DOE/METC/SP-2

SEMI-ANNUAL REPORT FOR THE UNCONVENTIONAL GAS RECOVERY PROGRAM

Period Ending September 30, 1979

April 1980

United States Department of Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

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R. D. Manilla, Editor

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1. SUMMARY

This document is the third 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 Sands 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 the following paragraphs.

This report covers the period of April 1, 1979 through September 30, 1979.

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1.1 METHANE RECOVERY FROM COALBEDS

This section contains a summary of MRCP accomplishments during the six-month period April 1, 1979 through September 30, 1979, organized by the four major elements of the project. Significant activities and results discussed in previous reports are recorded and updated as appropriate.

RESOURCE ENGINEERING

Resource Engineering activities, a significant thrust of the MRCP during this period, focused primarily in the following areas:

- Implementation of the MRCP Resource Delineation Plan (RDP), to increase the amount of available site specific data, particularly from unmined coalbeds.
- Continued definition of a test program, to determine the feasibility of producing methane from unmined coalbeds.
- Initiation of studies, analyses, and other supporting activities.

Implementation of the RDP is currently organized to:

- Operate in a reconnaissance mode and use a basic 1,000 square mile sampling pattern within the areas of interest and as limited by availability of wells for sampling and testing.
- Operate first in those areas which are geologically best known and have the highest probability of early commercialization.

Portions of major coal basins were selected as the initial targets for resource delineation activities. These basins contain coalbed methane reservoirs of immediate interest to the MRCP. To investigate specific sites within the basins where desirable opportunities are presented, cooperative agreements or contracts for well drilling, coring, logging, gas flow tests, and coal sample analyses have been established with multiple private companies and several government agencies.

Detailed reports are being prepared for each of the basins (or other reservoir areas) of interest. Six basin reports scheduled for completion in CY 1979 are in preparation; initial drafts of two reports were complete by the end of this reporting period. These reports incorporate results of the individual well site investigations, redefine the project target areas where appropriate, and provide/update other basin information to guide on-going and future delineation activities.

Tabulated below is a summary of the delineation activities for twenty-three well sites located in eight basins where investigations are complete or on-going as of the end of the reporting period. The site, the cooperating company or agency, and gas desorption results to date are noted for each site. Gas-in-place and gas deliverability estimates are noted where available. Much of the information reported at this time is preliminary and the final results of long term tests and analyses (e.g., gas desorption from coal samples) are yet to be determined. Also, investigations of additional specific sites are needed to provide more complete knowledge of individual basins, and the coalbed methane resource as a whole, before reliable conclusions can be presented as to the true extent of the resource. Additional coalbed methane resource information, including detailed geologic features, is being incorporated in the basin reports. Preliminary information from basin report drafts now complete or in preparation is included in the basin summaries located at the beginning of Sections 2.2.9 through Section 2.2.16.

<u>Arkoma Basin</u> (Oklahoma and Arkansas)

- <u>Site AA in Pittsburg County, Oklahoma - Arkla Exploration Company</u>.

  - Gas desorption data indicate 73 to 210 cf/ton.

  - Reservoir simulation estimates indicate:
    Gas-in-place 1.4 Bcf/square mile
    10 year gas deliverability* 3,500-40,000 Mcf/well

- <u>Site AB in Pittsburg County, Oklahoma - Mustang Production Company</u>.

  - Gas desorption data indicate 163 cf/ton (Stimulation is planned).

- <u>Site AC in Haskell County, Oklahoma - Mustang Production Company</u>.

  - Gas desorption data are undergoing evaluation.

- <u>Site AD in LeFlore County, Oklahoma - U. S. Bureau of Reclamation</u>.

  - Gas desorption data indicate 160 cf/ton.

<u>Green River Basin</u> (Wyoming and Colorado)

- <u>Site AA, location and cooperator are confidential.</u>

  - Sidewall core gas desorption data indicate 132 to 210 cf/ton.

  - Conventional core gas desorption data indicate 62 to 340 cf/ton.

  - Reservoir simulation estimates indicate:
    Gas-in-place 1.8 to 4.0 Bcf/square mile
    10 year gas deliverability* 16,000-40,000 Mcf/well

* The reservoir gas deliverability estimate is for a cumulative discounted ten year deliverability, Ø, as discussed in Section 2.2.3.

- Site AB in Sublette County, Wyoming - Belco Petroleum Company.

  - Sidewall core gas desorption data indicate 214 to 35 cf/ton.

  - Conventional core gas desorption data indicate 384 to 480 cf/ton.

  - Reservoir simulation esimates indicate:

Gas-in-place	6.1 Bcf/square mile
10 year gas deliverability*	25,000-90,000 Mcf/well

Upper Cretaceous Mesaverde group coal from one well in this basin yielded 420 to 524 cubic feet of methane per ton of coal. These values are very high.

Illinois Basin (Illinois, Indiana, and Western Kentucky)

- Site AA in Clay County, Illinois - Hagen Oil Company

  - Sidewall core gas desorption data indicate 28 cf/ton in the Danville No. 7 seam only.

  - Conventional core gas desorption data indicate 32 to 48 cf/ton.

  - Reservoir simulation estimates indicate:

Gas-in-place	200 MMcf/square mile
10 year gas deliverability*	1,000-2,000 Mcf/well

- Site AB in Marion County, Illinois - Geowest, Inc.

  - Gas desorption data indicate 13 to 29 cf/ton.

Northern Appalachian Basin (Pennsylvania, Ohio, and West Virginia)

- Site AA in Greene County, Pennsylvania - Kinloch Development Company.

  - Gas desorption data indicate 33 to 425 cf/ton.

- Site AB in Greene County, Pennsylvania - Waynesburg College.

  - Field activity is scheduled for last quarter 1979.

Piceance Basin (Colorado)

- Site AA in Rio Blanco County, Colorado - Fuel Resource Development Company.

  - Gas desorption data indicate 18 to 80 cf/ton.

* The reservoir gas deliverability estimate is for a cumulative discounted ten year deliverability, Ø, as discussed in Section 2.2.3.

- Site AB in Rio Blanco County, Colorado - Twin Arrow Drilling Company.

  - Dry hole.

- Site AC in Rio Blanco County, Colorado - Twin Arrow Drilling Company.

  - Gas desorption data indicate 108 to 339 cf/ton.

  - Reservoir simulation estimates indicate:

Gas-in-place	157 MMcf/square mile
10 year gas deliverability*	Zero (no gas flow in Site AB test)

- Site AD, location and cooperator are confidential.

  - Gas desorption data indicate 41 to 49 cf/ton.

- Site AE, location and cooperator are confidential.

  - Gas desorption data indicate 25 to 62 cf/ton.

- Site AF, location and cooperator are confidential.

  - Gas desorption data indicate < 1 to 4 cf/ton.

- Site AG, location and cooperator are confidential.

  - Gas desorption data indicate <1 to 19 cf/ton.

- Site AH in Rio Blanco County, Colorado - Fuel Resources Development Company.

  - Gas desorption data indicate 7 to 16 cf/ton.

Powder River Basin (Wyoming and Montana)

- Site AA in Powder River County, Montana - United States Geological Survey.

  - Gas desorption is in process.

* The reservoir gas deliverability estimate is for a cumulative discounted ten year deliverability, $\emptyset$, as discussed in Section 2.2.3.

- Site AB in Big Horn County, Montana - Montana Bureau of Mines and Geology.

  - Gas desorption is in process.

- Site AC in Big Horn County, Montana - Montana Bureau of Mines and Geology.

  - Gas desorption is in process.

San Juan Basin (Colorado and New Mexico)

- Site AA in San Juan County, New Mexico - Western Coal Company.

  - Gas desorption data indicate 16 to 73 cf/ton.

Southern Appalachian/Warrior Basin (Alabama and Mississippi)

- Site AA in Fayette County, Alabama - Grace Petroleum Corporation.

  - Analysis of results are in progress.

RESEARCH AND DEVELOPMENT

As of the end of the reporting period, five R&D projects were in progress:

- Development and test of a downhole turbodrill motor for use in directional drilling applications in the extraction of methane from coalbeds - Maurer Engineering Contract DE-AC21-78MC08380.

  - Performance testing of the 5-3/8 inch turbodrill at TerraTek was completed in April 1979. Penetration rates of 30 to 50 feet per hour were achieved in granite.

  - Preliminary field testing of the 7-7/8 inch turbodrill was conducted at the Los Alamos Hot Dry Rock site in June and July 1979. Penetration rates of 20 feet per hour and above were observed. A prototype tachometer for use in subsequent tests was successfully tested.

  - Although drilling performance is generally acceptable, there has been a number of bearing/seal problems.

- Evaluation of the feasibility of explosive fracturing of coal to increase permeability - Physics International Contract DE-AC21-79MC10642.

  - Work was initiated in April 1979. Test equipment was identified, designed, and modified/fabricated. Coal samples were prepared.

- Permeability measurements were obtained for six coal samples using nitrogen gas and water.

- Investigation of water jet drilling for methane drainage - Sandia Laboratories Contract MR-11098.

  - Work was initiated in March 1979. A need was identified for the development of improved water jet drilling head design (University of Missouri-Rolla subcontract) and a sensor to keep the drill within the coal seam.

  - A significant advance was made in the design of the device used to rotate the water jet drilling head assembly 90 degrees while downhole and to then advance it horizontally into the coal seam.

- Study of the fracture mechanics of coal - West Virginia University Contract DE-AT21-79MC11284.

  - Work began in June 1979. Initial activities have included design and fabrication of experiment apparatus and preliminary tests of coal specimens (10 fracture toughness tests and about 15 tension tests).

- Determination of the effectiveness of carbon dioxide (CO_2) to increase methane production from coal - University of Pittsburgh Contract DE-FG-21-79MC10831.

  - Redesign and calibration of experiment equipment was completed early in the reporting period.

  - Two experiment tests have been conducted: (1) a dry coal sample was evacuated, pressurized in a methane environment to adsorb the equivalent of 53 cf of gas per ton of coal, pressurized in water for 5 weeks, exposed to atmospheric pressure, and observed until methane production ceased. CO_2 was then injected and 53% additional methane production was observed; (2) a coal sample stored under water since mining 8 months previously was injected with CO_2 (in situ gas only - no methane added) and methane production equivalent to 8.2 cf per ton of coal occurred in the first 5 days. In 15 days gas composition was 62% methane and 26% CO_2 (12% N_2).

TECHNOLOGY TESTS

Eight technology tests were in process at the close of the reporting period:

- Utilization of coalbed methane for on-site turbine power generation, Cambria County, Pennsylvania - Westinghouse Contract DE-AC21-77MC0809

  - A gob gas well was lost because of shutdown for a mine fire, and a methane predrainage well did not produce sufficient gas to support operation of the turbine.

  - The project site is being moved to Bethlehem Mariana No. 58 Mine in Greene County, Pennsylvania.

- Methane extraction and use for process heat generation (steam, hot water, space heating, and possibly fuel cell applications), Westmoreland County, Pennsylvania - Westinghouse Contract DE-AC21-78MC08332.

  - Three additional wells were drilled to further define methane content and to establish the production potential before proceeding into a final production demonstration phase.

- Demonstration of methane production from deep coal seams, Carbon County, Utah - Mountain Fuel Supply Company Contract DE-AC21-78MC10734.

  - Phases I and II were completed and Phase III was initiated in September 1979.

  - Well site plans for three wells were completed, and USGS and State of Utah approvals to drill were received for the Whitmore Park Wells No. 1 and 2. The USGS denied the application for Well No. 3 because of questions concerning gas ownership and coal "minability". The application was resubmitted in September without hydraulic stimulation.

  - Detailed environmental assessments were completed, and surface and subsurface protection plans were filed with the USGS.

  - Drill sites and access roads for the Whitmore Park Wells No. 1 and 2 were completed and final preparations were ready as of the end of the reporting period. A drilling rig is expected on site in October.

- Methane extraction techniques and production test, Rio Blanco County, Colorado - Intercomp/COSEKA Contract DE-AC21-78MC08384.

  - Activity was resumed in April (after a winter shut in period) with dewatering, pressure measurements, and gas flow test activities.

- A total of 680 Mcf of gas and 640 barrels of water were measured during a 75 day production test. Additional wells are planned; however, there are questions concerning gas ownership and coal "minability".

- Long horizontal boreholes from within an active mine, Buchanan County, Virginia - Occidental Research Corporation/Island Creek Coal Company Contract DE-AC21-78MC08089.

  - An in mine Acker "Big John" horizontal drill was placed in operation and several short (less than 500 feet) boreholes were drilled in shakedown activities prior to entering the cost-sharing agreement in April.

  - A 500 foot horizontal borehole drilled into coal not being mined produced 200 cf of gas per ton of coal per foot of hole length.

  - Two long boreholes, 1550 and 1730 feet, were drilled; the first in the face cleat direction, the second essentially perpendicular to the face cleat. Drilling of both holes was stopped short of a planned 2000 feet because of the large amounts of methane and high pressures encountered.

- Multiple completion development test, Greene County, Pennsylvania - Waynesburg College Contract DE-21AC-79MC08089.

  - Multiple completion of a single well is planned to extract methane from coal seams underlying an urban developed area. The produced gas will be used for local heating.

  - Drilling plans and an environmental assessment have been completed and the well is expected to be drilled during the last quarter of 1979.

- Anthracite coal drainage using multiple stimulated wells, Luzerne County, Pennsylvania - Pennsylvania Energy Resources Inc. (PERI) Contract DE-AC21-78MC08089.

  - PERI prepared a conceptual design, obtained gas rights, selected sites for four wells, and obtained coal samples in conjunction with preparation of the project proposal.

  - Detailed design and an environmental assessment were started; however, the project has been deferred because of funding limitations.

- Multiple vertical borehole degasification test project, Jefferson County, Alabama - U. S. Steel Corporation Contract ET-75-C-01-9027.

  - In March and April 1979, the total gas production from the active methane predrainage wells in a 21 well grid reached 1.2 Mcfd. By August 1979, production had dropped to approximately 1 Mcfd because of multiple dewatering problems.

  - Although well maintenance and repair activities have been extensive, total gas production remains high and the methane content averages more than 96 percent. No sulfur has been found and the heating value of the gas is greater than 970 Btu/cf.

- Directional Drilling Degasification Test Project, Greene County Pennsylvania - J & L Emerald Mine Corporation Contract ET-77-C-01-8891.

  - A directional borehole was drilled from the surface to intercept the Pittsburgh coal seam horizontally. From this single vertical entry, four horizontal boreholes have been drilled into the coal seam for a total length of 8837 feet. The horizontal boreholes fan out from the bottom of the directional borehole in a "birdfoot" pattern.

  - An array of seven vertical boreholes were drilled in the same area to provide for dewatering and monitoring of subsurface conditions. Other horizontal boreholes are planned.

- Vertical Drilling Jawbone Coalbed Degasification Test Project, Dickenson County, Virginia - Clinchfield Coal Company Contract ET-77-C-01-9151.

  - A vertical degasification well drilled and stimulated in May, 1978, has continued to produce gas. During this reporting period, production increased to 26 Mcfd from a low of 23 Mcfd in July as mining operations advanced to approximately 550 feet of the well. Total cumulative gas production approaches 6 MMcf. Other wells are planned.

PROJECT INTEGRATION

The Resource Engineering, Research and Development, and Technology Test activities summarized above were coordinated, and the MRCP Project Plan Document (PPD) draft was updated for FY 1980.

A Methane Recovery from Coalbeds symposium was held in Pittsburgh, Pennsylvania on April 18, 19, and 20, 1979. The sumposium was sponsored by the U. S. DOE Morgantown Energy Technology Center and featured 17 technical papers. The symposium proceedings are being published separately as a METC special publication.

1.2 EASTERN GAS SHALES

The following is a summary of significant EGSP accomplishments from April 1, 1979 through September 30, 1979.

RESOURCE CHARACTERIZATION AND INVENTORY

Six Devonian Shale wells were cored and logged during this reporting period, and one well was being drilled at the end of the period. Details of these wells are given in Table 1-1. Figure 1-1 shows the location of all EGSP core wells to date. Another six cores are planned to be taken during the next reporting period.

Table 1-1 Summary of Coring & Logging Activities During Second Half of FY79

DATE	CONTRACTOR	EGSP WELL NO.	COUNTY STATE	TARGET FORMATION	DATA COLLECTED	SHALE CORE LENGTH (ft.)
4/79	Thurlow Weed & Assoc.	OH #3	Knox, OH	Devonian Shale	Core/Log (W&D)	694
8/79	Mound	OH #4	Ashtabula, OH	Devonian Shale	Core/Log (W&D)	440*
9/79	Columbia Gas Corp.	OH #5	Lorain, OH	Devonian Shale	Core/Log (W&D)	875
9/79	Mound	PA #3	Erie, PA	Devonian Shale	Core/Log (W&D)	130**
9/79	Mitchell Energy Corp.	OH #6-1	Gallia, OH	Devonian Shale	Core/Log (W&D)	180
9/79	Columbia Gas Corp.	OH #7	Trumbull, OH	Devonian Shale	Core/Log (W&D)	524***
9/79	Gruy Federal	ILL #5	Wayne, IL	Devonian Shale	****	****
						2843 Total

(W) Wet-log suite

(D) Dry-log suite

* includes 20 ft. of pressurized core

** includes 10 ft. of pressurized core and coring operation is continuing

*** coring operation continuing

**** drilling operation in progress

The cores noted above include two pressurized cores. Study of these has shown that shale gas contents based on the normal method of testing canned samples contain only 40% of the content obtained with pressurized cores. The controlled off-gassing method, using non-pressurized cores but producing a series of readings of gas pressure versus time, provides 70% of the values obtained from pressurized cores. These precentages are preliminary and subject to revision as more pressurized core analyses are completed.

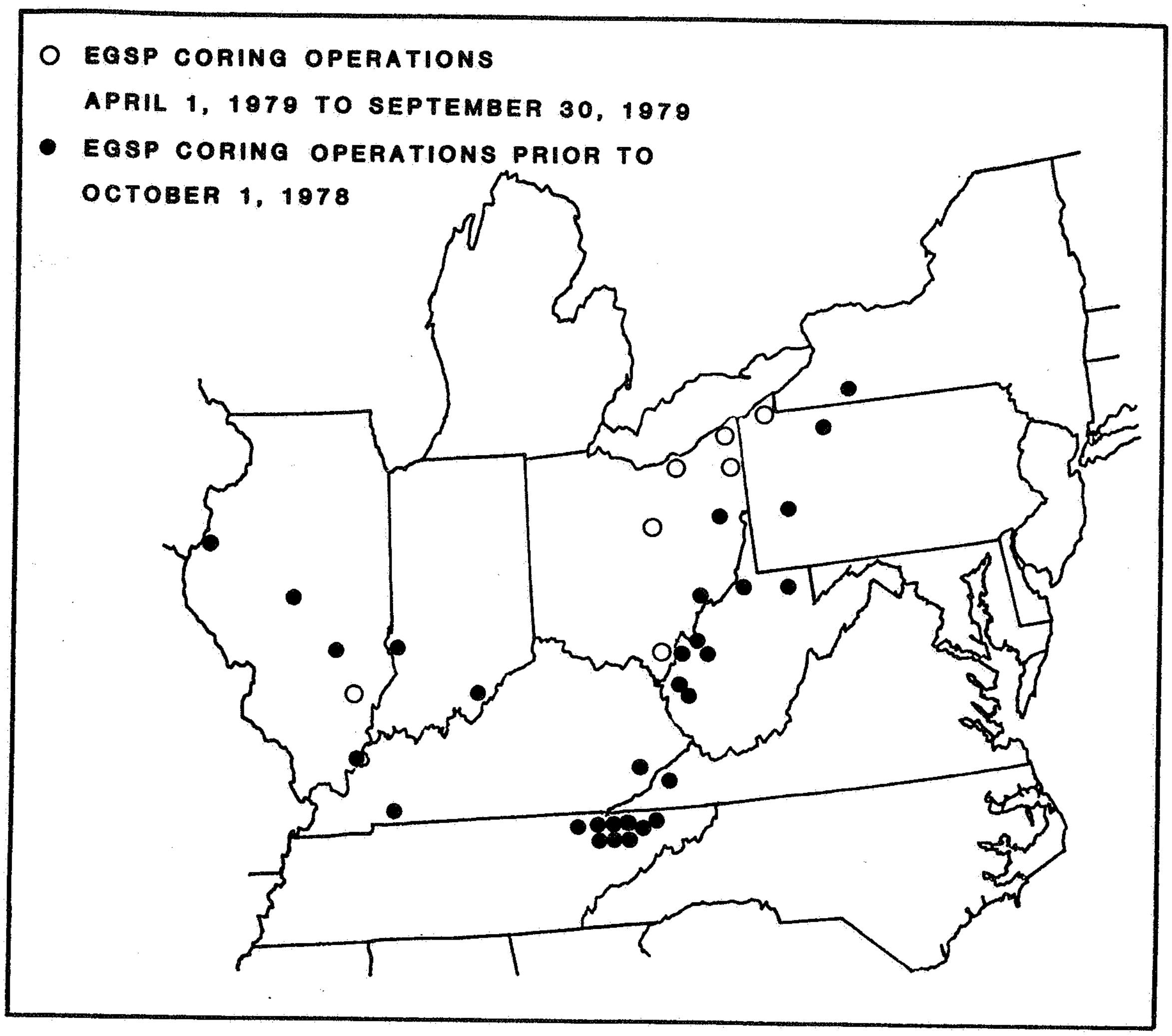


Figure 1-1 EGSP Core Wells

Equipment for obtaining high pressure adsorption isotherms has now been calibrated, and isotherm data have been generated. Some of these data have already been used for reservoir modeling and resource assessment.

Subsurface information from the Tennessee Geological Survey study has been used to site an exploratory shale well in the Greendale Syncline of eastern Tennessee to test an exploration rationale that relates fractures to thin-skinned tectonic deformation. This well will be drilled in 1980.

Preliminary results indicate that gas production in the Eastern Kentucky Gas Fields is related to preferential fracture directions, possibly due to tensional stresses associated with folding and thrust faulting in the basement rocks.

A study of off-gassing produced by the EGSP showed that the difference in gas content of the same stratigraphic horizon between well sites appears to be controlled by the thermal maturity of the shale. Thermal maturity in the Appalachian Basin is determined by basin position and proximity to structure features.

EXTRACTION TECHNOLOGY R&D

Seven new contracts for experimental and theoretical research into fracture mechanics were signed late in the reporting period. Laboratory studies to date with very lightly coupled charges have shown that borehole pressurization rate plays a very important role in fracture propagation.

In situ stress has been previously identified as one of the important parameters in selection of stimulation treatments in Devonian Shale. A review of commercially available components has shown that all the components required for the fabrication of a reliable wireline *in situ* stress measuring tool are currently available. The detailed design of the tool is currently underway.

A preliminary review of a field test program in explosive fracturing technology indicated that the displaced explosive method or some modification to it might yield attractive stimulation effects. Nearly all of the problems associated with the application of the displaced explosive approach can be related to engineering implementation difficulties rather than to basic inadequacies of the concept.

Reservoir modeling by several contractors has indicated that early performance of shale reservoirs is dominated by fracture system parameters (primarily permeability) while later performance is primarily controlled by shale matrix and desorption parameters. The question as to whether the contribution of the shale matrix to gas production is significant in the time-scale of typical wells (30 years) has not yet been answered.

TECHNOLOGY TESTING AND VERIFICATION

Contracts are in progress to test two exploration rationales, one based on seismic velocity analysis, and one on reconstruction of structure at the time of deposition. Sites have been selected for seven wells, two to test the first rationale, and five for the second. Only one well has so far been drilled, and the results of this have not yet been analyzed.

Three stimulation treatments were performed during the period, two with foam and one cryogenic treatment. The results of these are being evaluated. Two wells have been drilled and one is currently being drilled on a ten well contract to test various stimulation treatments in Lorain and Trumbull Counties, Ohio. None of the wells have yet been stimulated.

In addition to the above, another six wells are scheduled for stimulation during the next reporting period under three contracts. Five of the wells are in Ohio, and one is to be in West Virginia. Location of the field test projects are shown in Figure 1-2.

