 4A through 7 of Mobil well F31-13G were analyzed using standard pressure transient analysis techniques. The first portion of the work was preparation of type curve plots of the pressure data. These are shown in Figures 4-17 through 4-21.

A type curve plot is used to determine the time after which the pressure data measured during a buildup test are no longer affected by wellbore storage.

Pressure buildup data, dominated by wellbore storage, lie on a unit slope straight line on a type curve plot. As wellbore storage effects die out, the data begin curving away from the unit slope line. They plot on a curve having a very low slope.

The type curve plot of pressure data taken on the five zones all show the unit slope line. This line lasts for a minimum of 1.5 hrs for data from zone 7 to a maximum of 30 hrs for data from zone 4B. Data measured during this time are used to estimate the effective wellbore volume, V_w, during the test.

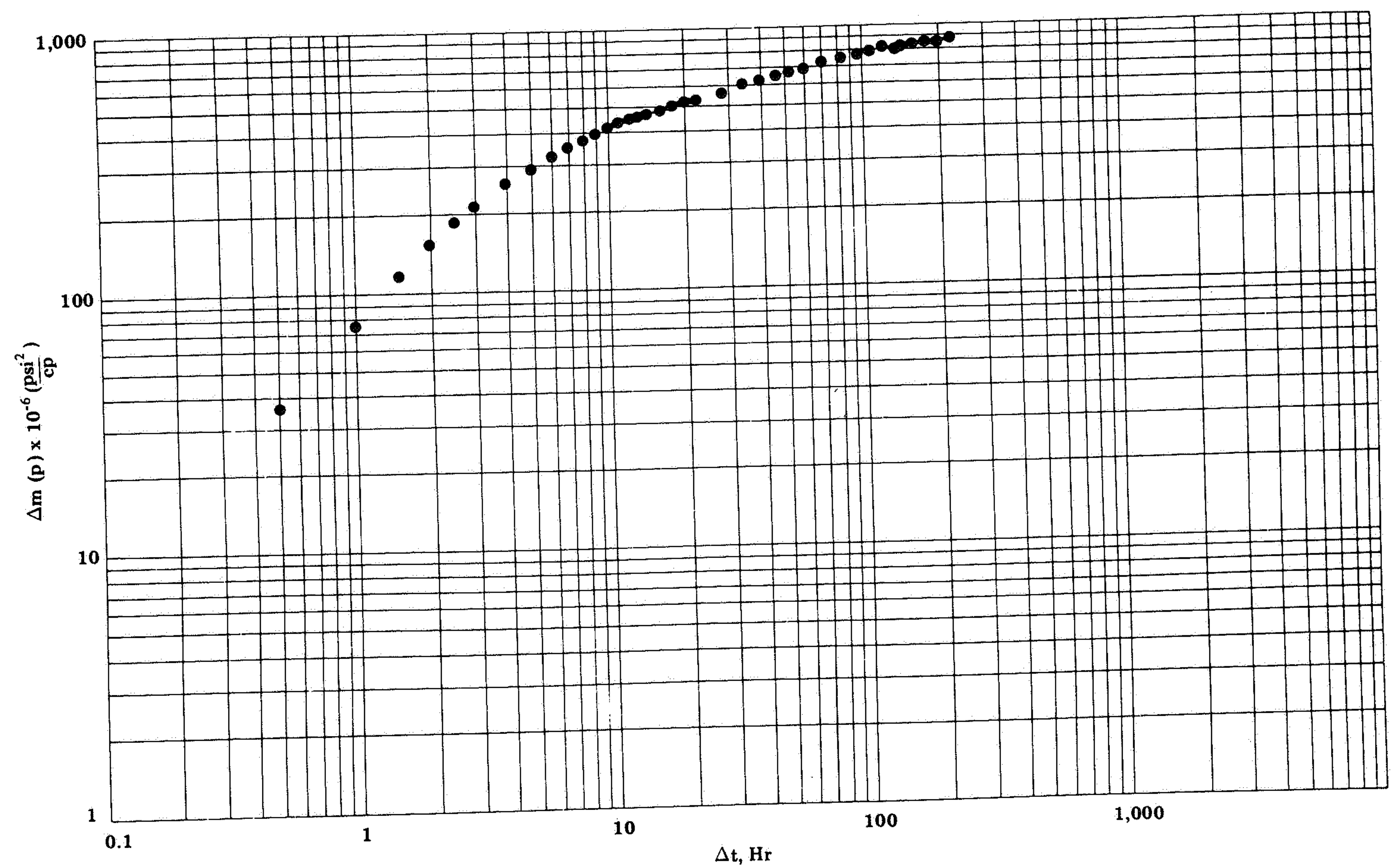


Figure 4-15 Type Curve Plot for Mobil Well F31-13G, Zone 3 Build-Up

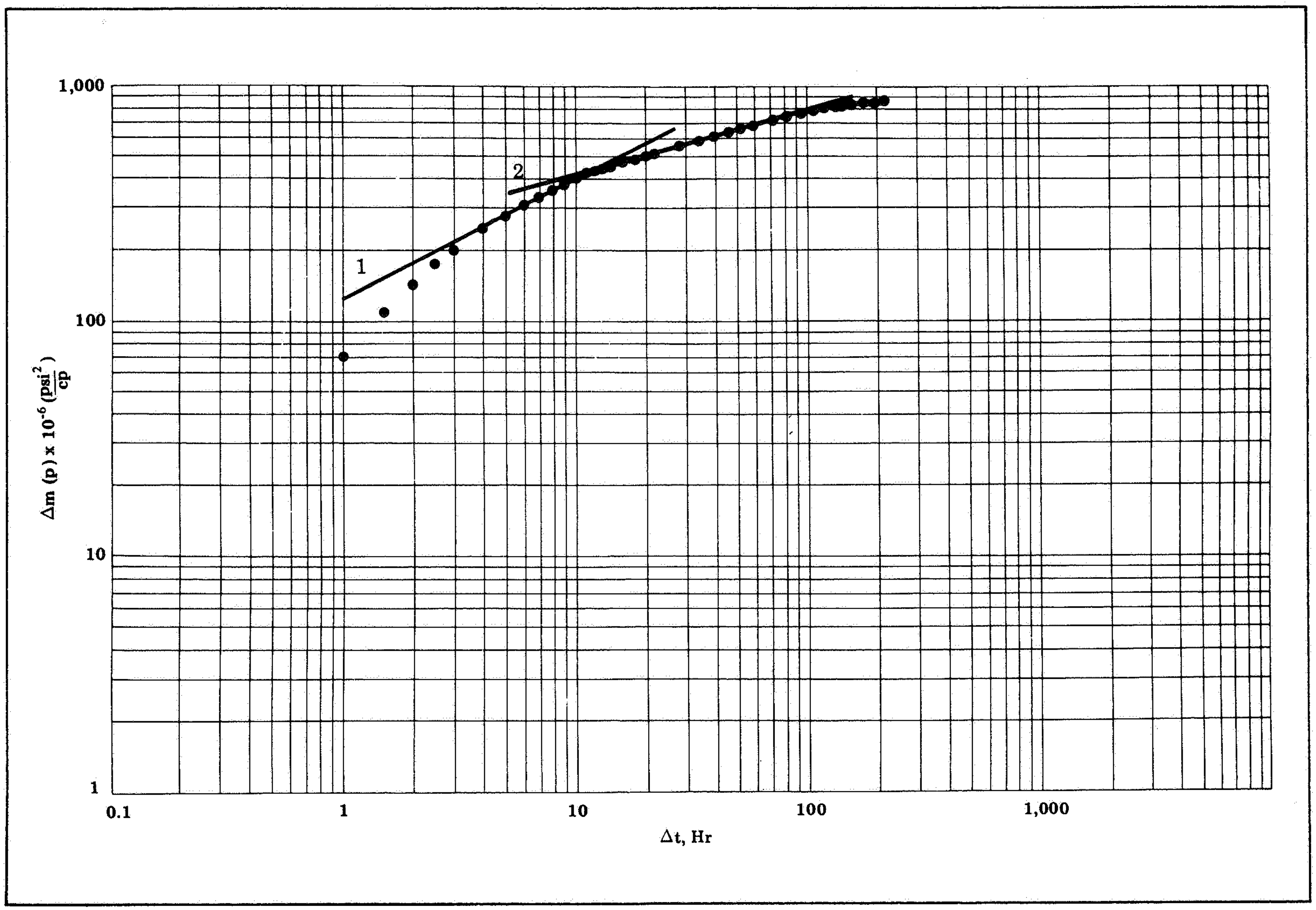


Figure 4-16 Type Curve Plot for Mobil Well F31-13G, Zone 3 Build-Up with Slopes Defined

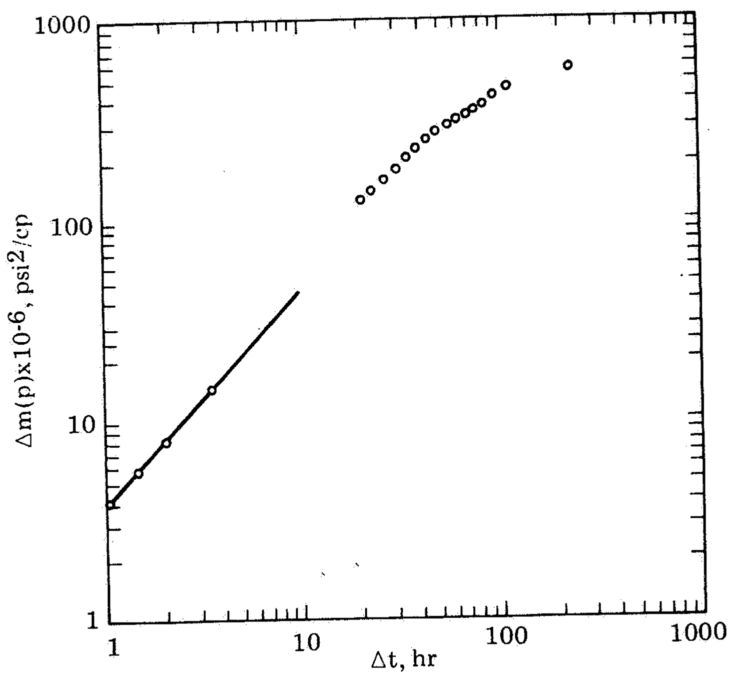


Figure 4-17. Type Curve Plot of Pre-Frac Pressure Buildup Data from Zone 4A

Table 4-3 gives the wellbore volume estimated from the test data. The calculated wellbore volumes are low when compared to the volume calculated from well completion data. While they are low, the majority are fairly good ballpark values. The exception is the data from zone 7. Its V_w is considerably below that of 2-3/8 in. tubing in 7 in. casing without a packer. This may indicate some anomaly in the pressure data or that the annulus was packed off.

All of the type curve plots show the data breaking away from the unit slope line. None of the plots shows the flattening of the data which indicates the end of wellbore storage effects. This means that none of the data can be analyzed from a conventional Horner plot. For this reason, all data were analyzed using type curve plot matching.

The values of porosity and permeability calculated from the test data using type curve analysis are given in Table 4-3. The porosity values seem fairly good but the permeabilities seem high. All of the test data give a good match with Ramey's curves for a skin factor of zero.

Values of porosity and permeability obtained from the type curve match were used to simulate the zone 4B test with the 3-D RDGAS simulator. The results are shown on Figure 4-22. Buildup pressures generated by the simulator are much higher than those measured during the test. The slopes of the two curves are very similar. The simulated data assumed an original reservoir pressure of 4,000 psig. A reduction in reservoir pressure would cause an equivalent

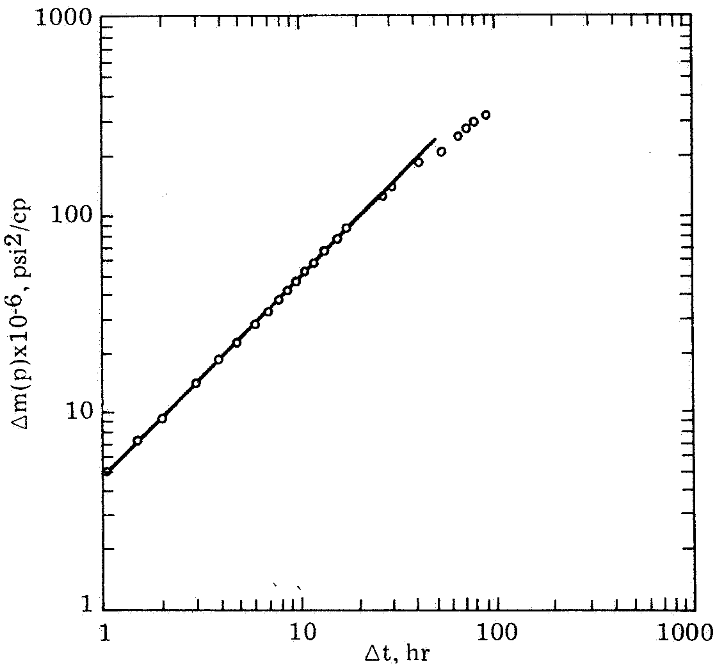


Figure 4-18 Type Curve Plot of the Pre-Frac Pressure Buildup Data from Zone 4B

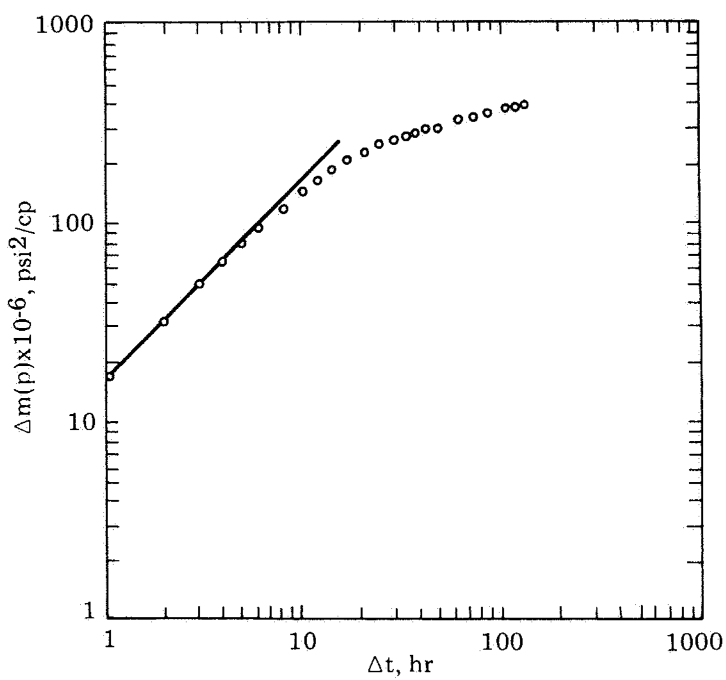


Figure 4-19 Type Curve Plot of Pre-Frac Pressure Buildup Data from Zone 5

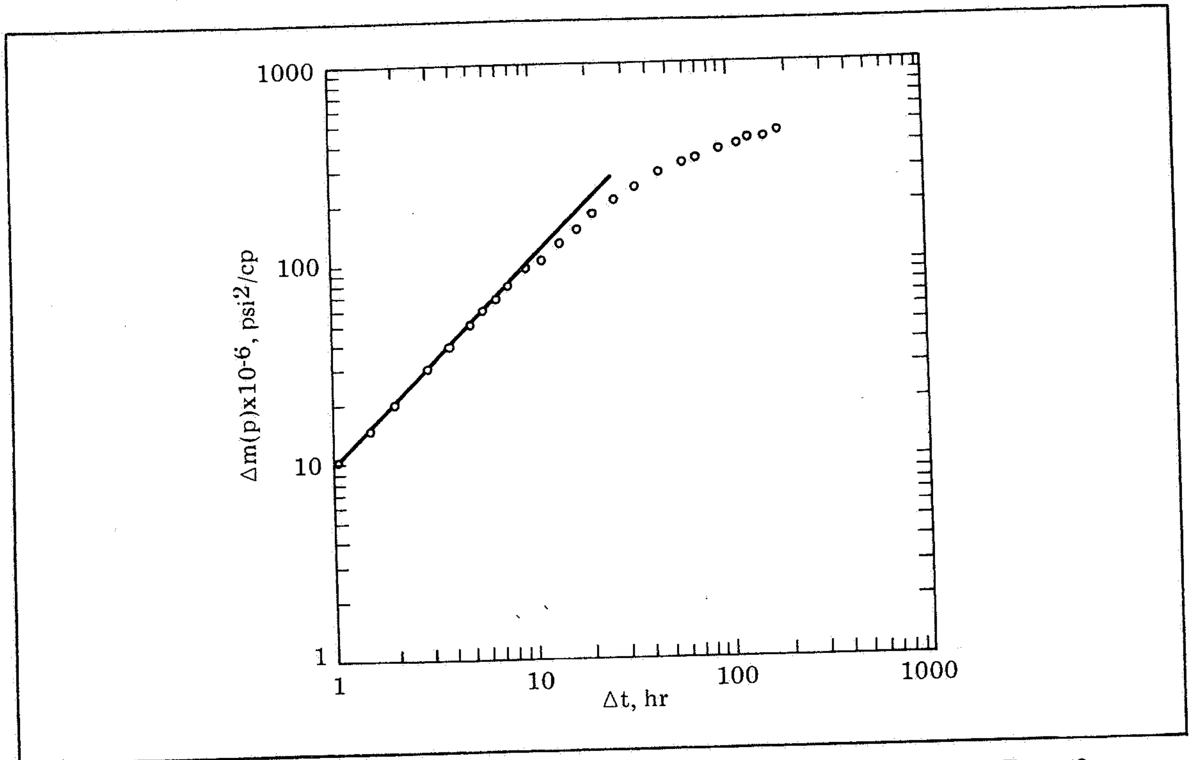


Figure 4-20 Type Curve Plot of Pre-Frac Pressure Buildup Data from Zone 6

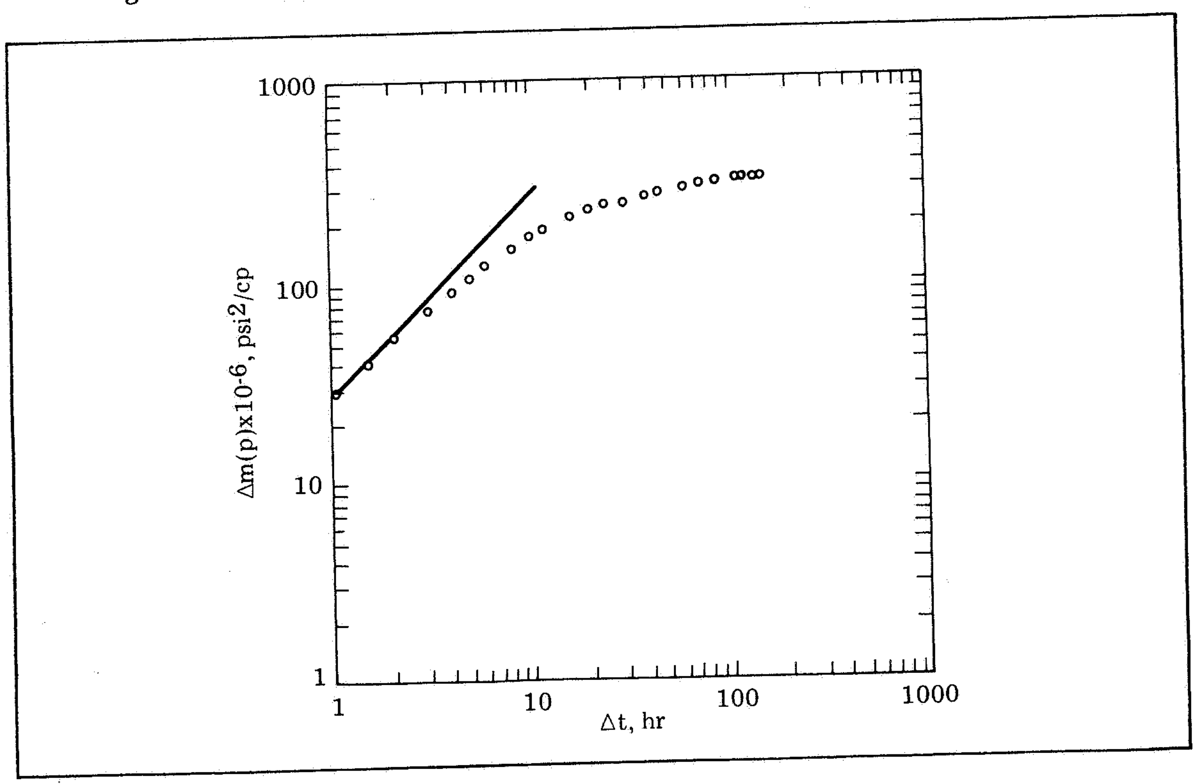


Figure 4-21 Type Curve Plot of Pre-Frac Pressure Buildup Data from Zone 7

Table 4-3 Wellbore Volume Estimated from the Test Data

Zone	C, ft^3/psi	V_W, ft^3	k, md	ϕ, fraction
4A	2.74	1232	0.037	0.036
4B	1.15	1081	0.025	0.039
5	1.69	1482	0.017	0.035
6	1.79	1207	0.064	0.028
7	0.37	446	0.070	0.089

Note: s = 0 for all zones.

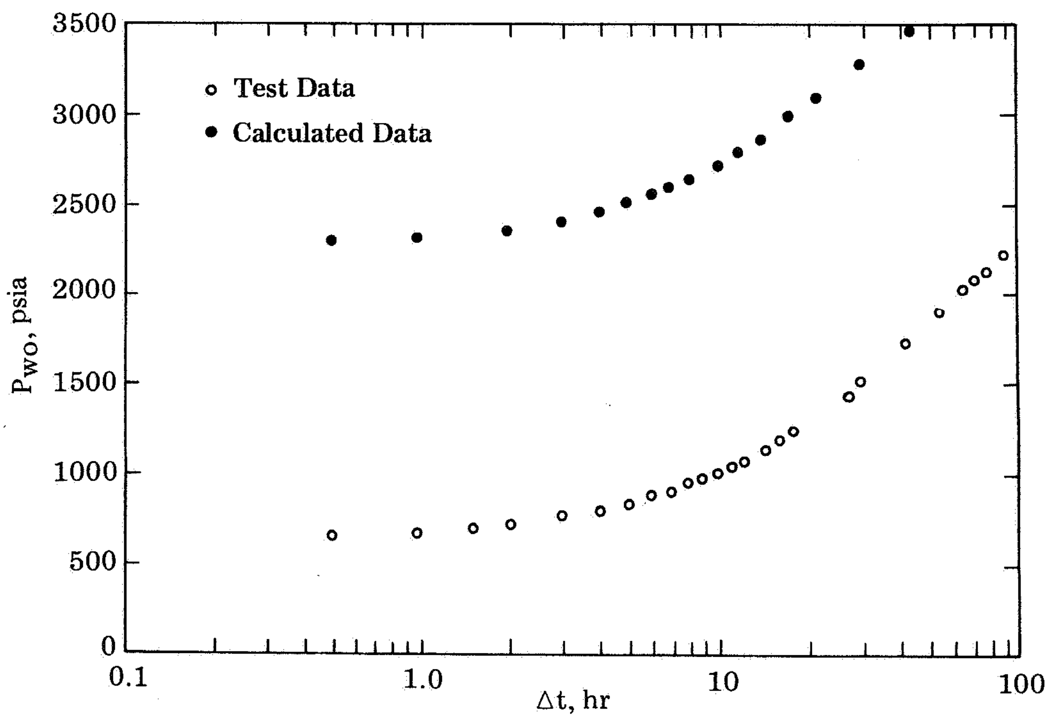


Figure 4-22 Computer Match of Zone 4B Pre-Frac Buildup Using Reservoir Properties

reduction in the error between the two sets of data. Reservoir pressure would have to be reduced to approximately 2,300 psig to get the two curves to match. This is extremely low considering the depth of zone 4B.

Subsequent computer runs in which the value of the skin factor was changed showed improvement, but did not give a good match to the test data. For this reason, matching the test data by varying all of the reservoir data within reasonable limits has been attempted.

The best match obtained thus far is shown on Figure 4-23. The computed data are high during the first 30 hrs, but matched fairly well after that.

Results of this work demonstrate that conventional pressure transient analysis techniques do not work with the buildup data from zone 4B. Since computer matching appears to give better results, all of the test data will be analyzed using computer matching.

ROCK-FLUID INTERACTIONS

Particle size analysis was performed on three samples of frac fluid produced from GPE well CIGE No. 2. The range of particle size of two samples is between 2 to 40 microns. This particle distribution which is present at a very high concentration (approximately 200,000/ml) in the produced frac fluid could probably plug the propped fracture. Such plugging would result in a buildup of pressure until the particles were forced out, then replugging would stop fluid production again.

Particle size distribution and numbers have been obtained from 40-60 mesh sand placed in a 0.2 in. thick fracture between two core halves. A 10 in. long x 1-1/2 in. diameter Berea core was cut in half and reassembled with a 0.2 in. fracture, packed with 40-60 mesh sand. The assembled high-pressure core apparatus was arranged with the simulated fracture in the vertical position, then a 2 percent KCl solution pumped through the pack. The overburden pressure was increased in 1,000 psi increments starting at 1,000 psi and continuing up to 6,000 psi. Samples of the passing fluid were examined and the particles counted and sized. Generally, as the overburden pressure increased, the proppant particles were fractured and traveled in the 2 percent KCl solution. Table 4-4 shows the particle size and concentration in the effluent 2 percent KCl solution.

A 2 percent KCl solution in demineralized water was pumped through a 10 in. long, 1-1/2 in. diameter Bandera core split in half length-wise and packed with 40-60 mesh sand to form a 3/64 in. fracture. The actual overburden pressures imposed on the core system were: 500, 1,000, 2,000, 3,000, 4,000, 5,000, 6,000, 7,000, and 8,000 psig. The initial liquid flowrate (injection rate) was approximately 2.86 ml/min. However, this decreased to 2.5 ml/min as the overburden pressure increased.

100 ml. samples of 2 percent KCl solution, containing fines, were collected at the exit end of the mounted core for each of the overburden pressures. The first six samples were collected during the flushing operation on the mounted core in order to establish a constant background particle count for the saturation fluid.

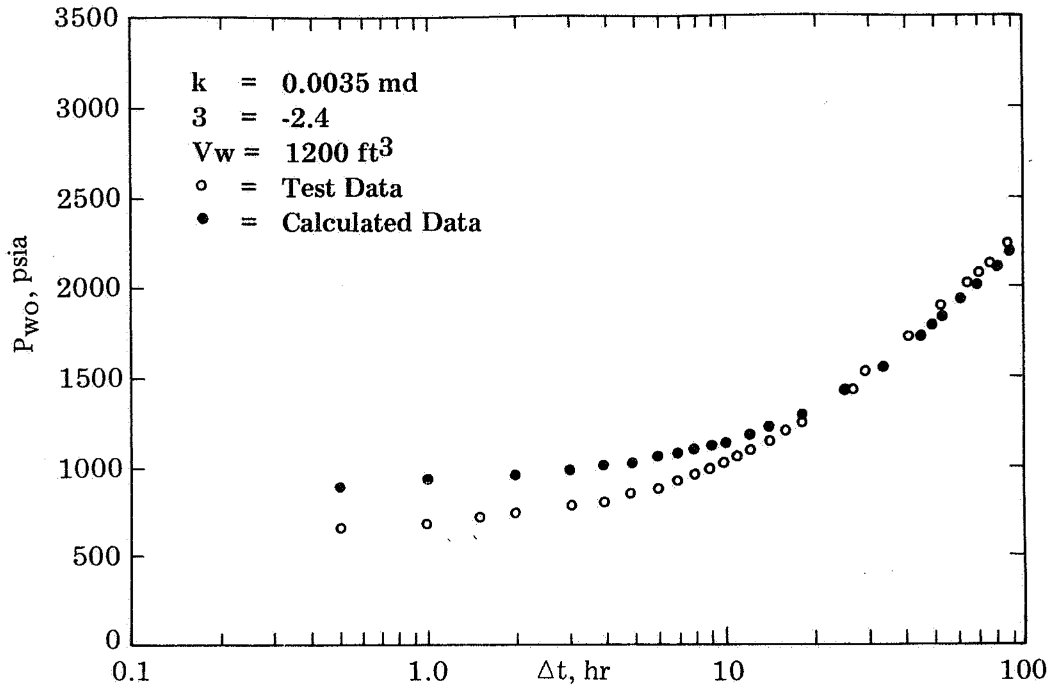


Figure 4-23 Computer Match of Zone 4B Pre-Frac Buildup

Table 4-4 Particle Size Distribution in Simulated Frac Fluid

SAMPLE NO.	OVERBURDEN PRESSURE (psi)	MAXIMUM COUNTS per ml	PARTICLE SIZE IN MICRONS Mean	Mode	Range
1	1,000	27,000	2.1	1.8	1.6 - 6.8
2	2,000	13,000	2.7	1.8	1.6 - 6.2
3	3,000	62,000	2.5	1.8	1.6 - 6.3
4	4,000	53,000	2.2	1.8	1.6 - 5.5
5	5,000	53,000	2.2	1.8	1.6 - 5.8
6	6,000	57,000	2.4	1.8	1.6 - 7.8

The injection pressure at first was too low to be measured with the pressure gauges used. However, it did increase to about 3.0 psig at the end of the experiment. Thus, a gradual plugging off of the fracture was occuring as the overburden pressure increased, which is attributed to the proppant inbedding into the formation.

At the conclusion of the above injection experiment, two sand samples were scraped off of the faces of the core halves in the center of the fracture and at the exit end (including the sand adhering to the exit screen). Each of these sand samples was then placed in glass beakers and covered with 100 ml of 2 percent KCl solution. The mixtures were run through a 45 micron sieve to remove the unfractured material preparatory to analyzing them with the particle counter.

The effluent samples of 2 percent KCl solution and sand fines from the filtering operation and from the injection experiments were then analyzed with the particle counter. The particles were centered about a mode of approximately 1.77 microns and ranged from 1.65 microns to 5.0 microns for all samples. Only small deviations from the mode and range were noted.

As overburden pressure was applied up to 9,000 psi, injection pressure varied from 0 to 4.5 psig. A trace of the injection pressure is shown in Figure 4-24. The injection pressure continued to increase during the sampling time when the overburden pressure was constant indicating plugging of pores by the particles from the crushed proppant.

One-hundred ml samples of 2 percent KCl solution containing fines were collected at the exit end of the mounted core for each of the overburden pressures. The first four samples were collected during the flushing operation on the mounted core in order to establish a constant background particle count for the saturation fluid. This background contained fines from the sand proppant and clays from the core face.

Two sand samples were scraped off the faces of the core halves in the center of the fracture and at the exit end (including the sand adhering to the exit screen) at the conclusion of the injection experiments. Each sand sample was then placed in a glass beaker and covered with 100 ml of 2 percent KCl solution. The mixtures were run through a 45 micron sieve to remove the unfractured material preparatory to analyzing them with the particle counter.

The effluent samples of 2 percent KCl solution and sand fines from the injection experiments were then analyzed with the particle counter. The particle mode increased from 1.77 to 2.87 microns, but the most prominent change was the size range which increased to 12 microns. Particle concentration increased significantly. Since the experiment duration was short (designed to get the particle distribution), there was not enough time for complete plugging. Pumping a broken gel through will simulate the frac-fluid and will be continued until plugging occurs.

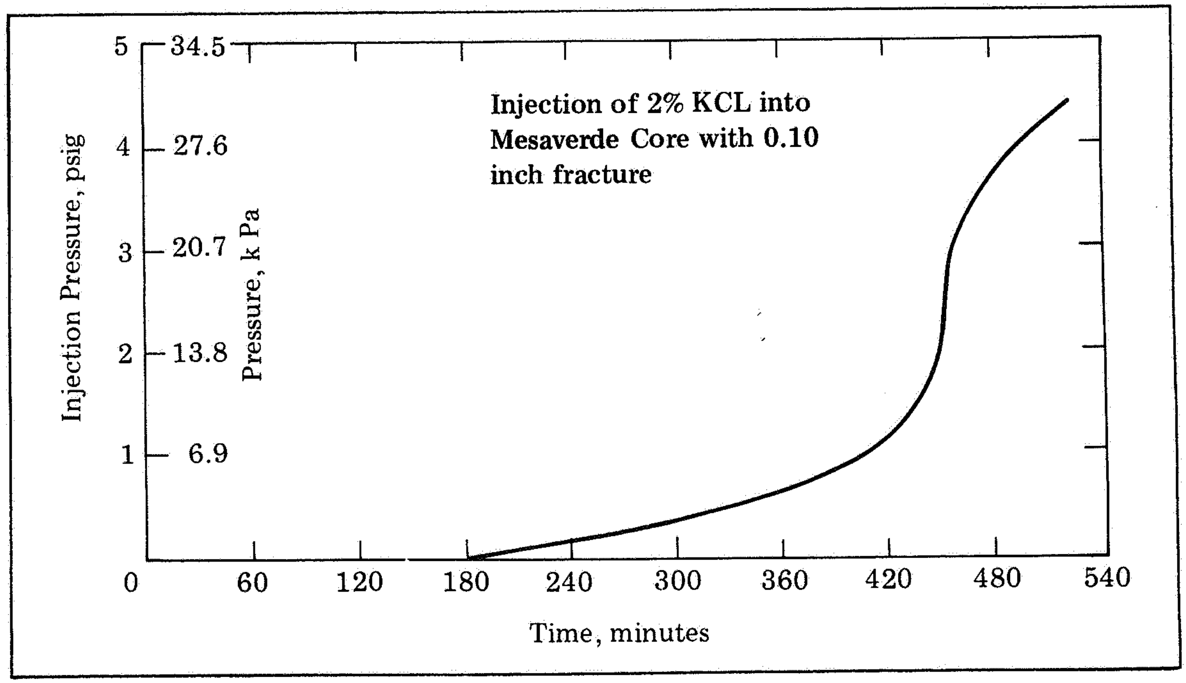


Figure 4-24 Pressure profile from injection of 2 percent KCl solution into the Mesaverde core with a 0.1 inch wide fracture propped with 40/60 mesh sand.

An experiment was conducted to simulate the effect of pumping a gel through a propped fracture. Fine diameter sand particles, which simulated crushed proppant and core face materials, were mixed with partially degraded 40 lb gel in a 2 percent KCl solution. The mixture had about 90,000 particles per ml with a mean diameter of 5.35 microns. The gel-particle mixture was injected through a 10 in. length, 1-1/2 in. diameter Mesaverde core split lengthwise and packed with 40-60 mesh sand to form a 0.1 in. fracture.