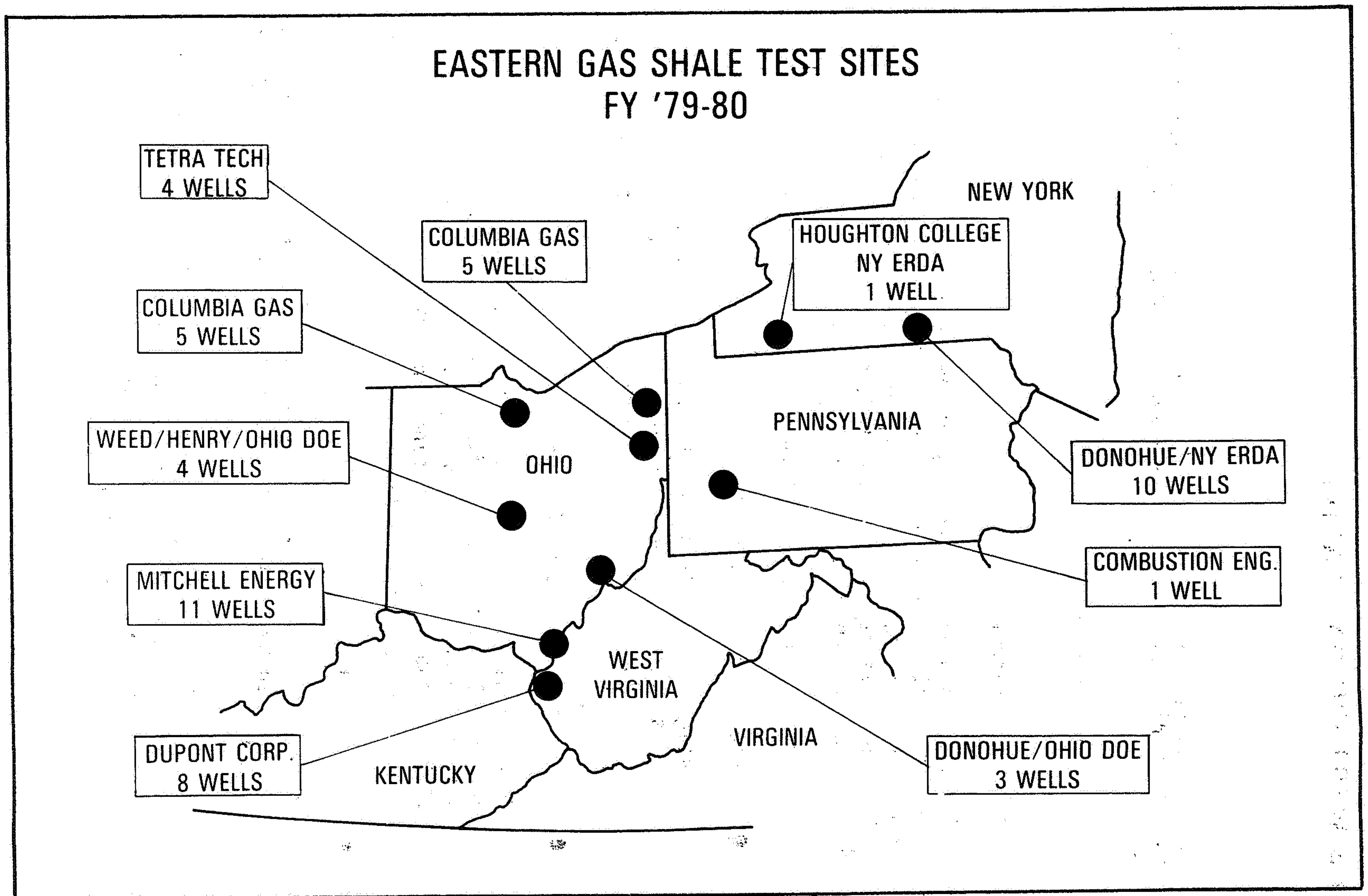


Figure 1-2 EGSP Field Projects

1.3 WESTERN GAS SANDS

The following is a brief summary of significant WGSP accomplishments during the period April 1, 1979 through September 30, 1979.

1.3.1 Resource Assessment

U.S. Geological Survey

The USGS is performing the majority of the geological, geophysical and reservoir evaluation studies necessary to define and characterize the resource base. During this reporting period, 12 reports were released and 3 drafted. Two maps were completed, 5 papers drafted, 8 finalized and 4 presentations were made to professional organizations.

USGS activities in the areas of interest are as follows:

- Greater Green River Basin

  Stratigraphic analysis of the Greater Green River Basin continued. Cross section maps were completed for the Greater Green River and the Sand Wash Basins. Cores were described and sampled from the Washakie Basin.

- Northern Great Plains Province

  Petrographic analysis of Eagle Sand equivalent rocks from the Joseph J.C. Paine/DOE cored well was completed. Petrographic and scanning electron microscope analyses of the Mesa Petroleum core of Eagle equivalent shelf sandstone from Liscomb Creek field, Custer County, was initiated.

- Piceance Basin - Uinta Basin

  Analyses of Cretaceous and Paleocene cores from the Price River Canyon area by x-ray diffraction and petrographic methods were compiled.

  Preliminary mineralogical investigation of CIGE Natural Buttes No. 21 core samples from the Green River, Wasatch-Colton, Tusher-Farrer and Sego Formations and the Mancos Shale continued. Green River Formation cores from the Pariette Bench field were described and sampled. A petrographic study of selected Cretaceous core samples from the Uinta Basin is near completion. Additional cores of Lower Tertiary hydrocarbon bearing rocks from the south-central Uinta Basin were examined.

Core Program

Many companies were contacted concerning the participation in the WGSP coring program. Several are considering the proposal and some have expressed interest in coring future wells. A 6-1/2 in. diameter core hole is being drilled by CK GeoEnergy through about 1,200 ft of the non-marine Mesaverde Group in the Westwater Canyon area of the Book Cliffs in eastern Utah. Sandia Laboratories, DOE and GRI are fielding a three-dimensional geophysical survey around this well in an attempt to define lens sizes and orientations by geophysical means.

Coring operations began on the Pacific Transmission Supply Company No. 22-12 Federal Barcus Creek well. Selected core samples will be sealed and sent to Bartlesville Energy Technology Center, Los Alamos Scientific Laboratory and Lawrence Livermore Laboratory for analyses.

Survey of Basin Activities

The monitoring of basin activities is an important part of resource assessment and promotes cooperation between industry and government. Active operators are located in areas recommended by the USGS for core acquisition by monitoring new activity in each area. A six-month summary of drilling activity is shown in Table 4-3.

Table 4-3. Summary of Drilling Activities From April to September 1979

Area of Interest	Wells					Production (MCFD)
	Wildcat		Development		Total	
	D&A	Discovery	D&A	Producer		
Northern Great Plains Province	29	10	30	82	151	36,741
Greater Green River Basin	13	13	11	61	98	99,338
Piceance Creek Basin	4	7	2	40	53	29,428
Uinta Basin	3	9	2	29	43	54,104
Totals	49	39	45	212	345	221,611

1.3.2 Research and Development by Energy Technology Centers and National Laboratories

Bartlesville Energy Technology Center

Room temperature static invasion tests were conducted on various particle size distribution polymer muds. Design work for the dynamic test apparatus which will allow testing of coring fluids under simulated drilling conditions was completed. Two freeze tests were completed to determine the low temperature properties of the polymer coring fluid. These tests showed that highly viscous HEC polymer muds did not freeze until about -60°F and that they could easily be scraped off a frozen core at -50°F. Compressibility/air entrainment testing was completed, and showed that air entrainment can be a serious problem.

Design and fabrication of 2-1/2 in., 3 in. and 6-1/2 in. pilot core bit bodies were completed. A laboratory test of a 3 in. pilot bit was run using low invasion mud for chip removal and cooling. The mud was extruded by the core entering the drill tube similar to that anticipated in the pressure core barrel assembly. Mud compressibility due to entrained air caused the barrel to plug from lack of mud flow across the cutter faces. In a field experiment, two coring runs were made with 100 percent core recovery. The first core was in perfect condition and completely encapsulated in the low invasion fluid. The second core was frozen in dry ice and shipped for analyses.

Selected core samples from the CIGE Natural Buttes Unit No. 21 and Mobil PCU F31-13G wells were analyzed for mineral and clay composition by x-ray diffraction. They were also analyzed for surface areas but the measured areas were affected by sample out-gassing temperatures.

A model of fracture propagation is being developed and remaining tasks include using realistic parameters to estimate the probability of obtaining a certain fracture length when a spectrum of inhomogeneities in stress or fracture toughness are imposed. Work continued in the characterization of sintered bauxite proppant. Proppant imbedment was tested between two waffers of varying hardnesses. As in previous wor, there was some proppant fracturing. Efforts to determine the feasibility of fabricating light weight proppants for application in gas and oil well stimulation continued.

The study of the sonic, neutron, and density logging of low permeability gas sands continued. Porosity of core samples from the CIGE Natural Buttes Unit No. 21 well were analyzed using the helium porosimeter and by determining the difference in dry weight and saturated weight. The well logs were digitized in terms of sonic, density, gamma ray, R_t and neutron. Computer runs of the digitized data were made but are not final.

The development of a laboratory method for accurate measurement of the dielectric constant in rock samples continued.

Lawrence Livermore Laboratory

Two-dimensional analyses of the dynamic propagation of fractures near interfaces were performed with the dynamic elastic computer code, and were used extensively to study dynamic fracture propagation and earthquake source mechanics. The code is based on Lagrangian techniques to solve equations describing the continuum.

Analyses of the crack propagation near an interface were completed using quarter-plane symmetry in an finite element model.

A time dependent finite element model has been developed, modified and used to determine the material overshoot characteristics from a crack which initiates, propagates bilaterally at half the dilatational wave speed, and stops when one tip reaches an interface.

Frictional experiments on dry Indiana Limestone have yielded static coefficients of friction of $\mu = 0.61$ and 0.51 for rough and smooth interfaces, respectively. Similar experiments on dry Nugget sandstone have yielded static coefficients of friction of $\mu = 0.59$ and 0.54 for rough and smooth interfaces, respectively. These preliminary values are subject to further analyses and interpretation. It was also found that with Indiana limestone, water saturation decreased the tensile strength.

These results indicate that the presence of water has different effects on crack growth across interfaces or different rock types.

Los Alamos Scientific Laboratory

A study of the microstructure and dynamic behavior of various Western gas sands core samples has been initiated. By elucidating the physical structure of these particular reservoir rocks, as well as their response to varying conditions of temperature and pressure, the macro scale behavior of fluids present in these formations can be more completely understood and predicted. The principal analytical methods employed in this effort included scanning electron and optical microscopy.

In order to establish the scientific feasibility of Nuclear Magnetic Resonance (NMR) logging using the remotely-produced region of a homogeneous field, experiments were initiated to measure the sensitivity of NMR detection to samples outside a radio frequency coil.

Sandia Laboratories

Seismic evaluation tests of the borehole seismic unit at the Nevada Test Site have been completed.

Signals arriving at an angle greater than approximately 55° from the horizontal may produce large errors due to the low amplitude of the P-wave signal. This was found to be true for the system grouted in the tuff. The S-wave onset is also detectable and apparently responsible for inducing the resonant ringing in the borehole siesmic unit.

Further examination of the data is necessary to determine the accuracy of measuring the vertical angle to the seismic source and accuracy of predicting distance to the source.

Ongoing experiments in electromagnetic logging techniques performed at Sandia Laboratories are yielding information concerning the resistivity, dielectric constant and magnetic permeability of formation materials. A major part of the Sandia logging efforts is to relate these electrical parameters to reservoir parameters such as porosity, gas to water ratios, and fluid flow permeabilities.

1.3.3 Field Tests and Demonstrations

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.

Colorado Interstate Gas Company

The ongoing field test 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.

DOE Well Test Facility

The DOE well test facility, comprised of a 10 ft x 50 ft instrument and winch trailer, a two-ton mast truck and two trailer mounted generators, was transferred to the RBNG-397-19-1 Government well to acquire reservoir data prior to the fracturing experiment.

Sandia Laboratories - Mineback

Research being performed at the DOE's Nevada Test Site includes in situ testing of hydraulic fracturing and technology, modeling of hydraulic fracturing behavior and laboratory testing. The tests include interface fracture experiments and a series of interface tests.

WGSP Multi-well Experiment

A multi-well experiment has been developed as a part of the Western Gas Sands Project. The objectives are to obtain a comprehensive geologic characterization of lenticular low permeability reservoirs in the western United States, and to apply and evaluate state-of-the-art and developing technology for the recovery of natural gas from these reservoirs. As a research-oriented project, it will be conducted to obtain the maximum amount of technical information.

1.3.4 Project Management

The Western Gas Sands Project Quarterly Basin Activities Report, January 31, 1979, the Western Gas Sands Project Quarterly Basin Activities Report, April 30, 1979, and the Western Gas Sands Project Quarterly Basin Activities Report, August 31, 1979, were released in April, June and September, respectively. Data for July, August and September's basin activities are being compiled.

The WGSP financial supplements for April through September, 1979, were released within the reporting period. A final report on the CER-managed government/industry Rio Blanco Massive Hydraulic Fracture 3 demonstration well was released in April. The WGSP logging program report and the DOE Well Test Facility Manual were revised in July. The Western Gas Sands Project Northern Great Plains Province Review by H.E. Newman III of CER Corporation was released in August.

1.4 METHANE RECOVERY FROM GEOPRESSURED AQUIFERS

The following is a summary of significant activities in this program through September 30, 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 well was drilled and completed 500 feet southeast of the initial attempt. The well is presently undergoing tests. The plugged-back hole is being used as a disposal well. Two additional wells have been designed and contracted for in Louisiana.

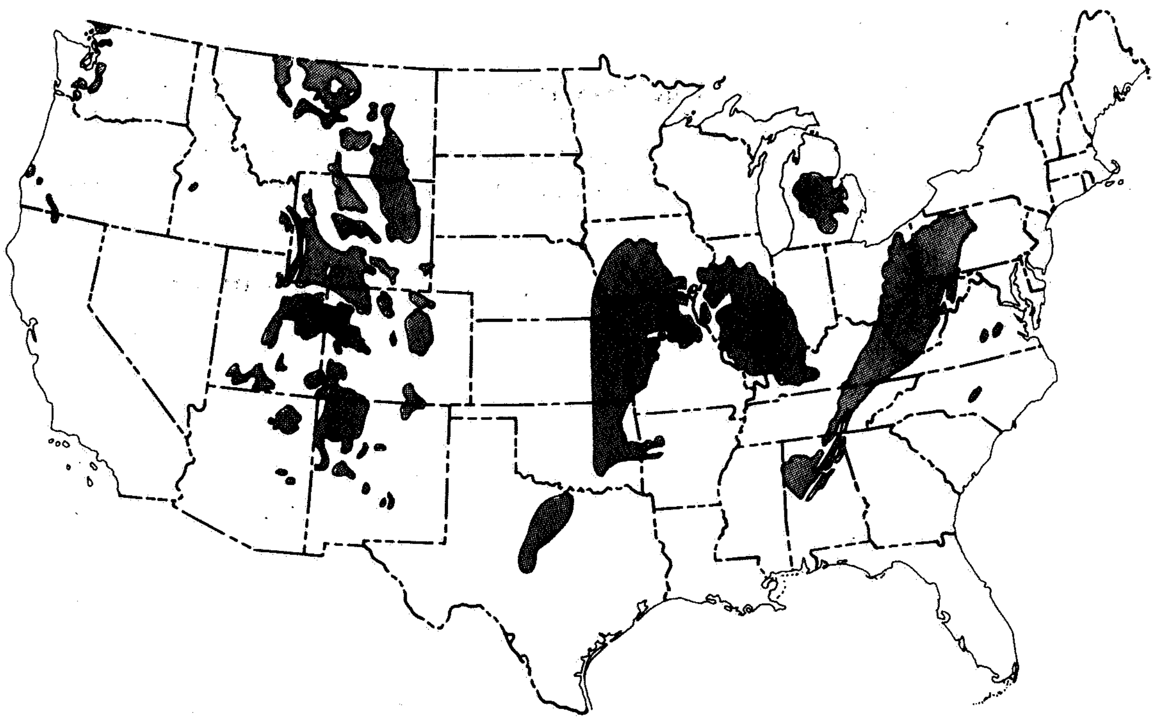
Under the wells of opportunity program, the two wells for short-duration tests have been completed in Louisiana. Tests have been completed on the first well. The second well is presently in the process of being tested.

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.

Four geopressured geothermal symposia have been held and others are planned for FY 1980.

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 surrounding areas. The total magnitude of the coalbed methane resource in the U. S. 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 space into which the methane can migrate and mix with air to form a potentially flammable or explosive mixture. The most widespread method of controlling methane concentrations to safe levels is dilution with ventilating air which sweeps the methane from the mine. This is an expensive method of control and the methane is lost to the atmosphere.

The Federal Government and some mining companies have been investigating techniques for draining methane from coalbeds to prevent gas migration into mine working areas. The techniques investigated include drilling vertical or directional wells into virgin coalbeds in advance of the 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; mixtures range from 25 to 90 percent methane. Such techniques significantly reduce ventilation requirements necessary to maintain gas concentrations at a safe level and at the same time improve mining productivity by reducing downtime caused by hazardous gas levels.

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 that profitable recovery and utilization of this resource is feasible. The variations in quality, available quantities, and geographic locations 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 feedstock production. The technology necessary to use this valuable resource exists today, although some modification may be required to accommodate the requirements of specific applications.

2.1.2 METHANE RECOVERY FROM COALBEDS PROJECT

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

It is recognized that other efforts involving methane recovery/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 used. Project results guide ongoing R&D to advance the technology and to 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 as a result of the removal of gas which often otherwise seeps into the mine. This avoids mandatory work shutdown periods while dangerous methane buildup is reduced to a safe level by ventilation.

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

- Resource Engineering: Identification, definition and evaluation of the coalbed methane resource so that productive and economically attractive target sites may be reliably predicted and selected in advance.

- Research and Development: Development of improved, more cost-effective systems and methods for extraction, preparation, and utilization of methane from coalbeds and for mine planning.

- Technology Tests: Field testing technical and economic viability of a number of different system-coalbed combinations to accommodate the variety of specific site conditions encountered in mine planning and large-scale commercialization.

- Project Integration: Management and technical overview and control, project activity planning/liaison, supporting studies/analyses (environmental, regulatory, safety, and economic), report development, 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 described below.

RESOURCE ENGINEERING

Delineation of the methane content of coalbeds in the United States has been accomplished on a very limited basis, mostly in conjunction with active mining. Previous work included only a very small percentage of the coal resources and does not provide the knowledge needed to locate recovery and utilization projects in coalbeds with the greatest potential for methane production.

Historically, about 80 to 90 percent of U. S. coal has been produced from the Pittsburg area. Thus, much of the delineation of coalbeds has been limited to that area and has addressed only minable coal. Some data obtained by industrial organizations are retained as proprietary information. Moreover, the available acquired data are not centrally located, making acquisition difficult.

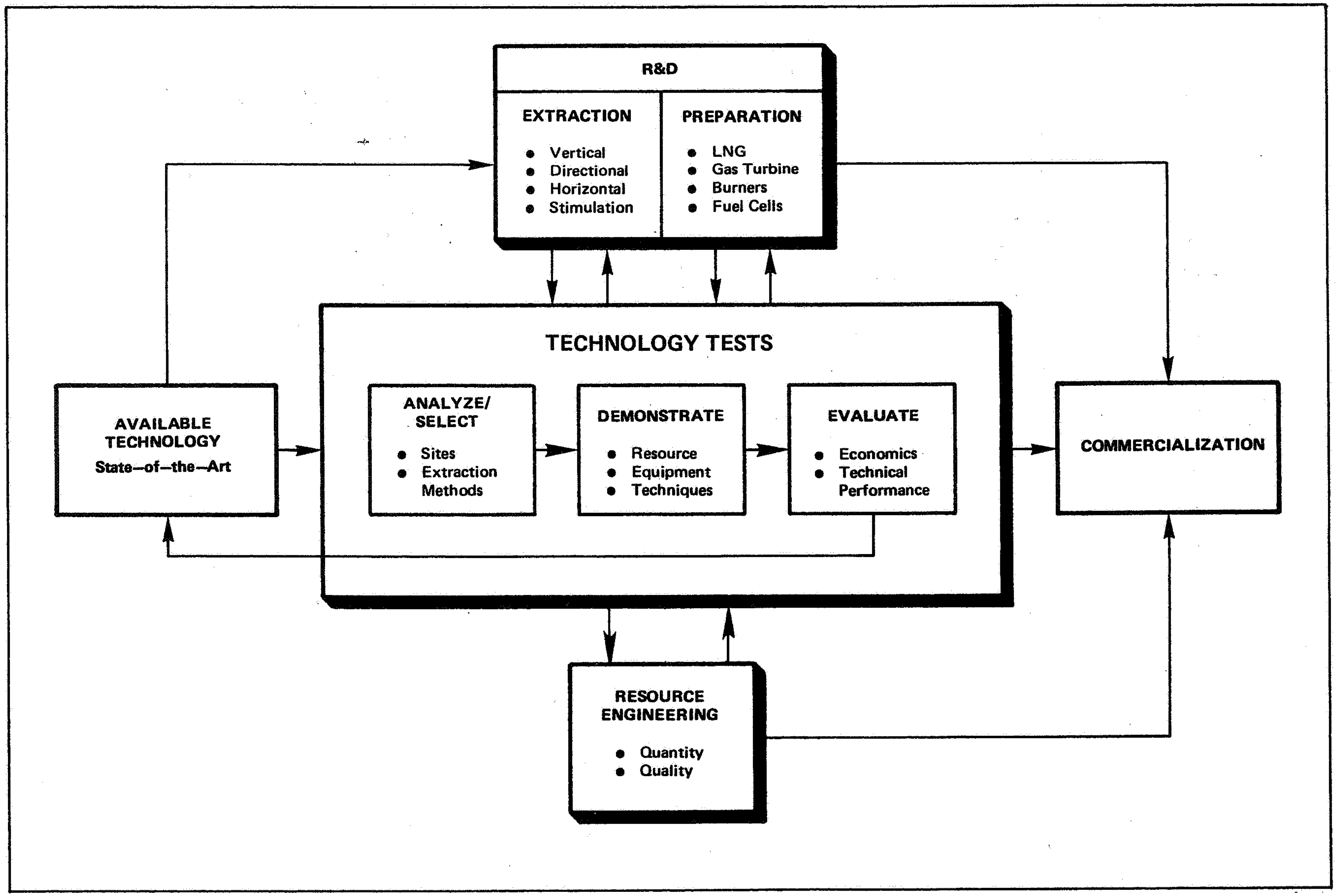


Figure 2-1. Methane Recovery from Coalbeds Project Interrelationships.

The MRCP Resource Engineering effort includes:

- Development of overall methane resource identification and definition planning
- Development of cooperative core/sample/well test/drilling plans
- Acquisition of characterization information--existing data sources and cores/samples from additional coalbed locations
- Analysis and evaluation of all available data
- Identification of reservoir areas and specific sites
- Production prediction efforts
- Information storage in a repository available to potential users

Methane resource characterization information also is acquired by other organizations. Support from these agencies and institutions is required to acquire available data located at multiple locations:

- USGS - Computerized data base (under development)
- USBM - Information source and laboratory analyses
- State Geological Surveys - Information sources, including geologic maps
- Universities/Institutions - Information sources and technical studies/analyses

A large increase is required in the depth and scope of methane resource characteristics to support assessment of the overall benefits that can be derived from the use of coalbed methane. The current price incentive has been insufficient to encourage widespread commercial interest.

To reduce project costs, an attempt is made, whenever possible, to conduct well coring and testing operations in conjunction with private companies who are drilling to deeper horizons within the MRCP areas of interest. The operations conducted with cooperating companies are categorized by well 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.

Much of the data available from existing sources at the onset of this project in late 1977 has been acquired and assimilated; however, acquisition of additional data and updating information continues from these sources. Other activities, a major increasing thrust of the Resource Engineering effort during this reporting period, have provided similar data on other national coal resources. Within the limitations inherent in this "wells of opportunity" operating mode, emphasis is placed upon obtaining new data from promising resource target areas, particularly those areas for which little or no information is otherwise available.

A Methane Resource Delineation Plan has been developed to guide delineation of the coalbed methane resources and to provide information prerequisite to commercialization.

Results of the Resource Engineering activities are discussed in Section 2.2.

RESEARCH AND DEVELOPMENT (R&D)

High risk R&D tasks (such as investigation of improved drilling tools and extraction techniques) are being identified and performed in conjunction with ongoing Resource Engineering and Technology Test project activities. Such tasks are funded primarily by the government due to high risk and cost factors which prevent timely investigation by industry. The primary purpose of R&D in the MRCP is to obtain answers to fundamental questions involving methane recovery from coalbeds and thereby provide the technological advancements necessary for economic production and utilization. This work involves proper instrumentation of wells to determine stimulation effectiveness, fracture containment, effects of water saturation, in situ stresses, etc. R&D tests such as mineback experiments are performed to evaluate roof integrity for subsequent mining operations. Present R&D planning includes technology development 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
- Improved gas drainage techniques to provide more economical recovery of methane and (when active mining is involved) to support mine planning and assist productivity
- Fracture containment to minimize mine roof damage.

Drilling technology is presently available for extracting methane from coalbeds. However, none are developed to the degree that efficiency and cost are optimum. Multiple wells are required to drain the gas effectively before mining. The spacing and pattern of wells for most effective methane drainage are essential to both safety and productivity when mining the coal is involved. Optimum geometries are unknown. Current hydraulic or foam fracturing techniques will suffice for near-term test projects to extract methane now wasted, but 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 LNG. Early systems use equipment developed for other uses, modified as necessary for adaptation to coalbed methane applications. To provide improved and efficient equipment for specific applications, design modifications and technology development are required.

Results of the R&D activities are discussed in Section 2.3.

TECHNOLOGY TESTS

Technology tests are designed to determine the technical and economic feasibility of specific combinations of methane extraction and utilization equipment, normally installed as complete and integrated systems operating under realistic field conditions. Approximately ten projects were underway or in firm planning during this reporting period, evenly divided between minable and unmined coalbeds.

Collectively, the Technology Tests examine a variety of different extraction methods in different coal formations, in combination with a wide spectrum of different utilization subsystems. Each test activity is planned and executed as a complete system test to ensure optimum test results and realistic contribution to the project information data base and to the MRCP technology transfer function. The parameters studied in technology tests through September, 1979 are illustrated in Table 2-1. Others will be initiated in subsequent years to investigate other important extraction or utilization features or the same methods in different geologic or environmental settings.

Results obtained from the Resource Engineering and R&D activities are used to assist in the selection of technology systems to be tested. However, these results alone cannot provide the overall data base necessary for rapid exploitation of the coalbed methane resource. Well planned and executed technology tests are required to demonstrate true economic and technical viability and environmental acceptability.

Results of the Technology Test activities are discussed in Section 2.4.

Table 2-1. Technology Test Projects

TECHNOLOGY TESTS	PREDRAINAGE	GOB GAS	EXTRACTION TECHNIQUE: SINGLE WELL	EXTRACTION TECHNIQUE: MULTIPLE 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
MINABLE COALBEDS													
Westinghouse	•			•						•		•	
U.S. Steel	•			•			•			•			
Occidental	•					•		•					•
Westinghouse	•	•	•								•		
Clinchfield	•			•						•			
J & L	•				•					•			
UNMINED COALBEDS													
Mountain Fuel				•			•	•		•			
Intercomp/Coseka			•				•			•			
PERI				•			•			•			
Waynesburg			•					•		•			

PROJECT INTEGRATION

Project integration and support activities play an important part in the implementation and management of the MRCP. In addition to normal project planning and function coordinating, a large amount of information exchange necessarily takes place between the several individual R&D and technology system tests and their supporting activities. Some of the information resulting from one activity is required as "feedback" input to another and much of it is technical and pressing the state-of-the-art. To support these needs, an open file information management system is used to maintain orderly flow, storage, and ready availability of the present level of data. Expansion capability is provided to handle the larger amount and variation in types of data expected in the future.

In the technology tests, it is planned to include a methane utilization subsystem with each extraction subsystem. Integrated planning is mandatory for these combined test projects to assure selection of optimum overall system designs and to provide coordination of operational procedures. Tradeoffs involving site locations and design features include: distance to a gas gathering line or other end use, site accessibility, methane quantity/quality, cost-sharing opportunities, project priorities, and confidence in the expected results. These very different factors require diverse technical and administrative knowledge. Also, detailed studies and analyses are required to support some of the test projects and to provide the requisite knowledge to enable good decisionmaking and selection of viable systems and site locations.

To provide identification and thereby facilitate the integration of all of the work required to accomplish the MRCP, the four major elements of the project have been subdivided into progressively lower levels in a typical work breakdown structure (WBS). Use of this technique proceeds to the level of detail necessary to plan and perform all required work.

It is recognized that other gas recovery efforts involving methane (not coalbed associated) are underway and that the planned MRCP activities must be coordinated with the appropriate agencies, particularly where mutual support or other interactivity will be beneficial to overall DOE Unconventional Gas Resource program goals and national energy interests.

Project Integration activities are discussed in Section 2.5.

2.2 RESOURCE ENGINEERING

2.2.1 GENERAL

During this reporting period the Resource Engineering activities focused in the following areas:

- Implementation of the MRCP Resource Delineation Plan to increase the amount of available site specific data.

- Continued definition of a test program to determine the feasibility of producing methane from coalbeds.

- Initiation of supporting activities

  - Evaluation of coalbed predrainage stimulation effects on coal recovery.

  - Determination of optimum reservoir fracturing and its effect on mining operations.

Results of these Resource Engineering activities are reported in this section. Where applicable, information appearing in prior MRCP semi-annual reports is summarized in this document to provide reporting continuity. This information is updated/corrected as appropriate.

Sections 2.2.2 through 2.2.8 review the efforts of the several organizations directly participating in MRCP Resource Engineering activities.

Sections 2.2.9 through 2.2.16 summarize by basin the results of investigating specific well sites usually by means of cooperative agreements with other organizations. The basin, MRCP well site designation, cooperating company or agency, and local well identification are tabulated in Table 2-2 for each field activity.

Table 2-2. Well Site Investigations by Basin
MRCP Resource Delineation Field Activities.

Basin	MRCP Well Site Designation	Cooperating Company/Agency and Well Identification
Arkoma	AA	Arkla Exploration; Brown 1-2
	AB	Mustang Production; Barringer 1-11
	AC	Mustang Production; Day 1-14
	AD	U.S. BuRec; DH-A17
Green River	AA	Confidential Well No. 1
	AB	Belco Petroleum; S-29-27
Illinois	AA	Hagen Oil; Henderson #2
	AB	GeoWest, Inc.; Confidential Well
Northern Appalachian	AA	Kinloch Development; Murdoch #1
	AB	Waynesburg College
Piceance	AA	Fuelco; Cathedral 0-28-3-101-S
	AB	Twin Arrow; C&K Well #1-13
	AC	Twin Arrow; C&K Well #4-14
	AD	Confidential Well No. 2
	AE	Confidential Well No. 3
	AF	Confidential Well No. 4
	AG	Confidential Well No. 5
	AH	Fuelco; D-26-3-101-S
Powder River	AA	USGS
	AB	Montana BMG; No. US-7735
	AC	Montana BMG; No. US-7746
San Juan	AA	Western Coal
Southern Appalachian/ Warrior	AA	Grace Petroleum; No. 1 — Grimsely 35-15

2.2.2 METHANE FROM COALBEDS RESOURCE DELINEATION

TRW Energy Systems
McLean, Virginia

Status:
Active

Contract:	DE-AC21-78MC08089
Contract Date:	December 12, 1977
Anticipated Completion Date:	February 12, 1981
Principal Investigator:	C.T. Rightmire (TRW)
DOE Technical Project Officer:	H.D. Shoemaker

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, MRCP Resource Engineering activities performed by TRW Energy Systems include:

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

PROGRESS PRIOR TO APRIL 1979

The Resource Delineation Plan (RDP), developed during previous reporting periods, describes the MRCP approach being used to provide an expanding project data base, to disseminate new information to potential users, and to guide management of the overall delineation effort. An important use of the information acquired is to determine more accurate estimates of the national coalbed methane resource and reserve.

The RDP encompasses examination of 380,000 square miles of coalbearing rocks in the conterminous United States, shown in Figure 2-2, and the determination of the quantity, distribution, and production characteristics of some 700 trillion cubic feet of methane estimated to be contained in these rocks. Early efforts are being concentrated on approximately 20 percent (80,000 square miles) of the total coalbed area where the probabilities of finding, producing, and using methane appear highest. An attempt is being made to obtain at least one data point every 1,000 square miles within these target areas. The initial target areas are shown in Figure 2-2.

Implementation of the RDP is organized to:

- Operate in a reconnaissance mode and use a basic 1,000 square mile sampling pattern within the areas of interest and as limited by availability of wells for sampling and testing.

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

Based upon criteria established in the RDP, portions of major basins were selected as the initial targets for resource delineation activities. The total area in these basins underlain by coal bearing rock and the target areas selected for early delineation field activities are tabulated in Table 2-3. In order to refine the target areas, detailed reports will be prepared for each of the basins (or other reservoir areas) of interest. The objectives of the basin reports are to:

- Assimilate all available regional geologic information related to coal bearing portions of basins.

- Provide better definition of MRCP gas target areas.

- Provide geologic information necessary for development of a framework for prediction of methane distribution.

Six basin reports were scheduled for completion in 1979. They include:

- Illinois Basin
- Powder River Basin
- San Juan Basin
- Arkoma Basin
- Green River Basin
- Western Washington

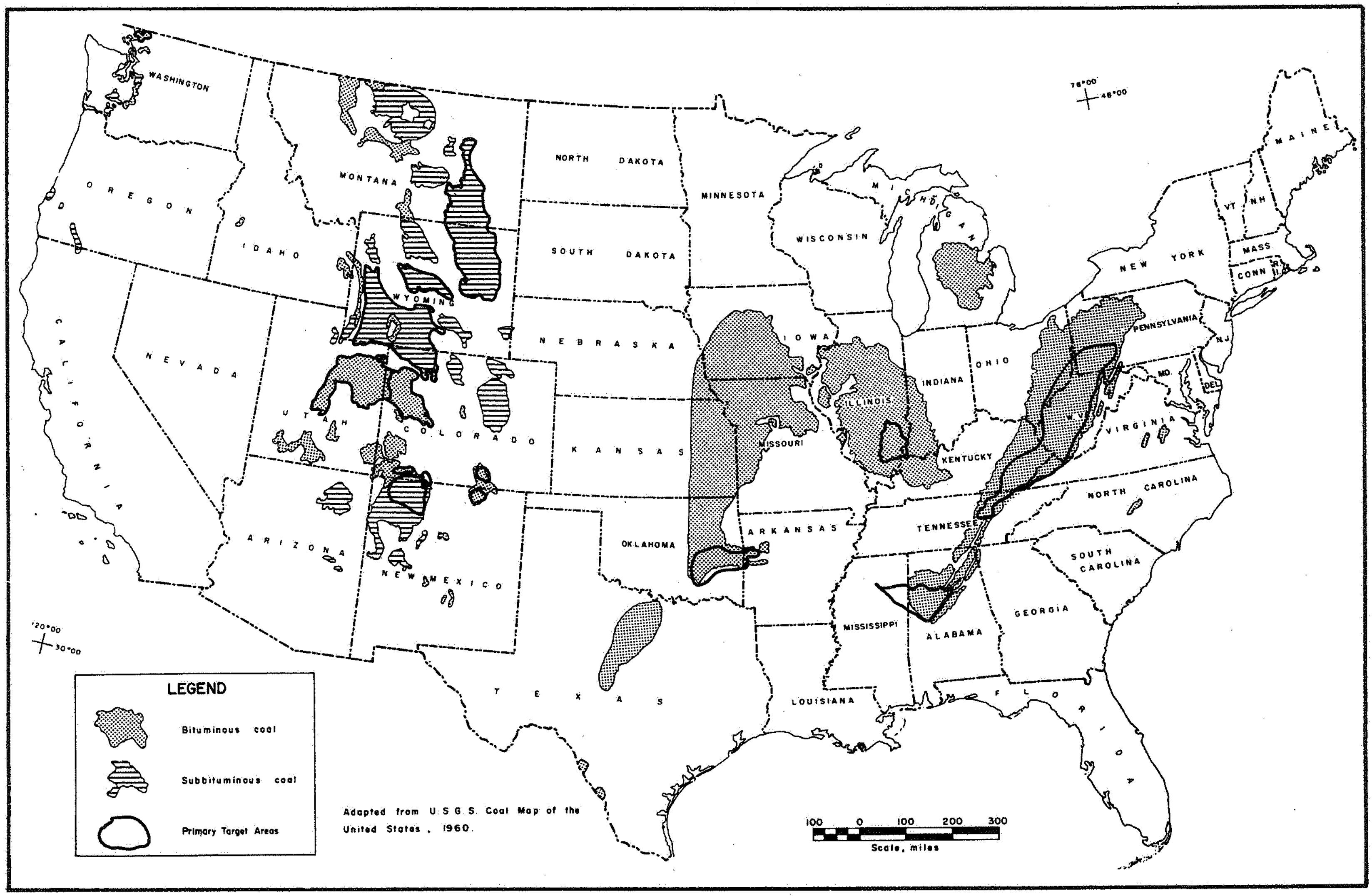


Figure 2-2. Bituminous and Subbituminous Coal Fields of the Conterminous United States, Showing Initial Primary Target Areas of the Methane Recovery from Coalbeds Project.

Table 2-3. Relationship of Size of Target Area to Total Area Underlain by Coal-Bearing Rock.

Eastern	51,400	4,300* (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	10,000* (Green River Basin)
Wind River	3,800	3,800
Powder River	22,700	12,800
Washington	400	400

*Area redefined since last reporting period.

Other Resource Engineering activities concentrated on identifying private companies planning to drill wells, often to horizons other than coalbeds, with a view to negotiating cooperative agreements for drilling, coring, logging, and performance of gas flow tests and sample analyses.

PROGRESS THIS REPORTING PERIOD

During the April to October, 1979 period two basin report drafts were prepared and reviewed. These reports were for the Illinois Basin and the Powder River Basin.

Preparation of four additional basin reports was initiated during this reporting period. The percentage of work accomplished on each of these reports approximately is as follows:

- Arkoma Basin - 60%
- Green River Basin - 80%
- San Juan Basin - 80%
- Western Washington - 25%

Also during this period, 35 potential cooperators were contacted for the acquisition of methane delineation information.

The current target areas and results of specific well site investigations as of the end of this reporting period are organized by basin and discussed in Sections 2.2.9 through 2.2.16.

2.2.3 EVALUATION OF DATA FROM UNMINED COAL SEAMS

Intercomp, Inc. Houston, Texas	Status: Active
Contract: Contract Date: Anticipated Completion Date:	DE-AC21-79MC10641 March 31, 1978 April 30, 1980
Principal Investigator: DOE Technical Project Officer:	H.S. Price H.D. Shoemaker

OBJECTIVE

To provide for the reduction of uncertainties in the critical parameters related to methane recovery from unmined coalbeds in the U.S.

SCOPE OF WORK

Contract DE-AC21-79MC10641 with Intercomp, Inc. provides for the identification of the critical parameters and the reduction in uncertainties related to methane extraction from unmined coalbeds. An earlier contract (EM-78-C-21-8352), partially implemented in 1978 and early 1979, specified an optimized test program. These contracts cross-cut other Resource Engineering projects and assist in the characterization of unmined coalbeds by providing particular emphasis on methane producibility. Specific activities include:

- Assistance in the location of well drill sites which are most favorable for resource characterization.
- Synthesis of available data and determination of standard data forms and tests.
- Assistance in the preparation of test plans for selected well sites.
- Establishment of the methane production potential from coal at the test well sites, in the geologic setting, and the geographical area by: (1) using test parameter data in a computer based model to determine its effect on well deliverability (2) estimating the in-place gas, (3) estimating potential deliverability over the reservoir life, if produced.

- Provision of a relationship of the critical production parameters to the overall production economics, including gas unit prices.

- Provision of on-site supervision and/or monitoring of the tests when required.

- Development of an assessment of the gas producibility of the coal type and rank with respect to data parameter ranges, gas in place estimates, and well deliverability potential.

PROGRESS PRIOR TO APRIL 1979

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 (referenced in this report as "gas deliverability", Ø).

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 distribiton of Ø 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, Ø.

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 2-4). 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.

PROGRESS THIS REPORTING PERIOD

The data resulting from the Kinloch Development Company #1 Murdock well (Greene County, Pennsylvania) were standardized for use as a test site.

Table 2-4. 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 2-4. Potential Test Activities
(Continued) 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	

Analysis of the Pennsylvania State University data was performed during this reporting period.

Results of these and other activities will be discussed in subsequent reports.

2.2.4 EVALUATION OF COLORADO COALBED METHANE POTENTIAL

Colorado Geological Survey
Denver, Colorado

Status:
Active

Contract:	**DE-AC21-79MC10643**
Contract Date:	**April 1, 1978**
Anticipated Completion Date:	**March 31, 1980**
Principal Investigator:	**L.R. Ladwig**
DOE Technical Project Officer:	**H.D. Shoemaker**

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.

PROGRESS PRIOR TO APRIL 1979

The Colorado Geological Survey was actively involved in the selection of potential operators and sites for drilling/coring activities within Colorado. Arrangements were made to acquire data taken from coal samples obtained in this geographic area. Long-term desorption tests of these samples were initiated.

PROGRESS THIS REPORTING PERIOD

Desorption of samples from the Piceance basin and the Douglas Arch area of the Uinta region was continued. Proximate and ultimate analyses were received for samples and will be reported in the respective well test summaries.

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:	November 28, 1978
Anticipated Completion Date:	December 31, 1979
Principal Investigator:	A.A. Lee (TRW)
DOE Technical Project Officer:	H.D. Shoemaker

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 models. The following activities are being conducted:

- 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.

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

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

- 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.

- 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.
- Application of the stability models developed to actual mines presently using degasification techniques. Comparison of the predicted and actual results.
- Recommendation of procedures/techniques for evaluating stability changes due to degasification procedures.

PROGRESS PRIOR TO APRIL 1979

The activities described above were initiated.

PROGRESS THIS REPORTING PERIOD

Review of previously reported theoretical studies, results of laboratory experiments, and limited field studies on hydraulic fracturing of coal seams have been completed.

The other tasks delineated above are in progress and results will be presented in subsequent reports.

2.2.6 EVALUATION OF UTAH COALBED METHANE POTENTIAL

Utah Geological and Mineral Survey Salt Lake City, Utah		Status: Active
Contract:		DE-FG-21-79MC11729
Contract Date:		June 1, 1979
Anticipated Completion Date:		May 31, 1980
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

The Utah Geological and Mineral Survey MRCP activities involve collection of 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 to 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.

PROGRESS PRIOR TO APRIL 1979

Under a prior contract (ET-76-G-01-9004), originally with the Bureau of Mines, more than 160 coal samples were collected and the gas content determined by the direct method. Coalfields from which samples have been obtained include the following (sample distribution for the first 164 samples is also indicated):

Coalfield	Sample Distribution
Alton	3
Book Cliffs	98
Emery	8
Henry Mountains	1
Kaiparowits Plateau	12
Sego	26
Wasatch Plateau	16

Gas content values were generally low (less than 64 cf/ton) in all of these coalfields except the Book Cliffs field. Values observed for Book Cliffs ranged up to a high of 406 cf/ton for a sample of unnamed coal collected at a depth of 2,056 feet.

The Book Cliffs coalfield, particularly that area east of a line running from Helper to Sunnyside, Utah, was delineated as having the highest methane gas potential.

Underground detailed mapping and sample collection was completed in the Sunnyside coalbed to investigate the variable gas emission rates observed in underground mining operations. Final conclusions will be formulated upon completion of analytical tests.

PROGRESS THIS REPORTING PERIOD

During the period May through August 1979, 85 coal core samples were obtained from seven locations in Carbon, Grand, Emery, and Sevier Counties in Utah. The collection of additional samples (some at new locations) was planned for September. After the "field season", a tabulation of all samples and related data will be compiled.

Most of the coal samples are being desorbed and their gas content and the results of subsequent laboratory proximate and ultimate analyses will be discussed in subsequent reports.

2.2.7 EVALUATION OF SOUTHERN COALFIELDS

Virginia Polytechnic Institute & State University
Blackburg, Virginia

Status:
Active

Contract:	DE-AC21-78MC08089
Contract Date:	June 1, 1979
Anticipated Completion Date:	December 31, 1979
Principal Investigator:	C.T. Rightmire (TRW)
DOE Technical Project Officer:	H.D. Shoemaker

OBJECTIVE

To determine the methane production potential of southern coalfields.

SCOPE OF WORK

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

- 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 concerning methods for sampling unminable coal seams for their methane content will be provided.
- 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.
- Development of an exploration program for the high priority unminable coal seams to determine the methane potential of the seams.

PROGRESS THIS REPORTING PERIOD

The Virginia Division of Mineral Resources, as subcontractor to Virginia Polytechnic Institute, is conducting field delineation of the Richmond Basin. A bibliography of the Richmond Basin is nearing completion with more than 60 references located. Most of these reference old reports and few indicate the presence of methane as of the end of this reporting period.

2.2.8 RESERVOIR FRACTURING AND MINING THROUGH FRACTURED AREAS

Pennsylvania State University
State College, Pennsylvania

Status: **Active**

Contract:	**DE-AC21-78MC08089**
Contract Date:	**June 1, 1979**
Anticipated Completion Date:	**December 31, 1979**
Principal Investigator:	**A.A. Lee (TRW)**
DOE Technical Project Officer:	**H.D. Shoemaker**

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

This study concerns reservoir modeling, fracturing, and mining through fractured areas. Planned activities include the following:

- Acquisition of a data base to provide methane recovery parameter information.
- Survey of literature concerning fracturing methods and techniques.
- Development of a rational scientific concept or methodology for determining the best method(s) for fracturing a bed.
- Development of a simulation model for coal seam methane reservoir prediction.
- Actual in-mine investigations and mapping of stimulation results.
- Actual on-site validation of successful scientific and laboratory-developed techniques for fracturing coal seams. Assistance in implementing the validation tests and independent analysis of test results.
- Evaluation of the impact of coal seam degasification on mine ventilation costs.

PROGRESS THIS REPORTING PERIOD

The following activities have been in progress during this reporting period:

- Assembly of a data base providing pertinent methane recovery parameters.
- Survey of coal seam fracturing methods literature.
- Determination of finite-difference approximations to the system equations describing coalbed methane gas production.
- Preparations for an in-mine laboratory experiment to assess the effects of coal mine degasification activities on mine ventilation costs.

Information resulting from these activities will be presented in subsequent reports.

2.2.9 ARKOMA BASIN (OKLAHOMA AND ARKANSAS)

The Arkoma basin encompasses an area of approximately 5,300 square miles in the states of Arkansas and Oklahoma (Figure 2-3). This basin contains extensive bituminous coal reserves in the Desmoinesian (Pennsylvanian) age rocks. Some minor coals occur in the Atokan Series of rocks which lie directly below the Desmoinesian age coal bearing strata.

Coals in the Arkoma basin were deposited in deltaic environments. The gassiest coals in the area are found in the Upper and Lower Hartshorne beds which total 3 to 7 feet in thickness and contain estimated resources of about 5 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 Hartshorne coals are of low to high volatile bituminous rank. The area is intensely folded and faulted with very steeply dipping beds. Overburden is less than 3,000 feet in approximately 610 square miles of Oklahoma and Arkansas.

The U. S. Bureau of Mines has investigated the methane content of the Hartshorne coals. The average methane content ranges from 211 cf/ton with an overburden of 0-500 feet to 672 cf/ton with an overburden of 2,000 to 3,000 feet. Recent MRCP Type I field tests have provided additional desorption data for some of the coals in the western part of the Arkoma basin. Upper Booch Coal is approximately 200 cf/ton in the Barringer No. 1-11 well. Tentatively identified Hartshorne coal is 73 cf/ton, lower Booch coal is approximately 211 cf/ton, and the McAlester coal is approximately 130 cf/ton in the Brown Estate No. 1-2 well.

Based on these limited desorption data, minimum and maximum ranges for expected in-place gas have been estimated for the Hartshorne coals. Assuming an average gas content of 200-450 cf/ton, the Hartshorne coals contain 1,600-3,600 Bcf methane.

The current MRCP target area of interest within the Arkoma basin is shown in Figure 2-3. As of the end of the reporting period, four sites had been investigated in the Arkoma basin. Results of these field tests are summarized in the following paragraphs. Activities conducted in prior reporting periods are updated/corrected where appropriate.