With an 8,000 psig overburden pressure imposed on the core, a constant volume pump was used to inject the mixture through the simulated fracture at a rate of 2.5 ml/min. After 28 min the injection pressure increased to 270 psig and after 60 min, the pressure increased to 990 psig. Aliquots of the core effluen indicated a decrease in particle number with an increase in particle diameter. Due to pump pressure limitations, the experiment was concluded with the fractur plugging. The data indicate that proppant pores and fracture were plugged due to the particle mixture and gel residue. Permeabilities of seven adjacent plugs from a uniform core interval from the Mobil PCU F31-13G well were measured for data consistency between plugs. Although replicate measurements for a single plug were reasonably consistent, permeability variation between different plugs was excessive for a core interval with uniform lithologic appearances as shown in Table 4-5. The data suggested a problem of gas leakage between the core and Hassler sleeve. Plugs of larger diameters were prepared for additional tests to study the problem of blow-by on low permeability cores.

Table 4-5. Permeability Values of Adjacent Plugs from a Uniform Core Interval

Plug Number	Permeability (md)
A	.050
B	.078
C	.075
D	.097
E	.073
F	.102

IN-SITU PERMEABILITY

The N_2 permeability for CIGE No. 21 core as a function of overburden pressure appears in Figure 4-25. As the overburden increases, the permeability decreases. Either physical compression of the core or pore plugging by mechanic formation of fines could cause this.

For a constant overburden pressure of 3,375 psi, the permeability decreases rapidly as the applied N_2 pressure is increased. A plot of permeability versu I/P is not linear, indicating a deviation from Darcy's Law (see Figure 4-26).

A 2 percent KCl brine solution was pumped across the core face at 1.7 ml/min with 3,375 psi overburden pressure. About 0.85 ml/min of brine flowed through the core with a backpressure of 1,400 to 1,500 psi. This is equivalent to a liquid permeability of 0.032 md under these conditions. The first 15 ml of brine collected were very turbid, indicating that colloidal particles were coming from the core. These fines could be those produced during core-cutting or core relaxation. The pH of this solution was 7.4, whereas the pH of the brine was 5.7. This increase might reflect the natural formation pH or invasion of alkaline drilling mud.

Nitrogen flow measured just prior to brine flooding gave a permeability of 23.4 μd for 3,390 psig overburden and 200 psig N_2 pressure. After flooding, it took about 1-1/2 hrs to clear the core and lines of brine, using 200 psig of nitrogen. The N_2 permeability then increased rapidly until after 24 hrs; the permeability had increased to 25.5 μd, and was still increasing. Greater permeability after brine flooding may be due to removal of fines by the brine. Core drying probably explains the generally slow increase in permeability.

A high pressure test cell purchased from Core Laboratories was received and has been used to study in situ formation characteristics of cores. Presently, work is in progress measuring gas permeabilities of cores from Mobil PCU F31-13G. Five adjacent plugs were taken from a uniform core interval. Permeabilities were measured for repeatability and data consistency between plugs. These measurements suggest problems with blow-by between the plug and the rubber sleeve. A plug, which was cemented to the rubber sleeve with Pliabond, had a flow of 20 percent of the original value. Work is continuing to establish the severity of blow-by on low permeability cores and possible solutions.

MEASUREMENTS OF FORMATION CHARACTERISTICS FOR WESTERN TIGHT SANDS -- INSTITUTE OF GAS TECHNOLOGY

Previously reported initial air permeability values for core from Mobil PCU F31-13G must be corrected. Because weights did not change significantly after vacuum heating, the low-permeability values could not be attributed to water in the core. On close investigation, it was found that due to a kink in the high pressure tubing, the end plug was set so that it did not touch the core and the rubber sleeve showed evidence of constriction at that point. It is likely that the sleeve, under pressure, closed off and controlled flow rates. After being in a vacuum oven (<0.1 psia, 90°C) for 10 days, air permeabilities were again tested at a confining pressure of 140 psig and differential pressure of 40 psig. New values are listed in Table 4-6 along with previous values

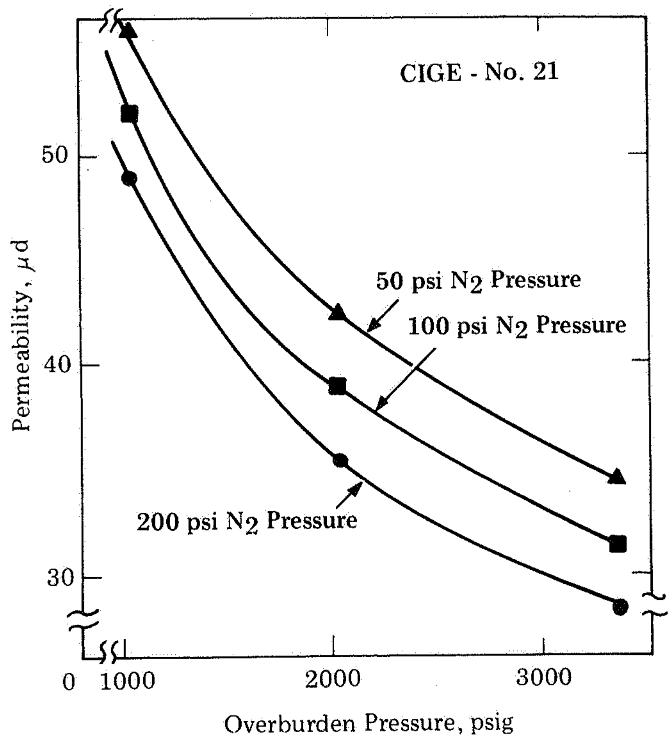


Figure 4-25 Permeability versus Overburden Pressure

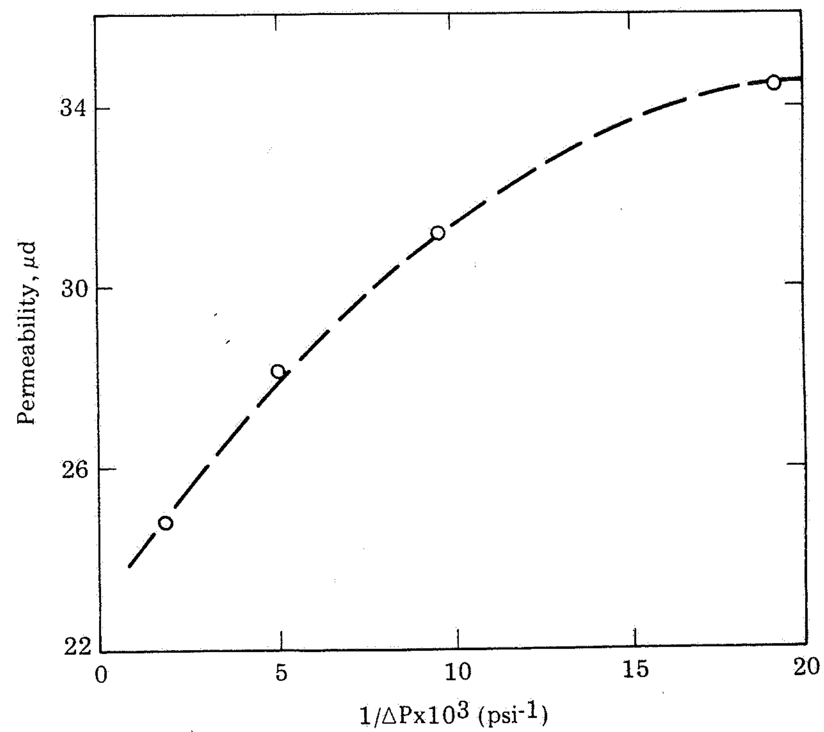


Figure 4-26 Permeability versus Reciprocal N_2 Pressure

for Canyon Largo No. 256 core. The curves shown in Figure 4-27 show values for permeability reduction with increasing overburden pressure intermediate between CL No. 256-7001 and CL No. 256-6949. A test for hysteresis, shown in Figure 4-28, on core No. 9957 also exhibited behavior similar to No. 7011.

Mercury capillary pressure tests were conducted to test for a correlation between pore size distribution and permeability reduction with increasing overburden pressure. There was a possibility that larger or smaller pores closed off first, leaving the other pores for gas flow. Capillary pressure curves are shown in Table 4-7 and Figures 4-29 and 4-30; a relationship between pore size distribution and permeability reduction as a function of overburden pressure is not apparent.

Sample size or handling can have an effect on the shapes of mercury injection curves. Samples that were crushed to -10 + 30 mesh exhibited linear plots of log pore entry diameter versus wetting phase saturation, Figure 4-31. However, the distribution displayed a significantly greater portion of large pores than uncrushed samples. The crushing appears to create fractures that seem to fracture the large number of pores of sizes between 1.5 and .27 microns. This could result from the nature of cementing since core No. 7011 had no fractures even after crushing as would also be indicated by Figure 4-31.

The relative permeability to gas for core No. 9957 was determined. Saturation was achieved by evaporation. This was performed on the core on which a hystere curve was also determined. Tests are now in progress to perform relative perme ability to gas determination for an unstressed core to see if there are any differences (i.e., have only certain pore sizes been primarily affected?). K_{rg} data for stressed No. 9957 are shown in Figure 4-32 and Table 4-8.

To complete the Canyon Largo No. 256 rock series, a test was performed on Canyon Largo No. 256 to No. 7105 for permeability as a function of confining pressure (Figure 4-33, Table 4-9). Tests were also conducted on PCU F31-13G cores No. 8498 and No. 9998 to observe changes in curve shape for previously unstressed core (Figure 4-34, Table 4-10). The unstressed core exhibits a stronger decrease in permeability as a function of confining pressure than the second test on the same core.

This is surprising since it would be expected that some micro-fracturing takes place on inducing confining pressure which should result in the opposite trend. Tests are proceeding on the other cores to confirm these results and these core will be tested again when they regain initial permeability. Whether the difference between the curves is a hysteresis effect or a reflection of precision of core testing is not yet known.

To determine the effect of core saturation history on relative permeabilities to gas and to water, cores were evacuated and resaturated with 10 g/l NaCl solution to test for precision of the saturation technique (Table 4-11). The results indicate that differences can be as high as 6.1 percent and less at lower water saturations. These differences in saturated weights probably do not result from variable filling of pore space, but from water on the surface of the core that is difficult to blot to a consistent wetness. A technique to avoid this problem is being developed that involves the use of a humidity-controlled chamber. The effect of permeability on gas for cores No. 7011, No. 8498 and No. 9998, and one point for No. 9957 and No. 7103 is shown in Figure 4-35 and Table 4-12.

Table 4-6 Effect of Overburden Pressure on Initial Gas Permeability

Canyon Largo No. 256 Core No.	Mercury Porosity (%)	K* (md)	Percent Initial Permeability At Overburden Pressures 500	1,000	2,000	3,000	4,000	5,000	6,000
6949	7.3	.042	49.4	31.9	18.3	11.2	6.9	4.6	3.6
7001	11.0	.067	38.8	29.9	22.4	17.9	13.3	7.7	3.6
7011H		.035	25.0	19.4	14.1	11.2	7.4	6.9	3.6
7103	6.9	.047	----	26.2	12.7	7.1	6.0	2.6	----
PCU 31-13G Core No.									
8498	6.4	.027	43.8	34.4	23.0	13.3	8.9	5.5	
9957	9.5	.110	53.9	47.7	28.7	18.4	12.7	9.7	
9957H		.055	34.1	24.7	16.0	12.2	10.3	9.7	
9998	7.3	.029	48.7	41.0	27.0	17.8	14.2	10.2	

H — Hysteresis test data. Percentages listed are of initial unstressed permeabilities.
*Permeability at 40 psi inlet pressure and 140 psi confining pressure.

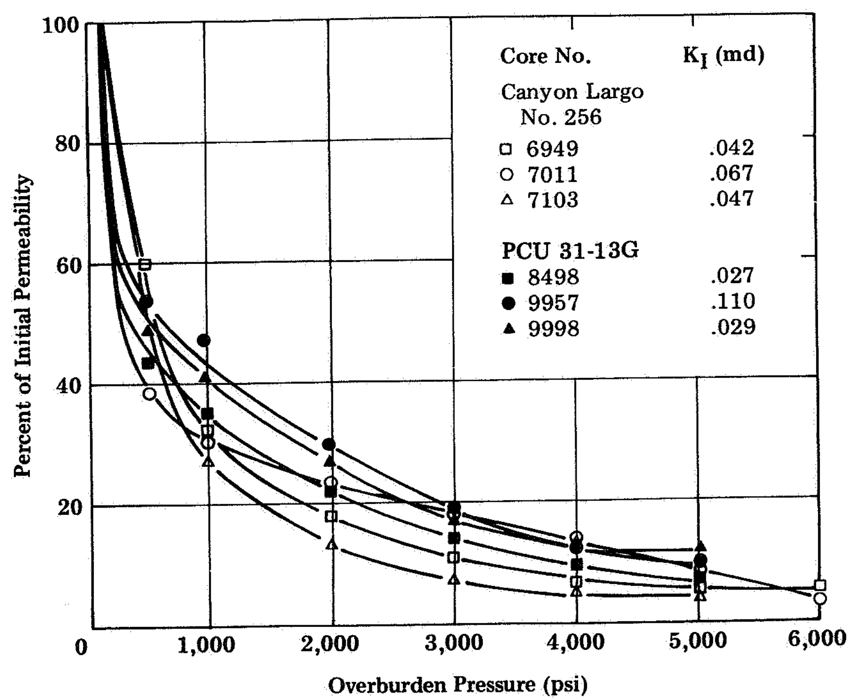


Figure 4-27 Effect of Overburden Pressure on Gas Permeability

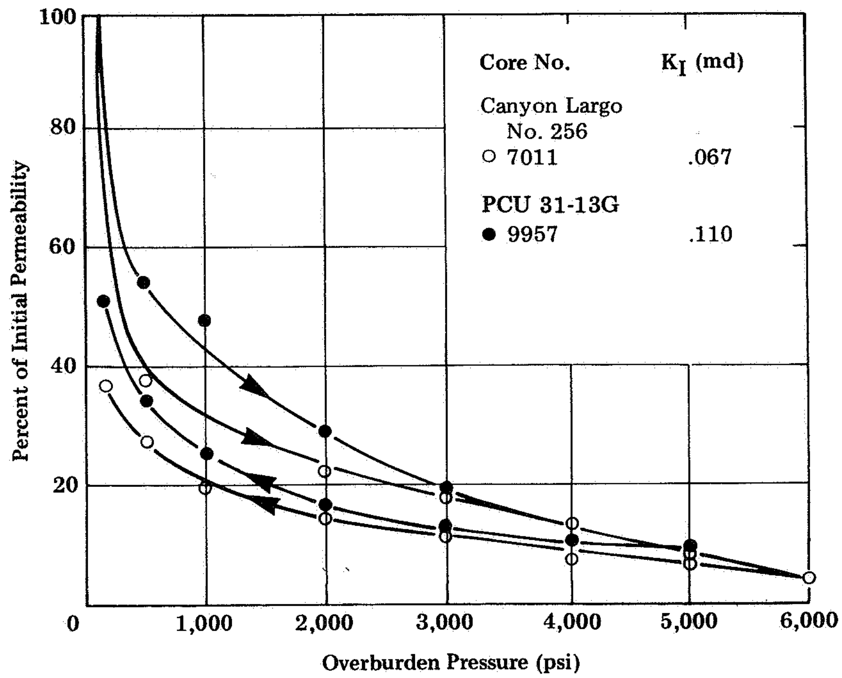


Figure 4-28 Effect of Hysteresis at Decreasing Overburden Pressure

Table 4-7 Mercury Injection Capillary Pressure Test Data for Uncrushed Samples

Pressure (psig)	Wetting Phase Saturation (%) 6949	7011	7103	8498	9957	9998
0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.6	3.1	0.0	1.5	0.9
20	1.0	1.1	4.8	0.0	2.9	1.8
35	1.4	1.7	5.7	0.5	4.0	2.2
50	3.2	1.9	7.0	1.0	5.1	2.6
75	3.6	3.1	4.9	1.9	5.9	2.6
100	4.5	3.6	9.6	2.4	8.1	3.1
200	6.8	7.2	11.8	4.8	24.9	4.8
400	10.0	22.2	31.0	23.8	47.6	14.0
600	14.0	43.1	41.9	33.3	53.1	28.4
800	19.0	53.6	47.6	44.8	56.4	39.7
1,000	24.4	60.3	51.1	51.4	59.3	45.0
2,000	36.2	73.6	61.1	64.8	68.5	59.0
4,000	57.5	84.4	76.9	77.6	79.1	76.4
6,000	72.9	90.3	84.3	86.2	86.1	85.6
8,000	83.7	94.2	91.3	91.0	91.2	90.4
10,000	90.5	96.7	95.2	93.8	93.8	94.8
15,000	100.0	100.0	100.0	100.0	100.0	100.0

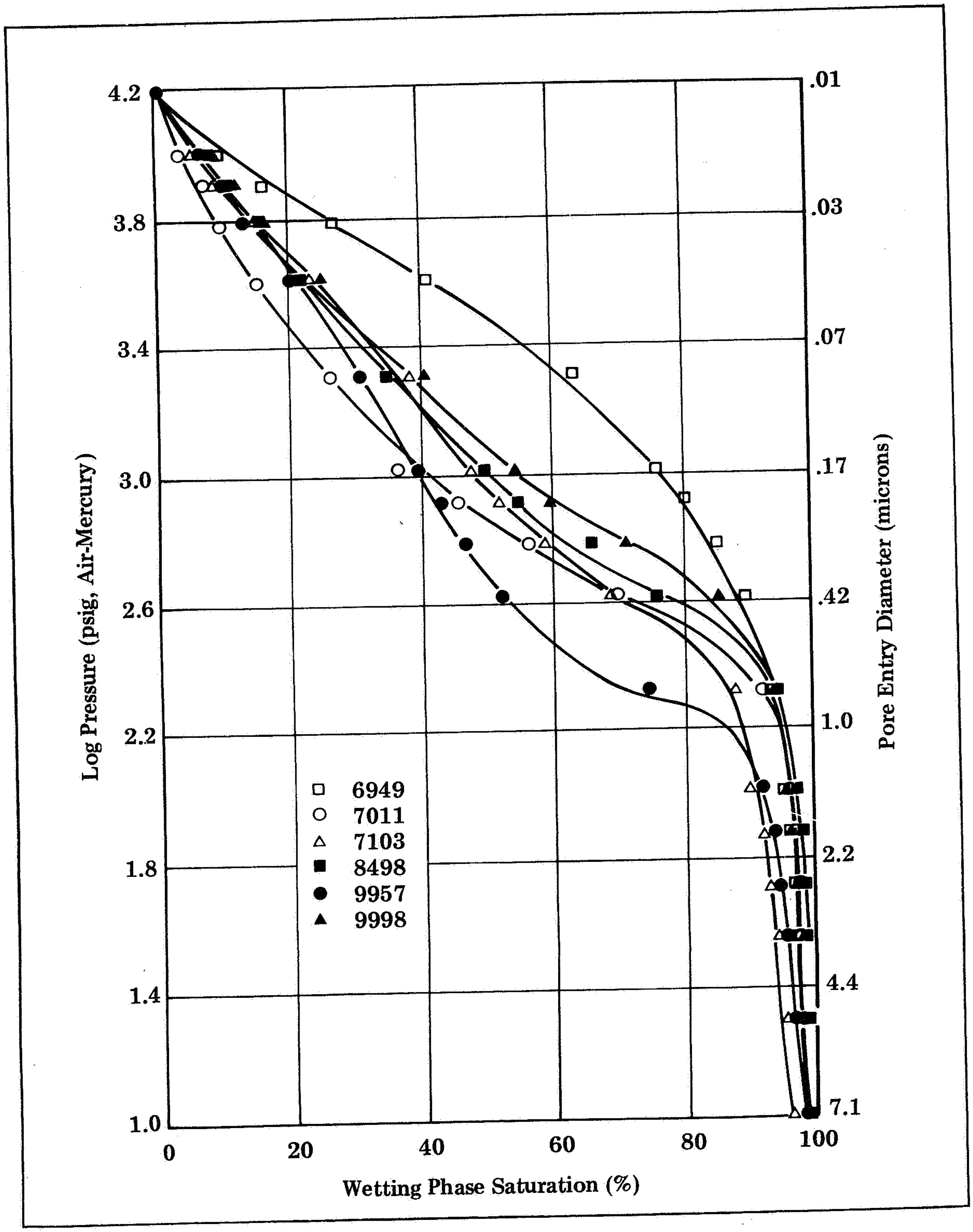


Figure 4-29 Mercury Injection Capillary Pressure Tests

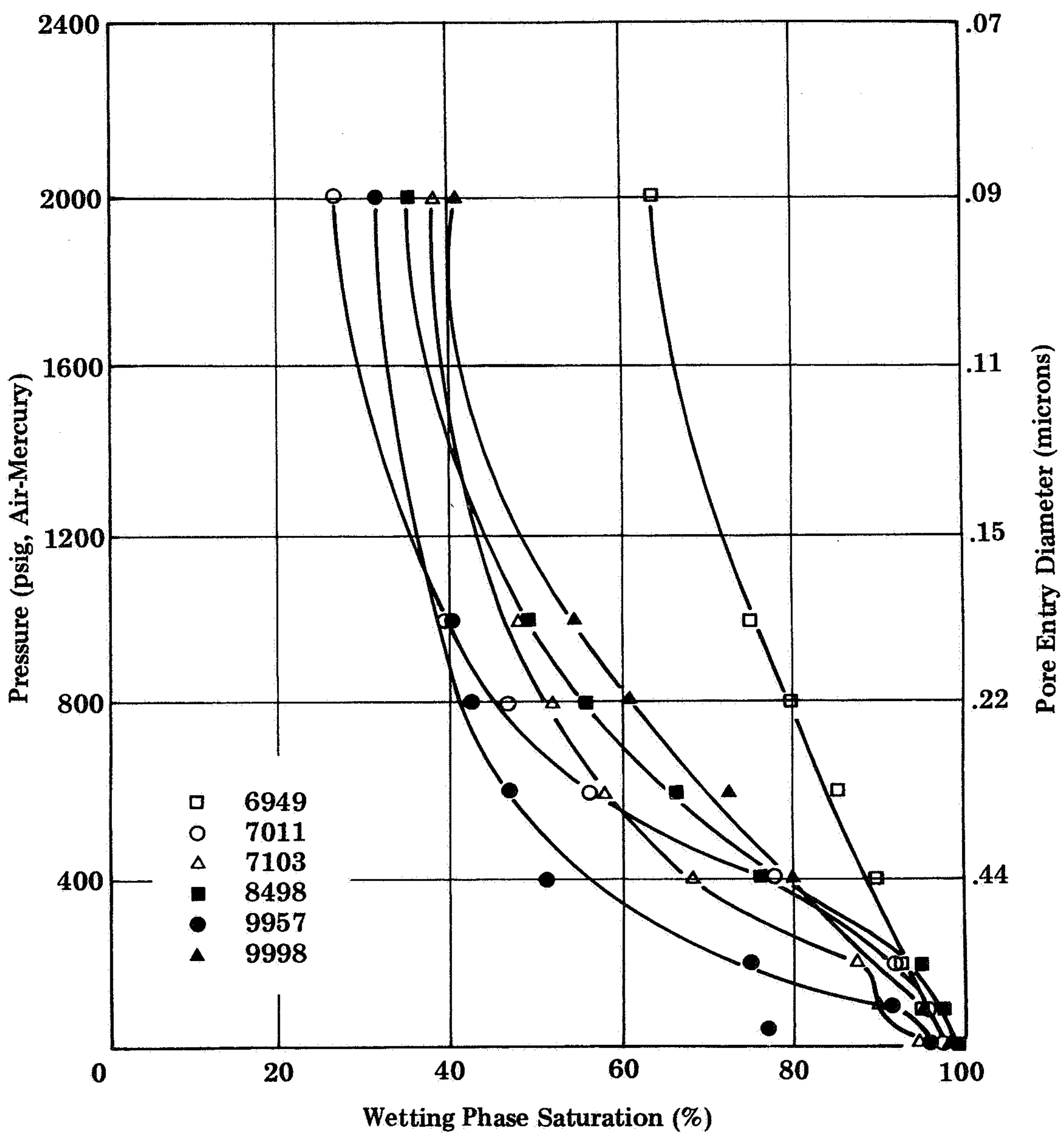


Figure 4-30 Mercury Injection Capillary Pressure Tests

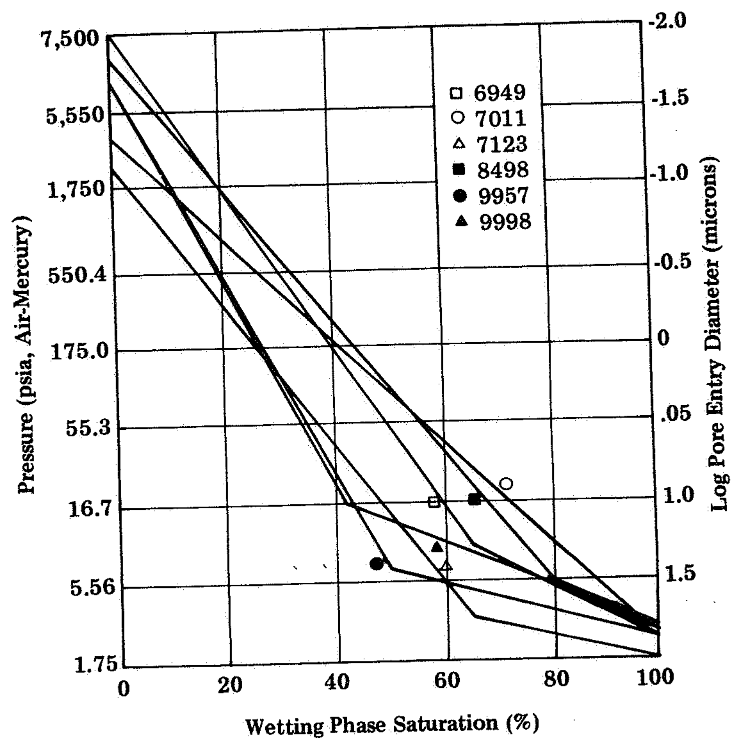


Figure 4-31 Mercury Injection Capillary Pressure Test for Crushed Samples

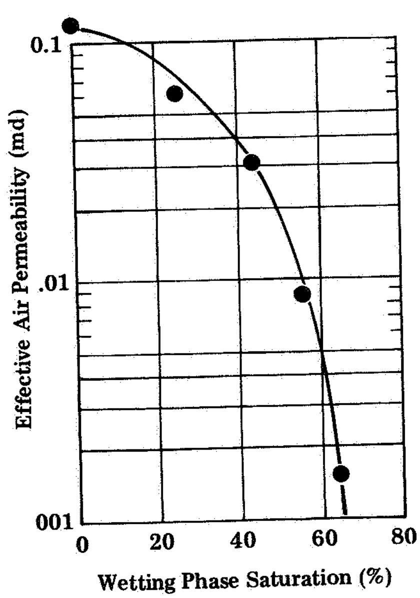


Figure 4-32 and Table 4-8
Effect of Water Saturation on Gas Permeability for PCU F31-13G Core No. 9957

S_W	Air K (md)	$\%K_{S_W} = 0$
62.6	1.3×10^{-3}	1.2
55.1	8.2×10^{-3}	7.5
43.4	2.8×10^{-2}	25.5
35.4	4.5×10^{-2}	40.9
24.2	5.7×10^{-2}	51.8
0.0	1.1×10^{-1}	100.0

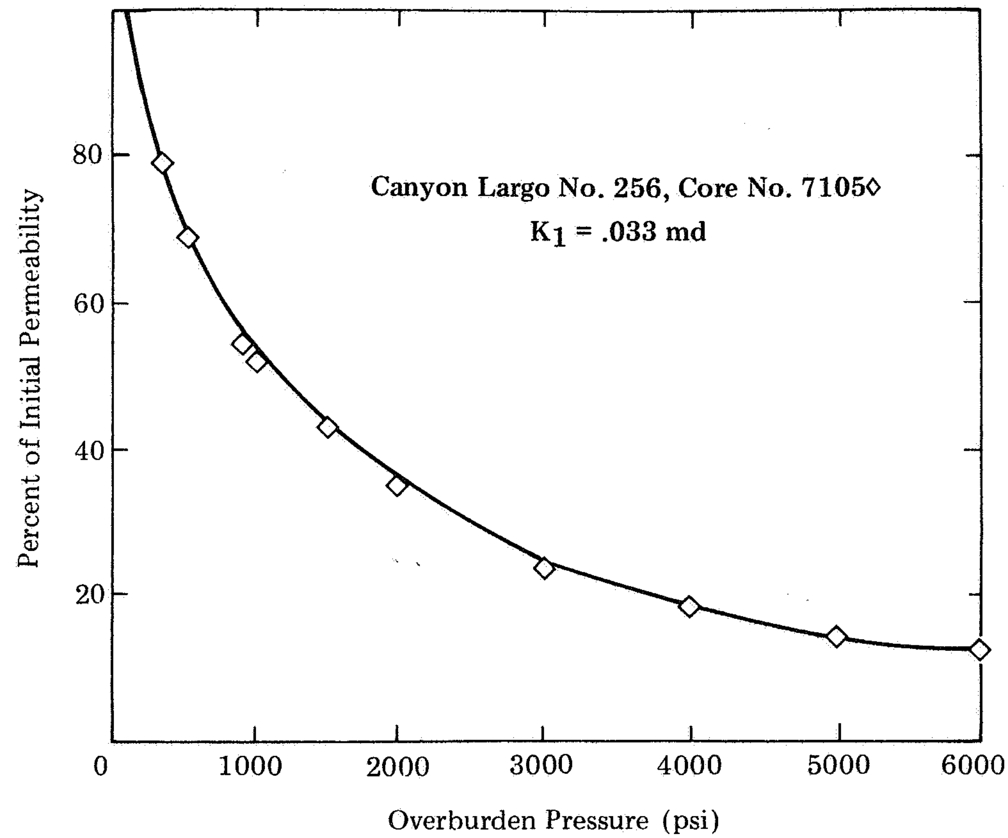


Figure 4-33 Effect of Overburden Pressure on Gas Permeability

Table 4-9 Effect of Overburden Pressure on Initial Gas Permeability

Canyon Largo No. 265, Core No.	K*(md)	Percent Permeability at Overburden Pressures										
		300	500	900	1000	1500	2000	3000	4000	5000	6000	7000
7105	.0334	79.34	70.66	55.09	52.99	43.17	35.48	24.91	18.95	15.33	13.17	11.11

*Permeability at 40 psi inlet pressure and 140 psi confining pressure

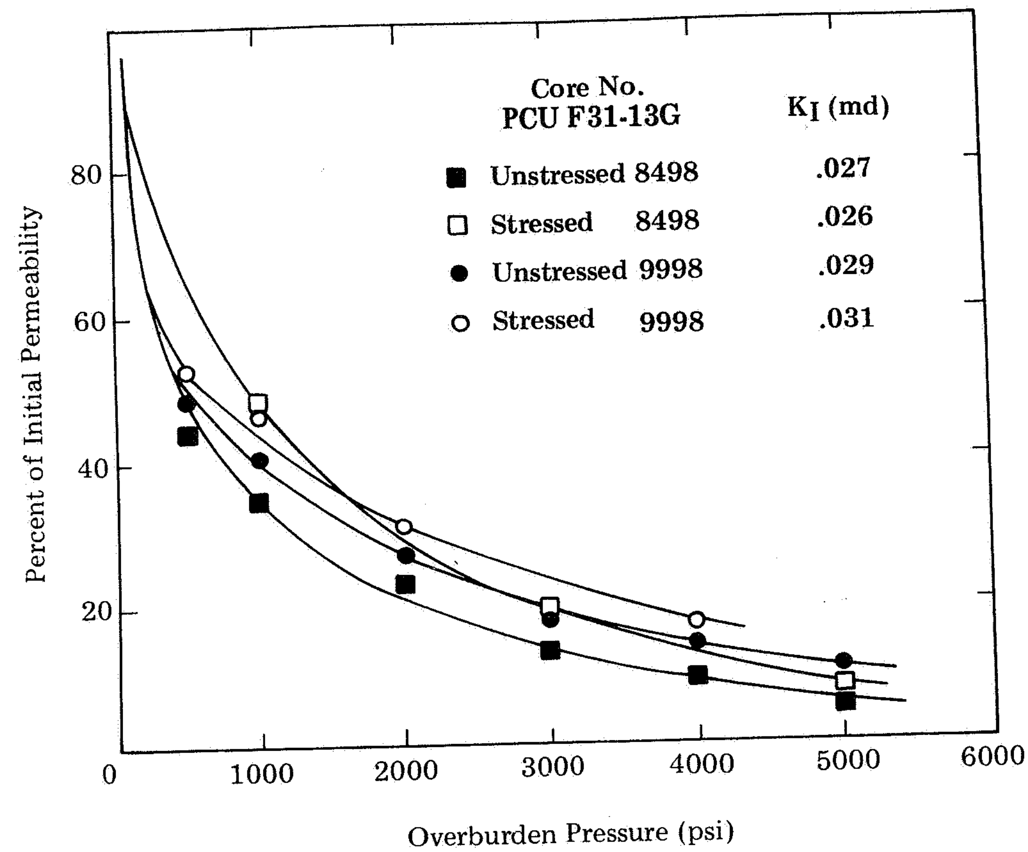


Figure 4-34 Effect of Overburden Pressure on Initial Gas Permeability of Stressed and Unstressed Core

Table 4-10 Effect of Overburden Pressure on Initial Gas Permeability of Stressea and Unstressed Core

Core No.	K* (md)	500	1000	2000	3000	4000	5000
Unstressed 8498	.027	43.8	34.4	23.0	13.3	8.9	5.5
Stressed 8498	.026	--	47.9	--	18.9	--	7.4
Unstressed 8498	.029	48.7	41.0	27.0	17.8	14.2	10.2
Stressed 9998	.031	54.3	47.0	31.0	--	17.1	--

*Permeability at 40 psi inlet pressure and 140 psi confining pressure

Table 4-11. Test of Water Saturation Technique Precision

Core No.	A Dry Weight	B 12-27-78 Wet Weight	C 1-22-79 Wet Weight	D B - A	E C - A	$\frac{D - E}{(D + E/2)}$ (percent)
6949	63.11	64.97	64.86	1.86	1.75	6.09
7011	58.82	61.29	61.27	2.47	2.45	0.81
7103	62.46	64.25	64.20	1.79	1.74	2.83
8498	62.60	64.01	64.01	1.41	1.41	0.00
9957	57.31	59.38	59.29	2.07	1.98	4.44
9998	61.45	63.05	63.00	1.60	1.55	3.17

Table 4-12. Effect of Water Saturation on Gas Permeability for PCU F31-13G Core

7011		8498		9998		9957		7103	
S_w (percent)	K_{eg} (md)	S_w (percent)	K_{eg} (md)	S_w (percent)	K_{eg} (md)	S_w (percent)	K_{eg} (md)	S_w (percent)	K_{eg} (md)
63.97	2.86×10^{-3}	61.70	4.67×10^{-3}	54.19	1.15×10^{-2}	48.99	2.08×10^{-2}	50.56	1.68×10^{-2}
53.85	6.25×10^{-3}	47.52	8.88×10^{-3}	39.35	1.91×10^{-2}			29.61	5.07×10^{-2}
43.32	1.12×10^{-2}	34.04	1.53×10^{-2}	26.45	2.60×10^{-2}				
33.20	1.92×10^{-2}	24.82	2.05×10^{-2}	0.00	3.15×10^{-2}				
21.05	3.14×10^{-2}	14.18	2.23×10^{-2}						
11.34	4.08×10^{-2}	0.00	2.76×10^{-2}						
0.00	6.21×10^{-2}								

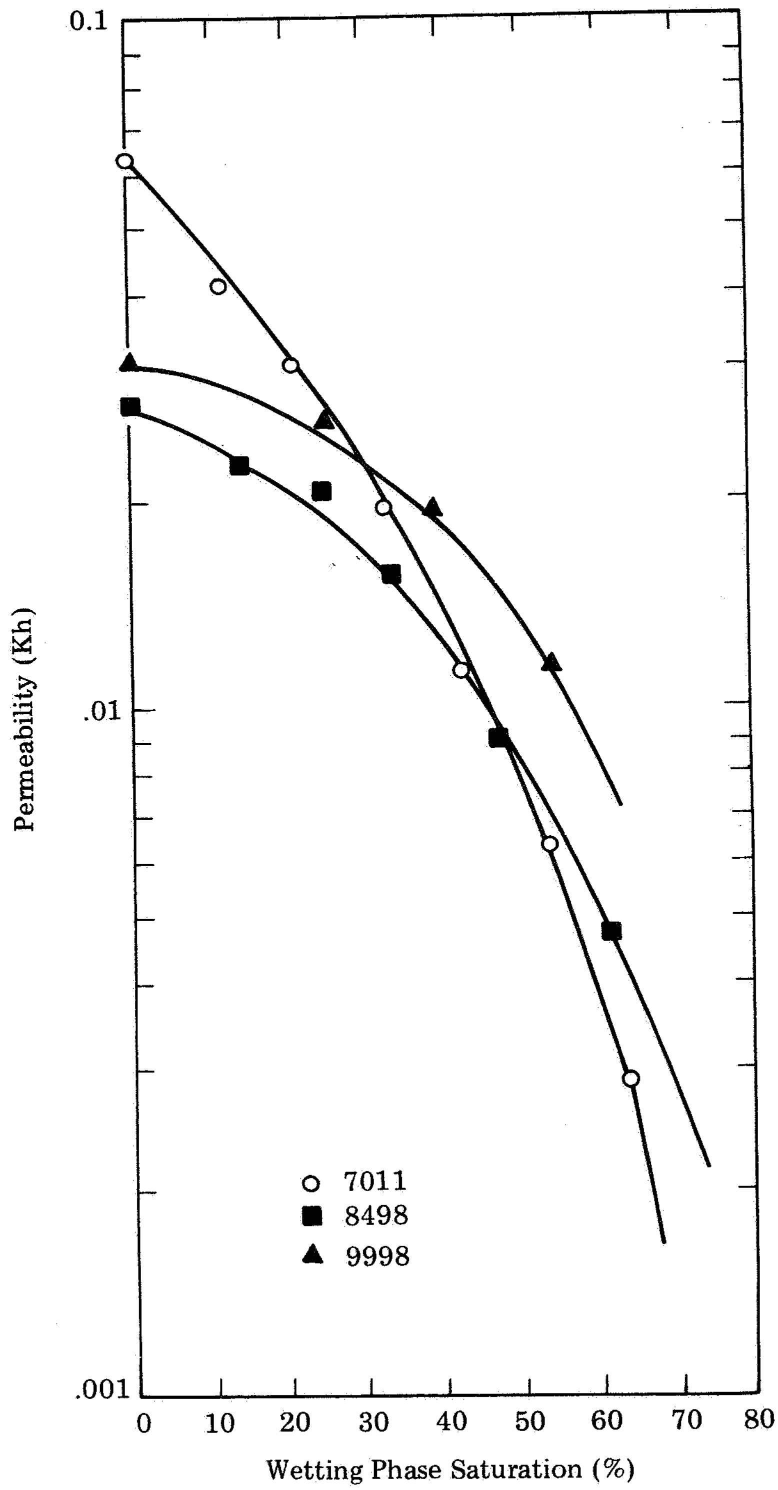


Figure 4-35 Effect of Water Saturation on Gas Permeability

The effective gas permeability for the one point determined for No. 9957 agrees very closely with the previously reported curve. These curves are being redone in new low pressure cells with more data points while the high pressure cell will be used to begin high pore pressure tests.