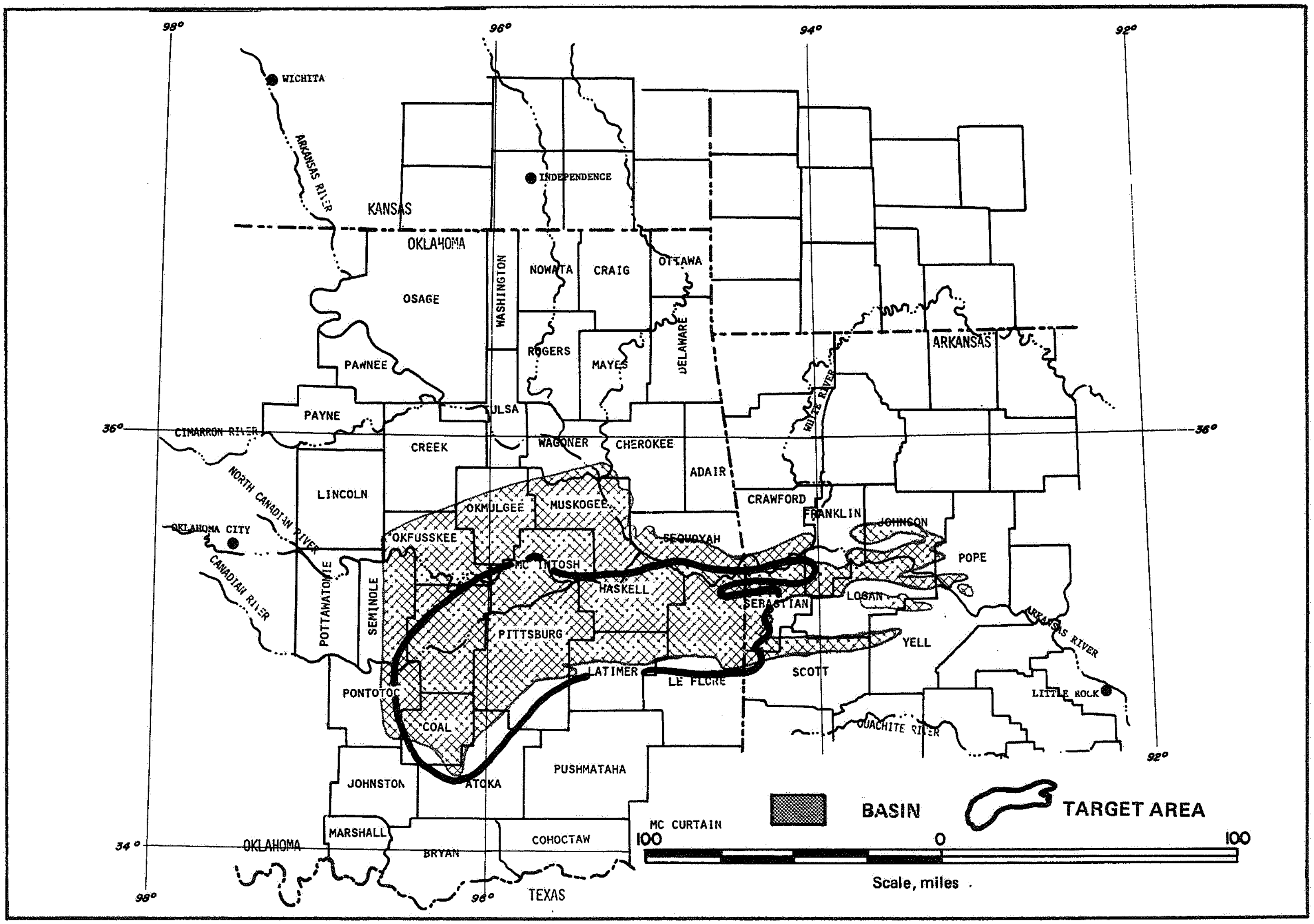


Figure 2-3. Arkoma Basin Target Area

ARKOMA BASIN, SITE AA,
PITTSBURG COUNTY, OKLAHOMA

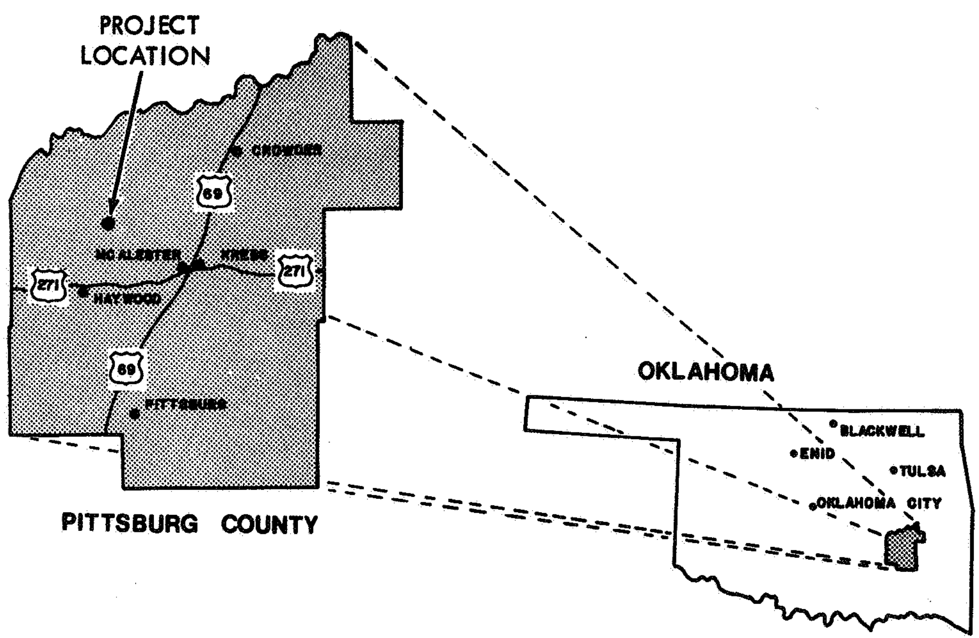
Status:
Active

Cooperating Company:
Arkla Exploration Company
Shreveport, Louisiana

Field Work Performance Period:	October, 1978
Principal Investigator:	**C.T. Rightmire (TRW)**
DOE Technical Project Officer:	**H.D. Shoemaker**

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.



SITE LOCATION

Arkla Exploration Company well Brown #1-2 located in Section 2, Township 6N, Range 13E, Pittsburg County, Oklahoma.

SCOPE OF WORK

The geologic target of this investigation is the Lower Hartshorne Seam in the Arkoma Basin.

Field Activity

Single well drilling, logging, sidewall coring, and drill stem testing.

Analysis

Gas desorption and permeability determination.

PROGRESS PRIOR TO APRIL 1979

Field activities were performed in October 1978 during the original drilling of the well to 3150 feet.

Logging

The well was logged on October 8 by Arkla (laterolog, neutron, density, and sonic).

Sidewall Coring

The following intervals were sidewall cored on October 9, 1979:

Interval (ft)	Shots	Cores Recovered
1833.0 - 1834.0	2	2
1903.0 - 1906.0	4	3
2124.0 - 2131.0	20	17
2703.0 - 2732.0	22	18

Drill Stem Testing

A good mechanical drill stem test was conducted in the Upper Hartshorne seam at a depth interval of 2700 to 2740 feet. A previous DST was unsuccessful because of a packer failure and a third planned DST was cancelled to eliminate a risk of sticking pipe below the packer. Results of the DST as calculated by Johnston using the Horner method are:

Flow	9.0 bbl/day, water
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

Gas-In-Place Estimate - Simulation

Reservoir simulation resulted in (1) a gas-in-place estimate of 1.4 Bcf per square mile (640 acre section) and (2) a cumulative discounted 10 year gas deliverability, Ø, estimate for an isolated well of between 3,500 and 40,000 Mcf. This range for deliverability 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 gas deliverability, Ø.

PROGRESS THIS REPORTING PERIOD

Gas Desorption

The sidewall core samples (reported above) were combined into three coal samples and analyzed by Geochem. Gas desorption results are as follows:

Core Interval (ft)	Lithology	Gas Content In Place (cf/ton)
1903 - 1905	Coal	130
2125 - 2130	Coal	210
2728 - 2733	Coal	73

ARKOMA BASIN, SITE AB
PITTSBURG COUNTY, OKLAHOMA

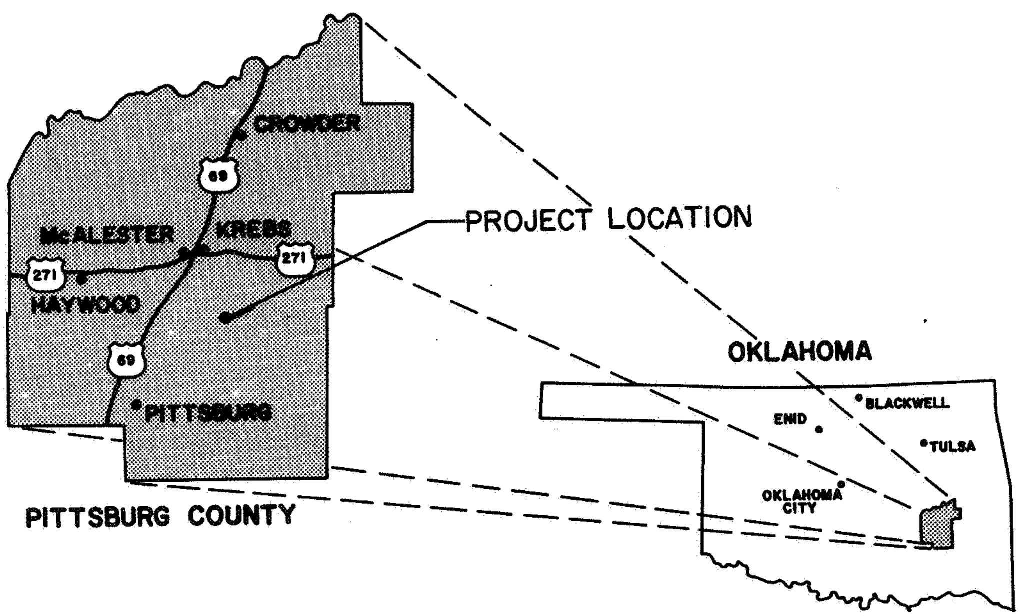
Cooperating Company:
Mustang Production Company
Oklahoma City, Oklahoma

Status:
Field Activity Complete
Analysis Active

Field Work Performance Period: July, 1979
Principal Investigator: C.T. Rightmire (TRW)
DOE Technical Project Officer: H.D. Shoemaker

OBJECTIVE

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



SITE LOCATION

Mustang Production Company well Barringer No. 1-11 located in Section 11, Township 4N, Range 15E, Pittsburg County, Oklahoma.

SCOPE OF WORK

The geologic target of this investigation is the Middle Booch Seam and Upper and Lower Hartshorne Seams in the Arkoma Basin.

Field Activity

Single well drilling, logging, and conventional coring.

Analysis

Gas desorption, computer analysis (relative rank, thickness, moisture, mineral content, ash content) and laboratory analysis.

PROGRESS THIS REPORTING PERIOD

Field activities were performed in July 1979 during the original drilling of the well.

Logging

Borehole geophysical logging of this well was performed in early July (electric, gamma-ray, spectralog, compensated density, and caliper).

Conventional Coring

Conventional coring was performed at three coal horizons as follows:

Coal Horizon	Interval Cored (feet)	Core Recovered (feet)	Sample
Upper Booch	3650 - 3662	10.5	11 inches, coal
Upper Hartshorne	4435 - 4458	None, core lifter failure	
Lower Hartshorne	4580 - 4593	5.5	Shale with sandstone parting

Gas Desorption

The total gas content measured to date is 163 cf/ton.

Gas-In-Place Estimate

Initial indications suggest high gas content. Gas desorption continues and final data will be presented in the next report.

Well Stimulation

Design of a fracture treatment is underway. A detailed procedure has been prepared and is under review.

ARKOMA BASIN, SITE AC
HASKELL COUNTY, OKLAHOMA

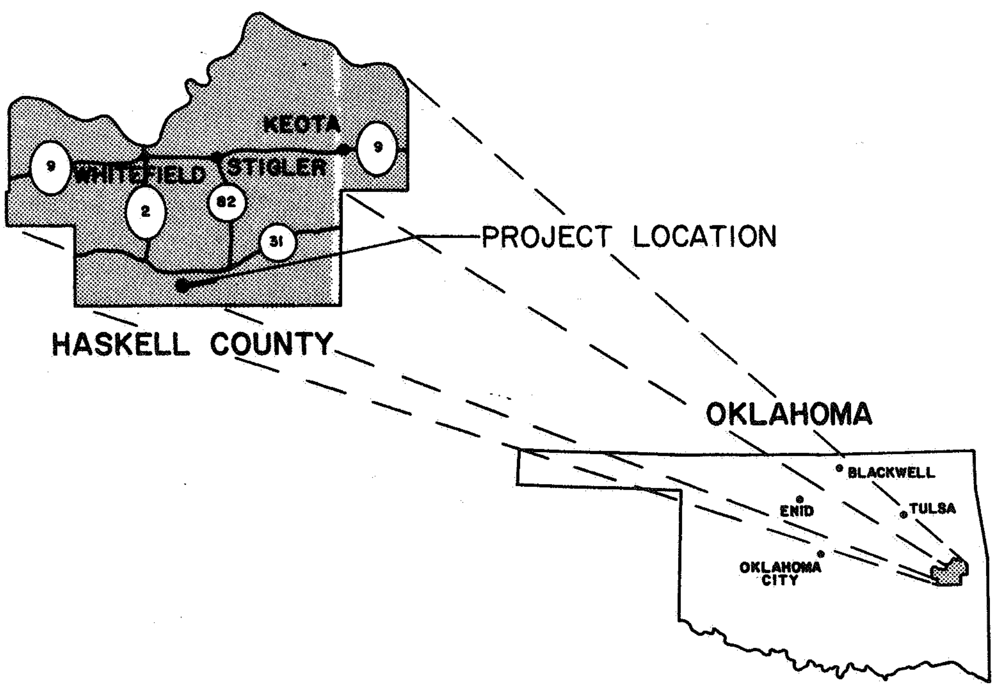
Cooperating Company:
Mustang Production Company
Oklahoma City, Oklahoma

Status:
Field Activity Complete
Analysis Active

Field Work Performance Period:	**July, 1979**
Principal Investigator:	**C.T. Rightmire (TRW)**
DOE Technical Project Officer:	**H.D. Shoemaker**

OBJECTIVE

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



SITE LOCATION

Mustang Production Company well Day 1-14 located in Section 14, Township 7N, Range 20E, Haskell County, Oklahoma.

SCOPE OF WORK

The geologic target of this investigation is the Upper Booch and Hartshorne Undivided Seams in the Arkoma Basin.

Field Activity

Single well drilling, logging, and conventional coring.

Analysis

Computer analysis of the well logs (relative rank, thickness, moisture, mineral content, gas content, and ash content of the coal seams).

PROGRESS THIS REPORTING PERIOD

Field activities were performed in July, 1979 during the original drilling of the well.

Logging

Borehole geophysical logging of this well was performed in July (electric, gamma-ray, spectralog, compensated density, neutron, and caliper).

Conventional Coring

Conventional coring was performed at two coal horizons; activities and results were as follows:

Upper Booch Coal Horizon - July 7

Projected Interval	1615 - 1643 ft
Core Size	3½ in., using standard steel inner barrel liner
Interval Cored	1615 - 1643 feet (28 ft), "air-mist"
Core Recovered	25.3 ft (90%), all shale
Core Loss	2.7 ft, caused by core lifter slippage

Hartshorne Undivided Coal Horizon - July 21

Projected Interval	2585 - 2613 ft
Core Size	3 in, using PVC plastic inner barrel liner
Interval Cored	2585 - 2613 ft (28 ft), "air-mist"
Core Recovered	18.5 ft (66%), shale with sandstone partings
Core Loss	9.6 ft - 6 ft of coal core loss was attributed to air jetting of soft, friable material; 3.6 feet of bottom rock loss was attributed to core lifter failure

Analysis

Computer analysis (relative rank, thickness, moisture, mineral content, gas content, ash content) of the well log data was performed for the coal seams encountered.

ARKOMA BASIN, SITE AD
LEFLORE COUNTY, OKLAHOMA

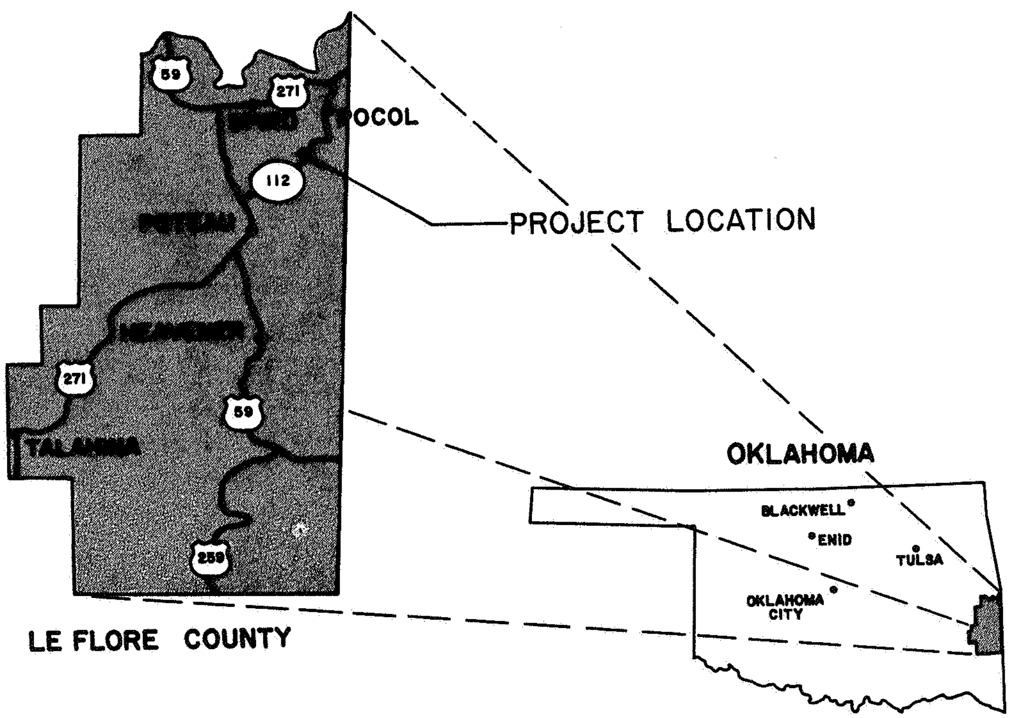
Cooperating Organization
U.S. Bureau of Reclamation
Amarillo, Texas

Status:
Field Activity Complete
Analysis Active

Field Work Performance Period: September, 1979
Principal Investigator: C.T. Rightmire (TRW)
DOE Technical Project Officer: H.D. Shoemaker

OBJECTIVE

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



SITE LOCATION

U. S. Bureau of Reclamation well #DH-A17 located in Section 14, Township 8N, Range 26E, LeFlore County, Oklahoma.

SCOPE OF WORK

The geologic target of this investigation is the Upper Hartshorne Seam in the Arkoma Basin.

Field Activity

Single well drilling, logging and conventional coring.

Analysis

Gas desorption and laboratory analysis.

PROGRESS THIS REPORTING PERIOD

Field activities were performed in September 1979 during the original drilling of the well.

Logging

Borehole geophysical logging was performed by the U. S. Geological Survey on September 13 (SP, gamma-ray, compensated density, caliper).

Conventional Coring

Conventional coring was completed on September 11 with 2.9 feet of coal recovered at an interval of 191.6 to 194.5 feet in the Lower Hartshorne seam.

Gas Desorption

Gas desorption of coal samples from conventional coring has resulted in the following data as of September 1979. Final results will be presented in the next report.

Sample Depth (ft)	Total Gas (cc)	Sample Weight (gm)	Gas Content (cc/gm)	Gas Content (cf/ton)
191.6 - 192.6	6980	1360	5.1	160

Analysis

Laboratory analysis is in process and the results will be presented in the next report.

2.2.10 GREEN RIVER BASIN (WYOMING AND COLORADO)

The Greater Green River Coal Region, Figure 2-4, occupies about 21,000 square miles in southeastern Wyoming and northwestern Colorado and includes the following structural units: the western Wyoming thrust belt, the Green River basin, the Rock Springs uplift, the Great Divide basin and the Washakie basin. This coal region contains significant quantities of both bituminous and subbituminous coal with the total original in-place resource estimated at more than 80 billion short tons. This coal is found in both upper Cretaceous and Tertiary units which crop out on the flanks of the surrounding uplifts and dip into the basinal areas. Very little is known about the quantity and stratigraphic distribution of coals in the deeper part of the basins. Therefore, the estimate of the total quantity of coal in this region is believed to be conservative. The following is a summary of the geology, coal resources and potential coalbed methane resource in the various structural units that make up this region.

The area in the western Wyoming thrust belt which contains coal outcrops is called the Hams Fork coal region. This coal region is the fifth largest coal producing area in Wyoming. Because of its location in the western Wyoming thrust belt, the structure of this region is extremely complex. The major coal-bearing units include the upper Cretaceous Frontier and Adaville Formations. Other formations containing coal are the lower Cretaceous Bear River, the upper Cretaceous Blind Bull and the Paleocene Evanston. Coals in this area range from about 3 to 118 feet in thickness and are subbituminous to high volatile C bituminous in rank. The total estimated original in-place coal resource, both bituminous and subbituminous, in the Hams Fork coal region is approximately 5 billion short tons. The estimated potential coalbed methane resource from this area ranges from approximately 9.3 billion cubic feet to 1.9 trillion cubic feet.

The Green River basin which is located in southwestern Wyoming between the western Wyoming thrust belt and the Rock Springs Uplift is a broad synclinal area of about 10,000 square miles. Only minor coals outcrop in the basin, but it is probable that substantial coal resources are present in the subsurface. However, presently, very little is known about the quantity and stratigraphic distribution of coals in the subsurface. Until more is known about the quantity of coal in the subsurface, any estimate of the potential methane resource would probably be extremely conservative. Upper Cretaceous Mesaverde group coal from one well in this basin has been sampled for desorption and yielded between 420 and 524 cubic feet of methane per ton of coal. These values are very high.

The Rock Springs Uplift is a north-south trending anticlinal feature of Laramide age, located in the center of Sweetwater County, Wyoming. The principal coal-bearing units in the area of the Rock Springs Uplift include the upper Cretaceous Rock Springs and Almond Formations of the Mesaverde group, the upper Cretaceous Lance Formation, and the Paleocene

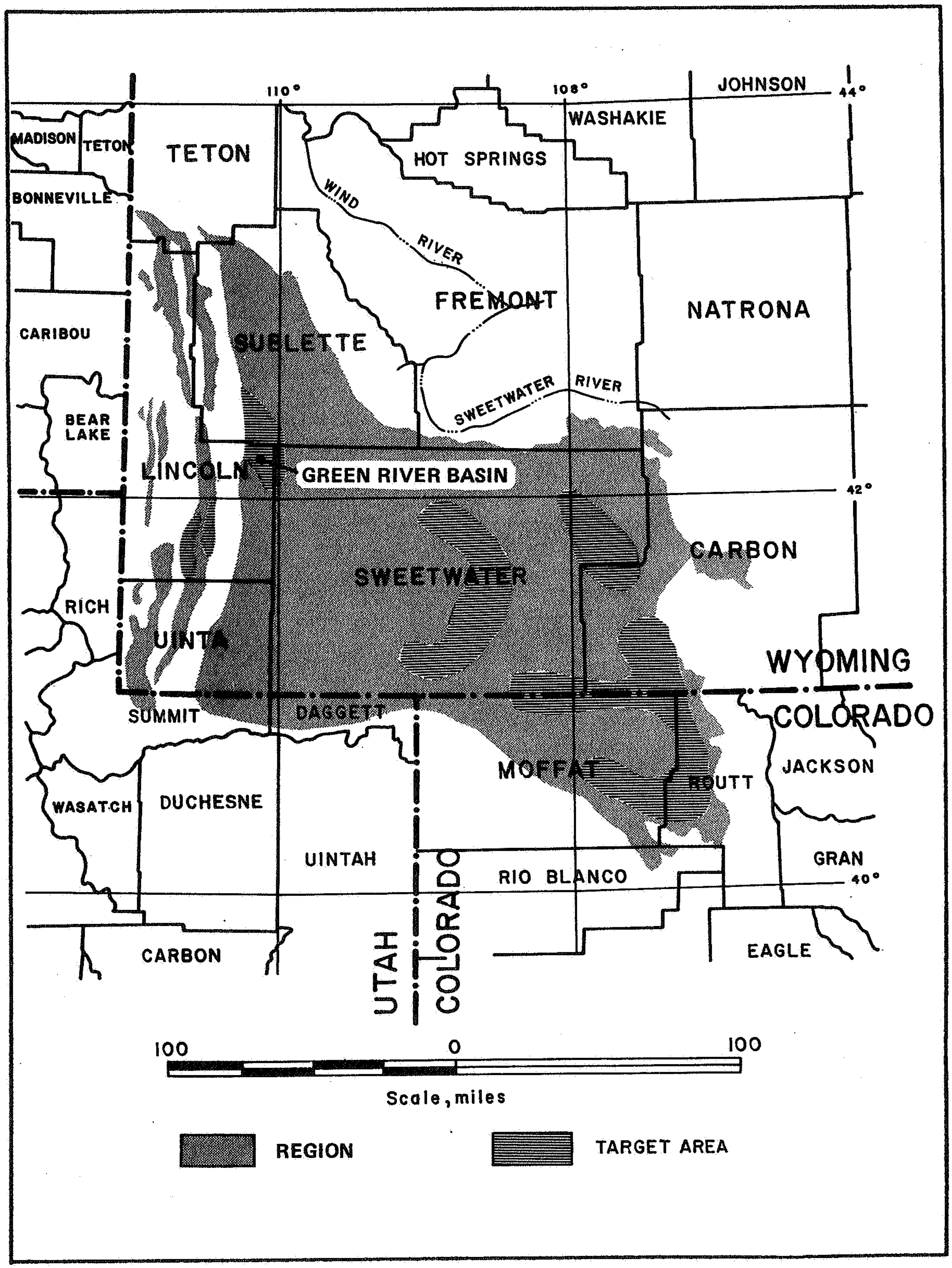


Figure 2-4. Greater Green River Coal Region

Fort Union formation. Coals from these formations are generally subbituminous B to high volatile C bituminous in rank, and average about 5 to 6 feet in thickness. The estimated total original in-place coal resource of this area, both bituminous and subbituminous, is approximately 13 billion short tons and the estimated potential methane resource is between 29 billion cubic feet and 5.5 trillion cubic feet.

The Great Divide basin, which is located in the northeastern part of Sweetwater County, Wyoming, is a large synclinal basin modified by broad shallow folds and widespread smallscale faults. The major coal-bearing unit in the Great Divide basin is the Eocene Wasatch formation. Coals in this formation are best developed in the southeastern and central parts of the basin where it is estimated that there is approximately 1.6 billion short tons of subbituminous coal within 3000 feet of the surface. The estimated potential coalbed methane resource of this basin ranges up to 160 billion cubic feet.

The Washakie basin is a broad syncline which covers an area of about 3000 square miles in south central Wyoming and northwestern Colorado. In the primary Washakie basin the major coal-bearing units are the upper Cretaceous Mesaverde Group and the Eocene Wasatch formation. These coals range in thickness from about 3 feet to 32 feet and are lignite to high volatile C bituminous in rank. The estimated total original in-place coal resource in this basin is approximately 23 million short tons of bituminous coal and 1.9 billion short tons of subbituminous coal. The estimated potential coalbed methane resource ranges from 67 million cubic feet to 200 billion cubic feet.