From Core Laboratories core analysis of the PCU F31-13G core, some interesting information was obtained from the Dean Stark fluid saturation determination. Core Lab's Mod II, "Fundamentals of Core Analysis" shows their estimates for reservoir fluid content in core before and after the coring operation. For a water base mud, as was used by Mobil, a gas productive formation that is badly flushed would result in a gas to water ratio about what is seen in these cores. It must be realized that this illustration is qualitative, describing "typical" fluid contents for "typical reservoirs" and not tight sands. In reality, as many may be apparent in the logs, these cores may have begun with approximately 50 percent in the gas cap.

High pore pressure tests have commenced on No. 7011 and No. 9957. These tests were conducted holding the overburden of effective stress at 100 psia. Due to a late discovered problem with calibration of the differential pressure transducer recorder, large differences between Klinkenberg extrapolated permeabilities and 10g/l NaCl brine permeabilities, results are being sorted out particularly since the high pressure effect upon gas slippage has been noted.

Table 4-13 and Figures 4-36, 4-37 and 4-38 show determination of K_{rg} on previous newly cut plugs for No. 8498A, No. 9998A, and a redetermination of No. 9957. The table and figures also show Corey approximations. The closeness of fit for No. 8498A to No. 8498 and No. 9998A to No. 9998 is good. The discrepancy between previously determined No. 9957 and the present data probably results from a systematic offset in weighing the core, resulting in a systematic shift. The Corey equation values shown apply for both curves if the second No. 9957 run is shifted over. This high value measured for the initial conditions was after the core had been dried in a vacuum oven at a temperature of 115°C which was 25°C higher than previous dryings. When the core was resaturated and dried again at 90°C, the original initial permeability was found. This may be due to clays giving up water at increasing temperatures. Runs of 10g/l NaCl solution through No. 9957 for Klinkenberg tests show that No. 9957 has a large number of fines in the pore spaces. Flow in one direction would quickly decrease. When flow was reversed, it would increase to a maximum value and then begin decreasing, indicating fines were dislodged and began resealing pores. Two oscillations showed that the flow reached the same maximum value before decreasing irrespective of flow direction. Cores of similar initial gas permeability exhibited different brine permeabilities, therefore brine flows will be tested.

Steady state and pulse determined permeabilities for cores No. 8498 and No. 7011 (Figure 4-39 and 4-40) display a decrease in permeability with increasing pore pressure. High pore pressure permeabilities are less than the Klinkenberg extrapolated permeabilities for the same effective stress at low pore pressure for No. 8498, but greater for No. 7011. Further testing is required to distinguish between possible Klinkenberg effects or deviations from the effective stress assumption. Figure 4-41 illustrates the difference in effect of overburden pressure on initial gas permeability for No. 7011 at low pore pressure and high pore pressure but similar overburden pressures.

Table 4-13. Effect of Water Saturation on Gas Permeability

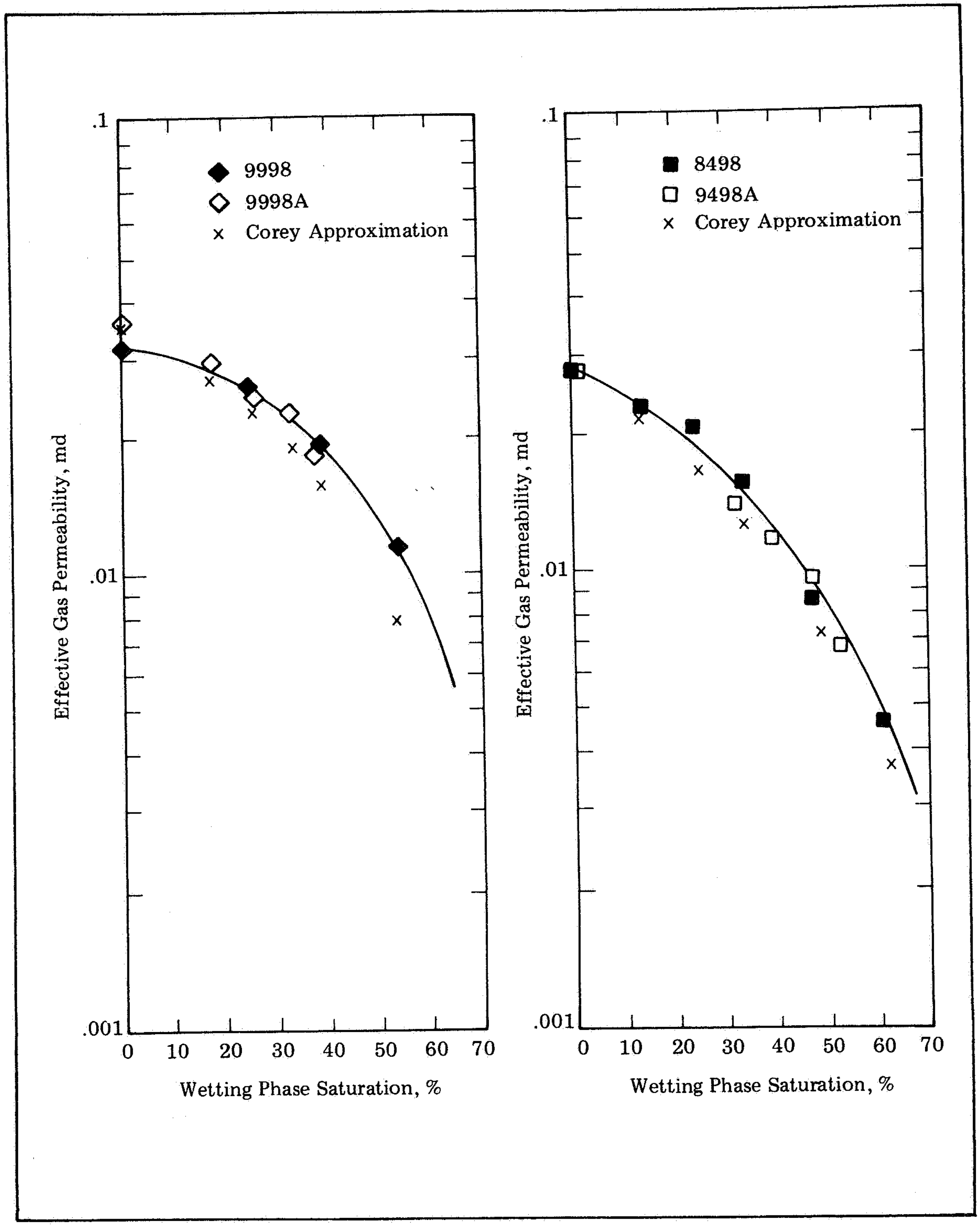
8498	S_w (%)	0	14.18	24.82	34.04	47.52	61.70
	K_{eg_1} (md)	2.76×10^{-2}	2.23×10^{-2}	2.05×10^{-2}	1.53×10^{-2}	8.88×10^{-3}	4.67×10^{-3}
	K_{eg_2} (md)	—	2.15×10^{-2}	1.66×10^{-2}	1.25×10^{-2}	7.08×10^{-3}	2.55×10^{-3}
8498A	S_w (%)	0	22.63	32.12	39.42	47.45	52.55
	K_{eg_1} (md)	2.73×10^{-2}	1.95×10^{-2}	1.38×10^{-2}	1.17×10^{-2}	9.86×10^{-3}	6.70×10^{-3}
	K_{eg_2} (md)	—	1.76×10^{-2}	1.34×10^{-2}	9.19×10^{-3}	7.11×10^{-3}	5.30×10^{-3}
9998	S_w (%)	0	26.45	39.35	54.19		
	K_{eg_1} (md)	3.15×10^{-2}	2.60×10^{-2}	1.91×10^{-2}	1.15×10^{-2}		
	K_{eg_1} (md)	—	2.25×10^{-2}	1.51×10^{-2}	7.66×10^{-3}		
9998A	S_w (%)	0	18.52	26.54	33.33	38.27	
	K_{eg_1} (md)	3.77×10^{-2}	2.94×10^{-2}	2.45×10^{-2}	2.24×10^{-2}	1.79×10^{-2}	
	K_{eg_2} (md)	—	2.72×10^{-2}	2.25×10^{-2}	1.85×10^{-2}	1.57×10^{-2}	
9967 (1)	S_w (%)	0	24.2	35.4	43.4	55.1	62.6
	K_{eg_1} (md)	1.10×10^{-1}	5.7×10^{-2}	4.5×10^{-2}	2.8×10^{-2}	8.2×10^{-3}	1.3×10^{-3}
	K_{eg_2} (md)	—	5.97×10^{-2}	3.85×10^{-2}	2.54×10^{-2}	1.02×10^{-2}	3.6×10^{-3}
9957 (2)	S_w (%)	0	27.09	36.45	40.89	49.75	70.44
	K_{eg_1} (md)	1.46×10^{-1}	8.35×10^{-2}	6.09×10^{-2}	5.10×10^{-2}	3.99×10^{-2}	2.45×10^{-3}
	K_{eg_2} (md)	—	7.16×10^{-2}	4.87×10^{-2}	3.89×10^{-2}	2.19×10^{-2}	—

Note: K_{eg_1} — Measured relative permeability.

K_{eg_2} — Relative permeabilities calculated using Corey equation. The parameters in the equation were assigned the following values:

8493	and 8498A :	$m = 1.1$	$S_{gc} = 0.25$	$S_{wc} = 0$
9998	and 9998A :	$m = 1.1$	$S_{gc} = 0.20$	$S_{wc} = 0$
9957 (1)	and 9957 (2):	$m = 1.3$	$S_{gc} = 0.30$	$S_{wc} = 0$

Neither curve is corrected for Klinkenberg gas slip. Each curve was at a constant mean pore pressure up to 5,000 psi overburden pressure. Differences between the curves indicate some difference in gas slippage and may also indicate some constant addition due to rock properties. The similar shape of the two curves up to 5,000 psi overburden pressure indicates any rock property difference due to different pore pressures is roughly constant for the entire overburden range. Four points are plotted for pore pressure decreasing from 2,500 psi to 500 psi at a constant confining pressure for core No. 7011. This simulates the behavior of an actual reservoir. No significant permeability change was noted. However, the contribution of gas slip with decreasing pore pressure would increase measured values. If the pore pressure had been kept constant from an overburden pressure of 5,000 to 7,000, the slope may have roughly paralleled the low pore pressure curve.



Figures 4-36 and 4-37 Effect of Water Saturation on Gas Permeability

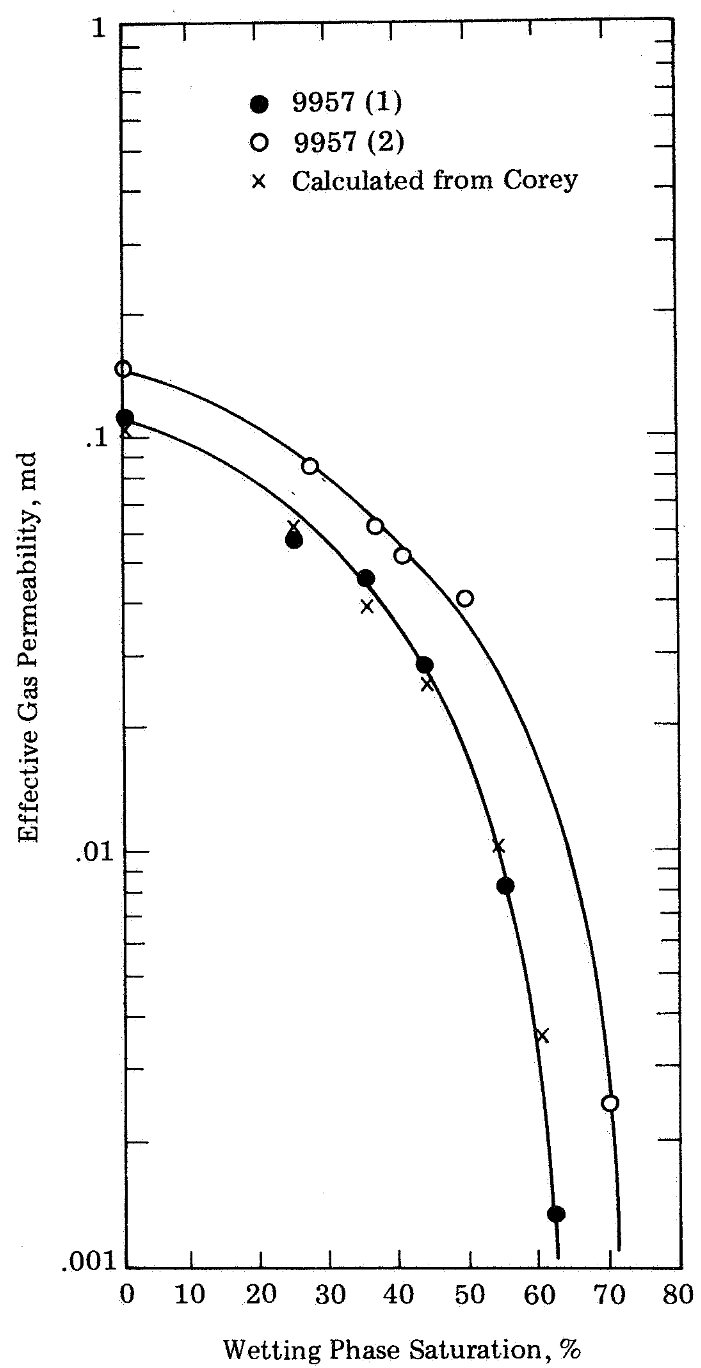


Figure 4-38 Effect of Water Saturation on Gas Permeability

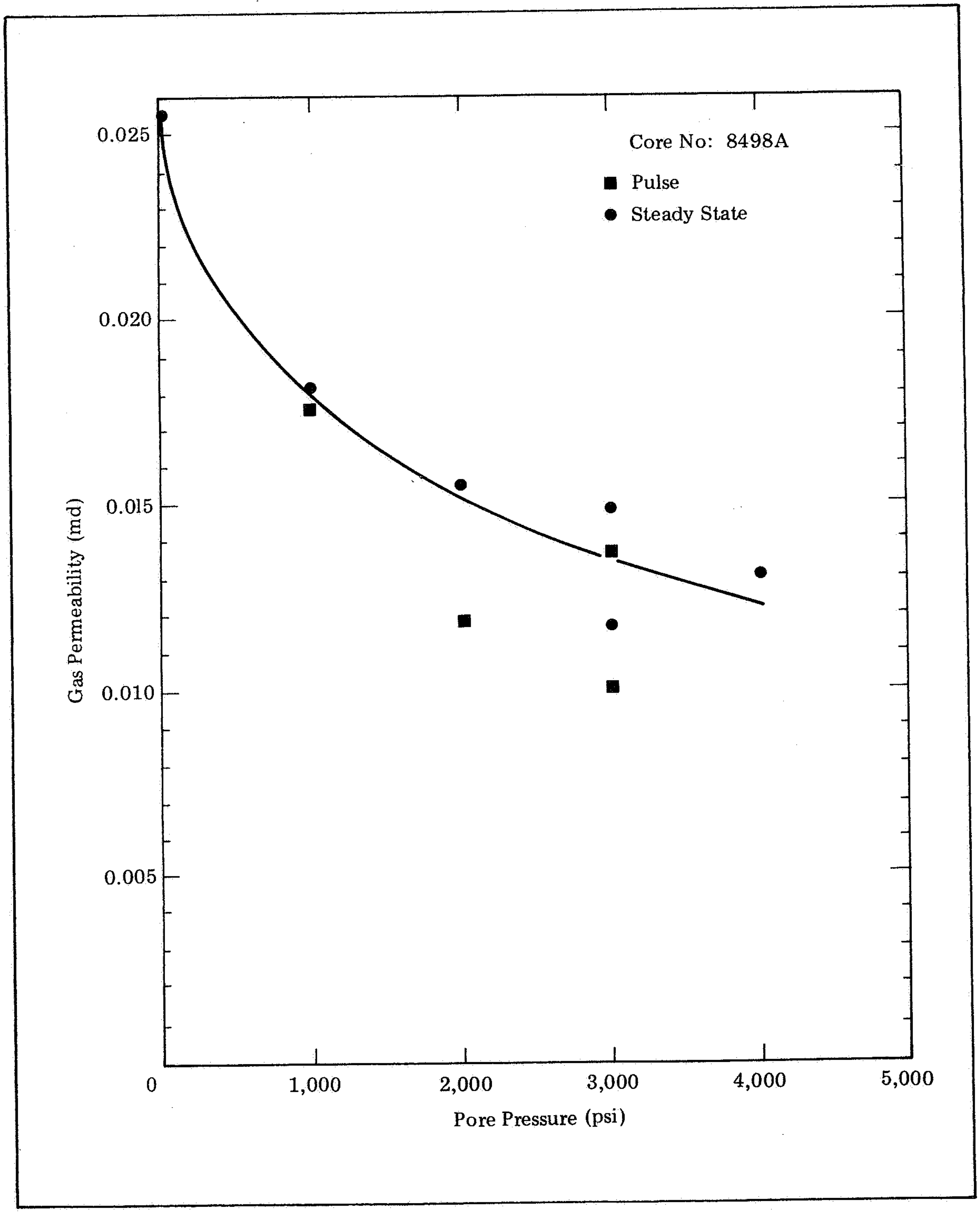


Figure 4-39 Effect of Pore Pressure on Rock Permeability

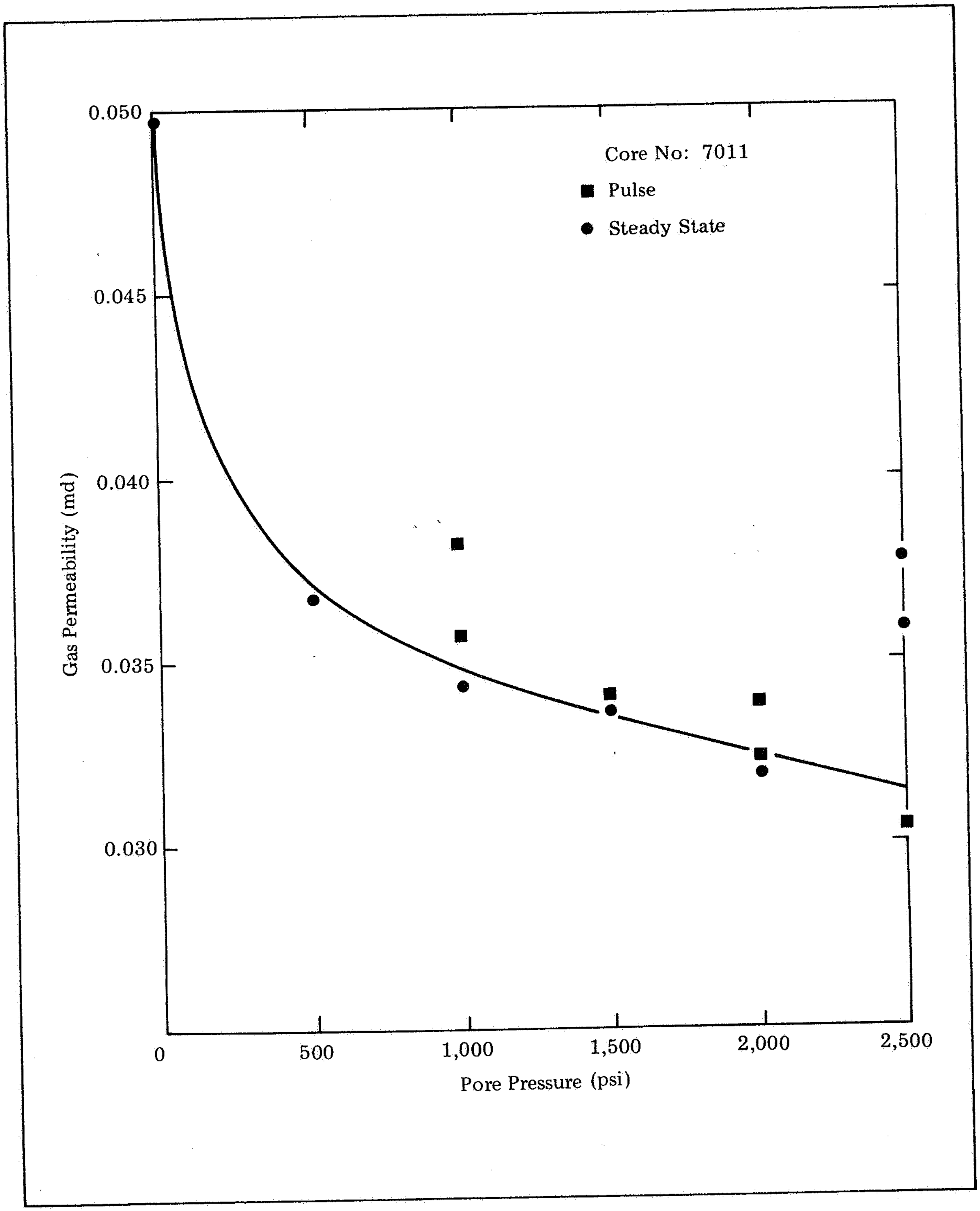


Figure 4-40 Effect of Pore Pressure on Rock Permeability

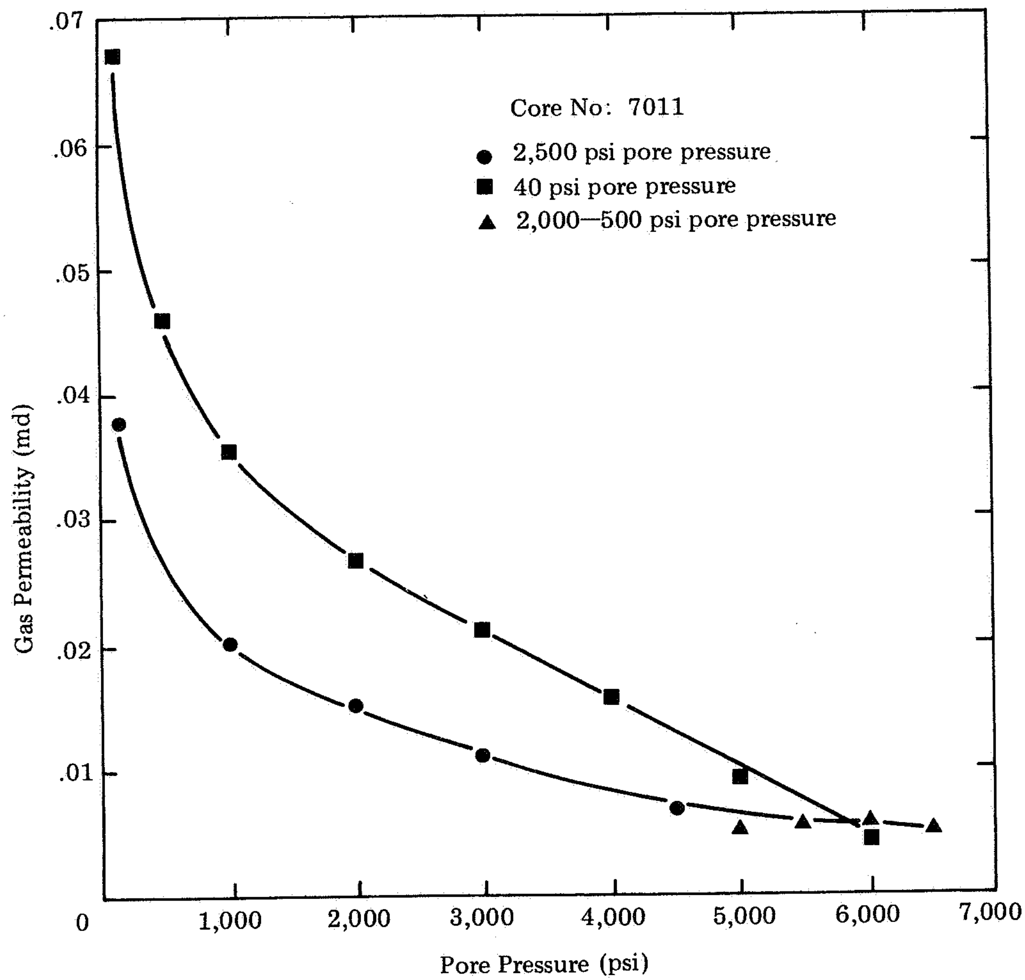


Figure 4-41. Effect of Overburden Pressure on Gas Permeability at High and Low Pore Pressures

In the four runs simulating a reservoir, the flows measured are under the same flow conditions as in the reservoir assuming no unknown instrumental effects. No Klinkenberg correction is required since gas slip is taking place at these pore presures in the apparatus, as it would in the reservoir.

Pulse decay data are shown in Figure 4-42 for PCU F31-13G No. 9957. These display the same trend as No. 7011 and No. 8498A. Steady state data were not as consistent and are being reviewed and retested.

Scanning electron microscopy revealed extensive fine clays blocking pores in Canyon Largo No. 256-No. 7011 and F31-13G No. 9957. There are extensive fine clay grains intergrown across and throughout pores in both rocks. A complete diagenetic description will follow after rock thin section work is completed. Testing is in progress on No. 9957A to find a fluid that will not significantly dislodge and move the clay particles and prevent pore blockage.

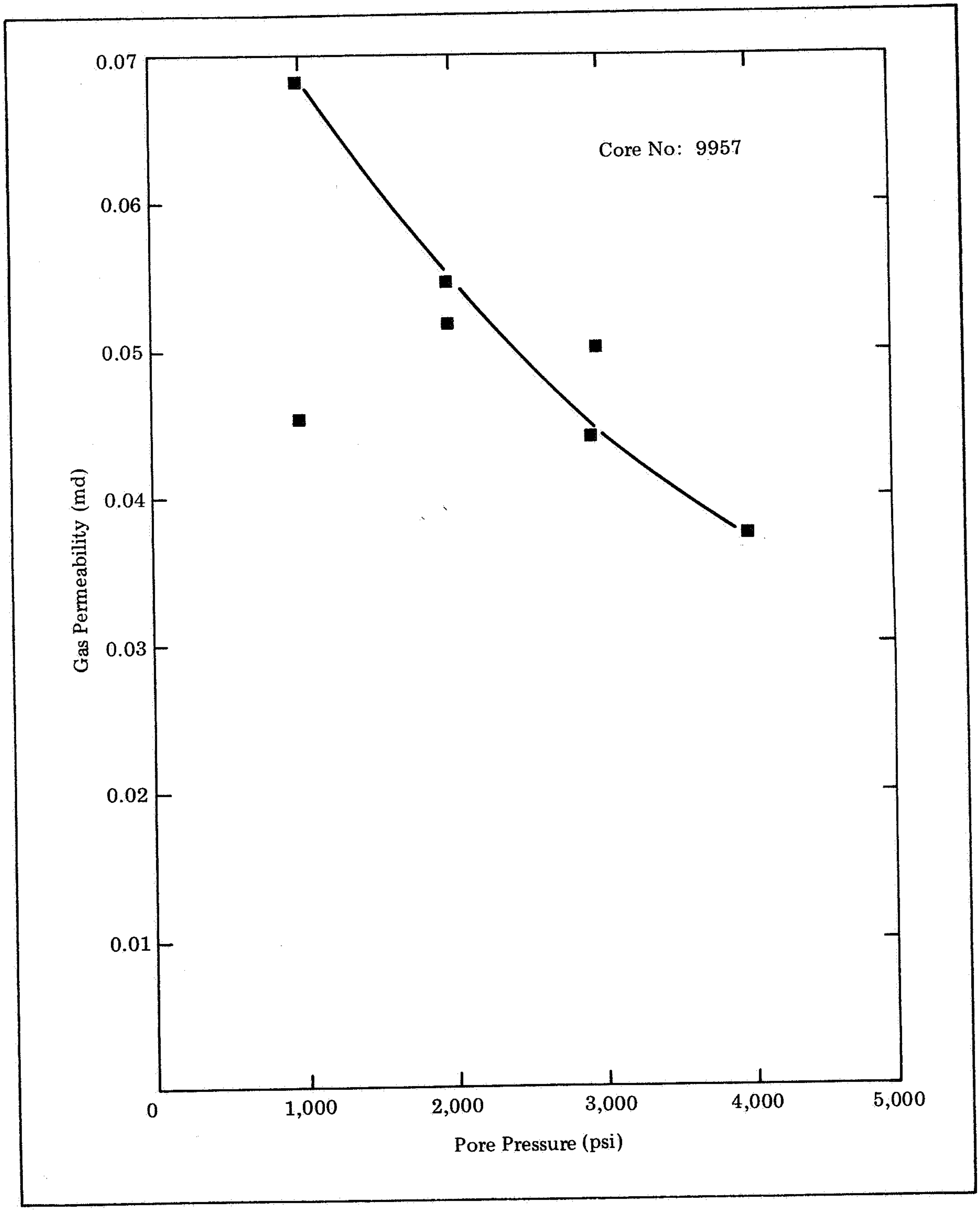


Figure 4-42 Effect of Pore Pressure on Gas Permeability Pressure Pulse Decay Measurements

PETROPHYSICS

Log analysis of the CER Corporation RB-MHF 3 well is currently underway. Initial crossplotting of log data has been completed.

Four other logs selected for study in the Western Gas Sands Project were reviewed. A series of crossplots spanning an interval of approximately 1,000 ft each examined the relationship of Compensated Neutron Log (CNL) porosity versus formation density. In order to select a clay point to be used in computing porosity from these low-permeability sands using a shaly sand model, gamma ray and caliper values provided additional control to distinguish between actual clay points and points attributable to washed out conditions in the hole. Because the Mobil well had a limited amount of core information available, a transform relating core porosity to Compensated Neutron Log-Formation Density Logging (CNL/FDC) porosity was generated. In reviewing the two computed porosities, it was decided that the lower values computed by the shaly sand model would be more consistent with the low porosities observed in the other wells in the area.

Water saturations using water resistivity recorded in the Mobil well were then calculated. A verbal report was made to Denver regarding the amount of possible net pay identified in their area of interest, the zones between 10,549 and 10,680 ft. In addition, a possible pay zone at approximately 10,100 ft was identified.

Similar crossplots of the other wells in the Rio Blanco Unit of the Piceance Basin and Uinta Basin were generated, and the shaly sand model was used in computing porosity. Tabulation of the results is in the final stage.

4.3.2 LAWRENCE LIVERMORE LABORATORY

MODEL DEVELOPMENT AND THEORETICAL ANALYSIS

In addition to the applications, LLL has been developing the mathematical forms to include interfacial friction for inclusion in the hydraulic fracturing models. The preliminary forms have been completed and written in Fortran and are currently being included in the models for debugging.

The analysis of the strain variables along the interface, for calculations where the interface between two materials is well bonded, is being conducted. These analyses, when compared to similar calculations with frictional contact along the interface, will provide insight on the effects of friction in the transport of strain energy across the interface.

Some analyses of the effect of the lenses themselves on the local stresses around the lenses have been completed. These calculations do not include the plastic relaxation. Although relaxation should normally reduce the stress variations around the lenses, these elastic calculations provide an indication of stress variation due to the presence of lenses of one type of material embedded in another material. To determine the stress perturbations caused by the presence of a lens, the problem was analyzed with a numerical model. A lens is embedded in a homogeneous material, shown in Figure 4-43.

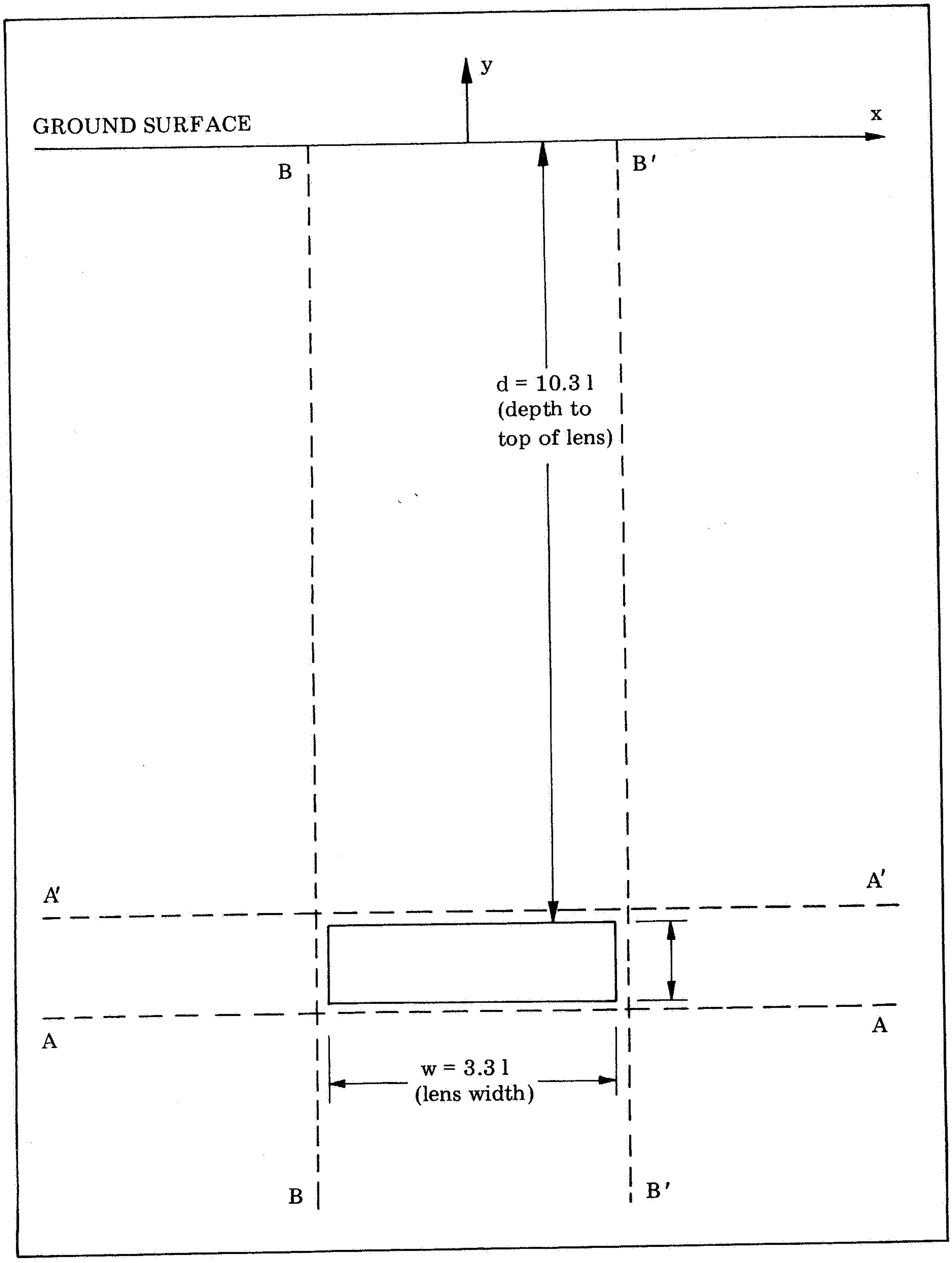


Figure 4-43 The Lens Geometry (Stresses along the dashed line are given later)

Poisson's ratio for both materials is 0.35 and Young's modulus for the lens (0.1 Mbar) is half that of the surrounding material. A constant normal stress (ϕ_0) is applied in the negative y direction along y = 0. Since the distances and displacements in the problem will scale, the distances are given in terms of the lens thickness, ℓ. Two-dimensional plane strain is considered so that the lens and the material are assumed to extend infinitely in the z direction. Furthermore, displacement in the x direction at $x = \pm 40\ell$ was not allowed.

The normal stress in the y direction (σy) along the lines labeled BB and B'B' in Figure 4-43 is shown in Figure 4-44. The stresses along the two lines are identical due to problem symmetry. Increasing $\sigma y/\sigma o$ corresponds to increasing compression. From Figure 4-44 compression is greatest along the lens and least about 2ℓ above and about 2ℓ below the lens. It is expected that a horizontal fracture entering from outside the area of the lens would tend to cross line BB or B'B' at one of these two points.

The normal stress in the x direction (σx) along the labeled AA in Figure 4-43 is shown in Figure 4-45. Again, increasing stress corresponds to increasing compression. The stress along line A'A' does not differ appreciably from the stress along AA. Inelastic deformation was not allowed in this analysis. Consequently, some of the severe character in the curve near the lens would be smoothed somewhat if plastic deformation occured. In Figure 4-45, the least compression occurs above and below the center of the lens. A vertical hydrofracture would be expected to interesect the lens near its center.

For comparison with the forthcoming calculations with a frictional interface, a series of calculations for a crack approaching a well bonded interface between two materials has been completed. The materials on either side of the interface were defined having identical Poisson's ratios with different Young's moduli. The medium around the pressurized fracture was assumed to be impermeable and the pressure in the crack was taken as constant. Two sets of calculations were performed, one with the pressurized crack in the lower modulus material and the higher modulus material across the interface and the other set of calculations had the material moduli interchanged. The calculations were performed in two dimensions for plane strain. Figure 4-46 shows the geometry of the problem. The distance, ξ, of the fracture tip to the interface has been non-dimensionalized with respect to the crack length.

Figures 4-47 and 4-48 show the maximum principal axis of strain resulting from a pressurized crack in the layered medium. One fracture tip is at $\xi = 0.4$ from the interface for both figures. Figure 4-47 shows the case where the fracture is embedded in the lower modulus material. On Figure 4-48, the fracture is embedded in the higher modulus material. It illustrates that the change in material properties significantly effects the orientation of the principal strains, especially directly in front of the crack tip.

To determine the stress perturbations caused by the presence of lenses the following problems were analyzed with an LLL numerical model. Three geometries of lenses embedded in a homogeneous material are shown in Figure 4-49, 4-50 and 4-51. In each geometry Poisson's ratio for both materials is 0.35 and Young's modulus (E) for the lenses (10 GPa) is half that of the surrounding material (20 GPa) for the first calculation (Case 1). For the

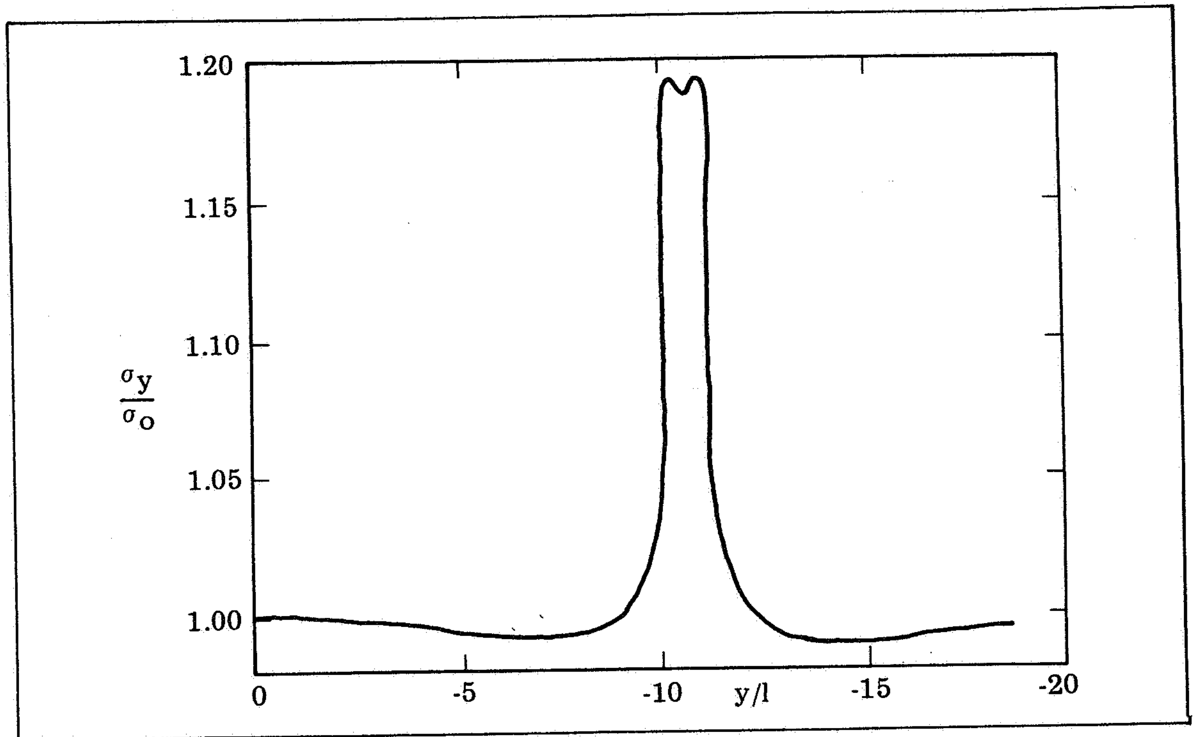


Figure 4-44 Normal Stress in the y Direction along the lines BB and B'B' in Figure 4-43. Increasing stress corresponds to increasing compression

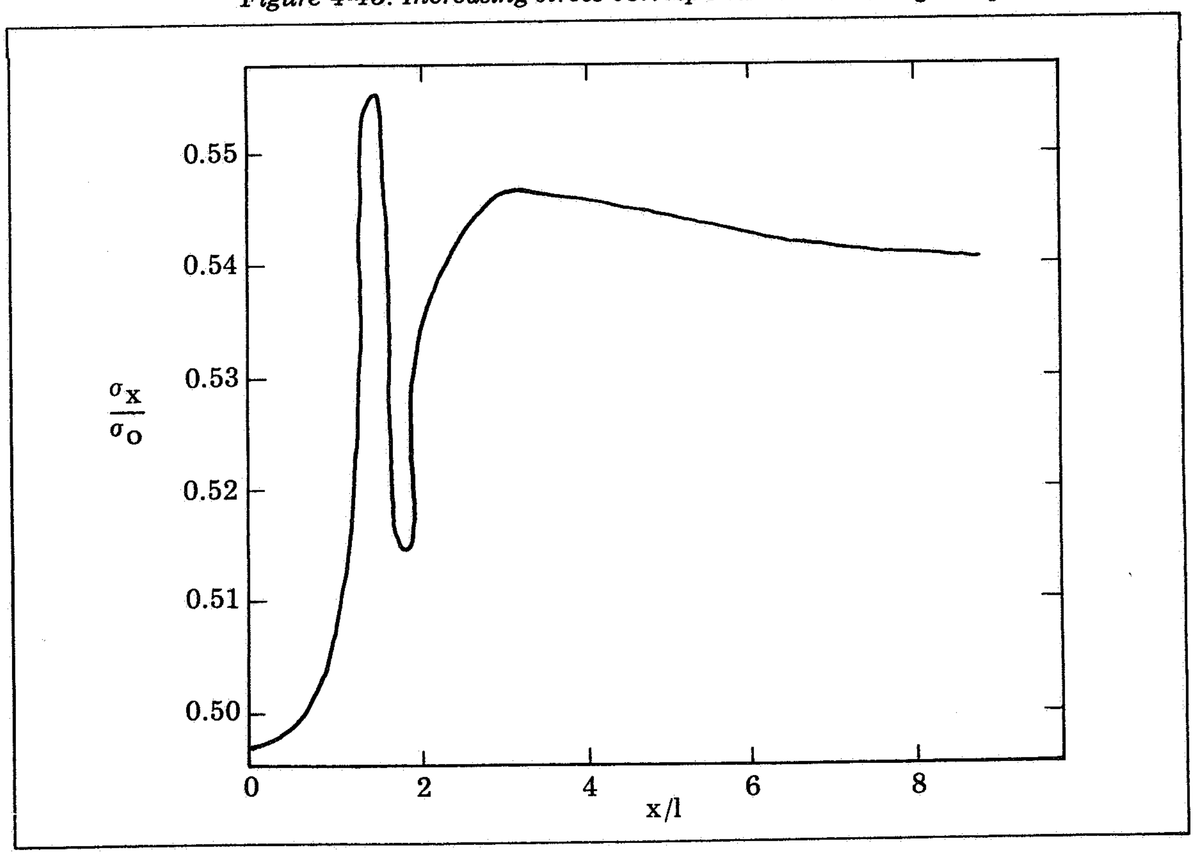


Figure 4-45 Normal Stress in the x Direction along the line AA in Figure 4-43

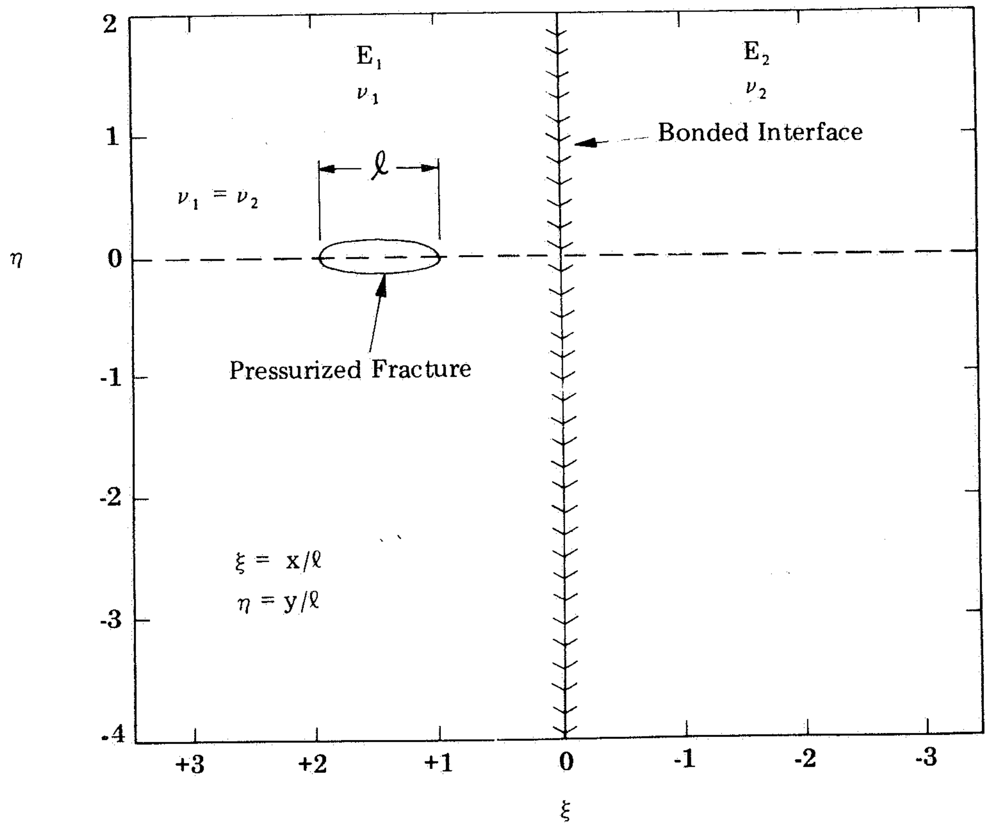


Figure 4-46. Geometry of Problems with Cracks Approaching Bonded Interface Between Two Materials Having Moduli E_1, v_1 and E_2, v_2

second calculation the Young's moduli were reversed (Case 2). A constant normal stress (σ_0) is applied in the negative y direction along y = 0. Since the distances and displacements in the problem will scale, the distances are given in terms of the lens thickness, ℓ. Two-dimensional plane strain is considered so that the lens and the material is assumed to extend infinitely in the z direction. Furthermore, displacement in the x direction at x = $\pm 40\ell$ was not allowed.

When a lens has a larger modulus than the surrounding material, these analyses indicate that a horizontal fracture would be drawn toward the lens. Conversely, the stress field around the lens would tend to impede the growth of a vertical fracture toward the lens. The results of crack growth near interfaces must also be taken into account to determine whether the fracture will penetrate a lens.

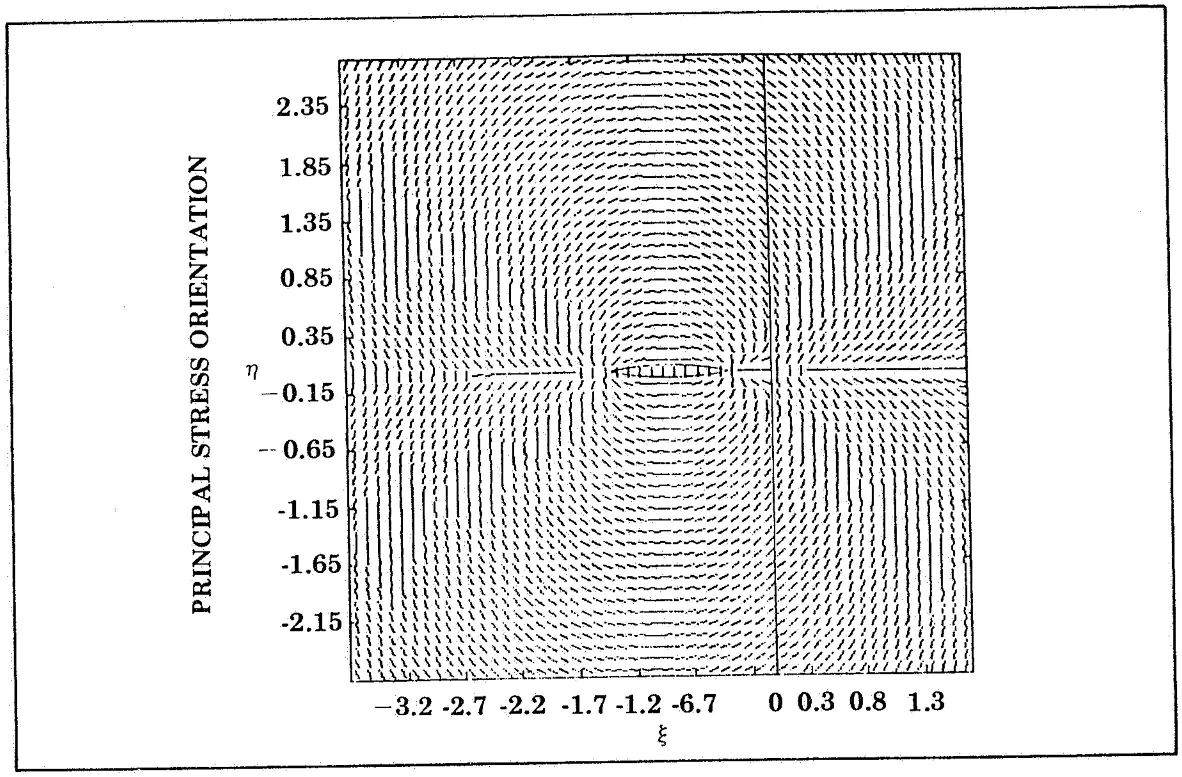


Figure 4-47 Axis of Maximum Principal Strain for the case E_1 = 10 GPa and E_2 = 50 GPa. Interface is shown as Solid Line. Fracture is Schematically shown as ELLIPSE.

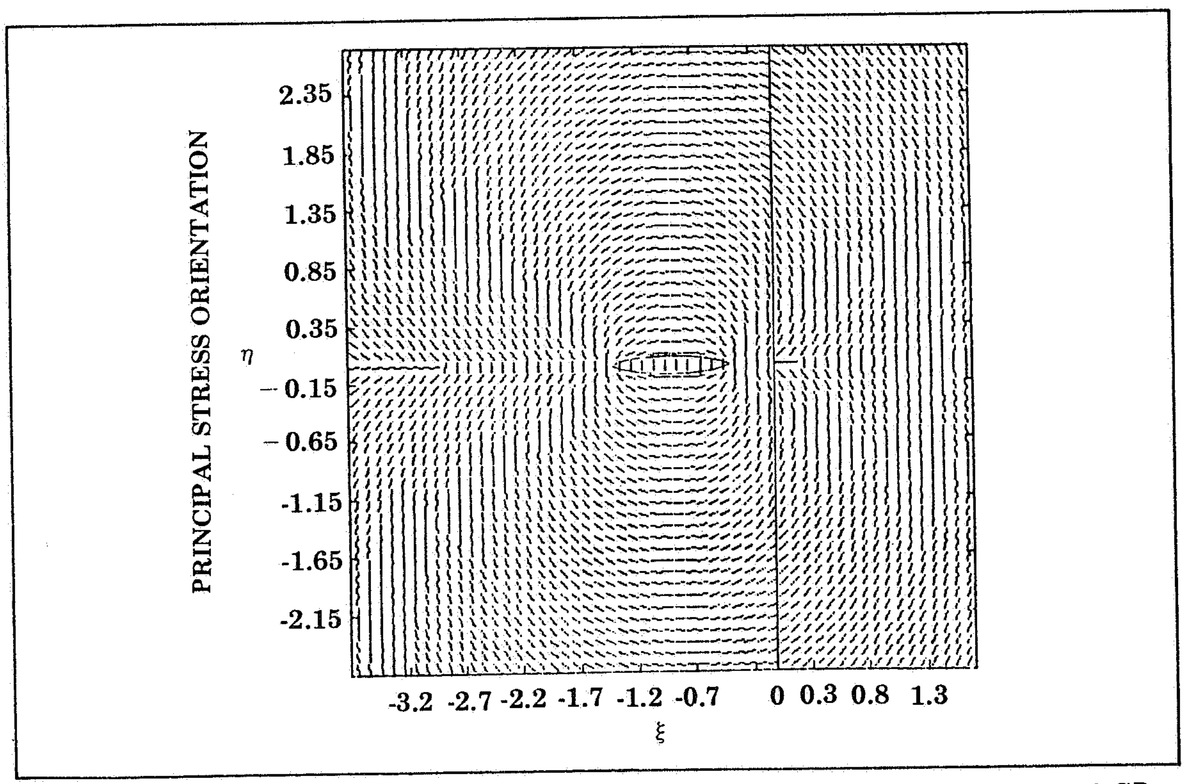


Figure 4-48 Axis of Maximum Principal Strain for the Case E_1 = 50 GPa and E_2 = 10 GPa. Interface is shown as Solid Line. Fracture is Schematically shown as ELLIPSE.

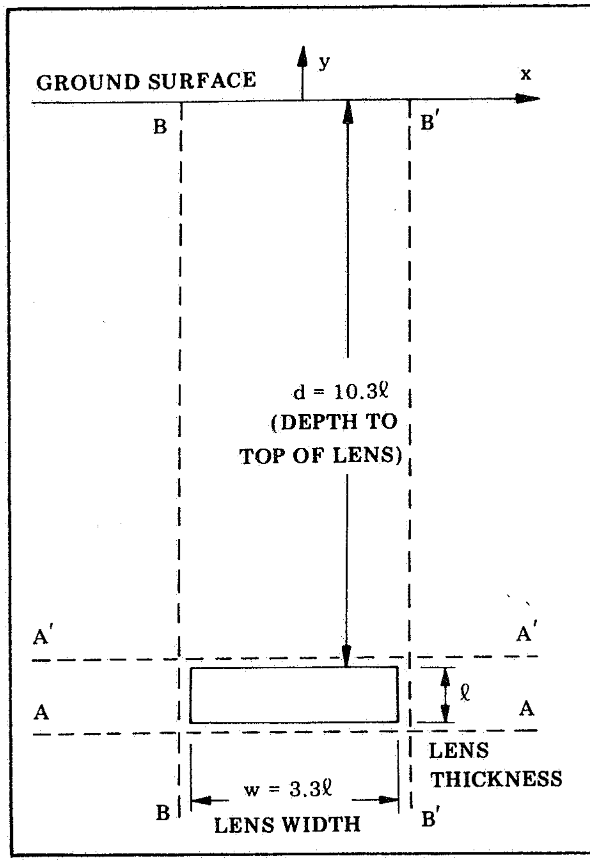


Figure 4-49 The Single Lens Geometry

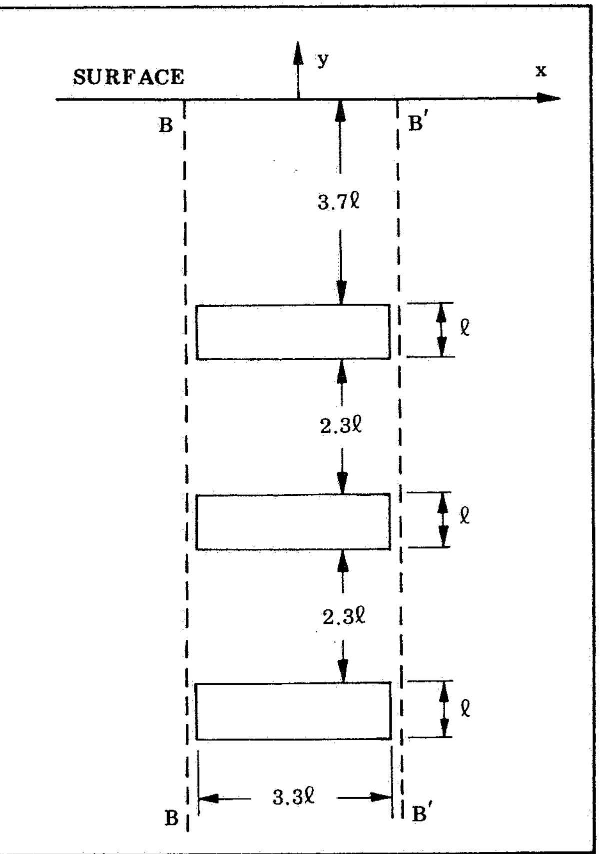


Figure 4-50 Geometry of Vertically Triple Lenses Stacked

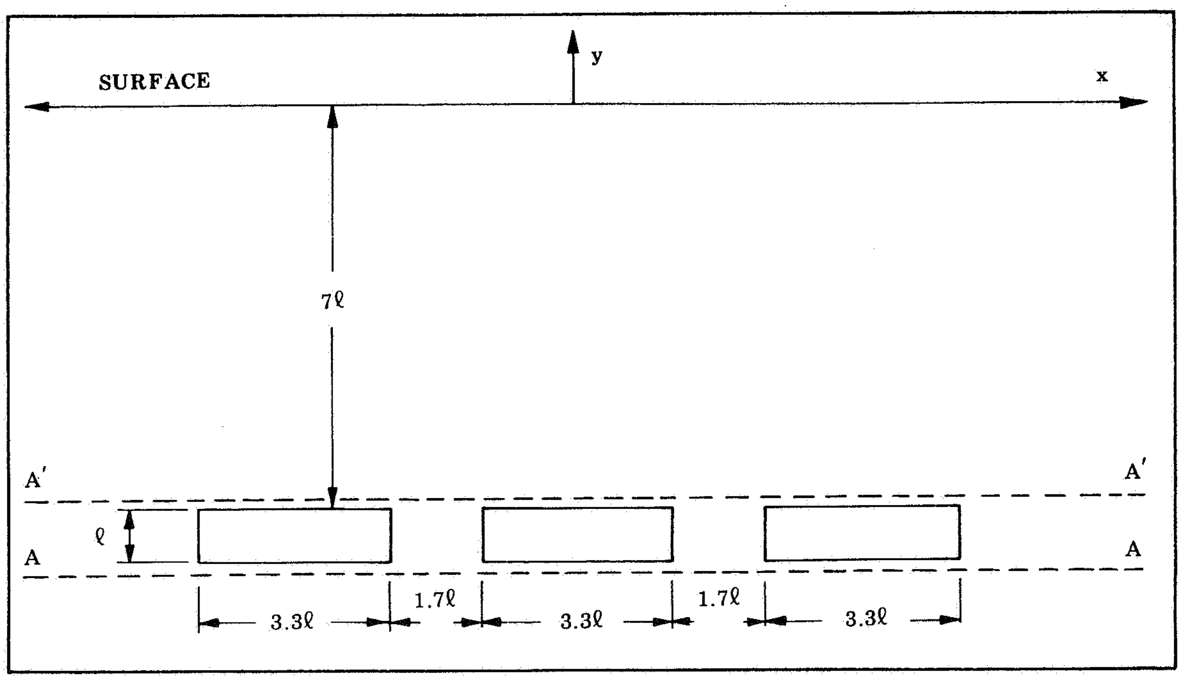


Figure 4-51 Geometry of Horizontally Arranged Triple Lenses

EXPERIMENTAL PROGRAM

The large sandstone cylinder which was fractured in late August, 1978, was broken open as the block remained intact after the initial fracture had partially surfaced. The fracture grew in a plane containing the injection tube. Below the bottom of the injection hole, the crack turned and grew toward the side of the cylinder. The bedding planes in the sandstone cylinder were perpendicular to the axis of the cylinder, i.e., the injection tube. It appears that the injection hole influenced the direction of crack growth in the region of the injection hole, but the direction of bedding had more influence below the injection hole. Several more fracture growth experiments were performed on 7-inch cubes of sandstone and limestone. But analyses of these experiments are not yet complete. However, preliminary observations imply that the initial burst of crack growth, indicated by a sudden drop in fluid pressure, is greater in area in the sandstone than in the limestone. Prior to fracturing, the limestone absorbs a relatively large amount of oil, becoming saturated and building pore pressure in the region around the bottom of the borehole. The sandstone absorbs relatively no oil due to its low-permeability and porosity. The larger crack growth seen in the sandstone is consistent with the theoretical model prediction that as the pore pressure builds around the top of the crack, the mode I stress intensity factor decreases, thereby making further crack growth more difficult.

Experiments were begun to study the effect of water saturation on crack growth across interfaces in Indiana Limestone. The standard three-block experiments were performed in which fracturing fluid was injected into the central block of a three-block sandwich. The blocks were placed in a hydraulic press which produced a normal stress load across the two interior interfaces. The central block and one of the outer blocks were dry; the other outer block was water saturated. Earlier experiments showed that the threshold normal stress for cracks to cross an interface between dry limestone blocks was about 625 psi. The current experiments indicate that the threshold normal stress for cracks to grow from a dry to a saturated block is about 500 psi.

The effect of the water in the interface might be expected to be that of a lubricant which would reduce the shear or frictional force transmitted across the interface at a given normal load. Such an effect would make it more difficult to grow a crack across that interface. The result that the crack may be sufficiently altered so that they more than compensate for the lubrication effects of the water. Since tensile strength is felt to be one of the important material properties, Brazil tests were performed to measure the tensile strength of the saturated limestone. The results indicated a tensile strength of 19 $\pm$ 3 bars as compared to about 50 bars for dry limestone. This dramatic increase in tensile strength may account for the lowering of the threshold stress for cracks to cross the interface.

The construction of an apparatus for friction measurements was completed and is shown schematically in Figure 4-52. A 2 inch cube of the rock to be studied is held between two 2 in. x 4 in. x 4 in. prismatic blocks of the same material. A normal load in the horizontal direction is applied across the two interfaces by a hydraulically driven ram. The load is determined by measurement of the hydraulic fluid pressure with a pressure transducer. A vertical driving force is applied to the center cube by a vertical hydraulic

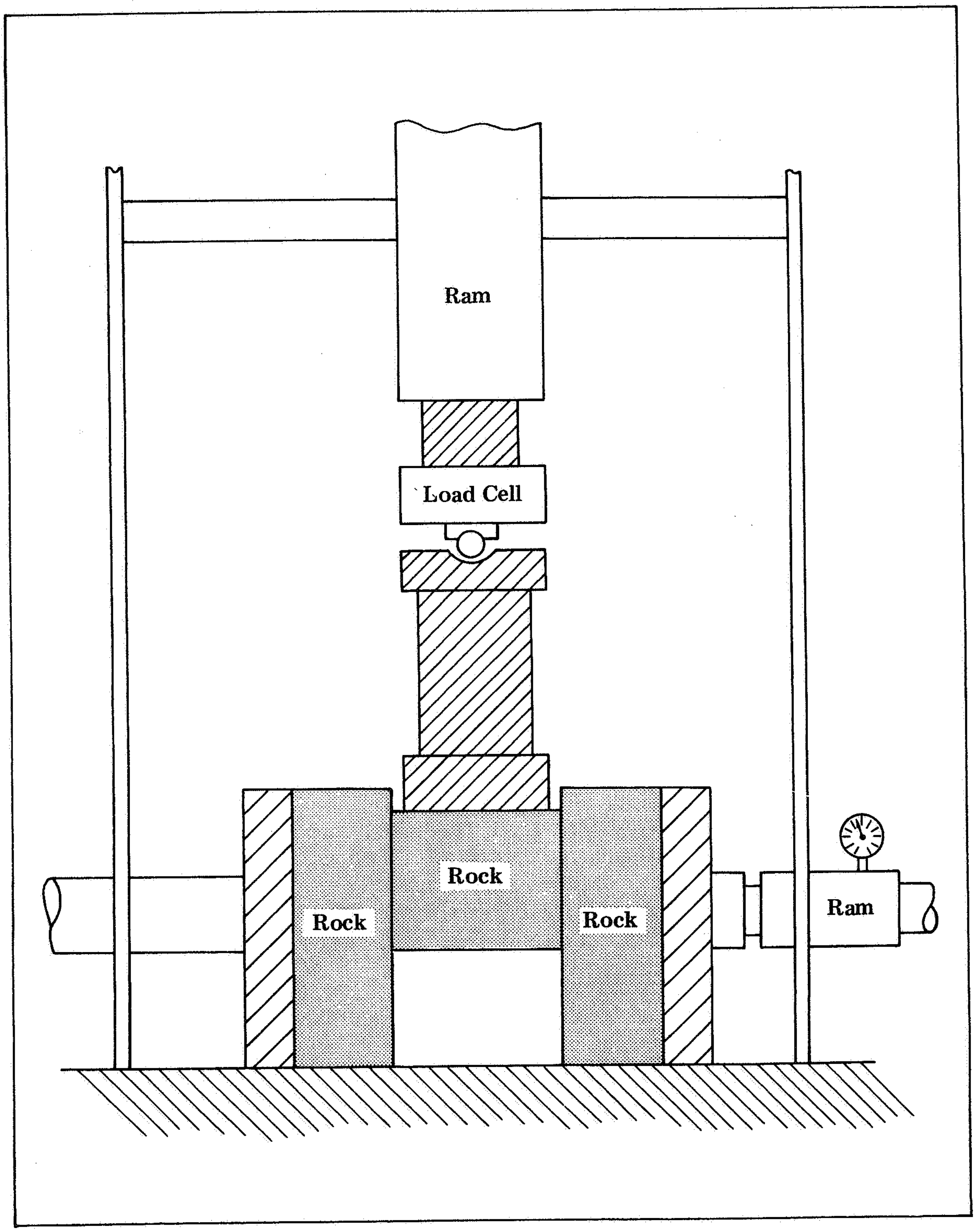


Figure 4-52 Schematic of the Apparatus for Friction Measurements

ram and the force measured by a load cell. The static coefficient of friction can then be determined from a measurement of driving force necessary to initiate slippage as a function of applied normal load. Both the driving force and the normal load are monitored as a function of time and recorded on chart recorders.