The Sand Wash Basin, is a southeasterly trending synclinal prong of the Washakie Basin. The major coal-bearing units in this basin are the upper Cretaceous Williams Fork and Iles Formations of the Mesaverde group, and the Paleocene Fort Union Formation. These coals range in thickness from about 2 to 20 feet and are subbituminous B to high volatile C bituminous in rank. The total estimated original in-place coal resource from this group is approximately 58 billion short tons. The potential total coalbed methane resource is estimated to range from 116 billion cubic feet to 23 trillion cubic feet.

The current MRCP target areas of interest within the Greater Green River Coal Region are shown in Figure 2-4. As of the end of the reporting period, two sites had been investigated in this area. Results of these field tests are summarized in the following paragraphs. Activities conducted in prior reporting periods are updated/corrected where appropriate.

GREEN RIVER BASIN, SITE AA
SPECIFIC PROJECT LOCATION CONFIDENTIAL (CONFIDENTIAL WELL #1)

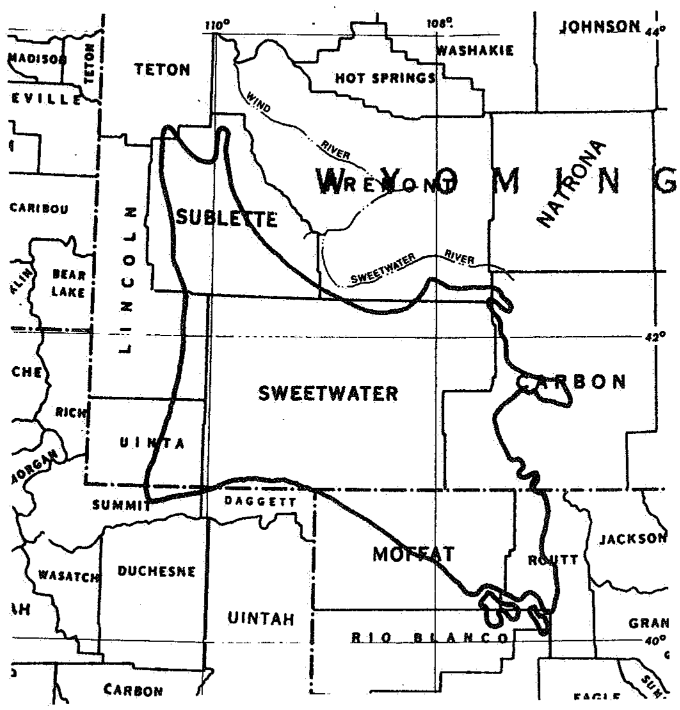
Cooperating Company:
Confidential

Status:
Field Activity Complete
Analysis Active

Field Work Performance Period:	**November, 1978**
Principal Investigator:	**C.T. Rightmire (TRW)**
DOE Technical Project Officer:	**H.D. Shoemaker**

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 REGION
SPECIFIC PROJECT LOCATION CONFIDENTIAL

SITE LOCATION

The specific location of well Site AA in the Green River Basin is currently confidential. This well is designated Confidential Well #1.

SCOPE OF WORK

The geologic target for the investigation is the Mesaverde Formation in the Green River Basin.

Field Activity

Single well drilling, logging, conventional coring, drill stem testing, and sidewall coring.

Analysis

Gas desorption and laboratory analysis (proximate/ultimate, heating value, and sulfur forms).

PROGRESS PRIOR TO APRIL 1979

Field work was performed in November 1978 during the original drilling of the well to 6540 feet.

Conventional Coring

Data were obtained from 16.2 feet of coal ranging in depth from 3652 to 4706 feet. Core and coal intervals are tabulated below:

Core intervals (ft) (30 foot core barrel)	3642-3702 (60), 3923-3953 (30), 4649-4679 (30), 4679-4709 (30) Total core 139 ft
Coal intervals (ft)	3652-3652.6 (0.6), 3674.7-3676.1 (1.4), 3923-3924.1 (1.1), 3937-3937.2 (0.2), 3947.9-3948.2 (0.3), 4649-4659.8 (10.8), 4660.8-4661 (0.2), 4704.4-4706 (1.6) Total coal 16.2 ft

Sidewall Coring

26 cores were obtained at depths ranging from 3683 to 4988 feet.

Drill Stem Tests

Two drill stem tests were performed: the first after 30 feet of conventional coring, the second after all conventional coring was completed.

DST #1 - November 19 and 20, 1978

Interval tested: 3700 - 3800 feet

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

DST #2 - November 29, 1978

Interval tested: 4634 - 4714 feet

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

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

Logging

The well was logged on December 2 by Schlumberger (compensated neutron. caliper, natural gamma, borehole compensated sonic, and dual induction).

Gas Desorption

Preliminary gas desorption data and gas-in-place estimates, previously reported, have been updated/corrected where appropriate and presented below with other current and newly acquired data.

Gas-In-Place Simulation

Reservoir simulation for the upper zone tested resulted in (1) a gas-in-place estimate of 1.8 to 4.0 Bcf per square mile (640 acre section) and (2) a cumulative discounted 10 year gas deliverability, Ø, estimate 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 gas deliverability, Ø.

PROGRESS THIS REPORTING PERIOD

Analysis of the results of the Green River Site AA field activities was continued.

Gas Desorption

Gas desorption data for conventional and sidewall core tests are summarized in Tables 2-5 and 2-6. Conventional core desorption continues and results will be presented in the next report.

Table 2-5. Preliminary Data from On-Going Conventional Core Desorption of Samples from Green River Basin Site AA as of July 31, 1979.

SAMPLE DEPTH (FEET)	LITHOLOGY	GAS IN PLACE (CC/GM)	(CF/TON)
3675	COAL	7.6	245.2
3923	COAL	1.9	62.4
3937	COAL	2.8	88.3
3948	COAL	2.2	70.4
4655	COAL	7.7	246.1
4656	COAL	6.8	219.2
4657	COAL	8.4	268.8
4658	COAL	8.4	268.8
4659	COAL	7.3	233.6
4660	COAL	9.2	293.7
4708	COAL	8.9	235.7
4906	COAL	10.6	340.3

Table 2-6. Preliminary Data from On-Going Sidewall Core Desorption of Samples from Green River Basin Site AA as of September 30, 1979.

SAMPLE DEPTH (FEET)	LITHOLOGY	GAS IN PLACE (CC/GM)	GAS IN PLACE (CF/TON)
4984	COAL	4.5	144.0
4982	VERY CARBONACEOUS SHALE	2.8	89.9
4980	COAL W/SHALE	4.9	157.4
4978	COAL	4.9	157.4
4976	COAL	4.3	142.0
4872	COAL	5.6	178.5
4868	COAL	4.9	157.4
4864	COAL	6.6	209.9
4986	COAL	4.2	132.8
4814	COAL	5.9	189.6
4720	COAL	4.3	136.0
4666	COAL	5.6	178.5

GREEN RIVER BASIN, SITE AB
SUBLETTE COUNTY, WYOMING

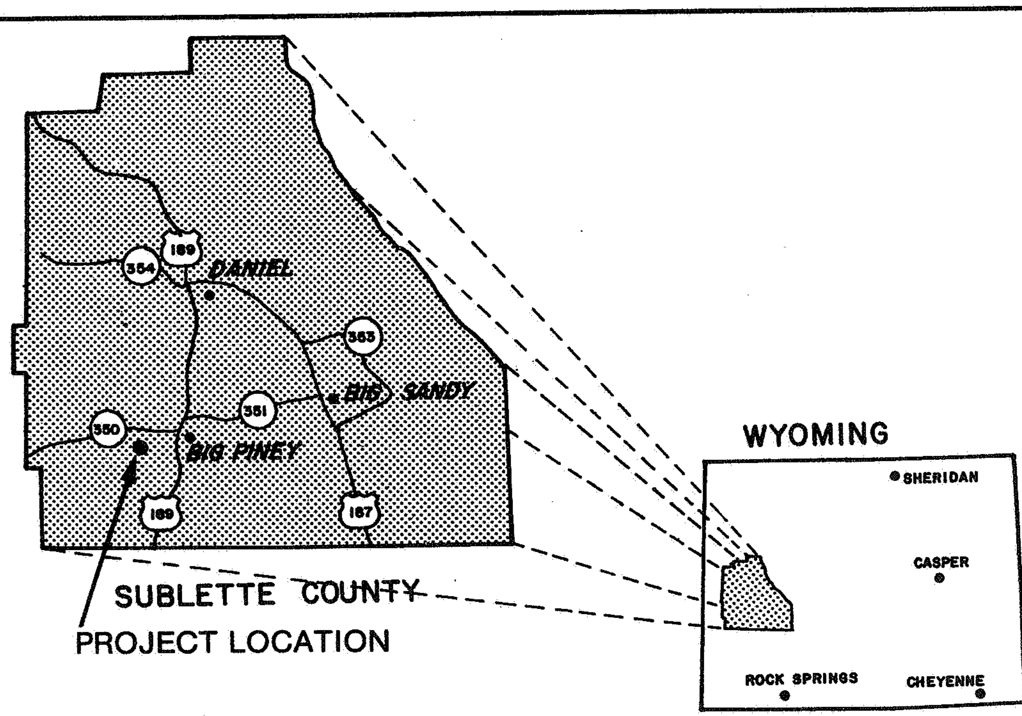
Cooperating Company:
Belco Petroleum Company
Lakewood, Colorado

Status:
Field Activity Complete
Analysis Active

Field Work Performance Period:	January, 1979
Principal Investigator:	C.T. Rightmire (TRW)
DOE Technical Project Officer:	H.D. Shoemaker

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.



SITE LOCATION

Belco Petroleum Corporation well S-29-27 located in Section 28, Township 30N, Range 11W, Sublette County, Wyoming.

SCOPE OF WORK

The geologic target for this investigation is the Mesaverde Formation in the Green River Basin.

Field Activity

Single well drilling, conventional coring, logging, sidewall coring, and drill stem testing (cancelled).

Analysis

Gas desorption and laboratory analysis (proximate/ultimate and gas-chromatograph).

PROGRESS PRIOR TO APRIL 1979

Field work was performed in January 1979 during the original drilling of the well to 7298 feet.

Conventional Coring

Conventional coring (30 foot core barrel) was performed on January 11 and 12. Core intervals showing a total of 5.6 feet of coal were ob- .ined as follows:

Date	Core Interval (ft)	Coal Interval (ft)
January 11	3450 - 3480.6 (30.6)	3479.1 - 3481.4 (2.3)
January 11	3480.6 - 3510.9 (30.3)	3494.8 - 3496.5 (1.7)
January 12	3510.9 - 3540.9 (30.0)	3526.6 - 3528.2 (1.6)

Logging

The well was logged on January 13 by Schlumberger (compensated sonic, gamma-ray, dual induction - SFL, compensated neutron and formation density).

Drill Stem Testing

Drill stem testing was cancelled because of inclement weather and potential well problems.

Gas Desorption

Conventional core gas desorption was begun and continued into this reporting period (see below).

Sidewall coring was completed by Geochem and results reported as of March 11, 1979, are:

Sample Depth Range (ft)	Lithology	Gas Content (cf/ton)
3438.5	Coal (1 split)	214
3440.0 - 3485.5	Carb. Shale (3 splits)	98 - 212
3498.0 - 3499.5	Coal (3 splits)	215 - 350

Gas-In-Place Simulation

Reservoir simulation resulted in (1) a gas-in-place estimate of 6.1 Bcf per square mile (640 acre section) and (2) a cumulative discounted 10 year gas deliverability, Ø, estimate for an isolated well of between 25,000 and 90,000 Mcf. See Section 2.2.3 for a discussion of gas deliverability, Ø.

PROGRESS THIS REPORTING PERIOD

Conventional core gas desorption and analysis of the results of the Green River Site AB field activities was continued. Current information is presented below.

Gas Desorption

Conventional core gas desorption data as of May 11, 1979 is reported below. Desorption of these core samples continues and final results will be presented in the next report.

Sample Depth Range (ft)	Lithology	Gas Content (cf/ton)
3479.1 - 3495.7	Coal (5 splits)	384 - 480
3506.0 - 3519.3	Carb. Shale (2 splits)	28 - 172
3525.1 - 3526.7	Coal (2 splits)	407 - 443

Analysis

The gas chromatograph analysis was completed.

Evaluation of the proximate/ultimate analysis results is in progress and will be presented in the next report.

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

The Illinois Basin encompases an area of approximately 53,000 square miles in east-central United States, covering a large portion of Illinois and extending into southwestern Indiana and western Kentucky (Figure 2-2). This basin contains extensive bituminous coal reserves in Pennsylvanian age rocks.

The U. S. Geological Survey has estimated that the total coal resource of the Illinois Basin might be 365 billion tons. More than 75 individual coal seams have been identified in this area, 20 of which are mined. The majority of the coals are not continuous and do not maintain constant thicknesses. Individual seams range from a few inches to 15 feet in thickness over large areas. The coals outcrop at the periphery of the basin and dip gently towards the deeper central portion in southeastern Illinois and western Kentucky. Lower and upper Pennsylvanian coals are thin and discontinuous while the middle Pennsylvanian coals are thick, generally continuous, and provide the major reserves of the basin. The thin lower and upper Pennsylvanian coals have not been studied in as much detail and are not as well correlated as the thicker coalbeds of the middle Pennsylvanian. The greatest cumulative thickness of coal seams presumably occurs in the southeastern portion of the basin (near the tri-state boundary) where the thickest Pennsylvanian section occurs. All Illinois basin coal seams are covered by less than 3,000 feet of overburden, and the major coals are within 1,500 feet of the surface.

The Springfield-Harrisburg (No.5) coals in Illinois and their correlatives, Springfield V in Indiana and No. 9 coals in Kentucky, are the most extensive and uniformly thick coals in the Illinois Basin; estimated coal reserves of these coals are over 67 billion short tons. The Herrin (No. 6) coal is also thick and extensive in Illinois and contains estimated coal reserves of over 77 billion short tons. Some deeper coals, the Colchester (No. 2) which is uniformly present over the entire basin, and the Davis (No. 6), and Mannington (No. 4) occurring primarily in Kentucky, contain combined reserves estimated at over 39 billion short tons. The coal is predominantly high volatile bituminous.

A recent investigation of gas desorption data indicates that the gas content of the coals in the Illinois Basin is generally low, ranging from less than 40 to 150 cubic feet per ton. Based on limited available desorption data, minimum and maximum ranges for expected in-place gas have been made for the Danville, Herrin, Springfield-Harrisburg, and their equivalent coals. The Danville coals are anticipated to have a minimum of approximately one half trillion and a maximum of nearly 1.7 trillion cubic feet of in-place gas. Likewise, the estimated range for Herrin coal is 2.5 to 3.4 trillion cubic feet of gas; and the Springfield-Harrisburg, 2.2 to 9.9 trillion cubic feet of gas. The minimum total in-place gas resource for these three seams totals over 5 trillion cubic

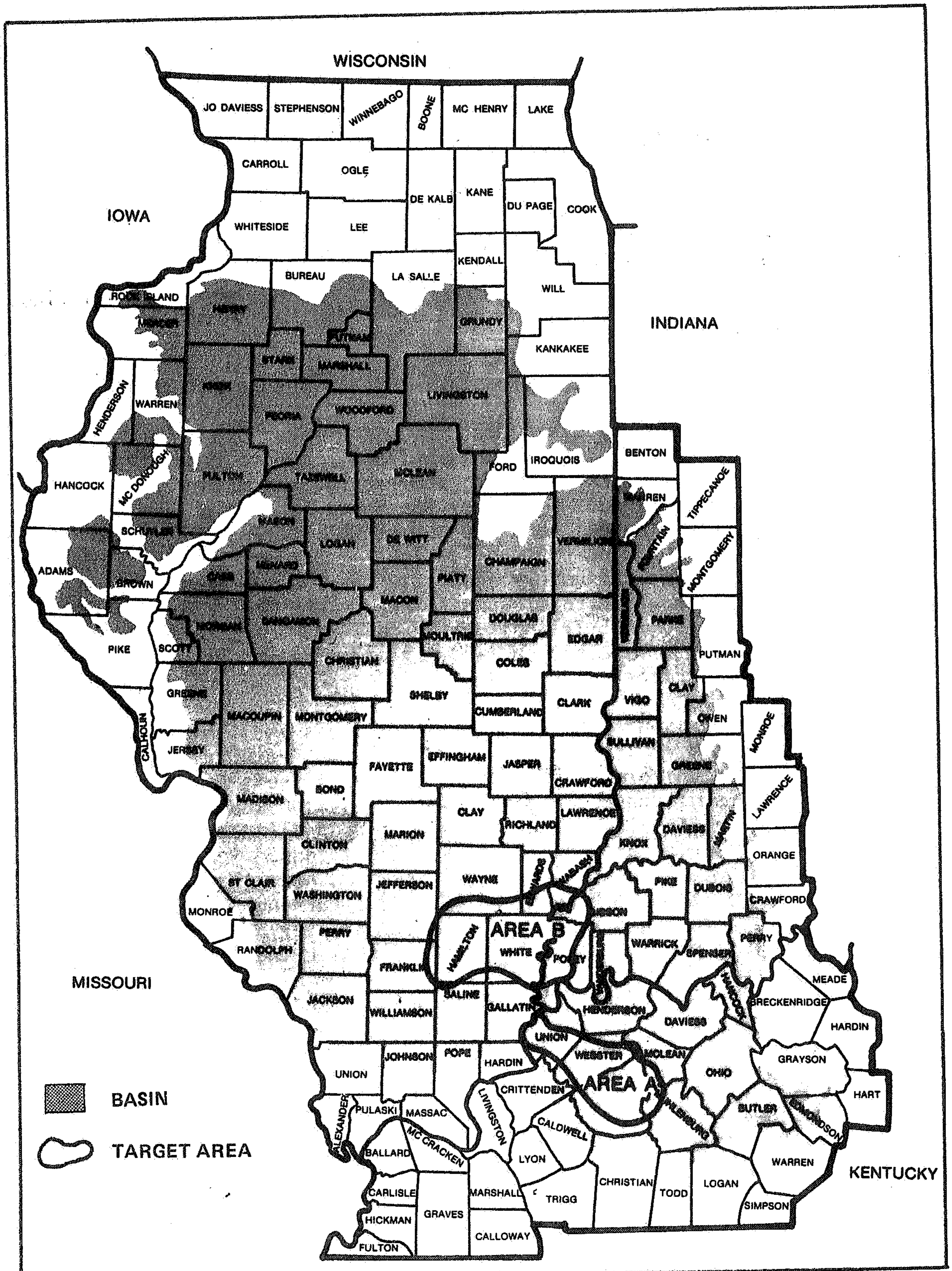


Figure 2-5. Redefined Illinois Basin Coalbed Methane Target Areas.

feet. It is assumed that the methane contained in major deeper coals (Colchester, Davis, etc.) could add significantly to this figure. It should be noted that although the specific gas content of coals in the Illinois Basin is quite low, the simple magnitude of the coal resource produces large in-place gas resource estimates.

The gas content of coals in the Illinois Basin is thought to be higher towards the southeastern portion of the basin and the initial target area defined by the MRCP for early coalbed methane delineation. Recently, the coals having the greatest probability for early commercial gas production were redefined and the primary MRCP target in the Illinois Basin now consists of two areas totalling approximately 4,300 square miles as shown in Figure 2-5.[1] Target Area A, located in western Kentucky, contains a thick section of deep coals in a highly disturbed structural belt. Target Area B, in southeastern Illinois and southwestern Indiana, retains part of the initial target area and contains previously reported gassy coals and thick coal sections at considerable depths.

As of the end of the reporting period, two sites had been investigated in the Illinois Basin. Results of these field tests are summarized in the following sections. Activities conducted in prior reporting periods are updated/corrected where appropriate.

[1]The initial MRCP target area in the Illinois Basin was approximately 9,111 square miles.

ILLINOIS BASIN, SITE AA
CLAY COUNTY, ILLINOIS

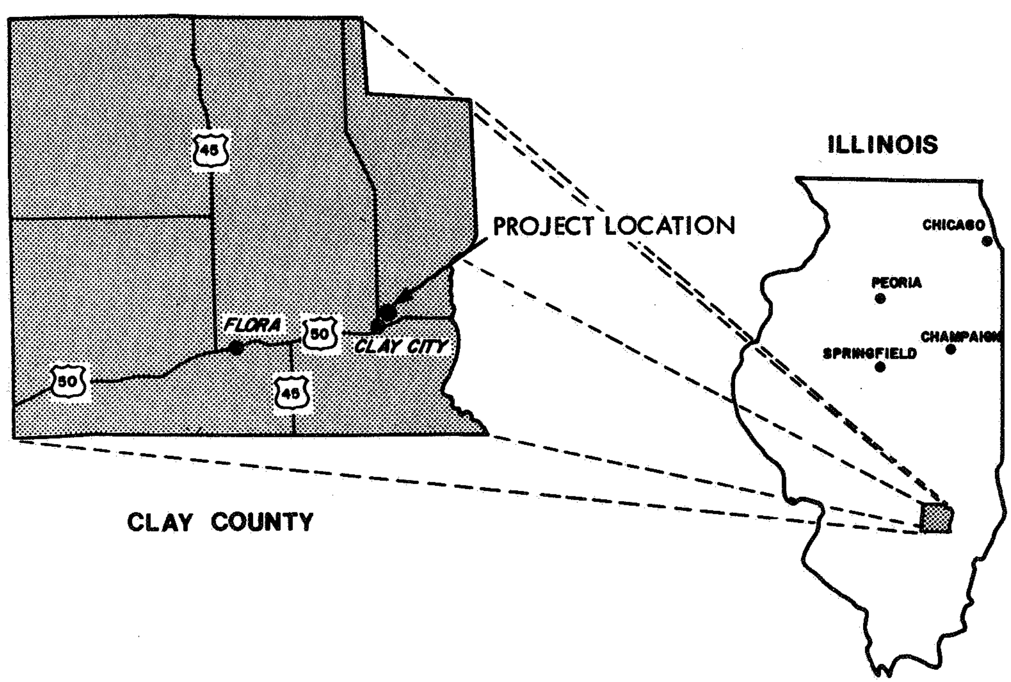
Cooperating Company:
Hagen Oil Company
Clay City, Illinois

Status:
Field Activity Complete
Analysis Active

Field Work Performance Period:	October, 1978
Principal Investigator:	C.T. Rightmire (TRW)
DOE Technical Project Officer:	H.D. Shoemaker

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.



SITE LOCATION

Hagen Oil Company Henderson No. 2 well located in Section 19, Township 3N, Range 8E, Clay County, Illinois.

SCOPE OF WORK

The geologic targets of this investigation are multiple coal horizons lying between the depths of 975 and 1,525 feet in the Illinois Basin.

Field Activity - Single well drilling, conventional coring, logging, sidewall coring and drill stem testing.

Analysis - Gas desorption and laboratory analysis (proximate/ultimate, porosity/permeability).

PROGRESS PRIOR TO APRIL 1979

Field activities were performed in late October 1978 during the original drilling of the well.

Conventional Coring

A total of 194 feet was conventionally cored (30 foot core barrel) by Christensen 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 (ft)	Thickness (ft)	Seam
994	2.8	Danville #7
1035	2.0	Herrin #6
1075	1.3	Briar Hill #5A
1090	1.5	Harrisburg #5
1352	0.5	Seelyville

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

Drill Stem Testing

Drill stem tests were performed by Lynes as follows:

Date	Coal Seam	Interval Tested (ft)	Shut In Pressure (psig)
October 27	Seelyville	1342 - 1354	479 - 466
October 28	Briar Hill No. 5A	1071 - 1083	239 - 176
October 28	Herrin No. 6	1026 - 1038	

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.

Gas Desorption

Desorption of the conventional core coal samples indicated gas content ranging from 32 cf/ton to 48 cf/ton.

Logging

The well was logged by Schlumberger on October 28 (induction, porosity, density, sonic, and fracture identification).

Sidewall Coring

Preliminary sidewall core gas desorption data indicated a gas content of 27.7 cf/ton in the Danville No. 7 seam. Attempts to sidewall core other seams was aborted due to zero return.

Gas-In-Place Estimate - Simulation

Reservoir simulation resulted in (1) a gas-in-place estimate of 0.2 Bcf per square mile (640 acre section) and (2) a cumulative discounted 10 year gas deliverability, Ø, estimate for an isolated well of between 1,000 and 2,000 Mcf. The estimate for deliverability was based on a permeability of less than 2 md and a pressure of 569 psia. See Section 2.2.3 for a discussion of gas deliverability, Ø.

Analysis

Based on the preliminary interpretation of desorption and drill stem test data, it was concluded that the coal seams tested in this portion of the Illinois Basin were not attractive as potential coalbed methane sources or reservoirs. Results of the drill stem tests of those intervals tested indicate low effective permeability and transmissibility.