Experiments have been performed on rough and smooth surfaces between blocks of Indiana Limestone and between blocks of Nugget Sandstone. A typical record from an experiment on friction between smooth surfaces of Indiana Limestone is shown in Figure 4-53. The horizontal axis is force.

The stairstep record is the applied horizontal load, i.e., the normal load across the interface, which is measured by a transducer. The calibration for this load is 666 lb/in. The lower trace is then increased until slip occurs. The normal load is then increased by a 666 lb increment and the vertical force is again increased until slip occurs. As this process is repeated, as shown in Figure 4-53, the frictional force exhibits a slip-stick character which is typical for rocks.*

In this type of experiment a large relative displacement (approximately 2 inches) occurs. As a result of the sliding, the nature of the rock surfaces changes. A considerable amount of limestone is pulverized, and a layer of powdered rock builds up in the sliding interface and acts as a lubricant. Frictional measurements after the first few increments of displacement are not representative of the frictional characteristics of the rock interface as it exists in one of the hydraulic fracture experiments. To obtain a representative measure of the frictional character of the surface, experiments have been performed in which the applied fractional driving force at each level of the applied normal load is increased only until sliding is initiated and then released slightly. The normal load is then increased and the process is repeated. In this way, the total relative displacement during an entire run is less than 1/4 in. and the resulting damage to the interface is much less than in the previous method of experiment. From a series of experiments on dry Indiana Limestone with smooth surfaces, a mean value of $\mu = 0.51$ was obtained for the coefficient of static friction. In the hydraulic fracture experiments using smooth unbonded interfaces in dry Indiana Limestone, it was found that the threshold normal stress across the interface for hydraulic crack growth was about 650 psi. At the normal stress level the friction experiments indicate that a shear stress of about 330 psi can be transmitted across that interface before significant macroscopic slippage will occur. This number compares to about 7 percent of the shear strength and 43 percent of the tensile strength of Indiana Limestone.

ROCK MECHANICS MEASUREMENTS

Rock mechanics work for the Gas Stimulation Program included:

- Model study of the hot-gas permeability measurement. The purpose of this study is to determine the suitable sizes of reservoirs for the hot-gas permeability apparatus and the time characteristics that may be dealt with in the measurement.

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*Jaeger, J. C., and N. G. W. Cook, Fundamentals of Rock Mechanics, John Wiley & Sons, New York 1976, p 61.

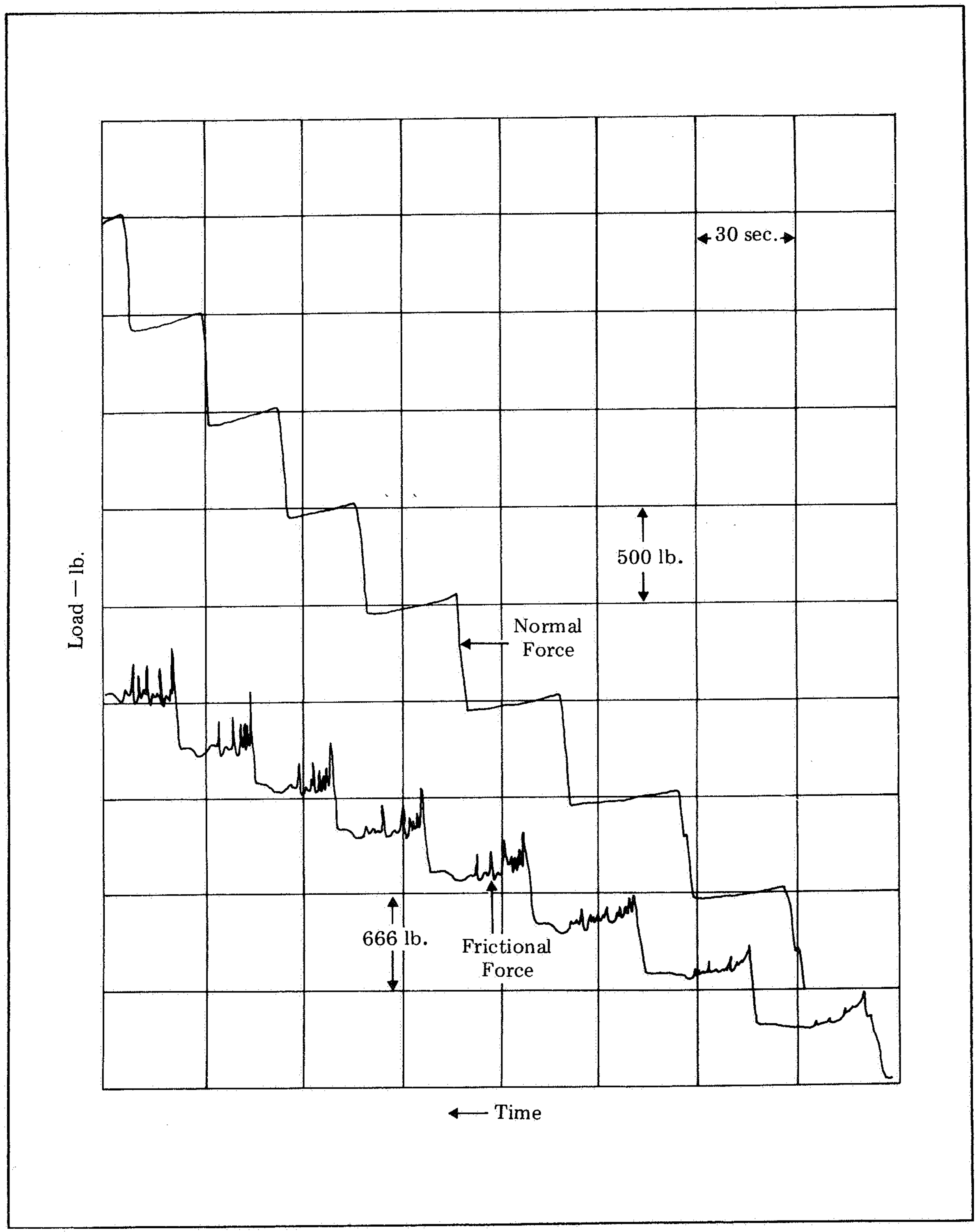

Figure 4-53 Frictional and Normal Forces Across Indiana Limestone Interface

- A 15 ft core sample was obtained (2 in. diameter) from the Mesaverde Group, Rio Blanco County, Colorado. The specimen preparation for the equation-of-state studies has been started.

The three units of rock samples were prepared (sandstone, shale, and a mixture of these two). The following studies have been planned for the sandstone and shale units.

- Brazil tests (tension), both parallel and perpendicular to bedding.

- Uniaxial stress loading in compression to determine failure envelopes. Values of confining pressures (σ_3) range to 0.5 GPa. The major stress axis (σ_1) is either parallel or perpendicular to bedding.

- Pressure/volume determinations at hydrostatic pressures up to 2.0 GPa in specimens with the axis either parallel or perpendicular to bedding.

- Determine the dynamic elastic constant tensor as a function of confining pressures up to 1.0 GPa by measuring ultrasonic velocities in six directions simultaneously.

- Hot-gas permeability measurements, either parallel or perpendicular to beddings, and confining pressure up to 50 MPa and temperatures up to 250°C.

About 90 percent of the specimen preparation for the first three studies has been completed.

Measurements and data reduction for material from the Mesaverde Group, Rio Blanco County, Colorado continued. Work on this material included the following:

- Uniaxial stress loading in compression to determine failure envelopes started.

- Data reduction for the Brazil tests was completed.

- Preparation for jacketing the samples for pressure/volume determination was started.

Most of the tool problems have been corrected. To facilitate data reduction and interpretation, it would be advisable to digitally record the data on magnetic tape in a computer compatible format.

RESERVOIR ANALYSIS

Additional analysis of the data from the Mobil Research and Development Corporation's Piceance Creek Unit Well F31-13G has been completed. The previous analysis* used "scum", a fracture-formation resistance factor similar to skin damage, but on the fracture faces, to fit the data. This

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*Hanson, et al., LLL Gas Stimulation Program Quarterly Progress Report, January through March 1978, Lawrence Livermore Laboratory Report UCRL 50036-78-1 (1978).

second model did not use "scum" but rather used a finite conductivity in the fracture. Figure 4-54 shows the good fit achieved by the two models to the data. Where there is a difference in the models, the finite conductivity fracture model shows a slightly higher pressure.

The model parameters that were used for the final fit are:

formation pressure	4,675 psi
kh	1.12 md-ft
$\phi L^2 h$	9,200 ft^3
well and fracture storage	3,350 ft^3
C_D	1.34
C_f	1.5 md-ft^2

The fracture conductivity is determined from C_D, the dimensionless fracture conductivity:

$$C_D = \frac{k_f w_f h_f}{k\ L_f\ h} = \frac{C_f}{C_{rf}}$$

Here, quantities with an f subscript refer to the fracture. The other quantities are for the formation. For a specific value of C_f a fracture conductivity can be calculated. If it is assumed that:

L = 100 ft
h_f = 100 ft
w_f = 0.05 ft (fracture half width)

then
k_f = 30 md

Also calculated, were the flow rates, Figure 4-55, and cumulative production, Figure 4-56, for 20 years. This is shown along with the results for a fracture with and without "scum".

A clear fracture, "scum" = 0, shows the highest flow rates and production. This is followed by the "scum" model. The effects of finite conductivity in the fracture are to lower the curves some more. This shows that while both models fit the data the effects on long term production are different.

4.3.3 SANDIA LABORATORIES

ADVANCED BOREHOLE LOGGING PROGRAM

Sandia Laboratories continued research of the capabilities of current, as well as proposed, borehole logging measurements in light of the numerous problems presented by low-permeability shales and shaly sands of the Enhanced Gas Recovery program. Earlier findings by this group have recommended concentration in two primary areas: nuclear magnetic resonance (NMR) and advanced electro-magnetic theory. Progress made in these areas follows.

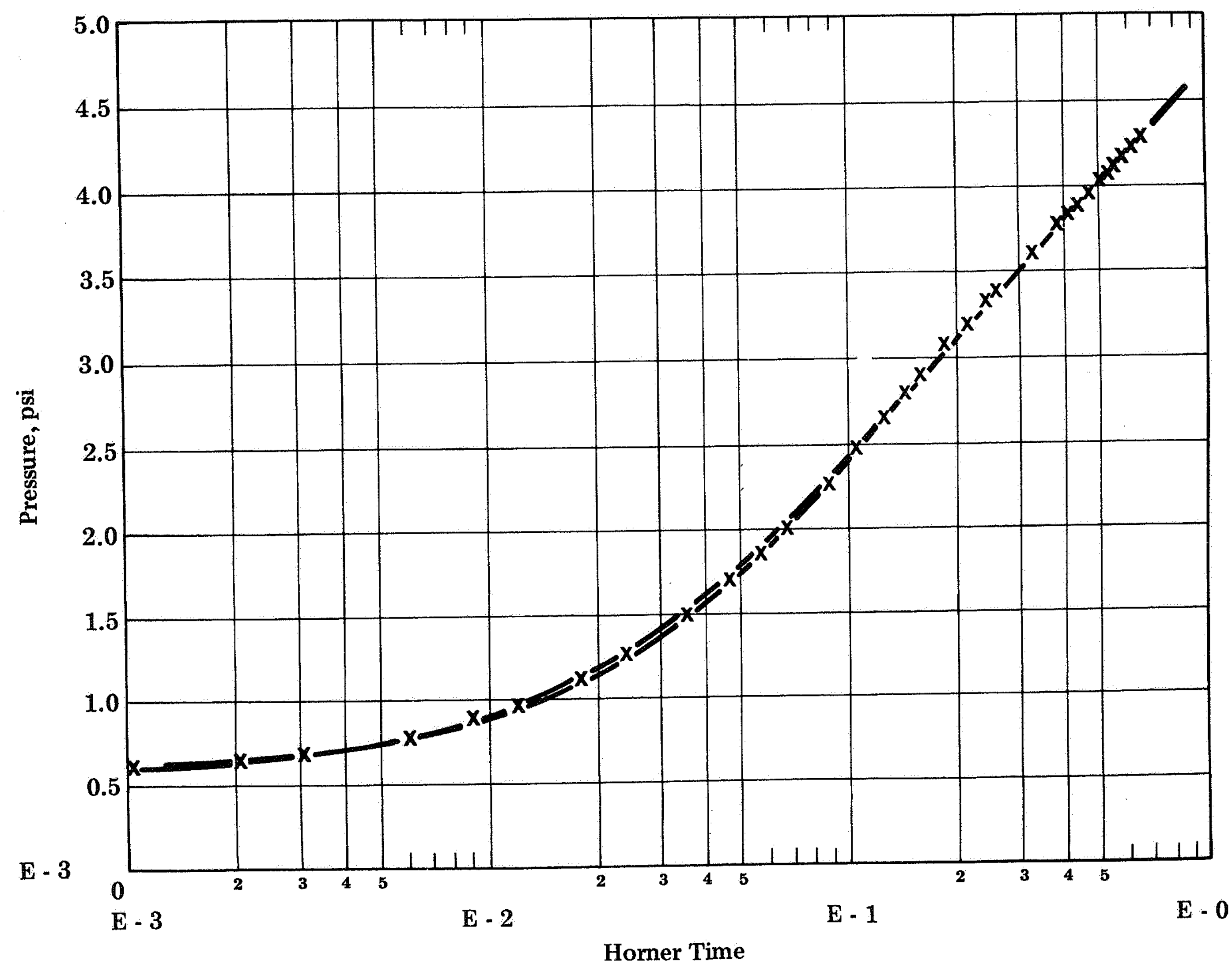


Figure 4-54 Fracture Conductivity Calculation Comparisons

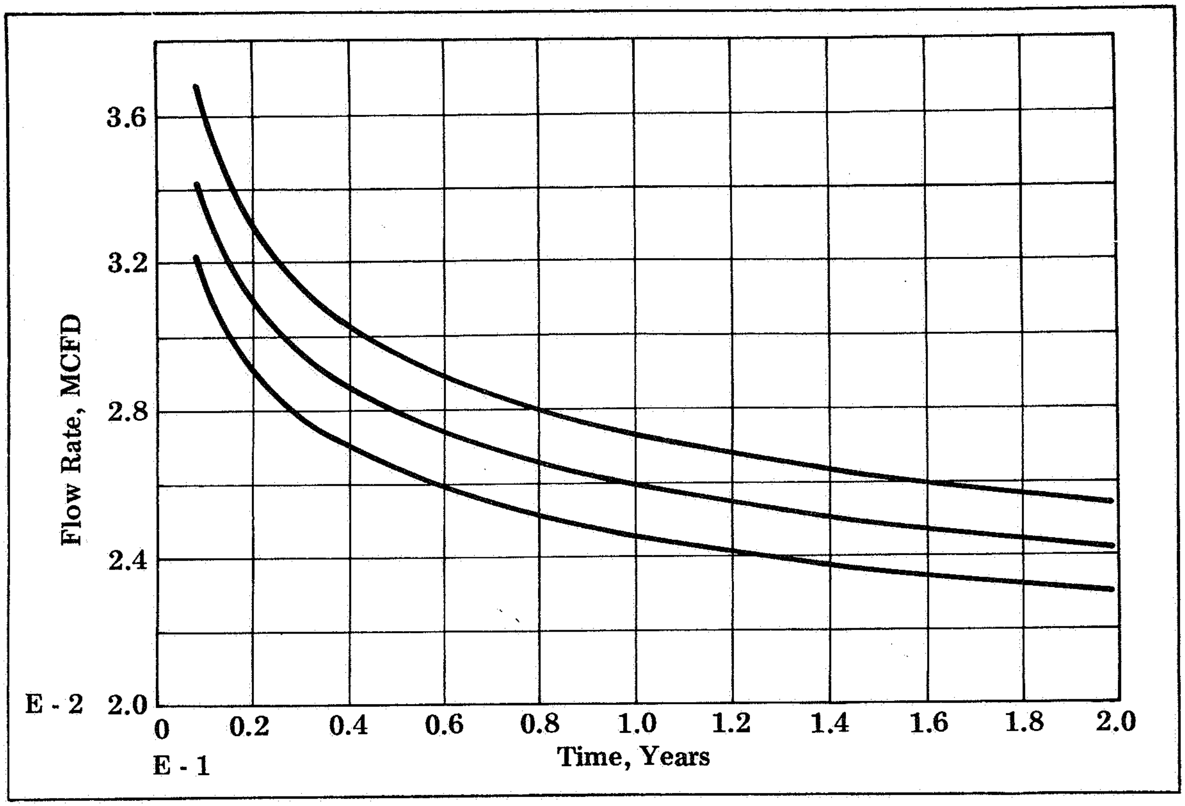


Figure 4-55 Flow Rate for Twenty Years

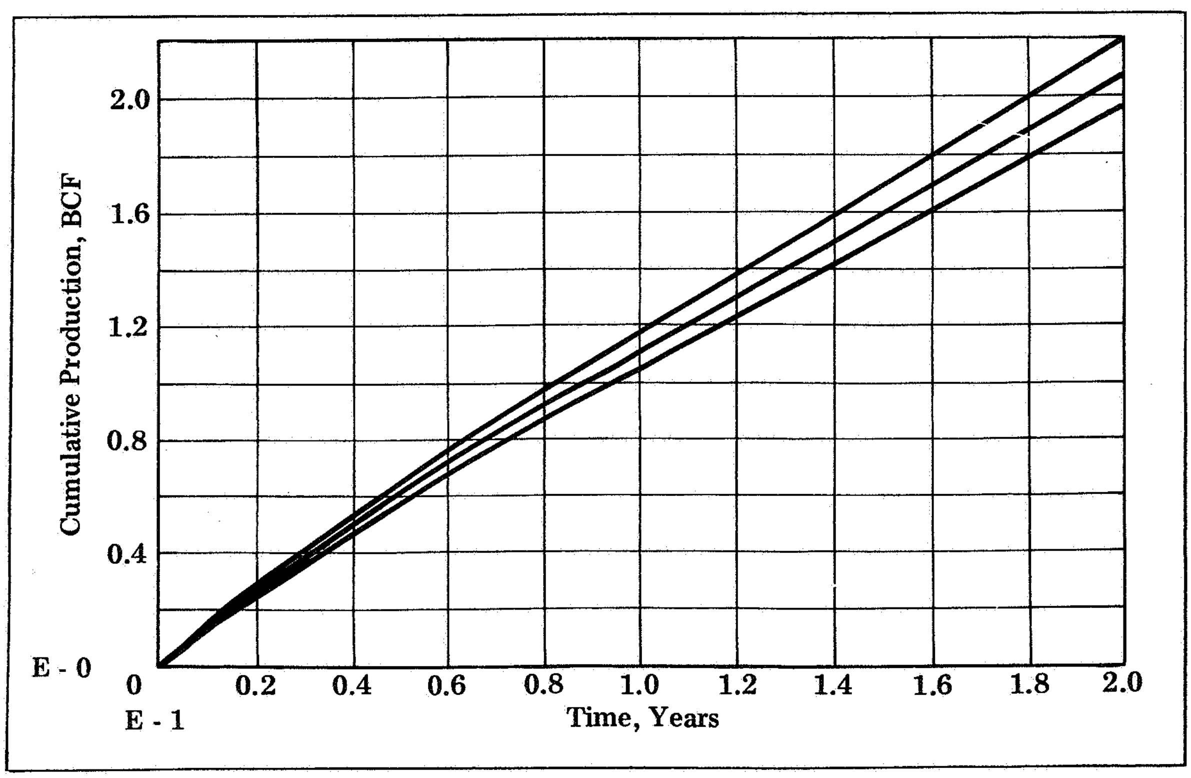


Figure 4-56 Twenty Year Cumulative Production

- NMR

Following a visit to Chevron Oil Field Research Labs, Sandia contacted Terra Tek to request representative core samples from the Uinta Basin, Natural Buttes, Well No. 21. Intervals were chosen on the basis of encouraging shows on the Schlumberger Saraband log of this well. Representative samples were requested from the following intervals:

Interval	Depth, ft
1	4,402 - 4,414
2	4,477 - 4,484
3	6,483 - 6,488
4	7,563 - 7,570
5	8,457 - 8,485
6	8,510 - 8,514

The cores will be subjected to core analysis and NMR analysis at Chevron Labs, in cooperation with Dr. Aytekin Timur of Chevron. The study is intended to determine the reliability of empirical NMR-petrophysical parameter relationships derived from the core sample study. In this way, an evaluation may be made of whether or not NMR techniques (given substantial future hardware improvements) can provide accurate measures of in situ permeability and fluid saturations in low-permeability reservoirs.

- Advanced Electromagnetic Theory

  Several recent publications have indicated potential for recording electrical measurements at very high frequencies (up into GHz frequencies). The findings of laboratory studies have shown a correspondence between dielectric constant measurements and petrophysical parameters such as porosity, formation water salinity, shaliness and saturation. At least two tools are being developed to provide measurements at high frequencies (both mono-frequency). Many time-dependent electromagnetic phenomena (e.g., induced polarization, complex dielectric, nuclear magnetism) are indicators of pertinent reservoir characteristics. Sandia has initiated computer code development to model tool response for an induction device within a borehole having horizontal layering and concentric layering (invasion) at the same time, allowing the electrical characteristics of the media to be frequency dependent. This code development is underway and not yet complete.

BOREHOLE HYDROPHONE ARRAY

Edo Western has completed delivery on the six hydrophones to be used in the first downhole hydrophone system. End caps were designed and fabricated in order to test the "O" ring seals at each end of the unit. Due to rework on the end threads of one hydrophone, only five of the units were tested to 10,000 psi. All five units passed the test and are now being prepared for electrical testing at high pressures.

High gain amplifier and power supply circuits have been assembled and are functioning properly. The amp mixer-line driver printed circuit board has been returned for rework.

HYDRAULIC FRACTURE CHARACTERIZATION

Participation was begun in a follow-on set of experiments in the AMOCO Wattenberg Field, north of Denver, beginning the week of November 6. A series of three gas wells are planned in the Muddy "J" Sands, approximately 8,000 ft deep.

A breakdown procedure experiment is planned for all three wells. Instrumentation will include the downhole three axis wallclamp geophone and the HP high resolution recording pressure gauge. The geophone has been instrumented with high temperature geophones in preparation for the high formation temperature.

Present planning calls for the Surface Electrical Potential (SEPS) to be installed on the first and third wells during the full fracture experiment. Residential congestion around well No. 2 makes the installation of the SEPS impractical. Additional instrumentation during the full fracture will include the HP recording pressure gauge and the surface tiltmeter. Fracture fluid pressure and flow data from the service company transducer will also be recorded by SEPS instrumentation.

The first well for the SEPS installation will be Gordon Turkey Farm D-1. This well has a depth of 7,972 ft and is uncased at the fracture interface. Current from the SEPS will be injected at this level via the downhole current probe. Previous attempts at this procedure have resulted in current pulser failure. Hardware checkout at this point indicates that this problem has been corrected. The surface electrical potential will be recorded at radii of 1,200 and 2,400 ft. Two current sink wells, approximately 90 degrees apart, will be used.

The electrical potential data collected during the MHF experiment on the AMOCO Oil Company's Gordon Turkey Farm D-1 well have been analyzed. No positive indication of a fracture was obtained.

Two factors prevented this information from being obtained, assuming it was available.

- Transient voltage spikes in excess of 1 volt were present on the leading and trailing edges of the millivolt level data potentials. These transients saturated the instrumentation amplifiers and prevented an accurate measurement of the desired signals. Since these transients were coincident with the leading and trailing edges of the induced current, transient suppression is being incorporated into the current generator.

- The induced current level increased abruptly from 4 amps to 12 amps approximately half-way through the experiment with no increase in applied voltage. The current probe was located in tubing at a depth of 8,000 ft. The change in current required a change in contact resistance between the probe and the surrounding tubing and frac fluid. Turbulence or fluid flow in the tubing could have caused a change in the character of the fluid surrounding the current probe, but this is mere speculation. Changes in excitation signals of this magnitude hinder the comparison of potential signals occurring before and immediately after commencing pumping, with the potentials occurring during the later states of the experiment.

The seismic signals received from the breakdown experiments on Gordon Turkey Farm D-1 and UPRR Pan Am 50E1 in the Wattenberg field have been examined. The analog playbacks do not reveal sufficient information to determine fracture direction. These signals will be digitized in an effort to determine fracture orientation.

The layout for the printed circuit boards was completed and the first boards delivered for circuit assembly and checkout. These consist of the high-gain amplifier, the amplifier line driver and mixer, and the power supply circuits. Three of the six hydrophones ordered from Edo Western have been received along with the hardware designs initiated for making a high pressure (10,000 psi) test on the hydrophone units. The EMR subcarrier discriminators for the system have also been received.

Two separate approaches for determining the location of an acoustic source in a formation were worked out and coded for use in the desk-top programmable calculator. One requires that the acoustic velocity in the formation be known and the other does not require any prior knowledge of the velocity.

The current generator has been modified in an effort to eliminate or at least reduce the transient potentials associated with the measurements observed during the Gordon Turkey Farm D-1 experiment. Techniques have also been investigated for reducing the effects of these transients in the measuring electronics; a satisfactory circuit modification has not been determined.

Data from the breakdown tests in Gordon Turkey Farm and UPRR 50E1 have been digitized. Analysis of the data after analog and digital filtering indicates a direction of fracture for Gordon Turkey Farm of approximately N 55° W to S 55°E. Orientation of the fracture on UPRR was from N 46°W to S 46° E.

Directions were obtained by plotting a hodogram of the horizontal geophones and observing the direction of break from noise level. A typical hodogram plot is shown in Figure 4-57. This plot shows a direction of 305° (N 55° W). P-wave and S-wave arrival times are also observable from the hodogram plot. The time difference of these arrivals indicates the fracture length was in the 150 to 200 ft range.

The current generator in SEPS was modified to increase the pulse risetime. One area of consideration is that of the distributed capacity between the downhole current probe cable and well casing, allowing significant high frequency content current injection at and near the surface. Increased pulse risetime will work against this possible effect. Risetimes in the range of 30-50 milliseconds can be achieved against a downhole current probe-sink well loop impedance of approximately 70 ohms. Increased pulse risetime is accomplished, however, at the expense of current injection magnitude.

At the receiving end of SEPS, long highpass time constants between the pick-up probe and the instrumentation input seem to be most effective against the effects of the transient voltage spikes on the leading and trailing edges of the millivolt level data potentials. This was determined experimentally using an input signal similar to that encountered in the field. These time constants

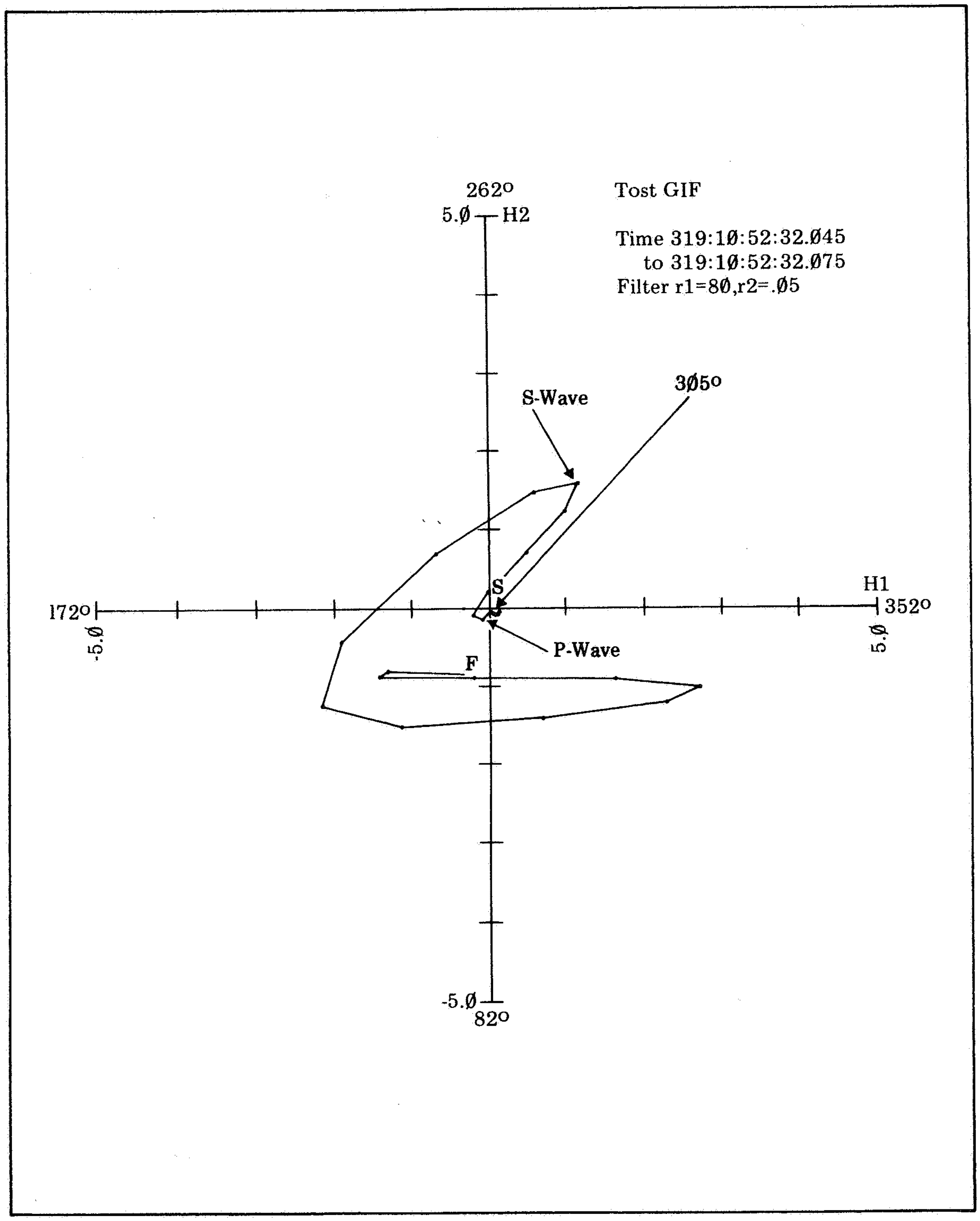


Figure 4-57 Seismic Hodogram

(70 seconds) limit the sampling rate due to the time required for the instrumentation to settle after being switched from calibration to a data probe. One approach being explored is that of a two-dimension time constant, a short one (0.2 seconds) during the settling period, and a long one during the data acquisition interval.

Information content in the tail of the seismic signals from the Gordon Turkey Farm and UPRR experiments is under investigation. It is felt that the periodic signal is fracture-related but it is not fully understood and could be mechanical resonance in the seismic unit.

FORMATION MAPPING

This new program is an outgrowth of discussions held at the Logging Program meeting in October, 1978, wherein concern was raised over the present inability to delineate and map individual sand channel reservoirs typical of the Mesaverde Group. It was proposed that state-of-the-art seismic reflection concepts (seismic stratigraphy, 3-D seismic) might be a means of delineating sand channels from surface derived data. The results of preliminary investigation were presented in a briefing and it was decided that a limited seismic program should be performed and that a coordinated effort with CK GeoEnergy Corporation, who is performing statistical analysis of primary sedimentary structures in channel sands in outcrop, would be mutually beneficial. At least three possible areas which may be appropriate for the proposed seismic study. These are near Rangely, Colorado, De Beque, Colorado, and Green River, Utah. The latter site is preferred, as this is the site of intense analysis by CK GeoEnergy with USGS cooperation. Future activities, based on the results of these meetings will include site visits, compilation of available geologic/geophysical data applicable to the sites, and determining instrumental, procedural, and processing specifications to be met by prospective seismic contractors.

4.3.4 M.D. WOOD, INC., TILTMETER

OBJECTIVE

On January 12, M.D. Wood, Inc. began a new contract for analysis and data documentation of all past DOE supported fracture mapping activities and to map hydraulic fractures in low permeability western gas reservoirs. Experiments will be fielded in Texas and Colorado in conjunction with AMOCO and Shell.

SUMMARY OF ACTIVITIES

Review Recent work was reviewed and future experiments were planned in February. An outcome of the meeting was additional independent confirmation of the determination of fracture azimuths that have been done in past work. An experiment was planned to support the hydraulic fracturing research in the Sandia Mineback project at the Nevada Test Site; and, during the latter part of March, the experiment was conducted. Tiltmeters were placed in the floor of a tunnel near the site where four small (40 ft diameter) hydraulic fractures were produced. Instrumentation strategy involved a technique for placing multiple tilt sensors in a single borehole for the purpose of measuring gradients of tilt along a single fracture radius.