PROGRESS THIS REPORTING PERIOD

Gas Desorption

Conventional core gas desorption yields the following gas contents, changed little from that previously reported:

Depth of Sample	Lithology		Gas Content (cf/ton)
994	Coal	Danville No. 7	42
995	Coal	Danville No. 7	38
1035	Coal	Herrin No. 6	29
1036	Coal	Herrin No. 6	35
1034	Shale	(roof rock)	10
1077	Coal	- Briar Hill No. 5A	32
1090	Coal	- Harrisburg No. 5	38
1352	Coal	- Seelyville	48

Analysis

Analysis of the results of the Illinois Basin Site AA field activities was completed. Proximate/ultimate laboratory analysis is complete. Analyses of porosity/permeability is also complete: porosity is estimated to be between 3 and 7 percent; permeability is less than 0.1 md.

ILLINOIS BASIN, SITE AB
MARION COUNTY, ILLINOIS

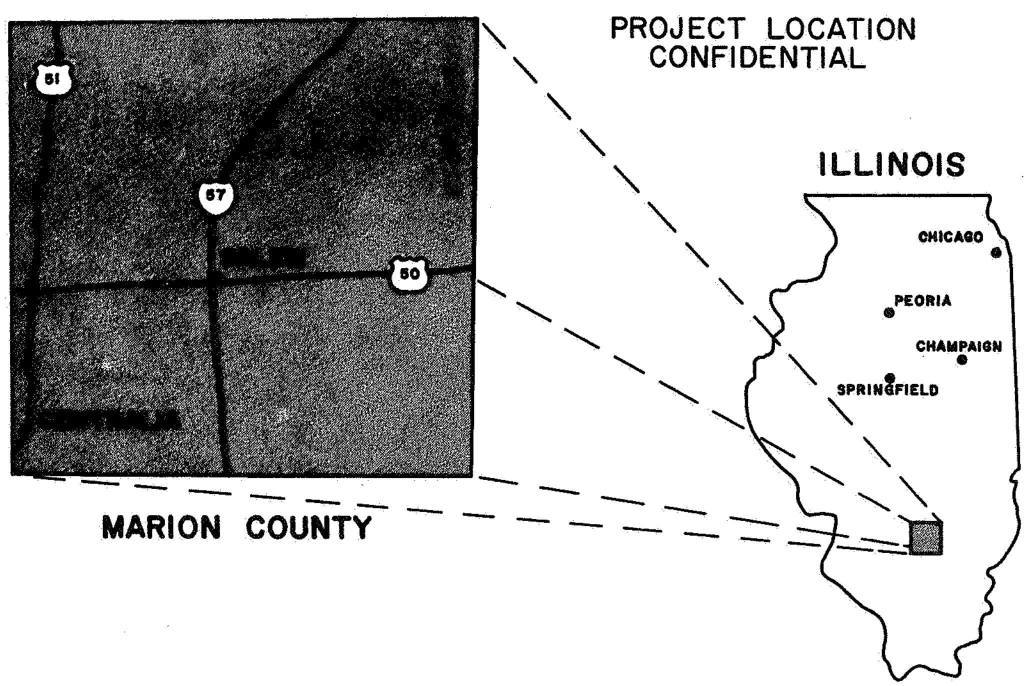
Cooperating Company:
GeoWest, Inc.
Billings, Montana

Status:
Field Activity Complete
Data Analysis Active

Field Work Performance Period:	**May, 1979**
Principal Investigator:	**C.T. Rightmire (TRW)**
DOE Technical Project Officer:	**H.D. Shoemaker**

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.



SITE LOCATION

GeoWest, Inc. well located in Marion County, Illinois. The specific location is confidential.

SCOPE OF WORK

The geologic targets for this investigation are multiple coal seams in the Illinois Basin.

Field Activity - Single well drilling, logging and coring.

Analysis - Gas desorption, and laboratory analysis.

PROGRESS THIS REPORTING PERIOD

Field work was performed in May 1979.

Coring

The well was drilled and cored on May 14-16 with the following results:

Seam	Depth (ft)	Thickness (ft)
Danville No. 7	663.7	2.8
Herrin No. 6	698.0	5.1 (Upper part of seam drilled through)
Briar Hill No. 5A	727.0	0.9
Harrisburg No. 5	732.4	4.0

Logging

The well was logged on May 16 (electric, gamma-ray, gamma-gamma density, and caliper).

Drill Stem Testing

Drill stem testing was aborted because of hole sloughing.

Gas Desorption

Gas desorption of the core samples is complete; however, determination of the remaining gas is in process. The gas content results are:

Depth of Sample	Unit	Gas Content* (cf/ton)
664.8	Danville No. 7 coal	22
698.0	Herrin No. 6 coal	29
727.0	Briar Hill No. 5A coal	13
735.7	Harrisburg No. 5 coal	29
733.4	Harrisburg No. 5 coal	29
732.4	Harrisburg No. 5 coal	16

*Excluding residual gas

Analysis

Porosity/permeability analysis and bulk density determination of mine roof and floor rock samples are complete.

Proximate/ultimate laboratory analyses are in process.

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 generally thin, less than 10 feet thick, but continuous over large areas. 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 current 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.

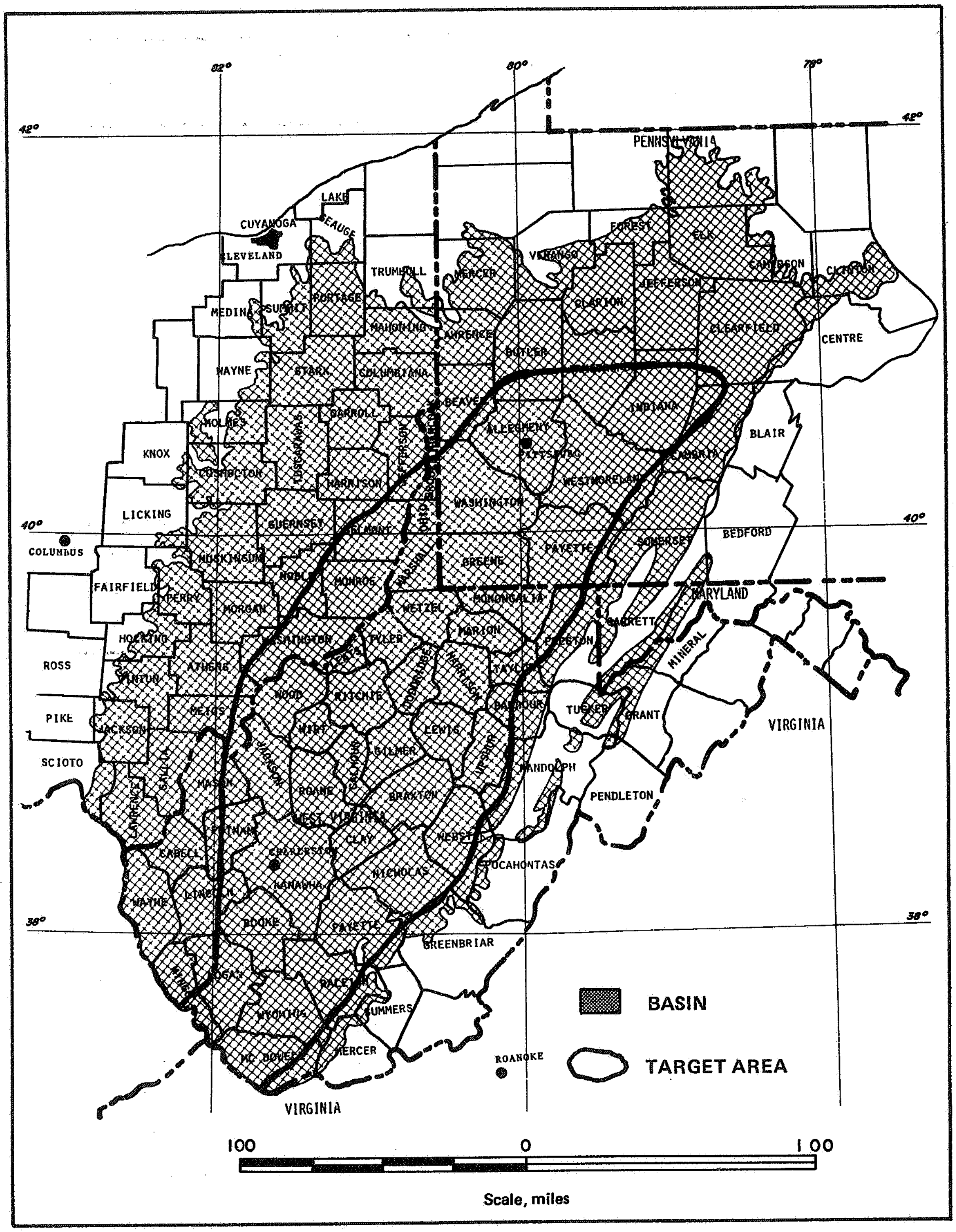


Figure 2-6. Northern Appalachian Basin Target Area.

NORTHERN APPALACHIAN BASIN, SITE AA
GREENE COUNTY, PENNSYLVANIA

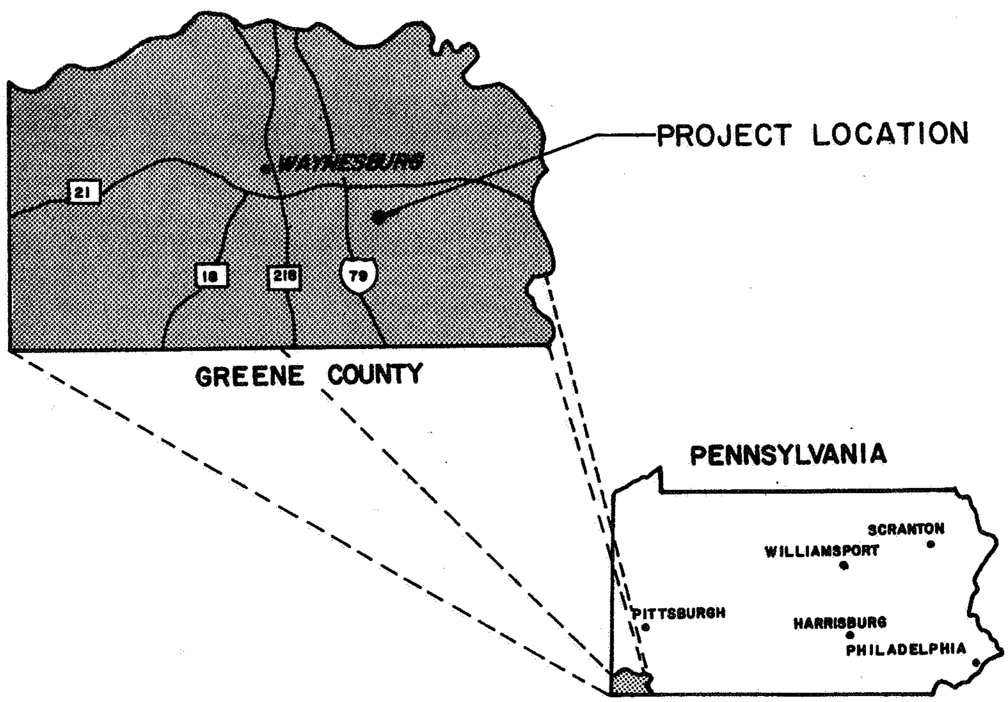
Cooperating Company:
Kinloch Development Company
Langley Park, Maryland

Status:
Active

Field Work Performance Period: April-June 1978
Principal Investigator: C.T. Rightmire (TRW)
DOE Technical Project Officer: H.D. Shoemaker

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.



SITE LOCATION

Kinloch Development Company Murdoch #1 well located approximately one mile north of Fordyce along Frosty Run in Whiteley Township, Greene County, Pennsylvania.

SCOPE OF WORK

The geologic target of this investigation is the several coal seams in extreme southwestern Pennsylvania.

Field Activity - Single well drilling, logging, sidewall coring and stimulation with pre- and post-fracture flow tests.

Analysis - Gas desorption.

PROGRESS PRIOR TO APRIL 1979

This well was drilled in early April 1978 and field activities continued through June 1978. Data was acquired and evaluation of field activities was initiated.

PROGRESS THIS REPORTING PERIOD

Evaluation and analysis of all data is complete.

Gas Desorption

Desorption of the sidewall core samples show that the gas content of coal seams encountered ranges from 33.3 to 425.6 cf/ton, with higher values from samples of the lower coals.

Well Stimulation

A prefracture water injection test through acidized perforations indicated permeabilities of 0.5 to 1.0 md depending on the zone tested.

A three stage Kiel hydraulic stimulation of the well was performed at 3800 - 3900 psi (well above design) by introducing 1533 barrels of fluid containing 18,480 pounds of 80-100 mesh sand and 15,750 pounds of 20-40 mesh sand.

After stimulation water flow from the well was about 80 barrels of water per day with a show of gas. A sucker rod pump was installed; however, no water or gas monitoring equipment was installed and quantitative measure of fluid production could not be made.

NORTHERN APPALACHIAN BASIN, SITE AB
GREENE COUNTY, PENNSYLVANIA

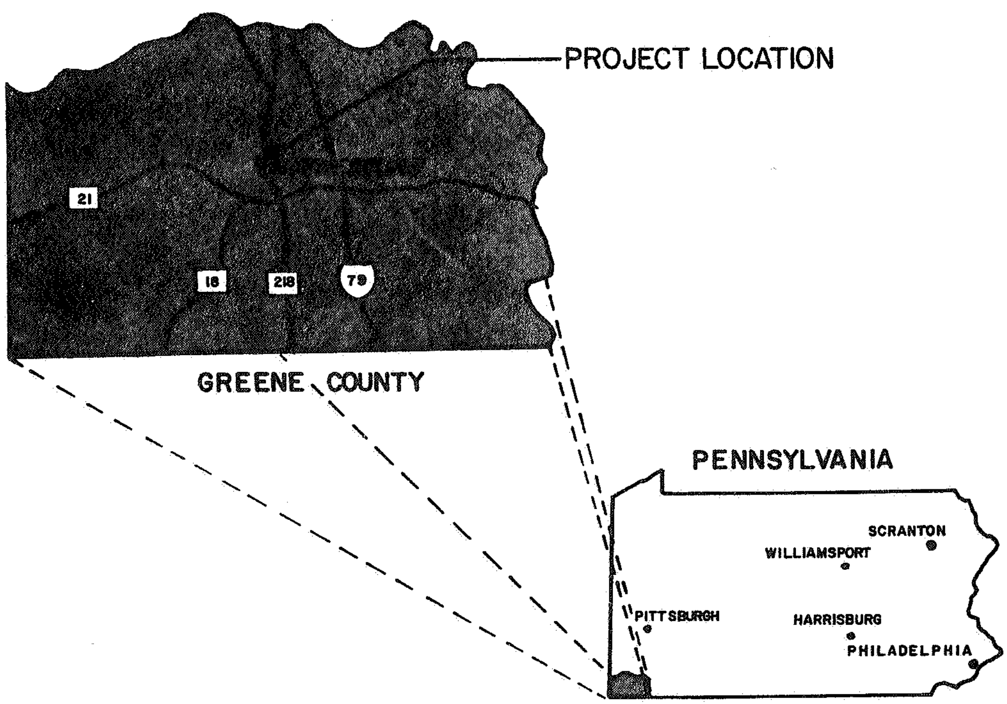
Cooperating Company:
Waynesburg College
Waynesburg, Pennsylvania

Status:
Active

Field Work Performance Period:
Principal Investigator: N.F. McGinnis (TRW)
DOE Technical Project Officer: H.D. Shoemaker

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.



SITE LOCATION

Waynesburg College well located on the Purman Run Tract on the campus just north of Waynesburg, Pennsylvania.

SCOPE OF WORK

The geologic target of this investigation is the coal seams of the Monongahelia, Conemaugh, and Allegheny Groups in extreme southwestern Pennsylvania.

Field Activity - Single well drilling (multiple completion), conventional coring, logging, and stimulation and gas flow tests.

Analysis - Analyses to include: proximate/ultimate analysis gas desorption, and rock strength testing.

PROGRESS PRIOR TO APRIL 1979

Resource delineation planning was initiated in conjunction with a Technology Test project planned at this sight (Reference: Section 2.4.7).

PROGRESS THIS REPORTING PERIOD

Planning was continued. Well drilling is scheduled for the last quarter of CY 1979, and the coalbed methane delineation results will be presented in the next report.

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 approximately 60 billion tons. Individual beds range from a few feet to 20 feet thick, but average about 10 feet thick. The coal is of subbituminous 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 approximately 6,700 feet.

The current MRCP target area of interest within the Piceance Basin is shown in Figure 2-7. As of the end of the reporting period, eight sites had been investigated in the Piceance Basin. Results of these field tests are summarized in the following paragraphs. Activities conducted in prior reporting periods are updated/corrected where appropriate.

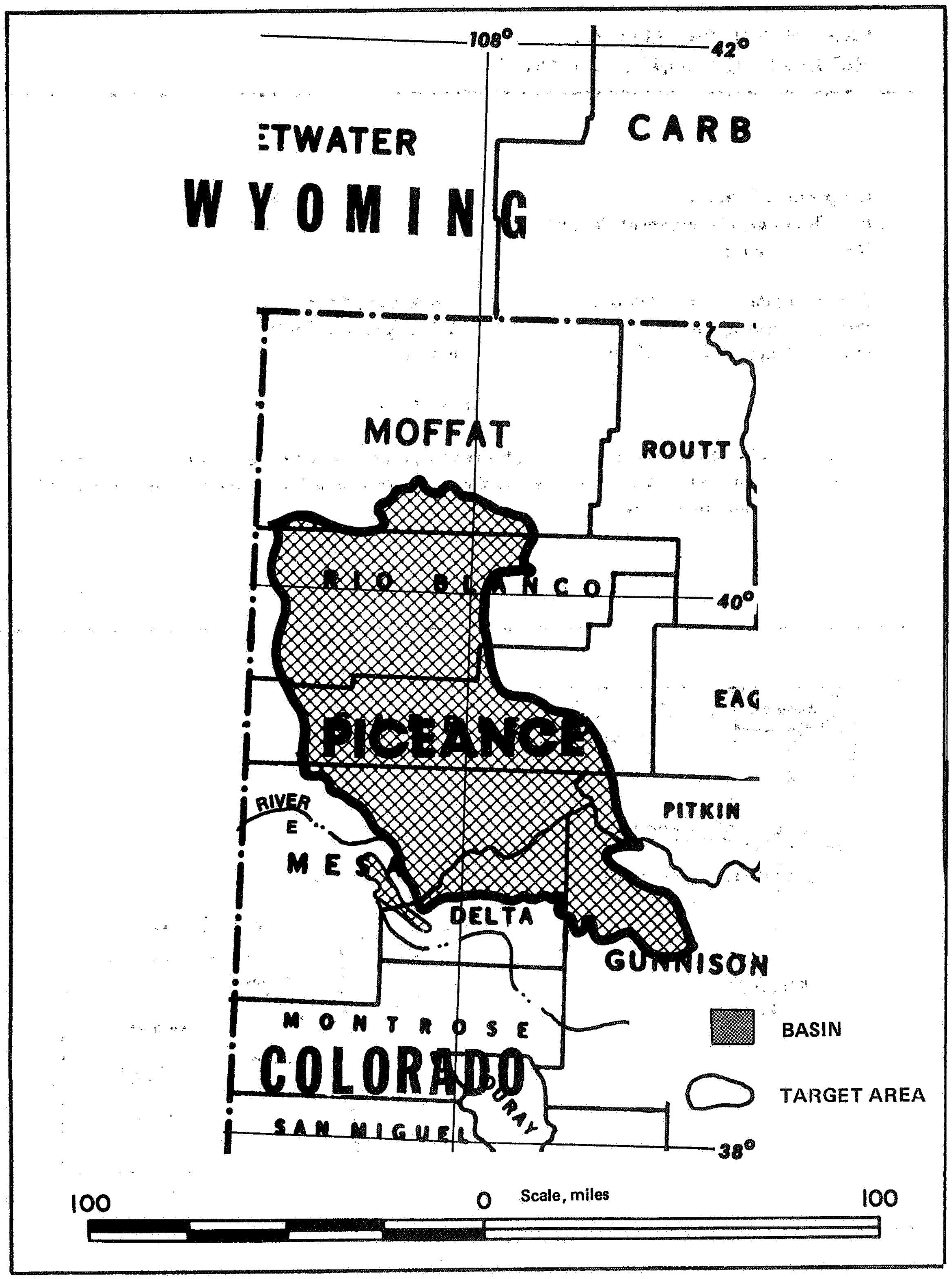


Figure 2-7. Piceance Basin Target Area.

PICEANCE BASIN, SITE AA
RIO BLANCO COUNTY, COLORADO

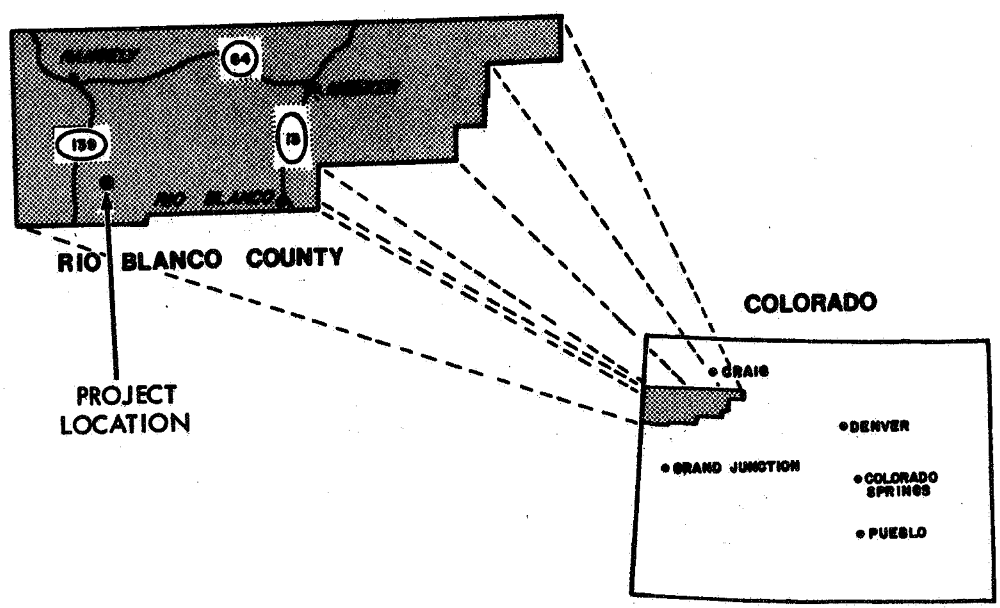
Cooperating Company:
Fuel Resources Development Company
Denver, Colorado

Status:
Active

Field Work Performance Period:	September, 1978
Principal Investigator:	C.T. Rightmire (TRW)
DOE Technical Project Officer:	H.D. Shoemaker

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.



SITE LOCATION

Fuel Resources Development Company (Fuelco) well Cathedral 0-28-3-101-S located in Section 28, Township 3S, Range 101W, Rio Blanco County, Colorado.

SCOPE OF WORK

The geologic target of this investigation is the coal-bearing Lower Mesaverde Group sediments in the Douglas Creek Arch area of the Piceance Basin.

Field Activity - Single well drilling, conventional coring and logging.

Analysis - Gas desorption and laboratory analysis (proximate/ultimate, heating value, and sulfur forms).

PROGRESS PRIOR TO APRIL 1979

The well was drilled, cored, and logged in September 1978; however, the primary objective coals were not encountered because of unexpected structural complexities. Less than five feet of coal was cored between 1,582 and 1,623 feet.

Gas Desorption

Two coal samples were collected by conventional coring. The resulting gas desorption data are:

Sample Depth (ft)	Total Gas (cc)	Sample Wt. (gm)	Gas Content (cc/gm)	Gas Content (cf/ton)
1585	898	1584	0.6	18
1603	364	144	2.5	81

Analysis

The laboratory analysis is complete.

SITE LOCATION

Twin Arrow Drilling Company C&K well #1-13, located in Section 13, Township 3S, Range 101W, Rio Blanco County, Colorado. Elevation 6910 feet.

SCOPE OF WORK

The geologic target of this investigation was several coal seams in the Mesaverde Formation in the Piceance Basin.

Field Activity - Pressure and flow test. Stimulation and second flow test was cancelled.

PROGRESS PRIOR TO APRIL 1979

A plug was set at approximately 1,050 feet in this well to isolate coal seams prior to testing. The well was in the process of being abandoned by Twin Arrow. The intervals tested were 573-811, 627-665, 726-736, and 801-810 feet.

Gas Flow Testing

Gas pressure and flow was negligible before and after five perforations and acid treatment. The field activity record is as follows:

- October 3. Swabbing attempted while awaiting bridge plug, unable to swab dry. Shut in.
- October 4. Bridge plug set at 1050 feet and hole swabbed dry. Hole continued to make water at 2.5 bbl/hr. Pressure and flow negligible.
- October 5. Hole cemented from top of existing cement (-1050 feet) to 320 feet.
- October 6. Cement Bond log. Perforated 5 zones at 1 shot/ft.
- October 7. Treated all zones with 7.5% MF. Total acid - 500 gal. Swabbed dry and pressure tested. Shut-in pressure zero. No flow observed through 1/8 inch orifice. Operations terminated.
- Service Contractors - Halliburton - Bridge plug, cementing, acidizing
Schlumberger - Bond log, perforating
Wellex - Original logs

Analysis

In this area the Mesaverde Formation is divided into upper and lower. Upper is brown and yellowish gray massive sandstone and gray shale with principal coalbeds near base. Lower is light gray and brown massive sandstone, gray shale and some coal. Based on Twin Arrow logs, coal is

PICEANCE BASIN, SITE AB, RIO BLANCO COUNTY, COLORADO

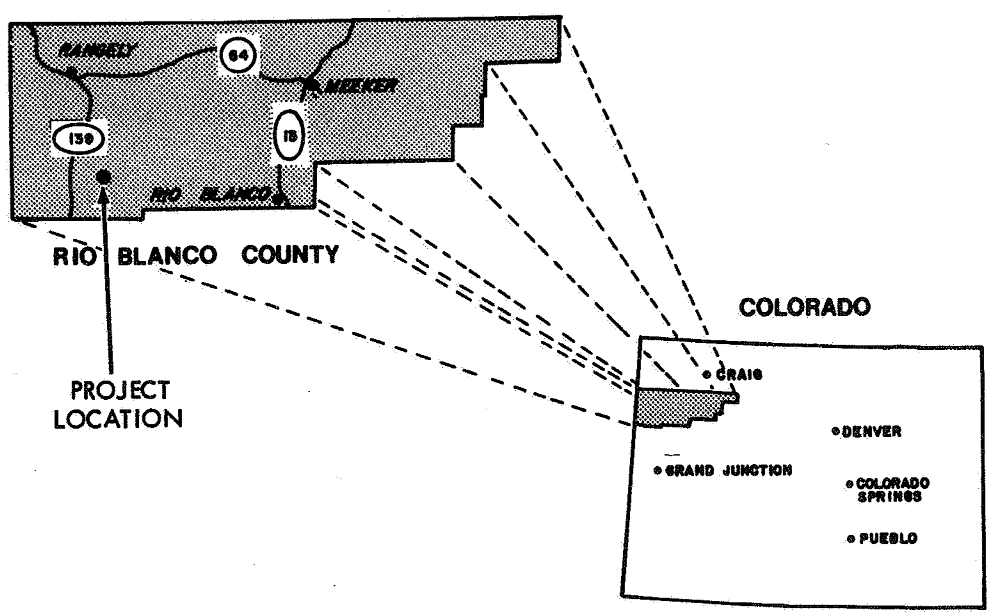
Status: Complete

Cooperating Company:
Twin Arrow Drilling Company
Rangely, Colorado

Field Work Performance Period: October, 1978
Principal Investigator: C.T. Rightmire (TRW)
DOE Technical Project Officer: H.D. Shoemaker

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.



present at 573-581, 627-633, 661-665, 726-736, 801-810. Other coal is in thinner, deeper seams and in washed out hole areas at 1278-1282, 1494-1496, 1864-1870, 2116-2119, and 2148-2154. These zones are to be tested in another well.

PICEANCE BASIN, SITE AC,
RIO BLANCO COUNTY, COLORADO

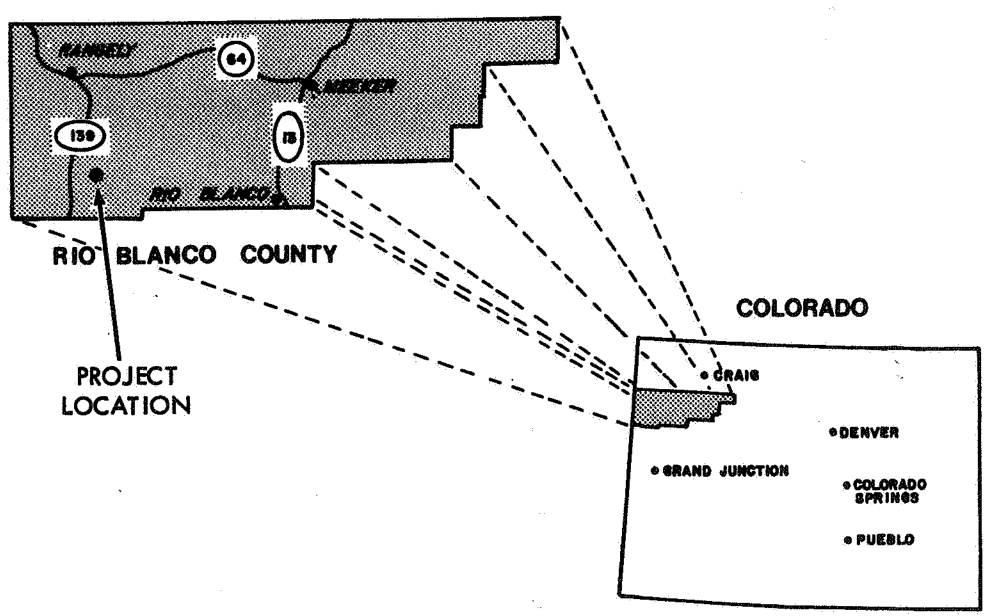
Cooperating Company:
Twin Arrow Drilling Company
Rangley, Colorado

Status:
Active

Field Work Performance Period: November—December 1978
Principal Investigator: C.T. Rightmire (TRW)
DOE Technical Project Officer: H.D. Shoemaker

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.



SITE LOCATION

Twin Arrow Drilling Company C&K well #4-14 located in Section 14, Township 3S, Range 101W, in Rio Blanco County in the Piceance Basin.

SCOPE OF WORK

The geologic target of this investigation is multiple coal seams of the Piceance Basin.

Field Activity - Single well drilling and conventional coring. Well testing was cancelled.

PROGRESS PRIOR TO APRIL 1979

Field activities were performed in November and December 1978 during the original drilling of the well to 6931 feet.

Conventional Coring

Conventional coring, spanning a six day period, totaled 150 feet and indicated coal at 9 intervals (ft):

685.2 - 685.6	772.5 - 773.8
698.1 - 698.5	801.9 - 802.6
770.9 - 771.6	804.4 - 805.0
759.2 - 760.0	809.4 - 809.7
986.5 - 987.3	

Gas Desorption

Preliminary gas desorption results are as follows:

Depth of Sample	Lithology	Gas Content (cf/ton)
685.2-685.6	Coal	151
698.1-698.5	Carb Shale/Coal	130
770.9-771.6	Carb Shale/Coal	33
759.2-760.0	Coal	156
772.3-773.6	Carb Siltstone	126
801.9-802.6	Coal	108
804.5-805.0	Carb Shale	137
809.3-809.7	Coal	339
986.5-987.3	Coal	111

Logging

Well logs could not be obtained; the hole was abandoned after unsuccessful repair procedures.

PICEANCE BASIN, SITE AD
SPECIFIC SITE LOCATION CONFIDENTIAL (CONFIDENTIAL WELL #2)

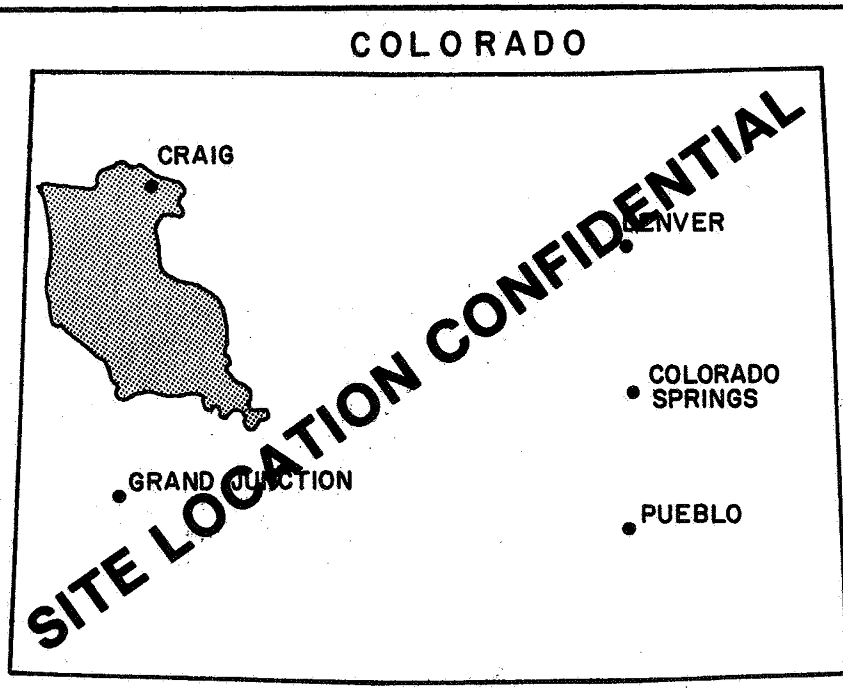
Cooperating Company:
Confidential

Status:
Field Activity Complete
Analysis Active

Field Work Performance Period: June, 1979
Principal Investigator: C.T. Rightmire (TRW)
DOE Technical Project Officer: H.D. Shoemaker

OBJECTIVE

To determine the quantity and quality of the coal, the methane content of the coal, and reservoir properties of three coal seams in the Piceance Basin to help determine the potential productivity of coalbed methane in this resource area.



SITE LOCATION

Colorado. The specific location is currently confidential.

SCOPE OF WORK

Field Activity - Well drilling, conventional coring, and logging.

Analysis - Gas desorption and laboratory analysis (proximate/ultimate, heating value, and sulfur forms)

PROGRESS THIS REPORTING PERIOD

Field activities were performed in June, 1979, during the original well drilling at 5463 feet.

Conventional Coring

Conventional coring was performed on June 19; the following coals were intercepted:

Seam	Depth (ft)	Thickness (ft)
"E"	1324.7	2.4
"D"	1330.6	8.2
"C"	1351.2	0.9

Logging

Borehole geophysical well logs were obtained on June 20 (electric, gamma-ray, gamma-gamma density, and caliper).

Gas Desorption

Preliminary gas desorption data of the conventional cores are:

Sample Depth (ft)	Total Gas (cc)	Sample Weight (gm)	Gas Content (cc/gm)	Gas Content (cf/ton)
1324.7-1325.9	2035	1558	1.3	42
1330.7-1331.7	2473	1599	1.5	49
1333.3-1334.3	2065	1614	1.3	41
1335.8-1336.8	1745	1651	1.1	34
1351.1-1352.1	2053	1453	1.4	45

Analysis

Laboratory analysis of the coal samples will be conducted and the results reported after completion of the gas desorption procedures.

PICEANCE BASIN, SITE AE
SPECIFIC SITE LOCATION CONFIDENTIAL (CONFIDENTIAL WELL #3)

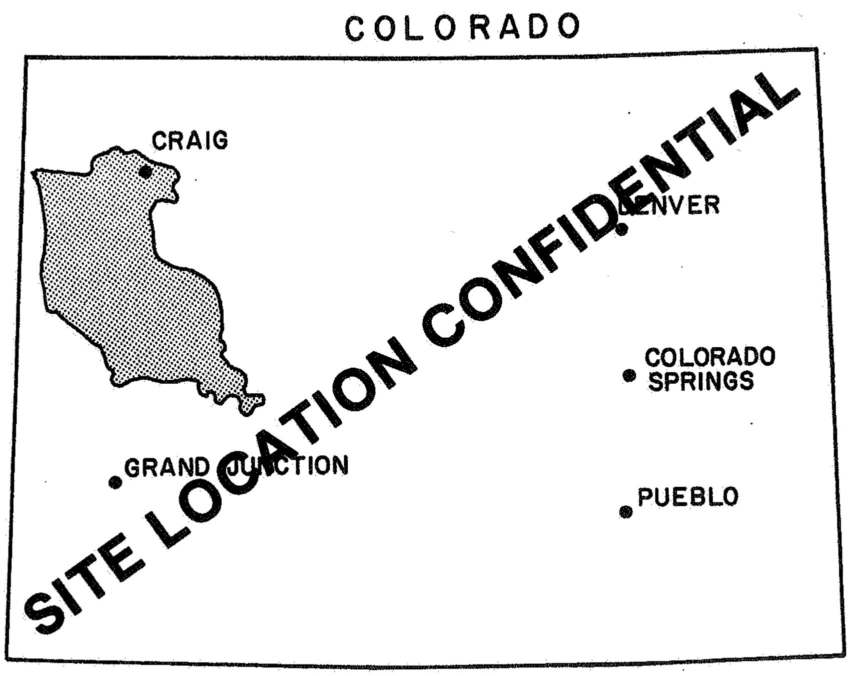
Cooperating Company:
Confidential

Status:
Field Activity Complete
Analysis Active

Field Work Performance Period:	June-July, 1979
Principal Investigator:	C.T. Rightmire (TRW)
DOE Technical Project Officer:	H.D. Shoemaker

OBJECTIVE

To determine the quantity and quality of the coal, the methane content of the coal, and reservoir properties of six coal seams in the Piceance Basin to help determine the potential productivity of coalbed methane in this resource area.



SITE LOCATION

Colorado. The specific location is currently confidential.

SCOPE OF WORK

Field Activity - Well drilling, conventional coring, and logging.

Analysis - Gas desorption and laboratory analysis (proximate/ultimate, heating value, and sulfur forms).

PROGRESS THIS REPORTING PERIOD

Field activities were performed in late June and early July, 1979 during the original well drilling to 5344 feet.

Conventional Coring

Conventional coring was performed on June 30 and July 1; the following coals were intercepted:

Seam	Depth (ft)	Thickness (ft)
"F"	741.8 - 748.2	6.4
"E"	758.7 - 761.0	2.3
"D"	764.9 - 770.0	5.1
"C"	794.6 - 796.8	2.1
"B"	797.5 - 801.5	4.0
"A"	805.6 - 811.0	5.4

Logging

Borehole geophysical well logs were obtained on July 2 (electric, gamma-ray, gamma-gamma density, and caliper).

Gas Desorption

Coal sample gas desorption from the conventional cores resulted in the following data as of September 25, 1979:

Sample Depth (ft)	Total Gas (cc)	Sample Weight (gm)	Gas Content (cc/gm)	Gas Content (cf/ton)
741.3-742.3	173	1678	0.1	3*
744.3-745.3	3145	1820	1.7	55
758.7-759.7	2303	1596	1.4	46
764.9-765.9	3105	1731	1.8	57
771.5-772.5	3125	1622	1.9	62
795.4-796.4	2483	1646	1.5	48
797.5-798.5	2225	1620	1.4	44
808.6-809.3	1330	1665	0.8	25

*Possible canister leak

Analysis

Laboratory analysis of the coal samples will be conducted and the results reported after completion of the gas desorption procedures.

PICEANCE BASIN, SITE AF
SPECIFIC SITE LOCATION CONFIDENTIAL (CONFIDENTIAL WELL #4)

Cooperating Company:
Confidential

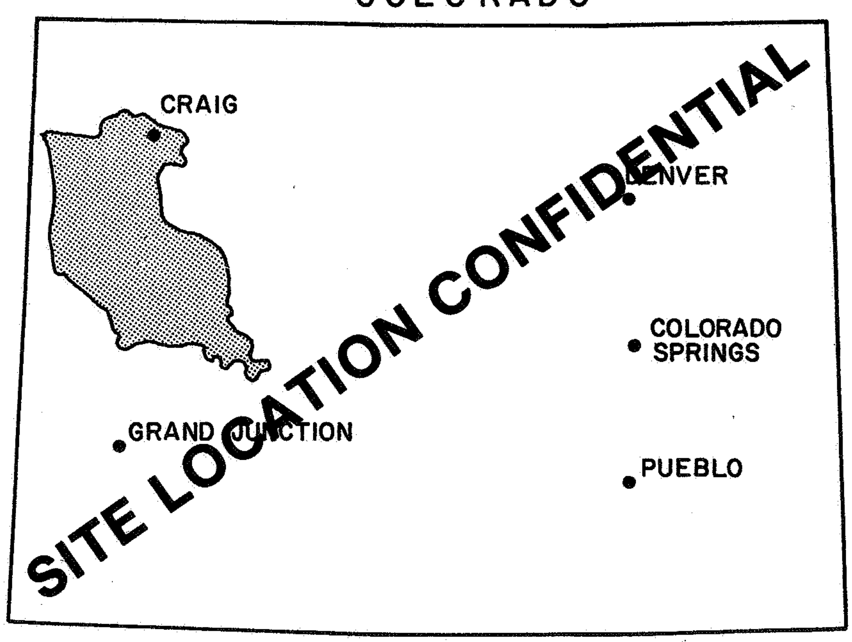
Status:
Field Activity Complete
Analysis Active

Field Work Performance Period:	**August, 1979**
Principal Investigator:	**C.T. Rightmire (TRW)**
DOE Technical Project Officer:	**H.D. Shoemaker**

OBJECTIVE

To determine the quantity and quality of the coal, the methane content of the coal, and reservoir properties of two coal seams in the Piceance Basin to help determine the potential productivity of coalbed methane in this resource area.

COLORADO



SITE LOCATION

Colorado. The specific location is currently confidential.

SCOPE OF WORK

Field Activity - Well drilling, conventional coring, and logging.

Analysis - Gas desorption and laboratory analysis (proximate/ultimate, heating value, and sulfur forms).

PROGRESS THIS REPORTING PERIOD

Field activities were performed in August, 1979 during original well drilling at 5877 feet.

Logging

Borehole geophysical logs of the pilot hole were obtained on August 26 (electric, gamma-ray, gamma-gamma density, and caliper).

Conventional Coring

Conventional coring was performed on August 28 and 29; 45 feet of core were obtained; the following seams were intercepted:

Seam	Depth (ft)	Thickness (ft)
"C"	879.2-882.5	3.3
"B"	904.3-912.0	7.7

Gas Desorption

Coal sample gas desorption from the conventional cores resulted in the following data as of September 25, 1979:

Sample Depth (ft)	Total Gas (cc)	Sample Weight (gm)	Gas Content (cc/gm)	Gas Content (cf/ton)
911.0-911.8	27	1527	<0.1	<1
904.3-905.3	50	1756	<0.1	<1
879.2-880.2	178	1483	0.1	4

Analysis

Laboratory analysis of the coal samples will be conducted and the results reported after completion of the gas desorption procedures.

PICEANCE BASIN, SITE AG
SPECIFIC SITE LOCATION CONFIDENTIAL (CONFIDENTIAL WELL #5)

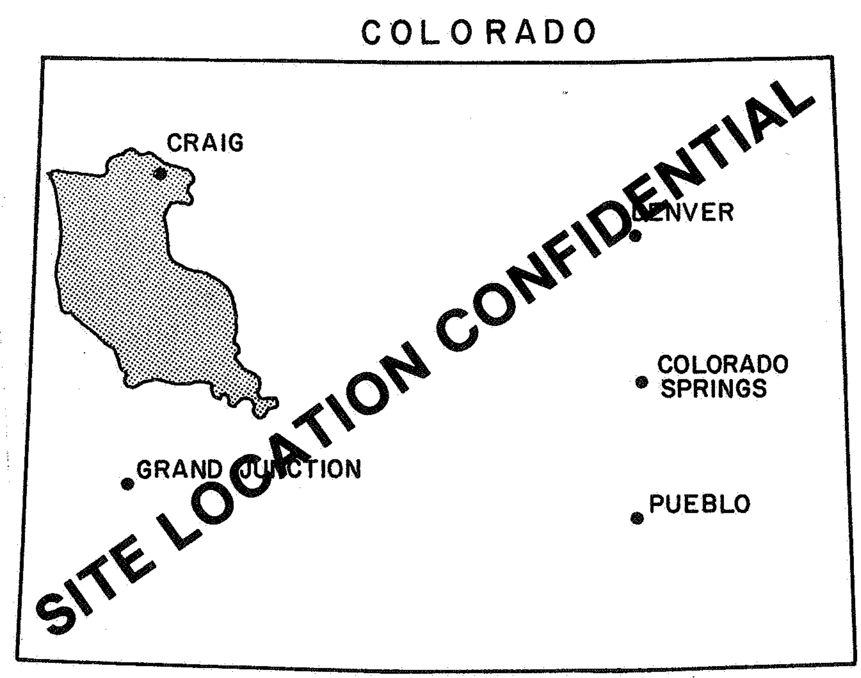
Cooperating Company:
Confidential

Status:
Field Activity Complete
Analysis Active

Field Work Performance Period:	**August, 1979**
Principal Investigator:	**C.T. Rightmire (TRW)**
DOE Technical Project Officer:	**H.D. Shoemaker**

OBJECTIVE

To determine the quantity and quality of the coal, the methane content of the coal, and reservoir properties of two coal seams in the Piceance Basin to help determine the potential productivity of coalbed methane in this resource area.



SITE LOCATION

Colorado - the specific location is currently confidential.

SCOPE OF WORK

Field Activity - Well drilling, conventional coring, and logging.

Analysis - Gas desorption and laboratory analysis (proximate/ ultimate, heating value, and sulfur forms)

PROGRESS THIS REPORTING PERIOD

Field activities were performed in August, 1979 during the original well drilling to 5562.2 feet.

Logging

Borehole geophysical logs of the pilot hole were obtained on August 25 (electric, gamma-ray, gamma-gamma density, and caliper).

Conventional Coring

Conventional coring was performed on August 29 and 30. 28.9 feet of core were obtained; the following coals were intercepted:

Seam	Depth (ft)	Thickness (ft)
"E"	1187.5 - 1191.0	3.5
"D"	1198.4 - 1206.8	8.4

Gas Desorption

Sample Depth (ft)	(Total Gas (cc)	Sample Weight (gm)	Gas Content (cc/gm)	Gas Content (cf/ton)
1191.0-1191.8	75	2783	< 0.1	<1
1205.1-1206.1	1177	2018	0.6	19

Analysis

Laboratory analysis of the coal samples will be conducted and the results reported after completion of the gas desorption procedures.

PICEANCE BASIN, SITE AH
RIO BLANCO COUNTY, COLORADO

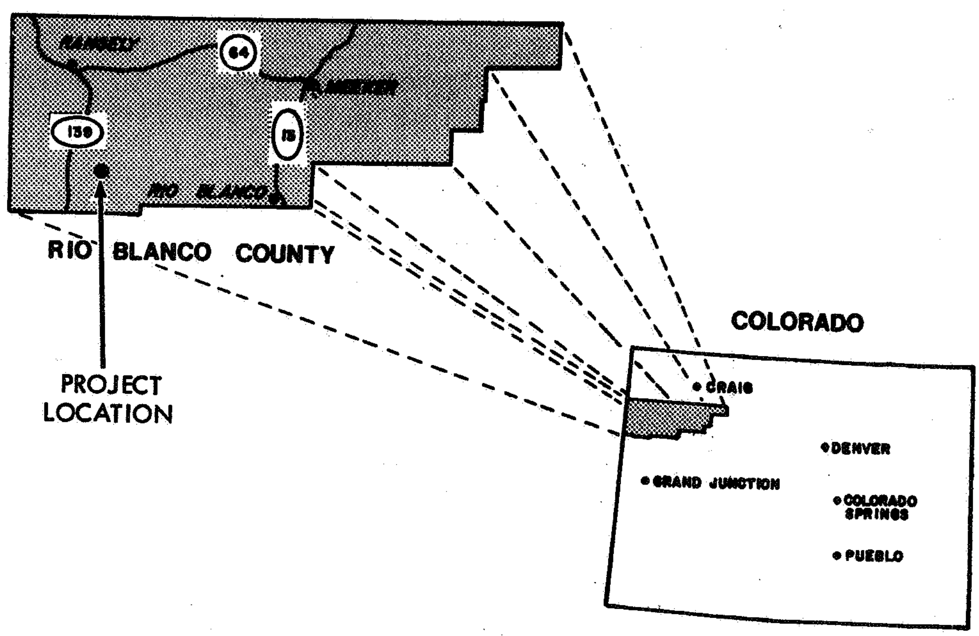
Cooperating Company:
Fuel Resources Development Company (Fuelco)
Denver, Colorado

Status:
Field Activity Complete
Analysis Active

Field Work Performance Period:	**August, 1979**
Principal Investigator:	**C.T. Rightmire (TRW)**
DOE Technical Project Officer:	**H.D. Shoemaker**

OBJECTIVE

To determine the quantity and quality of coal and the methane content of the coal in the Mesaverde Formation on the west side of the Piceance Basin.



SITE LOCATION

Fuelco Well D-26-3-101-S located in Section 16, Township 3S, Range 101W in Rio Blanco County, Colorado.

SCOPE OF WORK

The geologic target of this investigation is the coal in the Mesaverde Formation on the west side of the Piceance Basin.

Field Activity - Single well drilling, logging and coring.

Analysis - Gas desorption and laboratory analysis of the coal, roof rock, and floor rock.

PROGRESS THIS REPORTING PERIOD

Field activities were performed in mid August, 1979 during the original drilling to 7387 feet.

Conventional Coring

Conventional coring was performed on August 14 and 15. 96 feet of core were obtained as follows; the following coals were intercepted:

Seam	Depth (ft)	Thickness (ft)
"C"	1148.9 - 1151.9	3.0
"C"	1154.0 - 1159.0	5.0
"B"	1183.2 - 1185.7	2.5
"A"	1205.7 - 1206.5	0.8
"A"	1209.1 - 1217.8	8.7
Unnamed	1223.0 - 1225.0	2.0

Logging

Borehole geophysical logs were obtained (electric, gamma-ray, compensated density, and caliper).