Earlier in March, the formation of an hydraulic fracture at a depth of approximately 8,000 ft was monitored in the Wattenberg gas field of Colorado. A new type of tiltmeter array was used to provide better indications of the lengths of deep vertical fractures. Data analysis is currently underway.

4.4 FIELD TESTS AND DEMONSTRATIONS

4.4.1 BACKGROUND

Specific field tests are essential to verify the findings of laboratory tests and modeling studies. The field test and demonstration program involves cooperation between industry and government and also interacts geologic studies with laboratory research and development. The following projects are in active status in the WGSP:

- A dry gas injection experiment in the Wattenberg Field, Colorado, by Colorado Interstate Gas Company,
- MHF demonstrations by Gas Producing Enterprises in the Uinta Basin, Utah,
- MHF treatment of the Cotton Valley Limestone Formation in Limestone County, Texas, by Mitchell Energy Corporation,
- A mineback testing program by Sandia Laboratories.

Table 4-14 summarizes both completed and active WGSP MHF treatments. Progress of ongoing projects is presented in the following sections.

Table 4-14 MHF Contract Locations and Frac Data

COMPANY, BASIN	LOCATION T/R/Sec	WELL	INTERVAL FRACTURED ft	FRAC DATE	FRAC TREATMENT Lb of Sand	INJECTED FLUID 10^3 Gal
AUSTRAL Piceance, Mesaverde	7S/94W, Sec 3 Garfield Cty Colorado	Federal 3-94	5,170- 6,333	8-25-76	1,140,000	542 Gel Gel H O
CONSORTIUM MANAGED BY CER CORPORATION Piceance, Mesaverde	3S/98W, Sec 11 Rio Blanco Cty Colorado	RB-MHF-3	8,048- 8,078 7,760- 7,864 5,925- 6,016 5,851- 5,869	10-23-74 5- 2-75 5- 4-76 11- 3-76	400,000 880,080 815,000 448,000	117 Gel 285 Gel 400 Gel 228 Gel
GAS PRODUCING ENTERPRISES, INC. Uinta, Wasatch and Mesaverde	10S/22E/Sec 10 Uintah Cty Utah	Natural Buttes No. 18	6,490- 8,952	9-22-76	1,480,000	745 Gel
	10S/21E/Sec 21 Uintah Cty Utah	Natural Buttes No. 19	8,909- 9,664 7,224- 8,676	9-21-76 9-28-76	424,000 784,000	280 Gel 364 Gel
	9S/21E/Sec 22 Uintah Cty Utah	Natural Buttes No. 14	6,646- 8,004	3-15-77	1,093,000	544 Gel
	9S/21E/Sec 28 Uintah Cty Utah	Natural Buttes No. 20	8,498- 9,476	6-22-77	826,000	322 Gel
	10S/22E/Sec 18 Uintah Cty Utah	Natural Buttes No. 22	6,858- 8,550	11-21-77	1,091,000	479 Gel
	9S/21E/Sec 19 Uintah Cty Utah	Natural Buttes No. 9	5,661- 8,934	3-27-78	554,000	349 Gel
	10S/21E/Sec 29 Uintah Cty Utah	Natural Buttes No. 2	7,251- 8,774	8- 8-78	1,965,000	722 Gel
	10S/22E/Sec 7 Uintah Cty Utah	Natural Buttes No. 23	5,080- 6,294	10- 4-78	440,000	240 Gel
DALLAS PRODUCTION Fort Worth, Bend Cong.	Ben D. Smith Survey A-779 Wise Cty Texas	Ferguson A-1	5,957- 6,794	9-10-76	506,000	139 Foam 198 Emul
EL PASO NATL. GAS Norther Green River, Fort Union	30N/108W/Sec 5 Sublette Cty Wyoming	Pinedale Unit No. 5	10,950-11,180 10,120-10,790	7- 2-75 10-20-75	518,000 1,422,000	183 Emul 8 Gel 459 Gel
MITCHELL ENERGY Cotton Valley, Limestone Trend	Limestone Cty Texas	Muse-Duke No. 1	11,220-11,430	11-15-78	2,800,000	891 Gel
MOBIL Piceance, Mesaverde	2S/97W/Sec 13 Rio Blanco Cty Colorado	F-31-13G	10,549-10,680 9,392- 9,538 8,765- 8,972 8,163- 8,650 7,704- 7,794 7,324- 7,476	6-22-77 8-24-77 5-10-78 7- 6-78 9- 7-78 11-15-78	580,000 600,000 388,000 660,000 218,000 700,000	316 Gel 260 Gel 150 Gel 288 Gel 120 Gel 365 Gel
PACIFIC TRANSMISSION Uinta, Mesaverde	8S/23E/Sec 25 Uintah Cty Utah	Federal 23-25	NO FRACS PERFORMED			
RIO BLANCO NATL. GAS Piceance, Mesaverde	4S/98W/Sec 4 Rio Blanco Cty Colorado	Federal 498-4-1	6,150- 6,312 5,376- 5,960	10-22-76 11-30-77	766,000 243,000+ 22,500 Beads	276 Gel 164 Gel
WESTCO Uinta, Mesaverde	10S/19E/Sec 34 Uintah Cty Utah	Home Fed No. 1	7,826- 9,437 10,014-10,202	12-21-76 10- 1-76	500,000 600,000	412 Gel 248 Gel

4.4.2 RIO BLANCO MASSIVE HYDRAULIC FRACTURING EXPERIMENT

CER Corporation
Las Vegas, Nevada

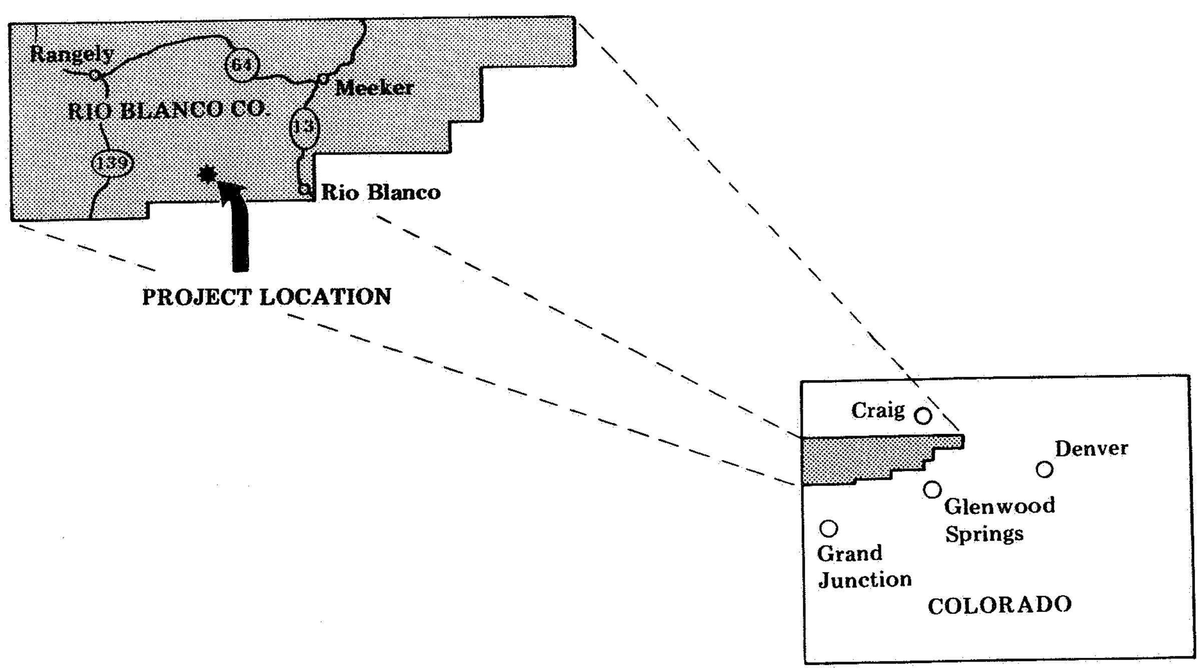
Status: Awaiting Advisory Committee Decision

Contract: EY-76-C-08-0623
Interagency Agreement Date: June 19, 1974
Anticipated Completion Date: July 1, 1979

Principal Investigator: G.R. Luetkehans
Technical Advisor for DOE: C.H. Atkinson

OBJECTIVE

This stimulation experiment is being conducted in low-permeability, massive gas-bearing sandstone reservoirs in the Piceance Basin in western Colorado, to test advanced hydraulic fracturing technology where it has not been possible to obtain commercial production rates. This test is located about 1 mile from the 1973 Rio Blanco nuclear stimulation site to permit comparison of nuclear and hydraulic fracturing techniques in this area.



SUMMARY OF ACTIVITIES

In March, 1974, CER Corporation was awarded DOE contract EY-76-C-08-0623. The contract provided for the drilling of a new well and two MHF treatments, and was later modified to add two more MHF treatments and extend the term of the contract.

CURRENT STATUS

Field activities on the Rio Blanco MHF 3 well have been suspended. Negotiations have taken place with an outside party to complete the commingling of fractured zones and to perform additional tests in return for the well and subsequent gas production. Legal documents are being prepared for distribution to the project participants.

The three volume final report on the RB-MHF 3 well will be distributed by the end of April.

4.4.3 DOE WELL TEST FACILITY

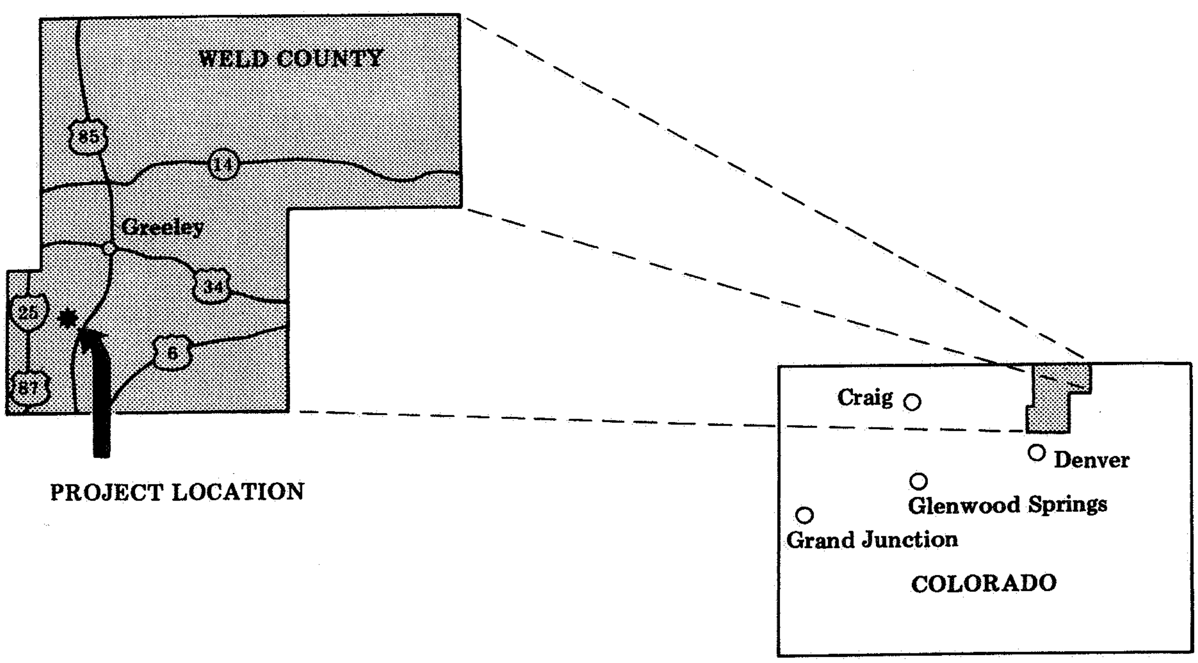
CER Corporation
Las Vegas, Nevada

Status: Equipment checkout and test proceeding

Principal Investigator: R.L. Mann
Technical Advisor for DOE: C.H. Atkinson

OBJECTIVE

The DOE Well Test Facility, consisting of two vehicles, will provide a deep well instrumentation and investigation system to monitor and evaluate the productive potential of all types of wells.



BACKGROUND

CER's DOE contract DE-AC08-79-BG-01569 provides for operating and maintaining a well test facility to be used at various locations selected by DOE. The facility is comprised of a 10 ft x 50 ft instrument trailer with 3 wireline draw works, a two-ton truck equipped with a telescoping 50 ft mast, and two trailer-mounted 30 kw and 90 kw electric generators (Figure 4-58).

CURRENT STATUS

During the later part of February, the DOE Well Test Facility was moved from Vernal, Utah to the Miller No. 1 well in the Wattenberg Field, Weld County, Colorado. The facility will be used to perform bottom-hole pressure buildup and related tests on both the Sprague No. 1 and Miller No. 1 wells in support of the Joint DOE/CIG Cyclic Dry Gas Injection Project (Figure 4-59).

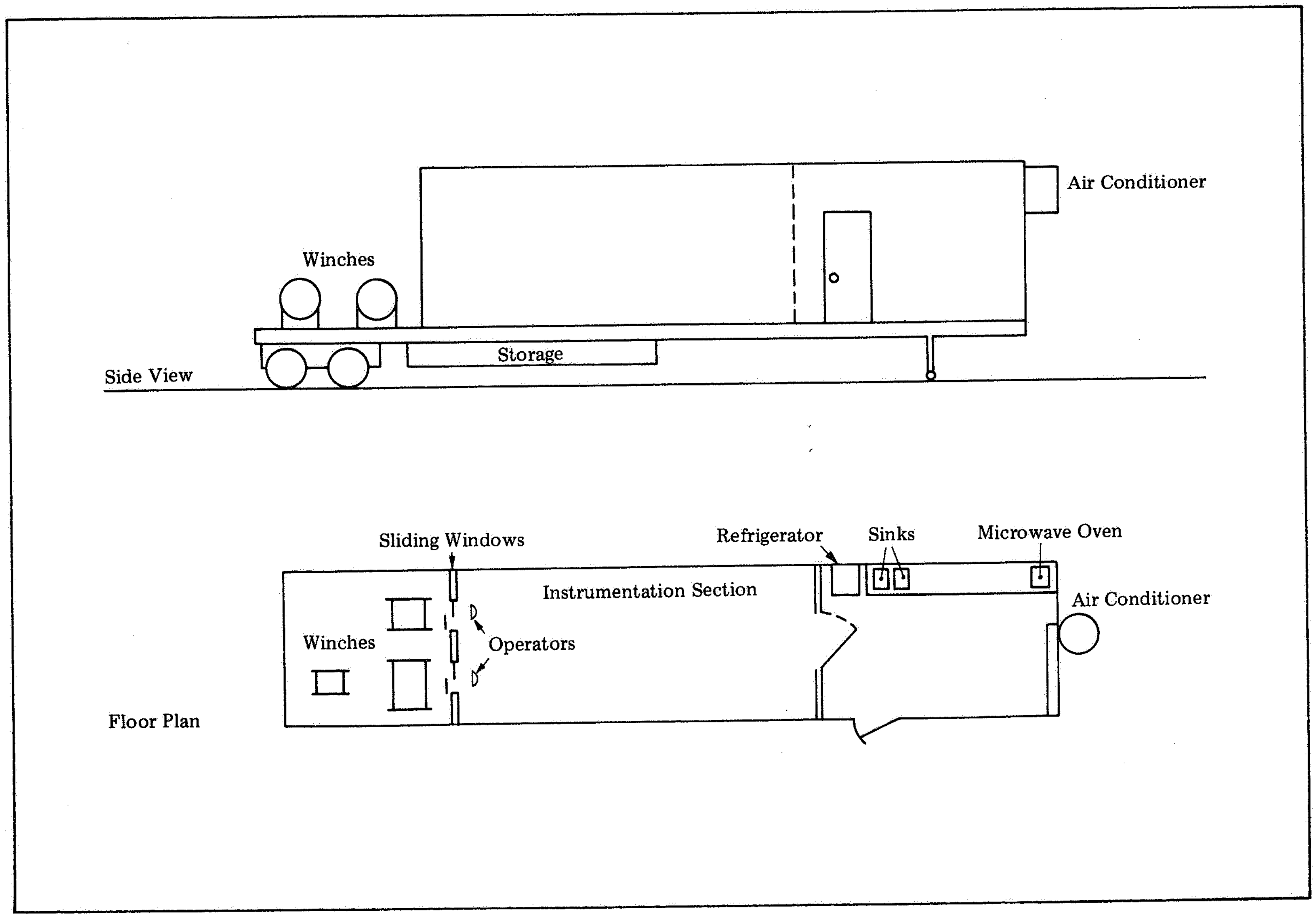


Figure 4-58 DOE Well Test Trailer

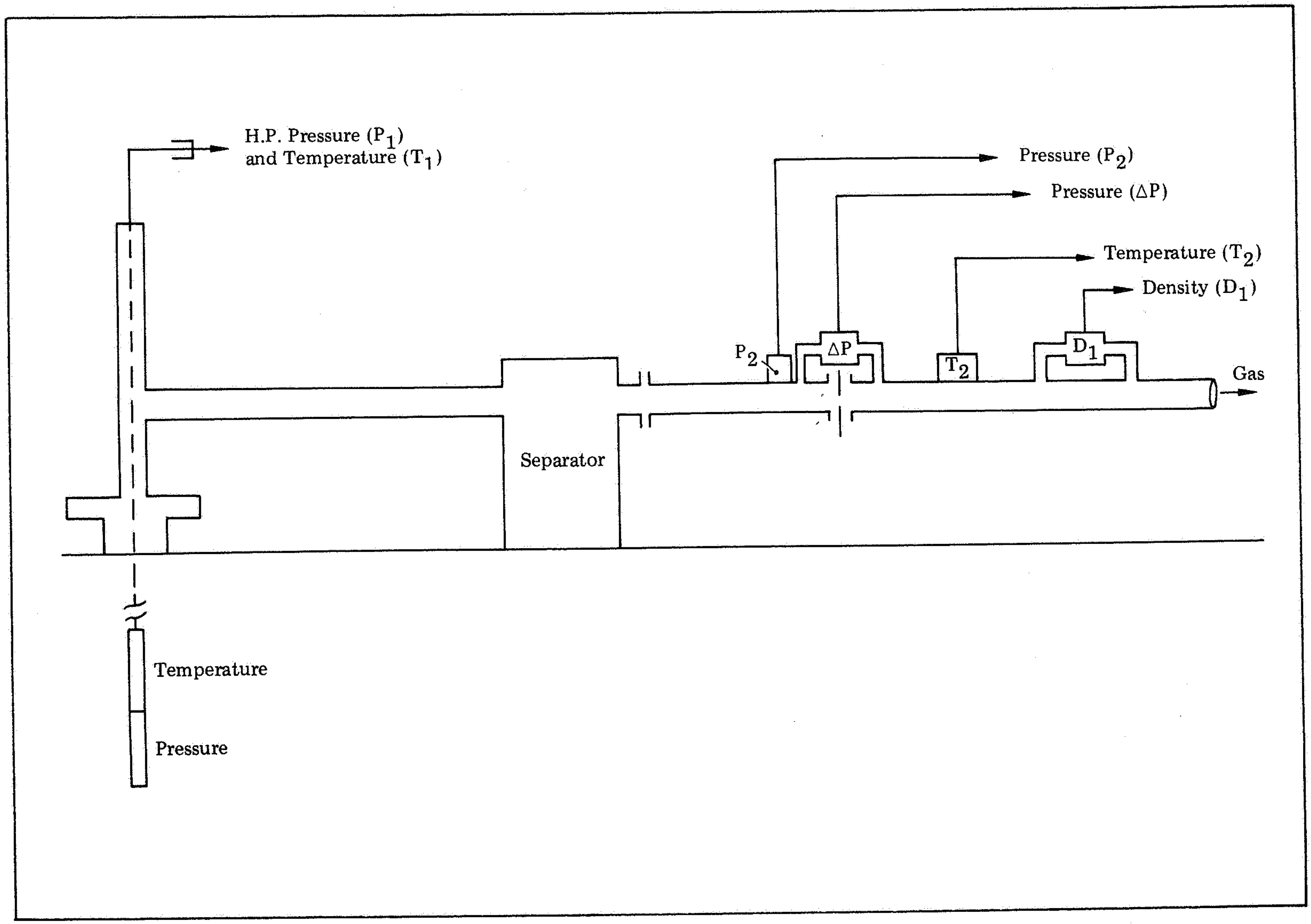


Figure 4-59 Schematic of Well Test Set-up

4.4.4 WATTENBERG FIELD

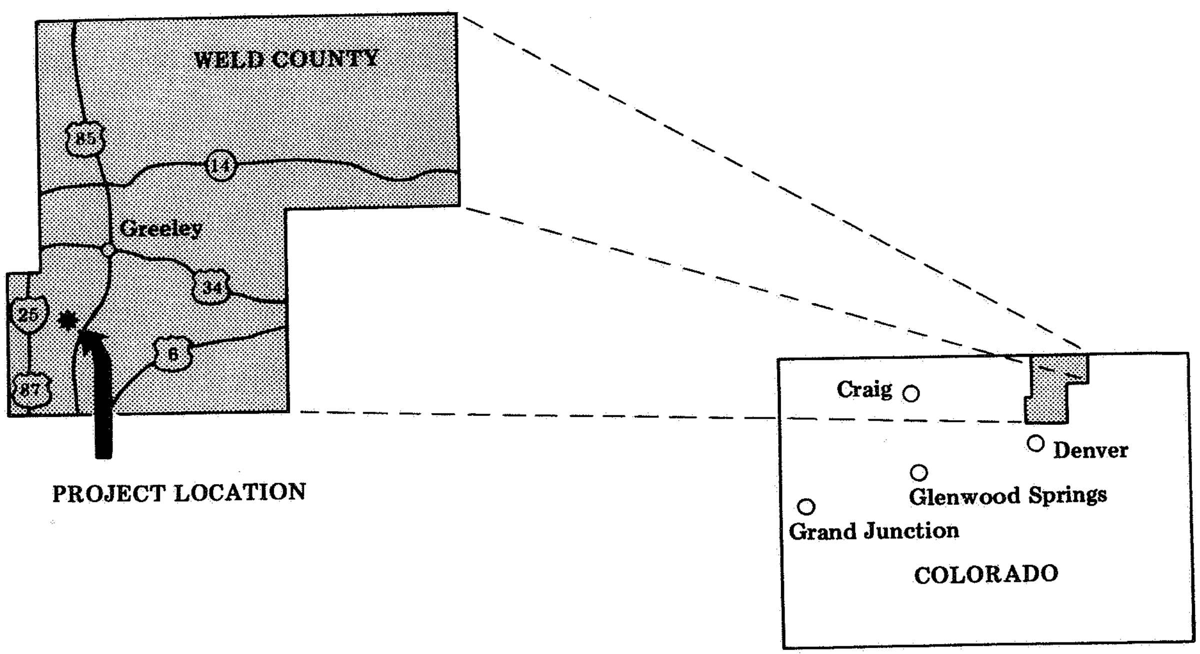
Colorado Interstate Gas Company
Colorado Springs, Colorado

Status: Active

Contract:	EY-77-C-08-1514
Contract Date:	September 1, 1977
Anticipated Completion Date:	March 1, 1981
Principal Investigator:	Howard Fredrickson
Technical Project Officer for DOE:	C.H. Atkinson

OBJECTIVE

Cyclic injection of dry natural gas is the method to be used to increase production of tight gas sands.



SCOPE OF WORK

DOE and Colorado Interstate Gas Company (CIG) entered into contract No. EY-77-C-08-1514 on September 1, 1977. The experiment will determine if productivity of wells completed in low-permeability natural gas reservoirs can be improved by reducing the interstitial water saturation by cyclic injection of dry natural gas. In addition, cyclic injection of dry natural gas may improve productivity by dehydrating matrix clays and by removal of formation damage adjacent to the surfaces of induced fractures.

CURRENT STATUS

The Ajax "DPC-160/HZ" compressor and three Rolo dry bed dehydrators have been delivered and installed at the Sprague No. 1 well.

Measurement of bottom-hole pressure in the Miller No. 1 and Sprague No. 1 wells is continuing. Bottom-hole pressure of the Miller No. 1 is increasing slowly at 4 to 6 lb per day and at an average of 3 lb per day in the Sprague No. 1 well. Since it is not advantageous to continue to measure BHP at this rate of buildup, the cycling process will be started as soon as all of the equipment is installed and working properly.

4.4.5 NATURAL BUTTES UNIT, UINTAH COUNTY, UTAH MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

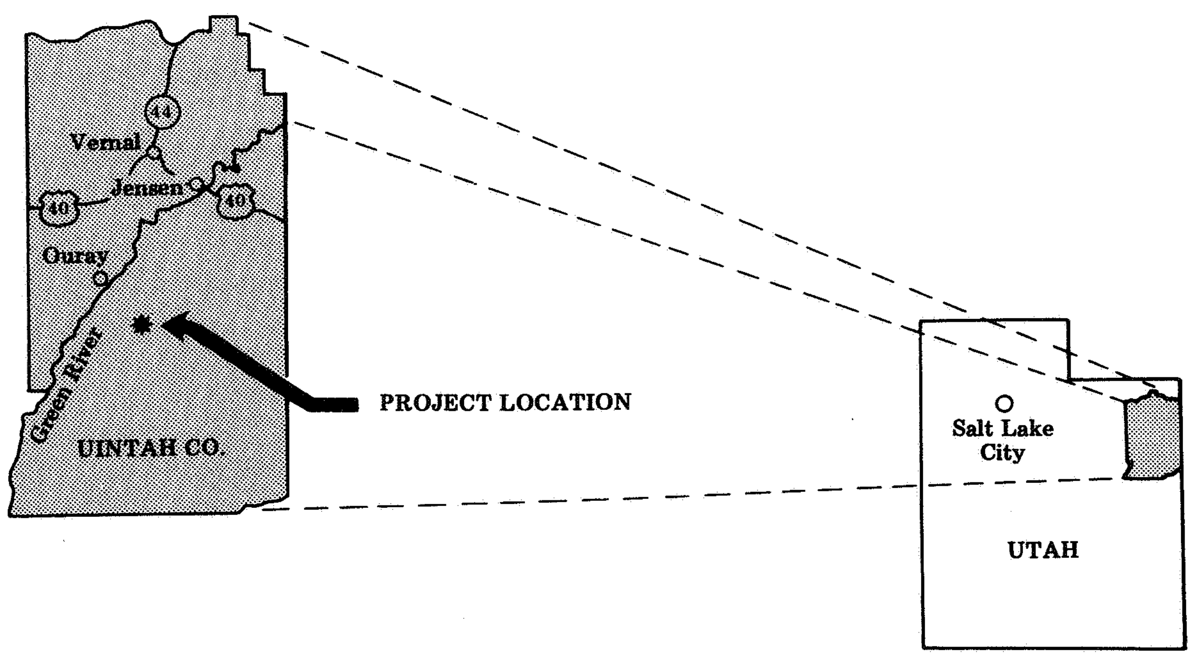
Gas Producing Enterprises, Inc.
Subsidiary of Coastal States Gas Co.
Houston, Texas

Status: Active

Contract:	EY-76-C-08-0681
Contract Date:	July 1, 1976
Anticipated Completion:	September 30, 1979
Principal Investigator:	W.E. Spencer
Technical Project Officer for DOE:	C.H. Atkinson

OBJECTIVE

To evaluate the effectiveness of massive hydraulic fracturing for stimulating natural gas production from thick, deep sandstone reservoirs having low-permeability.



SUMMARY OF ACTIVITIES

Gas Producing Enterprises was awarded DOE Contract EY-76-C-08-0681 in July, 1976. Originally, two old wells, Natural Buttes Unit Wells 14 and 18, and four new wells, 19, 20, 21 and 22 were to receive MHF treatments. Three contract modifications have been entered into, adding one old well, Natural Buttes Unit No. 9, two new wells, 23 and CIGE 2-29-10-21, and increasing the scope of work for Natural Buttes Unit Well No. 21.

CURRENT STATUS

The GPE wells, Natural Buttes Units 9, 14, 18 and 20 flowed to sales during March. Natural Buttes No. 19 and 22 were shut in and NBU No. 21 was temporarily abandoned. Table 4-15 is a summary of MHF treatments performed to date.

Table 4-15. Summary of MHF Treatments

Well	No. of Zones Perf.	Net Ft. of Pay	Net Ft. Per Zone	Average ϕ	Average SW	% Sd	Type of Fluid	Frac Job Size Gal of Gel	Lb of Proppant	Calc. Frac Length ft	Est. 1st Year Avg. Prod. Rate MCFD
Natural Buttes No. 18 DOE	18	224	12.5	10.0	48	88.0	Versa Frac	695,000	1,480,000	882	1,200
Natural Buttes No. 19 DOE	19	194	10.2	9.5	47	87.0	40# Guar Gum	655,000	1,237,000	950	60
Natural Buttes No. 14 DOE	15	271	18.0	9.9	49	65.0	YF4-PSD	544,000	1,082,000	879	600
Natural Buttes No. 20 DOE	8	65	8.1	9.9	44	88.5	YF4-PSD	309,000	826,000	1,150	800
Natural Buttes No. 22 DOE	24	196	8.1	12.0	45	85.0	YF4-PSD	478,758	1,091,000		
Natural Buttes No. 9 DOE	(35)	779*	22.0*	Unkn	Unkn	Unkn	40# Guar Gum	314,000	553,000		
CIGE 2-29-10-21 DOE Stage 1	10	91	9.1	10.0	40	80.0	MY-T-GEL III	195,000	170,500		
CIGE 2-29-10-21 DOE Stage 2	12	181	15.1	11.3	42	85.0	MY-T-GEL III	805,230	1,956,000		
CIGE 23-7-10-22 DOE	10	156	15.6	9.0	60	78.0	YF4-PSD	240,000	470,000		

*Using GR as only indication of net sand which more closely equals gross sand.

4.4.6 FALLON-NORTH PERSONVILLE FIELD, TEXAS MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

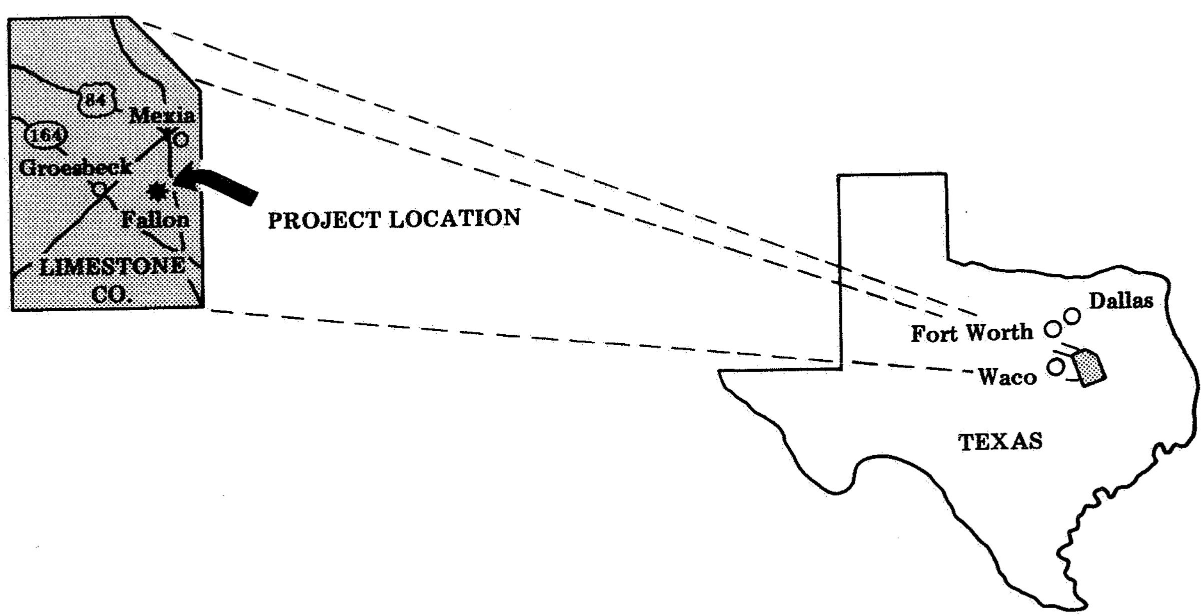
Status: Active

Mitchell Energy Corporation
Houston, Texas

Contract:	EF-78-C-08-1547
Contract Date:	March 15, 1978
Anticipated Completion:	April 30, 1979
Principal Investigator:	F.D. Covey
Technical Project Officer for DOE:	C.H. Atkinson

OBJECTIVE

To test massive hydraulic fracturing in the Cotton Valley Limestone Formation.



SUMMARY OF ACTIVITIES

The Mitchell Energy Corporation, Muse-Duke No. 1 reached total depth at 11,633 ft and was logged on August 31, 1978. Four hundred forty-seven ft of core was cut including 95 ft of overlying Bossier Shale, 210 ft of Cotton Valley Lime and 142 ft of underlying Buckner. The well flowed on a test at a rate of 2,034 Mcfd through a 7/64 in. choke at a flowing tubing pressure of 4,289 psi. On September 27, the Cotton Valley Lime was perforated with 15 shots and acidized with 15 percent HCl. The well was fractured on November 15, 1978 with a record treatment--891,000 gal of fluid and 2.8 million lb of sand.

The well flowed at an initial rate of 6 MMcfd and 89 bbl of water after fracturing. Unsuccessful attempts were made to determine the orientation of the fracture.

In February, the M.E.C. Muse-Duke No. 1 was flowing 4,100 Mcfg and 20 bbl of frac water per day through a 22/64 in. choke with a flowing tubing pressure of 1,575 psi.

CURRENT STATUS

Muse-Duke No. 1 was flowing 4,000 Mcfg and 25 bbl of frac water per day through a 24/64 in. choke with a flowing tubing pressure of 1,100 psi during March. Flow rates and pressures continued to drop at a slow rate.

The scheduled post pressure transient tests and clean-out work have not been completed.

4.4.7 PICEANCE CREEK FIELD, COLORADO MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

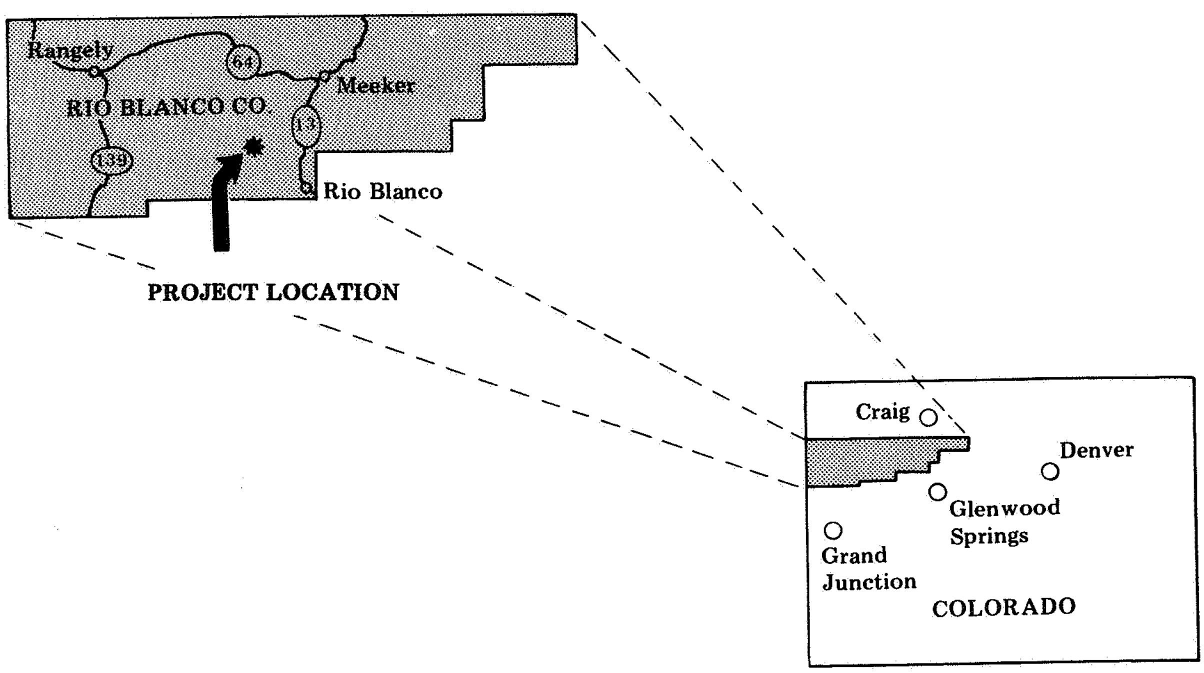
Mobil Research and Development Corporation
Dallas, Texas

Status: Active

Contract:	EY-76-C-08-0678
Contract Date:	July 1, 1976
Anticipated Completion:	June 1, 1979
Principal Investigator:	John L. Fitch
Technical Project Officer for DOE:	C.H. Atkinson

OBJECTIVE

To evaluate the effectiveness of massive hydraulic fracturing for stimulating natural gas production from thick, deep sandstone reservoirs having extermely low-permeability.



SUMMARY OF ACTIVITIES

Remedial cementing of zone 8 was accomplished. The casing was perforated at 7,818-7,820 ft with 8 shots. Circulation to the surface failed. After perforation at 7,650-7,652 ft with 8 shots, circulation across the zone was established. The zone was cemented with 150 sacks; circulation was lost during cementing.

Zone 8 was perforated in the intervals, 7,704-7,736 ft and 7,776-7,796 ft with 27 jet charges carried in a 4 in. centralized gun. The zone was then broken down with 138 bbl of 2 percent KCl water; ball-off was achieved. After breakdown, the well flowed a little water for two hours and died. Noise/temperature logs show most of the fluid was coming from the lower zone.

Zone 8 was fractured on September 7, 1978. The most severe treating pressure to date was encountered while pumping the treatment. Initial ISIP was 800 psi, after pumping 3,000 gal of pad. Initial (static) treating pressure measured on the tubing, while pumping the gel was 900 psi. Pressure increased rapidly to about 3,400 psi when sand-out occurred after pumping 218,000 lb of 20-40 mesh sand in 120,000 gal of gel at 15 bpm. Figure 4-60 illustrates the treated zones 6, 7 and 8. Table 4-16 lists completion information.

Zone 9 was completed during November and a long-term flow test of the zone started. The fracture treatment was executed as planned on November 15, and consisted of 700,000 lb of 20-40 mesh sand carried by 365,000 gal of gel. Temperature and gamma-ray logs were obtained on November 16 which indicated that the fracture did not extend much above the performations at the wellbore and that all of the perforated intervals took fluid. The well flowed to the sales line during December, but was shut-in on December 31 due to expiration of the temporary sales permit.

The well was shut in during January while awaiting extension of Mobil's temporary arrangements to sell gas. During February 1 through 14, zone 9 flowed at approximately 1.8 MMcfd. Work began on removing material (junk) and a sand fill at 8,444 ft.

CURRENT STATUS

Efforts to clean out the well continued through March. Junk from the top plug, partially drilled up, is resting on sand fill at about 8,829 ft. While attempting to mill-up this junk, the milling equipment, including a set of jars, became stuck. This was presumably due to influx of frac sand from the fractured intervals above. After backing off tools, the hole was circulated to remove sand and an overshot was run to retrieve the fish. During this attempt the fishing tools became stuck and also had to be backed off.

Operations will be suspended until a thorough study can be made of the problem and a new plan of action formulated. Tubing was landed just above the fish and the well swabbed in an attempt to establish flow. After 5 days of swabbing the well did not flow and was shut in.

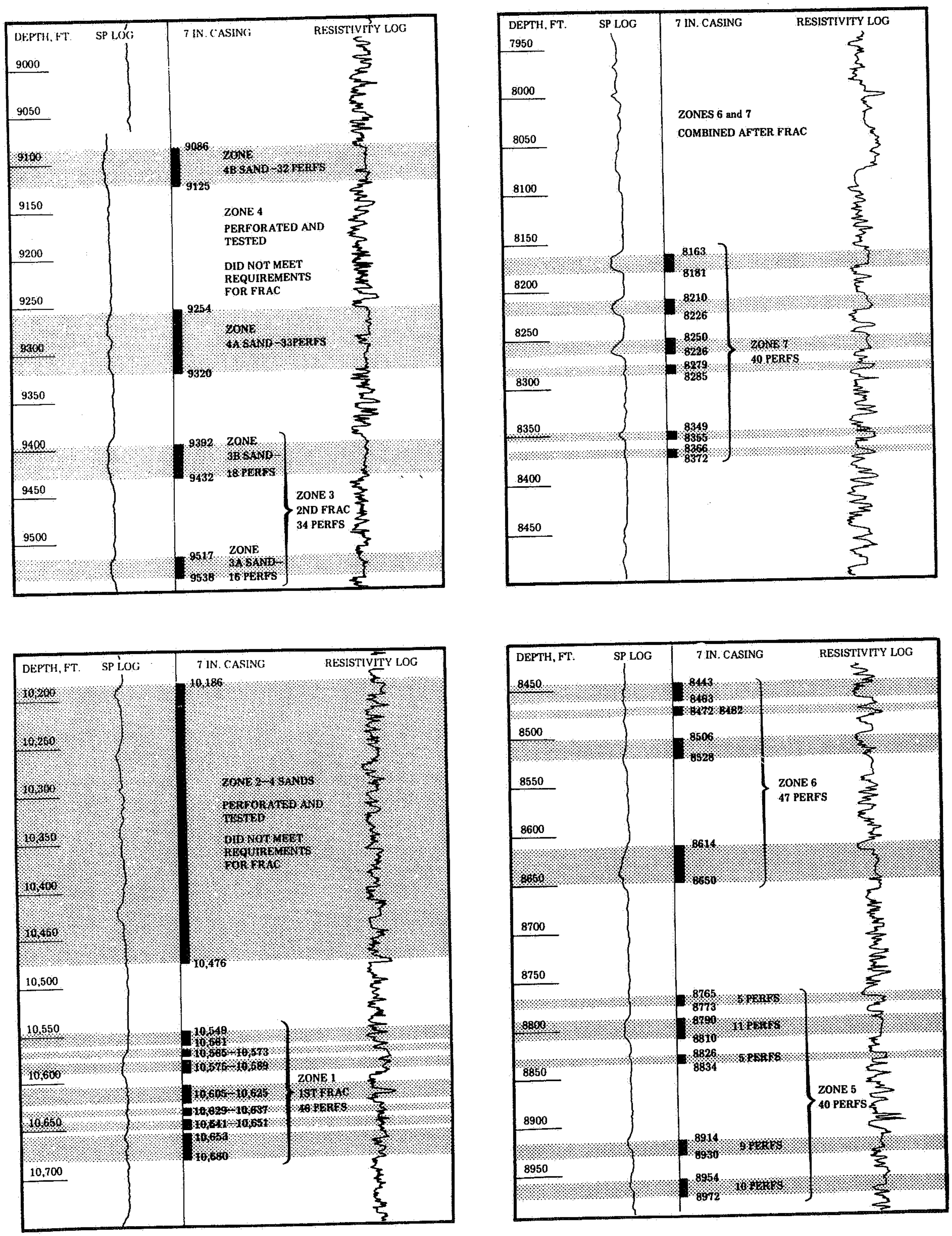


Figure 4-60 Mobil F31-13G Well Showing Sands Fractured

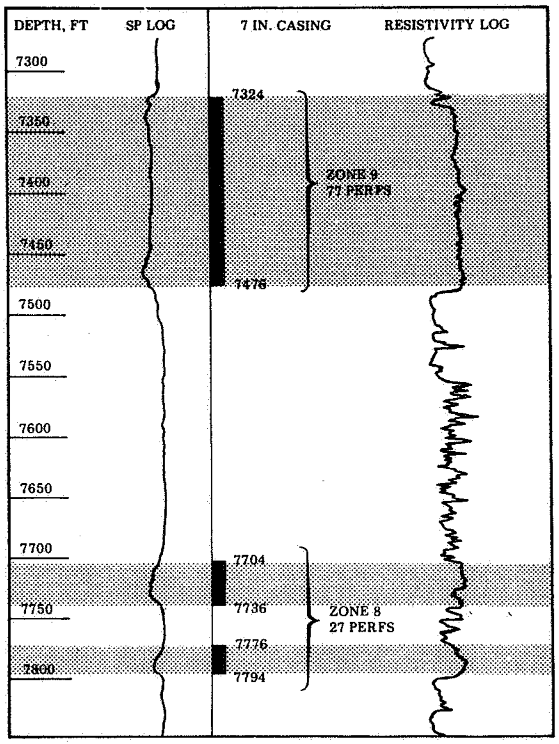


Figure 4-60 Continued

Table 4-16 PCU No. F31-13G Completion Information

Zone	Perfs No.	Perfs Interval	PBTD, ft.	Tubing	Packer	Gas Gravity	Temp.* °F	Porosity	Pressure Transient Tests Before Frac	After Frac
1	46	10,549-10,680	10,730	2-3/6 @ 10,450	None	N.A.	235		PBU	PBU
2	10 2 4 10 3	10,186-10,196 10,202-10,204 10,255-10,261 10,415-10,427 10,472-10,476	10,530	-------	----	N.A.	230		None	Not Fractured
3	18 16	9,392-9,432 9,517-9,538	9,600	2-7/8 @ 9,120	9,120	0.678	215	Average porosity for all of these zones is about 9% with an average water saturation of about 60%.	PBU	PBU
4A	33	9,254-9,320	9,370	2-3/8 @ 9,150	None	N.A.	212		PBU	Not Fractured
4B	32	9,086-9,124	9,210	2-3/8 @ 8,980	None	N.A.	209		PBU	Not Fractured
5	5 11 5 9 10	8,765-8,773 8,790-8,810 8,826-8,834 8,914-8,930 8,954-8,972	9,040	2-3/8 @ 8,625	None	0.669	205		PBU	PDD
6	10 6 12 19	8,443-8,463 8,472-8,482 8,506-8,528 8,614-8,650	8,725	2-3/8 @ 8,300	None	Zones 6 and 7 combined	199		PBU	Pressure drawdown (PDD) test was run
7	10 9 9 4 4 4	8,163-8,181 8,210-8,226 8,250-8,266 8,279-8,285 8,349-8,355 8,366-8,372	8,425	2-3/8 @ 8,050	None	after frac 0.668	194		PBU	Zones 6 and 7 combined after frac
8	27 27	7,704-7,736 7,776-7,794	7,812	2-3/8 @ 7,675	7,675	N.A.	191		PBU	

*From temperature logs run over various intervals at different times, the geothermal temperature gradient through the Mesaverde averaged about 1.75°F/100 ft.

Note: Casing is 7 in., 26 lb set at 10,800 ft.

4.4.8 RIO BLANCO COUNTY, COLORADO MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

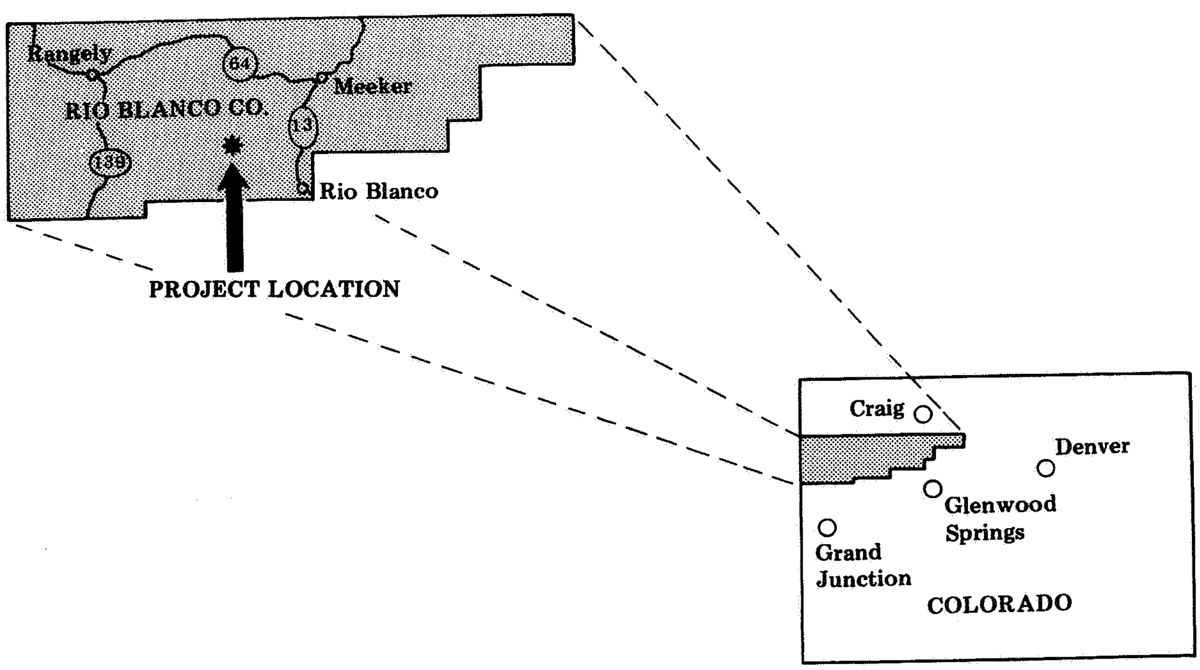
Status: Active

Rio Blanco Natural Gas Company
Denver, Colorado

Contract:	EY-76-C-08-0677
Contract Date:	August1, 1976
Anticipated Completion	December 15, 1978
Principal Investigator:	Robert E. Chancellor
Technical Project Officer for DOE:	C.H. Atkinson

OBJECTIVE

To evaluate the effectiveness of massive hydraulic fracturing for stimulating natural gas production from thick, deep sandstone reservoirs having extremely low permeability.



SUMMARY OF ACTIVITIES

Rio Blanco Natural Gas Company signed DOE contract EY-76-C-09-0677 in June, 1976. On October 22, 1976, the first MHF treatment was performed. A supplemental agreement effective October 1, 1977, provided for a second MHF treatment which was performed on November 30, 1977.

CURRENT STATUS

Due to persistant water production, gas flow continued to be restricted to a rate of 200 Mcfd. The well is currently shut in waiting on a sales outlet.

4.4.9 NEVADA TEST SITE
NYE COUNTY, NEVADA
MINEBACK TESTING

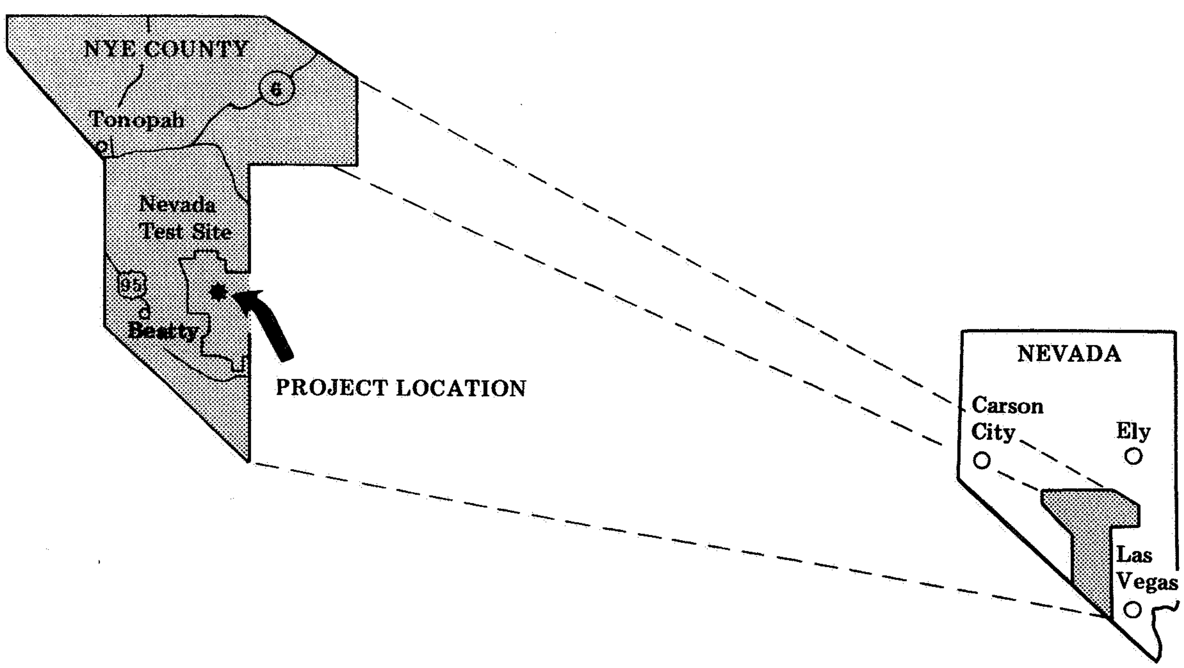
Sandia Laboratories
Albuquerque, New Mexico

Status: Active

Principal Investigator: D.A. Northrop

OBJECTIVE

To develop an understanding of the fracturing process for stimulation and thereby improve the production of natural gas from low-permeability reservoirs. This will be accomplished by conducting controlled fracture experiments which are accessible by mineback for direct observation and evaluation.



SUMMARY OF ACTIVITIES

The Formation Interface Fracture Experiment in Hole No. 6 is a field experiment conducted at the Nevada Test Site to determine the parameters that influence and control containment of hydraulic fractures. Grout-filled fractures were propagated above and below a welded tuff/ashfall tuff interface and subsequently mined back to examine the behavior of the fractures at the interface. It was found that the fracture that was initiated in the low modulus ashfall tuff propagated through the interface into the high modulus welded tuff. This suggests that present rock mechanics models, which predict that a bounding highly modulus material will contain a hydraulic fracture, are in error.

An exploratory coring program was undertaken to determine the general shape of the fractures. This shape should reflect upon the influence of the interface and the in situ stresses on overall fracture propagation and behavior. Figure 4-61 shows the results of this coring program to date with respect to Hole No. 6, the fracture intervals, and the subsequent mineback. Coreholes in which grout was located are shown as closed circles and the open circles indicate no grout. The four holes designated EV6-15 through EV6-18 are holes that were cored in January. The main thrust of fracture propagation is apparently downward, although the region above the welded zone has not yet been explored.

During February, analysis and modeling of rock and fluid mechanics continued. A rock mechanics/fracture mechanics model was extended to include a description of the orientation of the microcrack within a zone and the effects of an anisotropic in situ stress state. Preliminary studies of the fluid mechanics of the fracturing model showed that the system of equations did not readily converge. Photomicrographs of some microfractures from hydrofrac No. 6 were examined.

CURRENT STATUS

There was no further work on the Hole No. 6, experiment during March. Work has commenced on the Interface Test Series, a series of small hydrofractures that were conducted to test the effect of pump rate on the containment of a hydraulic fracture at a material property interface. Numerous zones in three different holes will be fractured at various flow rates.

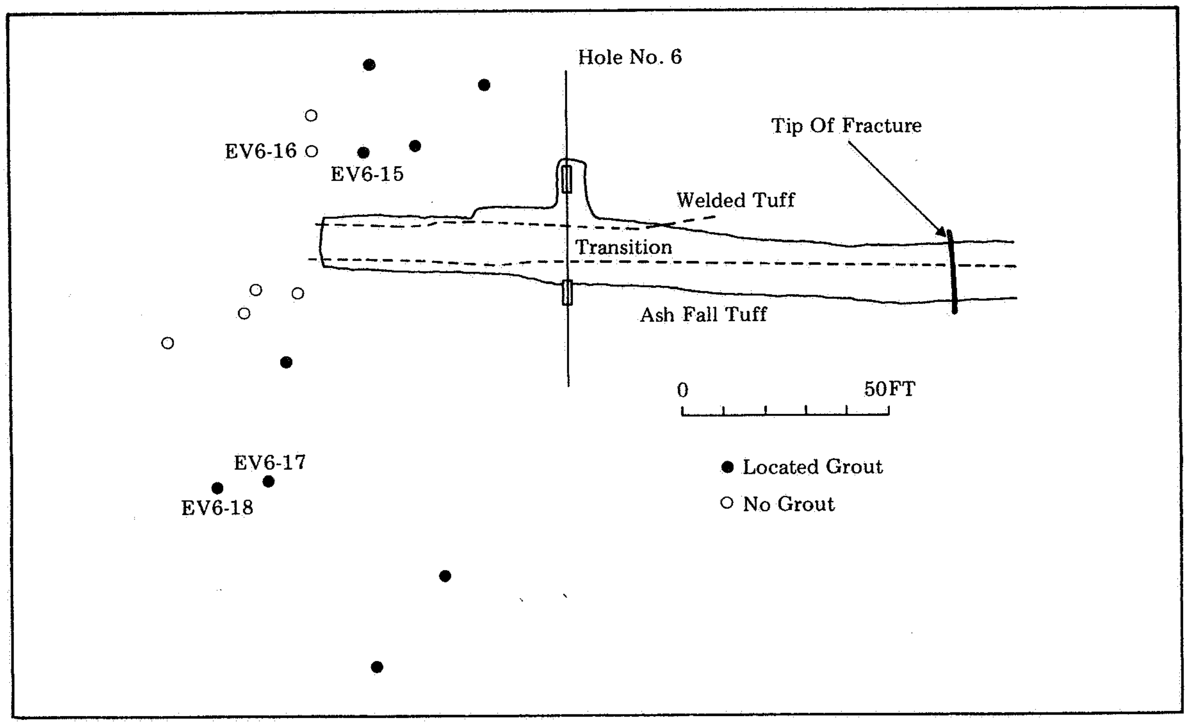


Figure 4-61. Results of Exploratory Coring

4.5 PROJECT MANAGEMENT

4.5.1 GENERAL

A WGSP Logging Program meeting was held October 24, 1978. Representatives from DOE-BETC/NV, DOE-BETC, DOE-NV, CER, Intercomp, Lawrence Livermore Laboratory, Mobil Research, Sandia Laboratories, and the USGS attended. The purpose of the meeting was to discuss the WGSP Logging Program document and to define the problems that exist with logs in tight gas sands. Also discussed was the need to identify which reservoir parameters require better definition, and whether logging problems should be approached with existing tools, improved existing tools, or with the development of new tools. The research laboratories identified areas for their research and delineated research tasks. These tasks were summarized in a revision to the WGSP Logging Program.

In addition to the ongoing coordination of project activities, the following project documentation was released or is in preparation:

- Western Gas Sands Project Status Reports for the months of October, November and December 1978, and January and February 1979 were completed and distributed.

- Progress reports for the months of February and March are in preparation.

- The fourth Quarterly Basin Activities Report for October, November, and December, 1978 was completed.

- The DOE Test Facility Operations Manual is in review.

4.5.2 PROJECT DATA BANK

Compiling of material for the WGSP Bibliography continued during the reporting period. Cognizance of industry activities in the basins of interest is maintained, not only for the purposes of obtaining relevant data and results, but also to identify potential industry partners for government/industry joint projects. Specific additions to the data bank include:

- Stratigraphy and correlation charts, and structure maps for areas within the Greater Green River Basin.

- A series of special reports on the sub-basins of the Greater Green River Basin for inclusion in the Quarterly Basin Activities Report.

- Proceedings of the Williston Basin Symposium.

- Pertinent stratigraphic and structural cross-sections, as well as a number of relevant papers.

- Topographic maps of Wyoming are being provided by the USGS, Denver, along with an east-west cross section of the Washakie Basin and an east-west cross section of the Green River Basin. Copies of several isolith and sand percentage maps for several Upper Cretaceous formations are also being provided by the USGS.

- A wildcat penetration map showing wells drilled into and through potentially gas-bearing, low-permeability Upper Cretaceous and Tertiary sands, Great Divide Basin, southwest Wyoming.

- Three structure maps of the Lance Formation and Almond Formation, a Rocky Mountain discovery map, 1978 and a preliminary geologic map of the Vernal 1° by 2° quadrangle, Colorado, Utah, and Wyoming.

A well data acquisition task was initiated which, for the western tight gas basins of interest, will compile the following types of information:

- Specification of producing horizons and reservoirs, gas flow before stimulation, gas production history after stimulation, and a detailed description of stimulation treatments for a significant fraction of wells in each basin.

- Current drilling, completion and stimulation costs.

This data base will be utilized in subsequent economic evaluations of stimulation methods applied to the western tight gas sands.

4.5.3 TECHNOLOGY TRANSFER

The Williston Basin Symposium was held September 24 - 27, 1978 in Billings, Montana. Papers were presented by industry, government and service companies from Canada and the United States. These papers included discussions of the geology and the problems associated with producing oil and gas from the Williston Basin. Most of the papers were centered around the Paleozoic carbonates, which make up the greatest percentage of Williston Basin production. Mr. D.D. Rice, USGS, Denver, presented a paper on the natural gas resources of the Northern Great Plains Province and Mr. G.W. Shurr, St. Cloud State University, St. Cloud, Minnesota, presented a paper on the potential gas occurrence of the Upper Cretaceous in western South Dakota.

The following technical papers relevant to the WGSP were presented at various symposia during the reporting period, were published or are in preparation.

"Density-Neutron Crossplot Analysis for Shaly Gas Sands Using Hand-Carried Calculators", Ching H. Wu, U.S. Geological Survey and Colorado School of Mines, and Jack Krug, Petro-Lewis Corporation

"Formation Evaluation and Gas Detection in Shallow, Low-Permeability Shaly Sands of the Northern Great Plains Province", Gerald C. Kukal, CER Corporation, to be presented at the SPE Symposium on Low-Permeability Gas Reservoirs, May 20-22, 1979, Denver Colorado

"Core Descriptions, Photographs and Core X-ray Analysis of Portions of the Upper Cretaceous Mesaverde Group, Washakie Basin, Wyoming", Theodore F. Tyler, USGS, Open File Report 78-708, 1978

"Influence of Diagenetic Reactions on Reservoir Properties of the Neslen, Farrer, and Tuscher Formations, Uinta Basin, Utah", C.W. Keighin, USGS, under preparation for presentation in Denver, Colorado, 1979 SPE Symposium

"Mineralogical Analysis of Drill Core Samples from Midlands Gas Corporation Wells - Federal 0370 No. 1 and 2962 No. 1, Phillips County, Montana", D.D. Rice, USGS

"Fracturing Fluid Rock Interaction of Cotton Valley Limestone Formation", U. Ahmed, L. Bucholdt, A.S. Abou-Sayed, Terra Tek

"Transient Pressure Analysis for Fractured Wells", Herber Cinco-L, Stanford University, and Fernando Samaniego-V., Instituto Mexicano del Petroleo, Members SPE-AIME, SPE 7490

"Detection Within the Wellbore of Seismic Signals Created by Hydraulic Fracturing", Carl Schuster, Sandia Laboratories, SPE 7448, presented at the 53rd Annual SPE Technical Conference

"An Overview of the Electrical Potential Method for Determining Fracture Orientation", Carl L. Schuster, Sandia Laboratories, presented at 1978 Annual ASCE Meeting

"High Energy Gas Frac", N.R. Warpinski, R.A. Schmidt, H.D. Walling, P.W. Cooper, and S.J. Finley, SAND 78-2342

"Preliminary Report of Authigenic, Euhedral, Tourmaline Crystals in a Productive Gas Reservoir of the Tiger Ridge Field, North-Central Montana", D.L. Gautier for the Journal of Sedimentary Petrology

"Bibliography of the Geology of the Green River Formation, Colorado, Utah, and Wyoming, to 1 March 1977", M.C. Mullens, U.S. Geological Survey, Circ.; No. 754, 1-52 (1977)

"Relation Between Facies and Low-Permeability (tight) Reservoirs in the Northern Great Plains", D.D. Rice and G.W. Shurr, USGS

"Continuity and Permeability Development in the Tight Gas Reservoirs", Eastern Uinta Basin, Utah", C.F. Knutson and C.R. Boardman, CK GeoEnergy Corp.

"Investigation of Hydraulic Fracturing Technology in Tight Gas Reservoirs", R.M. Forest and S.F. McKetta, Columbia Gas System Service Corp.

"Determination of the Optimum Massive Hydraulic Fracturing Design for the Stimulation of the Wasatch and the Mesaverde Formations", R.G. Merrill, Gas Producing Enterprises, Inc.

"Vast Potential Held by Four "Unconventional" Gas Resources", V.A. Kuuskraa, J.P. Brashear, T.M. Doscher, and L.E. Elkins, Lewin and Associates, Inc.

"Instrumentation for Formation Evaluation and Advanced Logging Techniques", C.L. Schuster and T.L. Dobecki, Sandia Laboratories

"Enhanced Gas Recovery Program", Third Annual Report, October 1977 through September 1978, SAND 79-0056

"Development of Shallow Gas Reserves in Low-Permeability Reservoirs of Late Cretaceous Age, Bowdoin Dome Area, North-Central Montana", by G.L. Nydegger and C.A. Brown of Kansas-Nebraska Natural Gas Company and D.D. Rice, USGS, prepared for presentation at the September 1979 SPE Symposium

"Bowdoin Dome Area, North-Central Montana - An Example of Shallow, Biogenic Gas Production from Low-Permeability Reservoirs", D.D. Rice, USGS, and G.L. Nydegger and C.A. Brown of Kansas-Nebraska Natural Gas Company

"Post-Depositional Control of Gas Reservoir Quality in the Eagle Sandstone of the Bearpaw Mountains, North-Central Montana", D.L. Bautier. The study provides a framework for comparing conventional reservoirs in the Bearpaw Mountains with low-permeability reservoirs to the east.

The following four papers were given at the Natural Gas Reservoirs Symposium held February 15-16, 1979 at Stanford University.

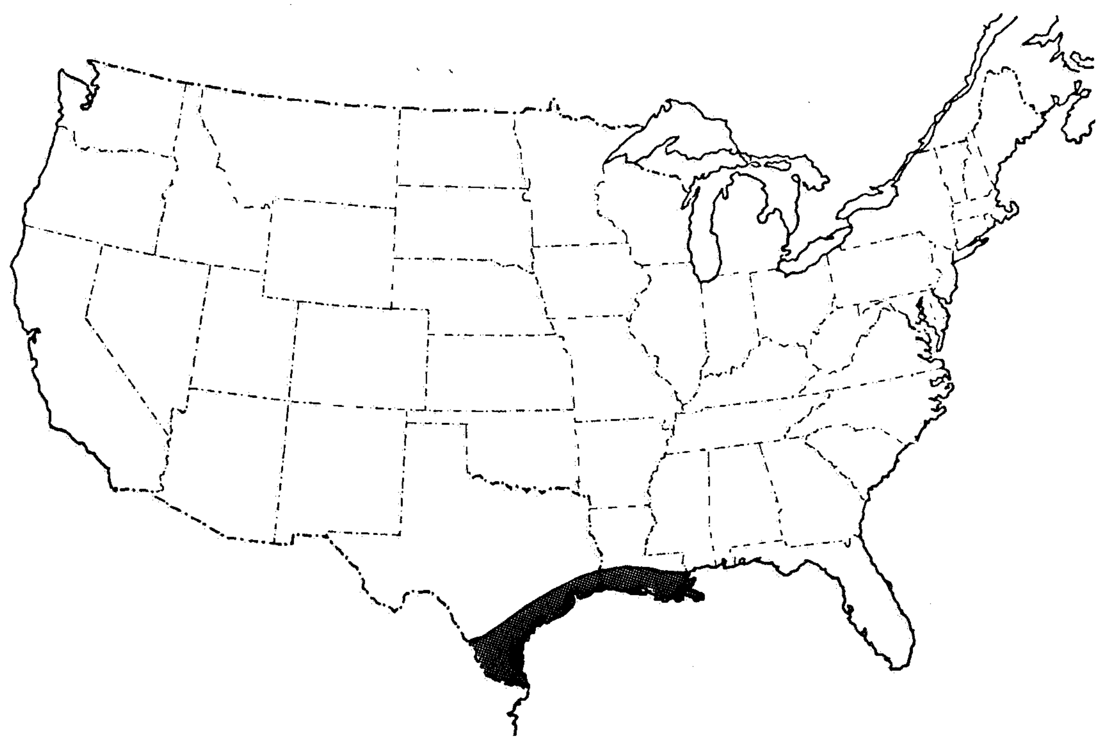
"Evaluation of Gas-Bearing Formations from Well Logs", Dr. Subir K. Sanyal, Petroleum Research Institute, Stanford University

"Conduct and Analysis of Well Tests for Determination of Gas Reservoir Parameters", Dr. R.C. McFarlane and D.J. Graue, Scientific Software Corporation

"Foamed Aqueous and Non-Aqueous Fluids for Effective Gas Reservoir Stimulation - An Update", D.L. Holcomb, Cardinal Chemical, Inc.

"Gas Potential of the Frontier Formation, Green River Basin - A Technological Frontier", J.R. Bergeson, Consultant, Bergeson and Associates.

5. METHANE RECOVERY FROM GEOPRESSURED AQUIFERS



5. METHANE RECOVERY FROM GEOPRESSURED AQUIFERS

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5.1 INTRODUCTION

5.1.1 BACKGROUND

Methane, the major constituent of natural gas, is slightly soluble in water at standard conditions; however, solubility increases rapidly with pressure and temperature (above 82°C). High-pressured subsurface zones (known as geopressured zones in the petroleum industry) containing water and its dissolved methane thus represent a potential resource base for natural gas. Geopressured zones are found in only a few coastal areas of the world. One of the largest of these zones underlies a large portion of the northern shoreline of the Gulf of Mexico, in a strip 200 to 300 miles wide slightly off the coast of Texas and Louisiana. Here, sedimentary deposits exhibit a maximum thickness of some 50,000 feet in some areas, with the upper 25,000 feet primarily composed of alternating series of rock layers which may be broadly classified as sandstones or shales, and the lower layers consisting almost entirely of shales, which are believed to be the origin of the methane in the geopressure formations.

Because of the many unknowns associated with this resource, quantitative estimates are difficult to make. This uncertainty is reflected in the current in-place-resource estimates which vary widely from a low of 984 trillion standard cubic feet (Tcf) to a high of 50,000 Tcf. Not enough is known at this time to estimate how much of this resource can be economically exploited. Since the geopressured aquifers contain water under high pressure and temperature, additional energy may be extracted in the form of useful heat and hydraulic energy.

The economics of natural gas production from geopressured aquifers depend on many factors, such as:

- The prevailing price for natural gas.
- The cost of drilling and equipping deep wells for production.
- The ability of these wells to produce large volumes (40,000 barrels per day) of water over a life time of at least 20 years.
- The absence of significant environmental impact, through proper mitigation, at such production levels.

Private industry has not investigated this potentially large resource so far because of the above uncertainties and, therefore, it is logical that the Federal government provide the initial effort to a point where such doubts are substantially removed for the private sector to take over further research and development.

5.1.2 METHANE FROM GEOPRESSURED AQUIFERS PROJECT

The Department of Energy (DOE), through its predecessor agencies, has been involved in geopressured aquifer research since 1974. Currently, this program is being carried out by DOE's Division of Geothermal Energy at the headquarters level with implementation of various projects being handled by the Geopressure Projects Office, Houston, and the Geothermal Branch, both of the Nevada Operations Office in Las Vegas, Nevada.

The goal of the program is to stimulate commercial development, by the private sector, of the geopressured-geothermal resource as an economical, reliable, safe, and environmentally acceptable energy source. In order to achieve this goal, DOE is evaluating production strategies for the recovery of methane from the shallower geopressured reservoirs and for "total energy recovery" (i.e., recovery of methane, production of electric power, and direct heat utilization) from the deeper, higher temperature reservoirs. Major program activities are aimed at improved understanding of the resource, including the confirmation of optimum reservoirs and the identification and resolution of key engineering, environmental, and institutional problems. If successful, the program will provide the information required by the industry to develop geopressured energy resources beginning in the mid-1980s.

To date, the DOE-R&D program has concentrated on resource characterization. These efforts have resulted in the identification of optimum prospects for reservoir confirmation drilling and testing. On the basis of these accomplishments, a long-term R&D strategy has been developed, in cooperation with industry and state and local government agencies, which is aimed at bringing geopressured-geothermal resources "on-line" in a planned and phased manner. This long-term program will cover the following five key areas, which are discussed in-depth in the rest of this section:

- Regional Planning
- Resource Definition
- Technology Development
- Environmental Control
- Facilities

REGIONAL PLANNING

Work in this area provides for the analysis of the economic, institutional, legal, and technological framework for geopressured-geothermal energy exploration, development, and utilization; and the identification and assessment of policy options and technical programs to encourage and expedite its development according to the intended schedule.

The major component of this effort is the regional operations research conducted by the Louisiana Department of Natural Resources and the University of Texas at Austin, in cooperation with appropriate organizations within the region; i.e., federal, state, and local government agencies; industries;

utilities; field developers; and public interest groups. These regional organizations are expected to play important roles in the identification of prospects for detailed evaluation.

This regional operations research program will be supplemented by other regional and national policy programs. On the regional level, DOE will work with cities, counties, and state governments, as well as the private sector to assess the legal and institutional barriers to the desired development objectives. On the national level, studies are directed toward determining the federal incentives which would most effectively accelerate commercial development of the resources. Incentives in the form of depletion allowances, investment tax credits, production tax credits, and price regulations have recently been enacted as part of the tax and price provisions of the National Energy Act.

RESOURCE DEFINITION

The work in this area is directed at resolving two major reservoir uncertainties; one, the number, location, characteristics, and producibility of individual geopressured aquifers; and, two, the amount of recoverable methane, a key factor in the economics of the utilization of geopressured resources. To this end, the assessment of all known onshore geopressured formations in Texas (Frio, Vicksburg, and Wilcox) and Louisiana (Miocene, Oligocene, and Tuscaloosa) will be conducted by the Texas Bureau of Economic Geology and Louisiana State University, respectively, in order to delineate optimum resource areas for reservoir confirmation drilling and testing. During the period 1979 to 1984, the reservoir confirmation program will consist of drilling and testing approximately five new wells a year specifically designed for long-term reservoir testing in the optimum resource areas delineated in the resource assessment studies. In addition, the program will include testing in up to five existing wells a year to obtain additional data on fluid and reservoir characteristics.

The reservoir confirmation program was initiated in 1977 with the recompletion and testing of the Edna Delcambre No. 1 well, an abandoned gas well in Vermilion Parish, Louisiana. Results of testing of two geopressured aquifers at 12,900 and 12,600 feet at rates up to 12,000 bbl a day indicated average gas production up to 80 standard cubic feet per barrel (scf/bbl), although recombined samples yielded solubilities of approximately 20 scf/bbl.

TECHNOLOGY DEVELOPMENT

Efforts in this area are directed toward reducing the cost of developing and using geopressured resources. Some research projects address critical problems that must be solved if exploitation of the resource is ever to support a significant industry. The technology development program is conducted under the following basic categories: direct heat utilization, well drilling and completion, geochemical engineering, advancing heat exchanger development, and advanced energy conversion systems.

Based on the results of the operations research and systems analysis work, which will identify energy markets in the region, a number of engineering and economic studies of nonelectric applications will be initiated. In addition, site-specific application studies will be conducted for those areas selected in the resource definition studies for confirmation drilling and testing. Nonelectric application experiments covering residential/commercial space heating and cooling, industrial processing, and agricultural uses will also be initiated to obtain site-specific and application-specific engineering and economic information.

The other technology development program categories include geopressured-specific, as well as broadly applicable (e.g., hydrothermal, hot dry rock) elements. The geopressured-specific elements address problems associated with high pressures, sand production, and fluid chemistry. Broadly applicable elements include, for example, development of high-temperature drill bits, more efficient and low-cost energy conversion systems, and materials research.

ENVIRONMENTAL CONTROL

The geopressured-geothermal environmental control program is conducted under two basic categories: one, programs associated with specific geopressured development sites or prospect-specific programs; and, two, programs aimed at resolving generic geopressured resource development concerns.

Prospect-Specific Programs

Four types of programs directly affecting the development of geopressured prospects or sites will be conducted in conjunction with well site selections resulting from the resource assessment studies. These programs include: regional baseline studies; environmental data collection and analyses associated with site selections; environmental impact analyses, including preparation of impact assessments and statements; and environmental monitoring.

Generic Programs

Environmental concerns associated with geopressured resources are similar to those identified with hydrothermal resources. These concerns include subsidence, induced seismicity, toxic gas release, well blowout, noise, and waste fluid disposal. The research and development activities will be directed to assess which of the concerns are justified and what, if any, mitigating procedures exist to minimize environmental impacts of full-scale development.

FACILITIES

Results of the reservoir definition studies, together with the information obtained from the operations research activities, will provide the necessary information to enable a decision on whether to proceed with the design and construction of pilot-scale or commercial-sized demonstration plant(s). If the conditions are favorable, it is anticipated that the pilot/demonstration plant(s) will be designed to produce and market electric power, separate the methane, and utilize the remaining heat in the geothermal fluids for direct heat applications. Specifically, the plant(s) will be designed to: demonstrate state-of-the-art technologies; obtain realistic cost data from which operating, maintenance, and production costs can be extrapolated with confidence; provide adequate instrumentation to obtain engineering data; and demonstrate reservoir deliverability and longevity. Efforts leading to the pilot/demonstration plant(s) will involve conceptual design, site evaluation, additional reservoir testing, and environmental studies and assessments.

5.2 RESOURCE ASSESSMENT

5.2.1 GENERAL

Current resource assessment activity is focused on the onshore portion of the Texas-Louisiana Gulf Coast. As a result of the high level of exploration and development effort related to oil and natural gas production, a large amount of information already exists concerning the subsurface geology of this area. Starting with this data base, a major effort is under way, principally at the University of Texas and the Louisiana State University, to prepare a regional assessment of the geopressured resources of the Gulf Coast.

5.2.2 TEXAS RESOURCE ASSESSMENT

Two units of the University of Texas at Austin, Bureau of Economic Geology (BEG) and Center for Energy Studies (CES), have performed most of the resource assessment work for the Texas Gulf Coast. The primary objectives of this assessment are to define the geopressure "fairways" in the Texas Gulf Coast and to delineate optimum areas which can be developed as test sites for long-duration testing. In the course of this study, well log information, geological data, well production information, and seismic survey results have been integrated to define geopressured fairways based on criteria such as minimum volume, temperature, pressure, porosity, and permeability. The primary areas of study have been in the Frio, Wilcox, and Vicksburg formations along the Gulf Coast.

Initial work resulted in choosing the optimum test well sites in Brazoria County, Texas (Section 5.4). Continuing work centers around high-resolution studies of other prospective sites in the Frio Fairway and using the same techniques in studying the Wilcox and Vicksburg fairways. To date, a total of five sites have been delineated in the Frio and four sites have been located on the Wilcox fairway.

In addition to the resource assessment, the following research is being carried out to define specific reservoir properties which will provide a major improvement in quantitative estimates of the resource in place:

COMPACTION MEASUREMENTS

The objective of this study is to determine the compaction mechanics of geopressured reservoirs. This information will help determine the drive mechanisms and reservoir physical properties that affect production and potential for subsidence. Existing core testing equipment is being modified and plans are to add capability for elevated temperature and long-term creep testing. Theories will be developed and validated for observed rock behavior. Data resulting from this research will be used for computer simulations of production performance and subsidence prediction.

To date, cores from the Brazoria County well have to be tested and preliminary results are available.

SANDSTONE CONSOLIDATION ANALYSIS

This work will identify factors controlling reservoir quality in Tertiary sandstones and will evaluate their significance to geopressured aquifer production. The research program is focused on the delineation of the origin of porosity with emphasis on secondary leached porosity; definition of the relationship between porosity, permeability, and mineralogy and to relate the effects of diagenetic mineralogy to acoustic log response; and delineation of the effects of concomitant shale diagenesis on cementation and leaching in adjacent sandstones. It is possible that these studies will lead to a predictive technique for determining reservoir quality.

To date, the sandstone consolidation sequences for the Frio, Vicksburg, and Wilcox formations have been documented.

FORMATION VELOCITY STUDIES

The objective of this project is to determine the elastic properties of normal-pressured and geopressured formations encountered in test wells. Compressional and shear wave data will be obtained from using Schlumberger long-spaced sonic log and Birdwell clamped geophones. Correlations with lithology and well logs will be made. Data obtained from this project will be used to determine permeability and porosity.

To date, the long-spaced sonic log has been run in the Brazoria County test well and the results are being analyzed.

5.2.3 LOUISIANA RESOURCE ASSESSMENT

As in the Texas studies, the objectives of this project are to define geopressured fairways and delineate optimum resource areas which can be developed for long-term testing. The analysis and interpretation of well log data, geologic information, and seismic surveys has resulted in list of 63 candidate areas. Further refinement has narrowed this list to ten sites of which five sites have been classified as primary sites for further investigation. The above work has been performed by the Louisiana State University (LSU).

The primary sites resulting from the above study (Atchafalaya Bay, LaFourche Crossing, Southeast Pecan Island, Johnson Bayou, and Rockefeller Refuge) will be further studied in detail to determine optimum well sites. This research will concentrate on:

- Analysis and interpretation of regional structural-stratigraphic framework of southern Louisiana;
- Detailed geologic and geophysical studies;
- Development and application of geophysical techniques, particularly seismic reflection and gravity, to resource prospect evaluation; and

- Geochemical studies of diagenetic changes in the prospect areas.

The remaining five sites will be investigated in a similar manner in the near future.

5.3 SUPPORTING RESEARCH

5.3.1 GENERAL

Resource assessment activities described in 5.2 will provide an estimate of the amount of gas-bearing water in place in geopressured aquifers. How much of this resource can be produced is influenced by many factors such as the amount of gas in solution, economics of production, environmental considerations, and legal and institutional barriers. To resolve some of these problems, research is being carried out in diverse areas affecting geopressured aquifer production.

5.3.2 AQUIFER FLUID CHARACTERIZATION

Three projects are underway which, when completed, will contribute significantly to the understanding of the nature of methane production from geopressured aquifers.

IDAHO STATE UNIVERSITY

One of the most important factors concerning geopressured aquifers that is not accurately known is the amount of methane that is contained in the water. This contract with Idaho State calls for a laboratory study to determine the solubility of methane in water at varying conditions of salinity, temperature, pressure, carbon dioxide, and higher hydrocarbon content.

Test runs are planned upon completion of assembly and testing of equipment. Projected upper limits for testing are 400°F. temperature, 20,000 psi pressure, and 250,000 ppm salinity.

UNIVERSITY OF SOUTHERN CALIFORNIA (DE-AS08-78ET11396)

The basic purpose of this laboratory study is to ascertain whether methane can be produced from geopressured aquifers at gas-water ratios which exceed the theoretical gas-water ratios in undisturbed aquifers. As fluid is withdrawn from an aquifer reservoir, pressure will decrease, resulting in liberation of gas from solution. If the gas saturation within the aquifer builds up fast enough, a point may be reached when the gas will be able to flow as free gas through the reservoir. In such a case, it may be possible to increase and accelerate the methane recovery from aquifers.

To accomplish this project, simulated geopressured aquifers will be constructed to represent consolidated (Berea Sandstone) and unconsolidated (graded loose sand) reservoirs. In-situ conditions will be created by using methane-saturated water and brine under high pressures. These "aquifers" will be produced and the rate of methane and brine production carefully monitored. The resulting data, including pressure and production history and fluids production, will indicate the nature of production, i.e., whether more gas is produced than the theoretical ratio.

Construction of the experimental facility is completed and production runs are planned for June 1979.

INSTITUTE OF GAS TECHNOLOGY (DE-AC08-78ET27086)

This contract will establish viscometer capability for measuring viscosity of geopressured fluids at in-situ temperature and pressure conditions. It is important to know the geopressured fluid viscosities so that the equations used to calculate reservoir porduction can provide more accurate solutions.

A capillary viscometer has been used successfully by IGT in the past to determine the viscosity of hydrocarbon mixtures. It can be upgraded to determine the viscosity of geopressured fluids up to the limit of 10,000 psi and 340°F. The refurbishing, upgrading, and calibration of this instrument will allow accurate determinations of brine viscosities and will indicate whether the dissolved gas under high temperature and pressure conditions has a significant effect on viscosity.

The viscometer upgrading has been completed and its calibration is expected to start in May 1979.

5.3.3 DATA PROCESSING

The data processing support is provided in three major categories: computer simulation of production and economics, interpretation of test data resulting from field activities, and creation of a data bank and information distribution.

INSTITUTE OF GAS TECHNOLOGY (DE-AC08-78ET27098)

The Institute of Gas Technology (IGT) will provide computer programs to determine production economic sensitivity to:

- relative permeability,
- cost of water disposed,
- reduction of permeability from production,
- changes in reservoir drive, and
- effect of two-phase flow.

The necessary peripheral equipment has been acquired and operational tests of computer programs are being run at present.

INTERCOMP, INC. (DE-AC08-78ET11395) AND IGT

Interpretation of field test data is very vital to the accurate definition of the resource. Data to be analyzed include:

- well logs;
- core analyses;
- drill stem tests;
- production and injection tests; and
- pressure build up, drawdown, and interference tests.

As field test data become available from the activities described in Section 5.4, both IGT and Intercomp, Inc., will perform the computer calculations and provide interpretations. In addition, Intercomp will simulate the reservoirs under production conditions to provide projections of long-term production potential. These simulations will be used to pin-point those reservoir parameters which exhibit the greatest influence on the production behavior of the aquifer. Parameters considered will include reservoir temperature, pressure, porosity, permeability, thickness, and areal extent. Also examined will be the variation of permeability with pressure.

UNIVERSITY OF TEXAS (DE-AC08-79ET27018)

This is a continuation of work previously funded under Contract No. EY-76-S-05-5243 and provides for the establishment of an automated information system containing available information in the geopressured aquifer research areas.

Known as the Geopressured Geothermal Information System (GGIS), the various tasks will include at least the following:

- A library of digitized well logs from known geopressured areas. Logs from geopressured wells will be digitized, processed, and interpreted to gain a regional and local understanding of the petrophysical and fluid properties of the reservoirs.
- Preparation and distribution of bibliographic information.
- Development and refinement of the thesaurus for use by researchers.
- Preparation and distribution of information on geopressured resources to users at cost.
- Quarterly newsletter preparation and distribution.
- Development of computer software for log analysis, file management, plotting, and automated data entry.

To date, approximately eight million curve-feet of data have been verified and stored in tape files. Most of these logs are of wells in the Brazoria Geopressured Fairway.

5.3.4 LEGAL, INSTITUTIONAL, AND OPERATIONS RESEARCH

Since geopressured aquifer methane production is a totally new and untried concept, many nontechnical factors that affect exploitation need to be identified and resolved. Legal issues such as definition, ownership, and leasing will directly impact on the future of the resource. To resolve such issues concurrently with technological development, several research projects have been funded to clearly identify the issues and propose possible solutions to alleviate any problems.

OPERATIONS RESEARCH

The overall objective of this work is to produce a recommended development plan for geopressured aquifer production. Currently, two projects are funded--one at the University of Texas (DE-AS08-78ET27087) and the other at Louisiana Department of Natural Resources (DE-FG08-78ET27085). Together, these two projects will cover the entire area of interest along the U.S. Gulf Coast. Detailed objectives for these projects are as follows:

- Characterize the resource: review and assemble existing data that describe the resource base.
- Identify impediments to geopressured energy development: environmental constraints, gas prices, resource ownership, field unitization, etc., will be analyzed.
- Preparation and analysis of development scenarios: information obtained from the above two tasks will be used to develop a time-oriented schedule for energy production. The likely effects of tax policies, production tax credits, gas prices, depletion, and intangible drilling allowances will be analyzed. Attention will be given to social and institutional factors that may affect development, such as expected employment levels and impacts on schools, roads, and other public services will be analyzed. Any action that is required by federal, state, and local governments to help development will be identified.
- Cost-benefit analysis for above development scenarios will be prepared.
- These scenarios will be reviewed with locally interested parties to aid in the promotion of regional planning efforts.

Currently, both of these projects are in the data-gathering stage.

In addition to the overall effort as described above, local studies will be carried out in areas recommended for testing. One such project is already under way in connection with the Brazoria County site (see Section 5.4). The Alvin Community College has been funded (DE-AS08-78ET27032) to establish an information network and data base for socioeconomic planning assistance in the county to educate the public, industry, and governmental entities in the geopressured aquifer development program.

LEGAL ISSUES

As already mentioned before, legal issues may create a possible hindrance to geopressured aquifer development. Under an ERDA contract (No. E(40-1)-5257), the Law School of Louisiana State University was asked to review this problem. The final report, covering the State of Louisiana, basically included the following tasks:

- Review the legal framework within which the geopressured resource will have to be developed and identify those problems which may be created by its development within that framework.
- Offer possible solutions to these problems or at least indicate techniques which might be considered in their resolution.
- Assemble a compendium of those statutory or regulatory provisions which may regulate or affect resource development.

5.3.5 ENVIRONMENTAL RESEARCH

Production of large quantities of fluids from geopressured aquifers has potential environmental impact on air, water, and land use. Preliminary investigations indicate that the areas of major concern are subsidence and water disposal. Impact on air quality and surface waters will be minimal. It is planned to prepare a generic impact assessment and site-specific environmental impact assessments for each test well.

OAK RIDGE NATIONAL LABORATORY (ORNL)

The ORNL is responsible for the preparation of generic and site-specific environmental assessment reports in support of the geopressured test well program. Both in-house expertise and subcontractors are used to accomplish this task. Current activity is as follows:

- Generic assessment completed for the wells of Opportunity Program (see Section 5.4) for the Frio formation.
- Work has been initiated on the generic assessment to cover the entire well test program.
- Site-specific assessments are under way for Southeast Pecan Island and Gladys McCall sites in Louisiana.

LOUISIANA GULF COAST STUDY

The Institute for Environmental Studies at Louisiana State University was contracted to environmentally qualify potential well sites in six areas of the Gulf Coast. The objective was to compare high priority prospect areas on the basis of potential environmental impacts. The assessment was made on the basis of the nature and extent of the proposed testing activities and how they affect land use, geology, air quality, water resources, ecological systems, and natural hazards. The following prospect areas were studied:

- South Johnson's Bayou
- Sweet Lake
- Rockefeller Refuge
- Southeast Pecan Island
- Atchafalaya Bay
- LaFourche Crossing

Final report (10/15/78) entitled "A Preliminary Environmental Assessment of Selected Geopressured-Geothermal Prospect Areas: Louisiana Gulf Coast Region--Volumes I and II," has been issued and the information from this report will be used as background data for future site-specific impact assessment reports.

TEXAS GULF COAST STUDY

Similar efforts are under way in Texas to environmentally qualify potential well sites for geopressured aquifer development.

- The Bureau of Economic Geology (BEG) at the University of Texas was contracted to study the geopressured fairway areas in Brazoria and Kenedy counties to study the following parameters:

  -active geologic processes,

  -current land use,

  -air and water quality base-line data, and

  -current flora and fauna.

- The final report is to be used in preparing environmental assessment reports for test well activity in these two counties.

- The Bureau of Economic Geology has started similar work for the areas overlying the Wilcox formation geopressured aquifer resources.

- Site-specific monitoring: The BEG is also conducting environmental studies at the DOE test well in Brazoria County, Texas (see Section 5.4). The objective of this program is twofold: to provide base-line environmental data and to continue monitoring during the testing phase. A number of surveys will be performed prior to, during, and after wells have produced large amounts of fluids. These include:

  -air quality monitoring,

  -water quality monitoring,

  -microseismic surveys,

  -leveling surveys,

  -disposal well monitoring, and

  -noise impact surveys.

The approximate data collection frequency is: air quality--daily, water quality--monthly, ground stability--semiannually, and microseismicity--continuously.

- The Lawrence Berkeley Laboratory (LBL) has been funded (a) to develop techniques for distinguishing naturally occurring subsidence from that which may be caused by fluid withdrawal from geothermal wells and (b) to develop techniques for operating geothermal fields in a manner that will prevent or minimize adverse effects due to subsidence.

  Five major areas will be covered by this research, namely:

  -characterization of subsidence,

  -physical theory of subsidence,

  -properties of materials,

  -simulation of subsidence, and

  -subsidence control.

  Most of the data generated from this study will be directly applicable to geopressured aquifer development.

- To provide first-order releveling of an area along the Texas Gulf Coast that contains potential geopressured resources, the National Geodetic Survey (NGS) has been funded to perform 3,200 km of vertical control releveling in East Texas. The first survey was completed in August 1978, and future surveys will be performed as needed.

5.4 FIELD TESTS AND DEMONSTRATIONS

5.4.1 GENERAL

The field testing program consists of both long- and short-term tests. The long-term tests under the Designed Well Program are based on resource assessment studies which identify optimum sites suitable for such testing. The estimated duration of these tests is two to three years during which all aspects of geopressured geothermal research will be investigated, including production testing, reservoir evaluation, and environmental impact evaluation.

In contrast, the short-term tests under the Wells of Opportunity Program are mainly designed for quick production tests and reservoir evaluation. Estimated duration of these projects is one to three months. The tests under this program are carried out on wells drilled by the industry that were found to be nonproductive, but they either penetrated a good geopressured aquifer (as indicated by local geology and well logs) or are in an area of known occurrence of geopressured aquifers which can be reached by deepening. Such well(s) will be acquired from the original operator for the express purpose of short-term tests and will be plugged and abandoned after the tests.

At the start of the Wells of Opportunity Program, it was difficult to locate appropriate wells for testing and it was decided to attempt reentry into plugged and abandoned wells located in promising areas. Because of the difficulties encountered in these operations, it seems unlikely that such reentries will be attempted in the future.

It is excpected that data obtained from both testing programs will allow a detailed characterization of the production potential of geopressured aquifers to be made and provide recommendations for optimum ways of exploiting this resource.

5.4.2 DESIGNED WELL PROGRAM

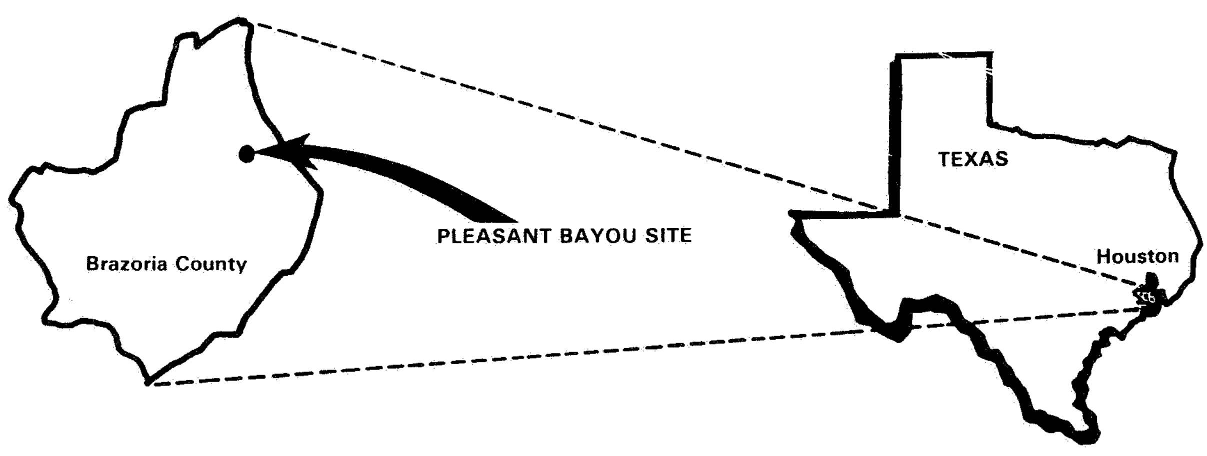
General Crude Oil Company
Houston, Texas

Status: Active

Contract:	DE-AC08-77ET28401
Contract Date:	November, 1977
Contract Completion Date:	October, 1980
Principal Investigator:	B.L. Draper (General Crude)
DOE Technical Project Officer:	J.K. Westhusing (Houston)

OBJECTIVE

To drill, complete, and test a well on a site in Brazoria County, Texas.



BACKGROUND

As a result of resource assessment studies performed by the Bureau of Economic Geology of the University of Texas, an optimum site was selected near Alvin, Texas. This site was chosen in accordance with the following criteria which define an "ideal" reservoir for commercial production:

- reservoir volume--at least three cubic miles
- fluid temperature--greater than 300°F
- minimum permeability--20 millidarcys
- water salinity--up to 80,000 ppm
- initial bottom hole pressure--greater than 10,000 psia
- production rate--20,000 to 40,000 barrels of water per day.

The test well is located on a five-acre site in Brazoria County (40 miles south of Houston) on the east bank of Chocolate Bayou on General Crude Oil Company's Martin Ranch property.

PROGRAM OBJECTIVES

The objectives of the well drilling and testing program are to determine the following parameters:

- Reservoir permeability, porosity, thickness, rock material properties, depth, temperature, and pressure
- Reservoir fluid content, specific gravity, resistivity, viscosity, and hydrocarbons in solutions
- Reservoir fluid production rates, pressure, temperature, production decline, and pressure decline
- Geopressured well and surface equipment design requirements for high-volume production and possible sand production
- Specific equipment design for surface operations, hydrocarbons distribution, and effluent disposal
- Possibilities of reservoir compaction and/or surface subsidence.

SUMMARY OF PROGRESS

Drilling was started on the GCO-DOE Pleasant Bayou No. 1 in July 1978. By November 1978, the well had reached 15,675 feet. A total of nine cores were taken and full suites of well logs were run. While attempting to take core No. 10, the core barrel stuck at 10,505 feet. All efforts to recover the drill pipe and resume drilling operations failed, and it was decided to plug this well and select a new location 500 feet away. This move was preferred over sidetracking because of the poor condition of 13 3/8-inch protection casing and the possibility of complications in reservoir testing due to influence of the existing hole. Pleasant Bayou No. 1 was plugged in January 1979. This well will be recompleted as an injection well upon completion of the new well.

The GCO-DOE Pleasant Bayou No. 2 was spudded 500 feet southeast of well No. 1 in January 1979. Drilling proceeded according to plan to 14,343 feet at which point it was decided to change the mud from water to an oil-based system. It was also decided to run 9 5/8-inch casing to avoid the problems encountered in well No. 1.

Currently, the well is drilling at 16,400 feet, the projected target being 16,500 feet. The well has been cased as follows:

20-inch casing at 1,395 feet--cemented to surface.

13 3/8-inch casing at 8,488 feet--cemented to surface.

9 5/8-inch casing at 14,284 feet-cement top at 13,800 ft.

It is planned to run a 7-inch liner to total depth. Upon completion, the well will be equipped with a 5 1/2-inch tubing string for flow testing. A sand interval below 16,000 feet will be perforated such that at least 5,000 md-feet of capacity can be obtained. Flow will be initiated and the rate increased in stages according to a preplanned schedule. Surface facilities will be installed for gas separation and fluid handling. A comprehensive testing program is planned which will take about two years to complete.

5.4.3 WELLS OF OPPORTUNITY PROGRAM

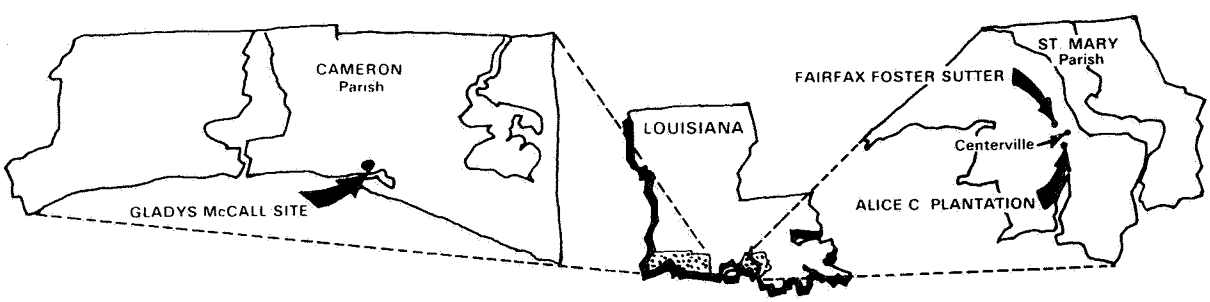
H. J. Gruy & Associates
Houston, Texas

Status: Active

Contract:	DE-AC08-77ET28460
Contract Date:	September, 1977
Contract Completion Date:	September, 1979
Principal Investigator:	R.J. Dobson (Gruy)
DOE Technical Project Officer:	J.K. Westhusing (Houston)

OBJECTIVE

Acquire, complete, and production test geopressured aquifer wells in the U.S. Gulf Coast.



BACKGROUND

Because of the unavailability of good candidate wells for this program, it was decided to attempt reentry into old, abandoned wells. Two such attempts were made without success. A brief account of each attempt is given below:

ALICE C. PLANTATION WELL NO. 2

The Alice C. Plantation No. 2 was selected as the first test well from among a number of reentry candidates. This well was originally drilled in 1964 to a total depth of 19,000 feet and was plugged and abandoned because it was nonproductive.

Drilling operations began in July 1978, and the well was cleaned out to a depth of 18,000 feet. While the drill pipe was being pulled out in preparation for running 7-inch casing, the well began to flow. Efforts to bring the flow under control were unsuccessful, however. The hole bridged over and the flow stopped. After installing proper equipment, the well was reentered, and it was found that the 9 5/8-inch casing had apparently collapsed beginning at the depth of 5,053 feet. At this point, it was concluded that it would be imprudent, both technically and financially, to continue operations and the well was plugged.

GLADYS MCCALL WELL NO. 1

This well was originally drilled in 1965 to a depth of 15,598 feet and subsequently plugged and abandoned as a dry hole. The well was selected for reentry since no adequate well of opportunity (i.e., the ones that were currently being drilled) was being offered by industry for testing.

The reentry and testing plan called for running a 7-inch tieback string, equipping the well with 3 1/2-inch tubing, and flow testing the geopressured sands. Operations began in October 1978. Upon reentry, it was found that the casing in the hole was badly damaged and the location and condition of tubulars were quite different from those anticipated, based on the plugging and abandonment records. After exhaustive and unsuccessful attempts at reentry at approximately 3,500 feet, it was decided to cease operations and to plug and abandon this well.

FAIRFAX FOSTER SUTTER WELL NO. 2

This is the first well of opportunity that was offered for testing right after the original operator determined it to be a dry hole. Plans call for running a 5 1/2-inch liner, 3 1/2-inch tubing, and production testing.

Operations began in March 1979, when a 5 1/2-inch liner was run to the total depth of 16,340. Production tubing was also run and surface equipment for testing installed. Initial tests through the separator indicated a flow rate of 5,078 barrels of water per day with a gas-water ratio of approximately 20.5 cubic feet per barrel. Testing will continue.

5.5 TECHNOLOGY TRANSFER

5.5.1 GENERAL

It is expected that the data from research described in the preceding sections will stimulate industry interest and result in participation by the private sector in the development of this resource. The DOE policy, from the very beginning, has been to involve the industry and the public in every stage of the research effort. There are two ways this is accomplished, namely through DOE/Industry Forum meetings and through large-scale symposia.

5.5.2 FORUM MEETINGS

These meetings are designed to bring together people doing research on geopressured aquifers and industrial participants who are interested in this resource development. Meetings are divided along the lines of interest in the following working subgroups:

- site selection
- drilling and testing
- environmental/lab research/legal
- technology overview

Meetings are held fairly regularly (one to three-month intervals) at which results of ongoing research are presented, usually by the principal investigators so that information can be exchanged on a first-hand basis. Active participation is continually sought from industry, government entities, and the public.

The first meeting was held in September 1977; and to-date, 19 such meetings have been held.

5.5.3 GEOPRESSURED-GEOTHERMAL SYMPOSIA

Three symposia have been held with the last one being in Lafayette, Louisiana, in November 1977. The fourth symposium is planned after the results from some of the field tests become available.

Results from ongoing or completed projects are presented formally at these symposia. The meetings are open to all interested parties and excellent participation has been obtained in the past. Proceedings are published after each symposium.

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