Gas Desorption

Coal sample gas desorption from the conventional cores resulted in the following data as of September 25, 1979:

Sample Depth (ft)	Total Gas (cc)	Sample Wt (gm)	Gas Content (cc/gm)	Gas Content (cf/ton)
1211.6 - 1212.4	474	1312	0.5	16
1209.5 - 1210.5	202	1498	0.2	7
1223.0 - 1224.0	200	1249	0.3	8

Analysis

The following laboratory analyses are in process:

- Laboratory analysis of coal (proximate/ultimate, heating value, sulfur form).
- Laboratory analysis of roof rock (triaxial compressive strength with elastic properties, permeability, porosity and natural bulk density).
- Laboratory analysis of floor rock (uniaxial compressive strength, permeability, porosity and natural bulk density).

2.2.14 POWDER RIVER BASIN (WYOMING AND MONTANA)

The Powder River Basin contains the nation's largest coal resources. Most of the thick coalbeds occur in the upper member--the Tongue River Member--of the Fort Union Formation, and the overlying Wasatch Formation. Coalbeds do occur in the lower members of the Fort Union Formation, as well as the Lance and Mesaverde Formations, but they are generally thinner and less continuous. Some of these older coalbeds crop out in the southwestern portion of the Powder River Basin, near Glenrock and Douglas, Wyoming.

The coal resource of the Powder River Basin has been calculated from subsurface data to be 1.3 trillion tons. Most of it is in thick beds which are relatively near-surface--with most of the coal at a depth less than 2500 feet, even in the basin center. Powder River Basin coal ranges in rank from lignite A through subbituminous A. Generally, Powder River Basin coals are low in sulfur with low to moderate ash contents, although ash content can vary considerably. Commonly, the coals have an as-received moisture content of 20 to 30 percent, and volatile matter and fixed carbon contents of 30-40 percent.

The total number of coalbeds in the Powder River Basin is difficult to determine because the beds split, coalesce, and are sometimes discontinuous, with beds pinching out and new beds appearing. Some correlations between the beds of various fields have been made, but much remains to be done in this respect. In the Sheridan County area of Wyoming, as many as 11 persistent coalbeds occur in the Wasatch Formation. In other areas, as many as 12-18 coalbeds occur, most of them within the Fort Union Formation. Most of the Wasatch beds occur under less than 200 feet of overburden. However, the Wasatch and Fort Union Formations together attain a maximum thickness of 3970 feet in the Buffalo area.

Two of the largest coalbeds in the basin are the Wyodak-Anderson and the Lake De Smet beds. The Wyodak-Anderson coalbed crops out over a north-south distance of 120 miles in the Gillette Coal Field. It, and the beds correlative to it, persist downdip to the deepest part of the Powder River Basin. The Wyodak-Anderson bed is locally up to 150 feet thick, but averages 50 to 100 feet in thickness. Based on these figures, the bed contains at least 100 billion tons of coal to a depth of 2000 feet. This is the largest tonnage in a single continuous coalbed anywhere in the U. S.

The Lake De Smet bed, which occurs in the Buffalo Coal Field, is thought to be the thickest coalbed in the U.S. and second thickest in the world. It is 15 miles in length, 70 to 220 feet thick and one-half to two miles wide.

All data collected to date indicate that the Powder River Basin should provide several favorable target areas for recovery of methane gas from coalbeds using shallow wells.

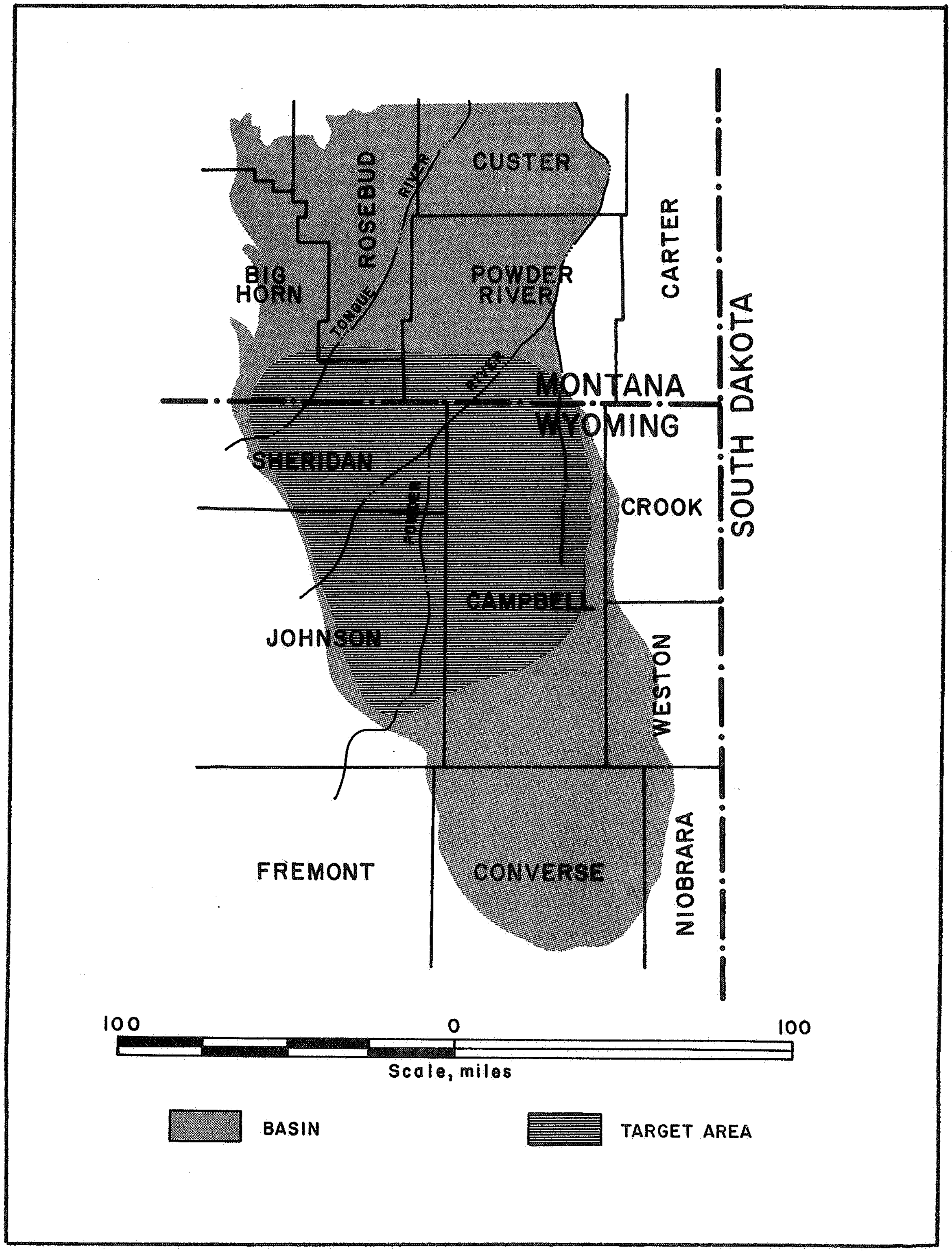


Figure 2-8. Powder River Basin Target Area.

The area considered as the prime methane exploration target within the Powder River Basin is illustrated in Figure 2-8. It encompasses portions of Campbell, Sheridan, and Johnson Counties in Wyoming and Big Horn and Powder River Counties in Montana. Factors used in delineating the target boundaries include:

- Restricting the area to lands underlain by the Tongue River Member of the Fort Union Formation, and additionally to
- Areas in which shallow drill holes are known to flow anomalously large amounts of methane,
- Areas in which flowing artesian wells are concentrated, or
- Areas in which three or more individually thick coalbeds are coalesced together into a single superbed.

As of the end of the reporting period, three sites had been investigated in the Powder River Basin. Results of these field tests are summarized in the following paragraphs.

POWDER RIVER BASIN, SITE AA
POWDER RIVER COUNTY, MONTANA

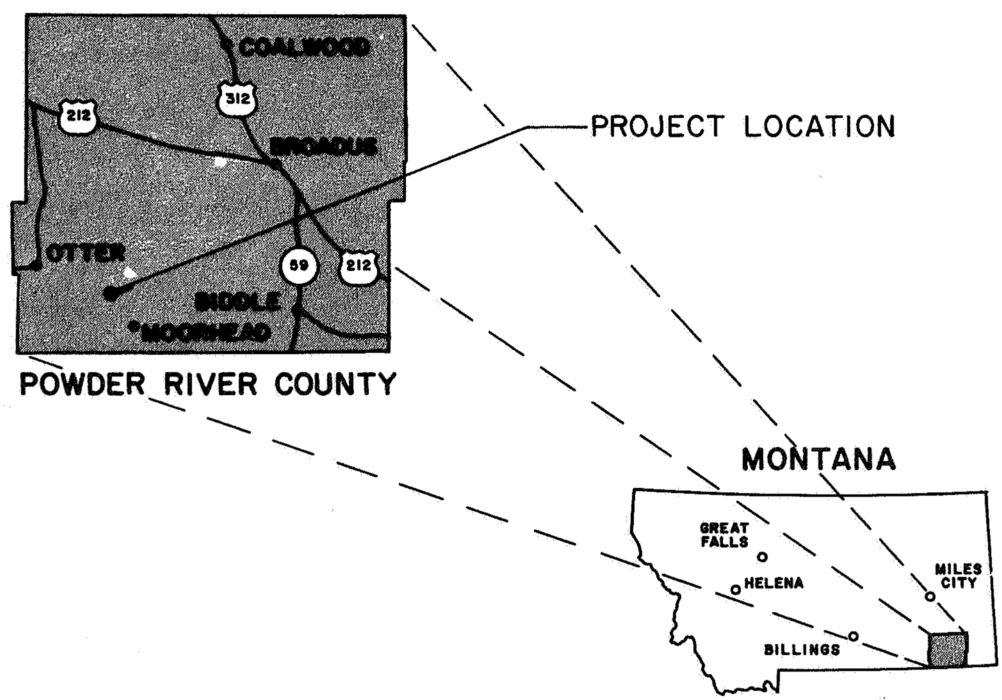
Cooperating Organization:
U.S. Geological Survey
Denver, Colorado

Status:
Field Activity Complete
Analysis Active

Field Work Performance Period:	**August, 1979**
Principal Investigator:	**C.T. Rightmire (TRW)**
DOE Technical Project Officer:	**H.D. Shoemaker**

OBJECTIVE

To determine the methane content and some reservoir properties of the Anderson and Canyon A & B (Dietz) coalbeds in the Fort Union Formation.



SITE LOCATION

Section 22, Township 8S, Range 47E, in Powder River County, Montana.

SCOPE OF WORK

The geologic target of this investigation is the Anderson and Canyon A&B (Dietz) coalbeds in Fort Union Formation in the Powder River Basin.

PROGRESS THIS REPORTING PERIOD

The field activities were performed in late August 1979 during the original drilling of the well.

Conventional Coring

Conventional coring was performed on August 29 and 31; the following coals were intercepted:

Seam	Interval (ft)	Thickness (ft)
Anderson	243.5 - 305.1	51.6
Dietz	377.0 - 401.5	24.5

Logging

Borehole geophysical logs were obtained on August 31 (gamma-ray, density, SP, and resistivity).

Gas Desorption

Coal sample gas desorption from the conventional cores resulted in the following data as of September 28, 1979:

Sample Depth (ft)	Total Gas (cc)	Sample Weight (gm)	Gas Content (cc/gm)	Gas Content (cf/ton)
		Anderson Seam		
247.5	62	1600	<0.1	<1
266.0	50	1652	<0.1	<1
291.0	41	1710	<0.1	<1
		Dietz Seam		
377.6	113	1603	0.6	20
385.0	41	1710	<0.1	<1
400.5	119	1637	<0.1	2

Analysis

Laboratory analysis is scheduled to be performed after gas desorption is complete (proximate/ultimate, equilibrium moisture).

POWDER RIVER BASIN, SITE AB
BIG HORN COUNTY, MONTANA

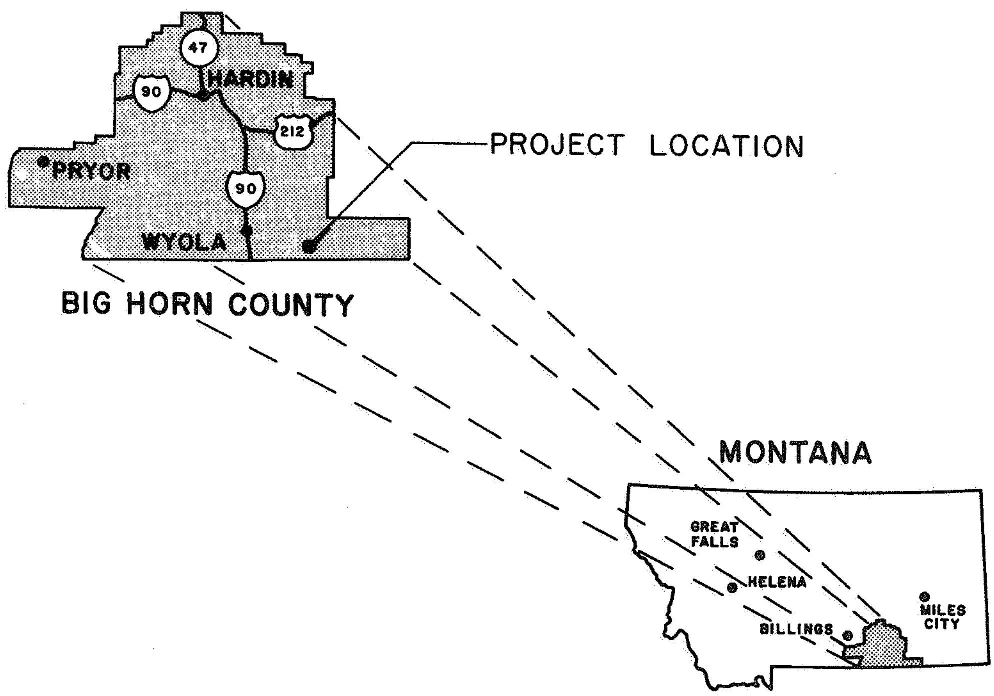
Cooperating Organization:
Montana Bureau of Mines and Geology

Status:
Field Activity Complete
Analysis Active

Field Work Performance Period:	**September, 1979**
Principal Investigator:	**C.T. Rightmire (TRW)**
DOE Technical Project Officer	**H.D. Shoemaker**

OBJECTIVE

To determine the quantity and quality of the coal, the methane content of the coal, and some reservoir properties of the coal seams in the Powder River Basin, This effort will help determine the potential producibility of the coalbed methane from this resource.



SITE LOCATION

Well No. US-7746 (Montana Bureau of Mines and Geology, Site II) located in Section 7, Township 9S, Range R40E in Big Horn County, Montana.

SCOPE OF WORK

The geologic target of this investigation is the coalbeds in the Powder River Basin in Montana.

Field Activity - Single well drilling, conventional coring and logging.

Analysis - Gas desorption and laboratory analysis of coal overburden, interburden, and underburden.

PROGRESS THIS REPORTING PERIOD

The field activities were performed in mid September, 1979 during the original drilling of the well.

Conventional Coring

157 feet of conventional coring was performed and a total of 145.4 feet of coal was obtained from the following intervals:

Seam	Interval (ft)	Thickness (ft)
Smith	154.7 - 174.5	19.8
Anderson/Dietz 1 & 2	424.0 - 503.4	79.4
Canyon	583.8 - 603.0	19.2
Wall	742.7 - 769.7	27.0

Logging

Gamma-gamma, density, SP, resistivity, gamma-ray, and caliper well log data were obtained.

Gas Desorption and Site Investigation Results Analysis

In Process.

POWDER RIVER BASIN, SITE AC
BIG HORN COUNTY, MONTANA

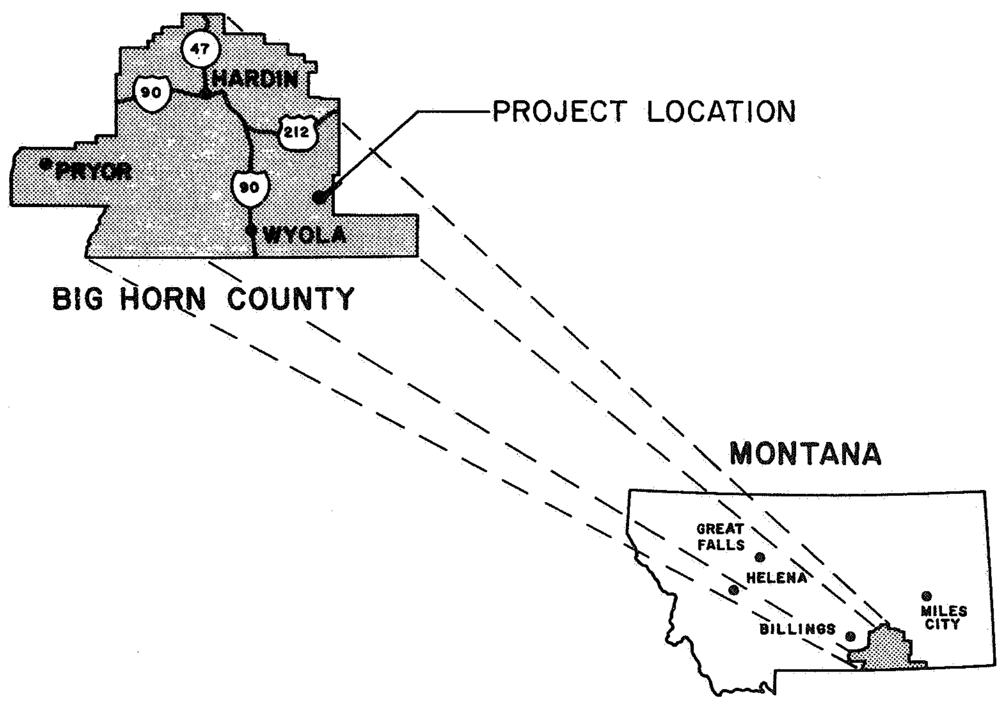
Cooperating Organization:
Montana Bureau of Mines and Geology

Status:
Field Activity Complete
Analysis Active

Field Work Performance Period:	**September, 1979**
Principal Investigator:	**C.T. Rightmire (TRW)**
DOE Technical Project Officer	**H.D. Shoemaker**

OBJECTIVE

To determine the quantity and quality of the coal, the methane content of the coal, and some reservoir properties of the coal seams in the Powder River Basin. This effort will help determine the potential producibility of the coalbed methane from this resource.



SITE LOCATION

Well No. US-7735 (Montana Bureau of Mines and Geology Site I) located in Section 5, Township 7S, Range 40E, in Big Horn County, Montana.

SCOPE OF WORK

The geologic target of this investigation is the coalbeds in the Powder River Basin in Montana.

Field Activity - Single well drilling, conventional coring, logging and drill stem testing.

Analysis - Gas desorption and laboratory analysis of coal overburden, interburden and underburden.

PROGRESS THIS REPORTING PERIOD

The field activities were performed in early September, 1979 during the original drilling of the well.

Conventional Coring

Conventional coring was performed; the following coal was intercepted:

Seam	Interval (ft)	Thickness (ft)
Dietz 2	121-145.5	24.5
Canyon Split	347-352.5	5.5
Canyon	390.3-402.8	12.5
Wall	620-673.5	53.5

Logging

Gamma-gamma density, SP, resistivity, gamma-ray, and caliper well log data were obtained.

Drill Stem Testing

A DST of the Wall seam was attempted on September 9. No data were obtained because of a plugged tool.

Gas Desorption

In process.

Analysis

In process.

2.2.15 SAN JUAN BASIN (COLORADO AND NEW MEXICO)

The San Juan Basin, Figure 2-9, is an elliptical structural depression encompassing an area of about 7,500 square miles in northwestern New Mexico and southwestern Colorado. A total resource of more than 200 billion tons of bituminous and subbituminous coal is contained there in Cretaceous age rocks.

A few individual coal seams have been named where mined locally, but most San Juan Basin coals are too irregular and discontinuous to be correlated across significant distances. Individual seams range from a few inches to 20 feet thick over broad areas. The shallowest major coal reaches a maximum depth of approximately 4000 feet in the northeast part of the basin Dip is generally shallow, steepening along the bordering structural uplifts and along the eastern margin.

Coal occurs in five formations or units. Not much is known about the thickness and extent of coal in the deepest formations, but these are not considered to contain the large reserves of the two major units, the Fruitland and Menefee formations. The Fruitland contains an estimated 200 billion tons of coal, the Menefee about 1 billion tons, of which more than half are deeper than 2000 feet. Coal is mainly low sulfur bituminous.

Recent studies of desorbed gas indicate the gas content of San Juan Basin coals is relatively low, ranging from about 10 to 135 cubic feet per ton. Preliminary, limited desorption data were used to calculate estimates of in-place gas. Based on a minimum depth of 1,000 feet, the Fruitland Formation contains a minimum of 1.8 trillion and a maximum of 25 trillion cubic feet of in-place gas. Similarly, the minimum and maximum in-place gas content estimated for the Menefee are 6.7 billion and 88 billion cubic feet. Thus, the total minimum in-place gas resource for the basin is estimated at 1.8 trillion cubic feet, most of which is in the Fruitland. Gas from deeper coals is not expected to add significantly to this total.

San Juan Basin coal gas content is thought to increase toward the north. Gassy mines and other indicators were used to target the area shown in Figure 2-9. The figure shows 3 areas totaling about 4,900 square miles, encompassing coals with the highest potential for early commercial gas production. 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.

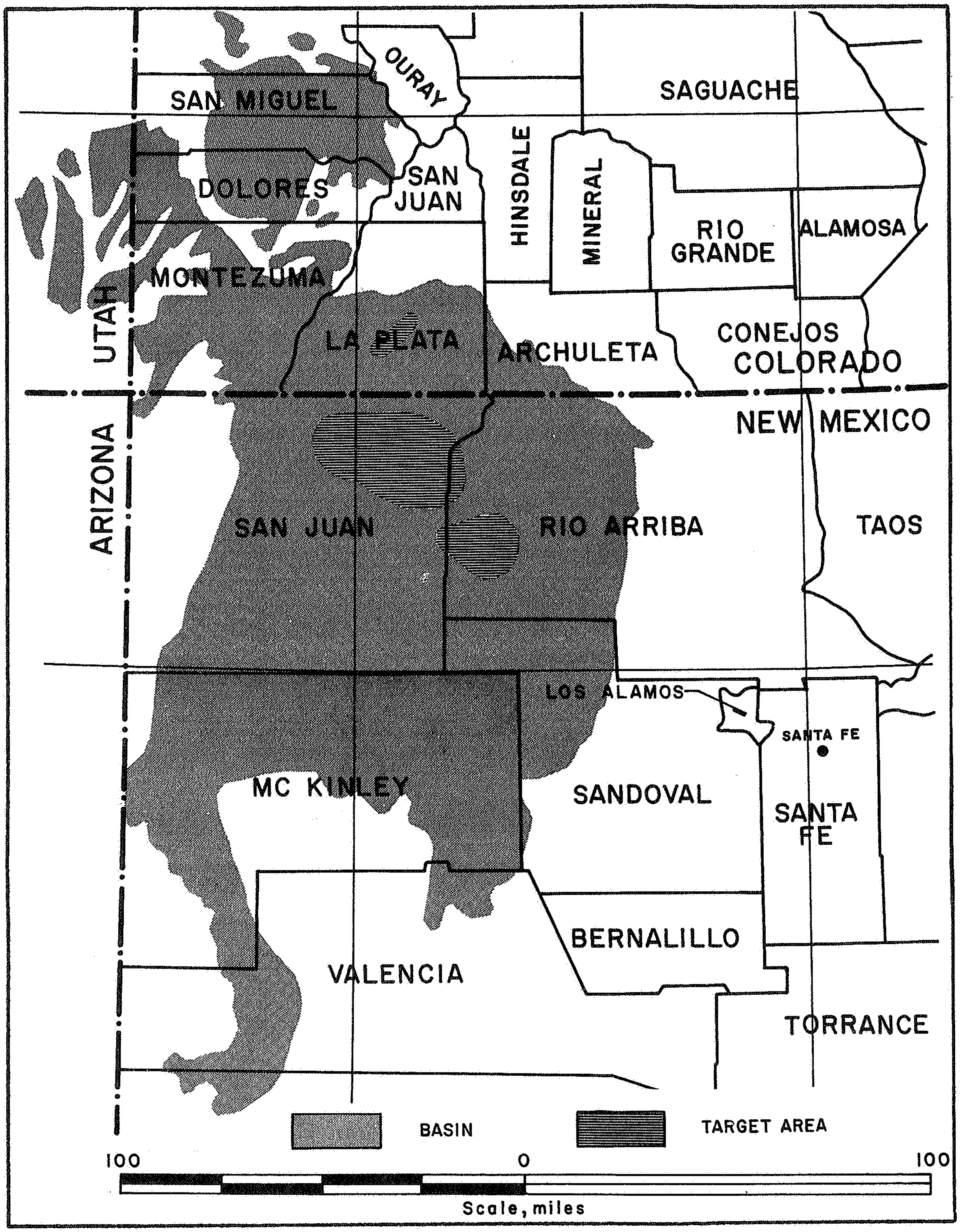


Figure 2-9. San Juan Basin Target Area.

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

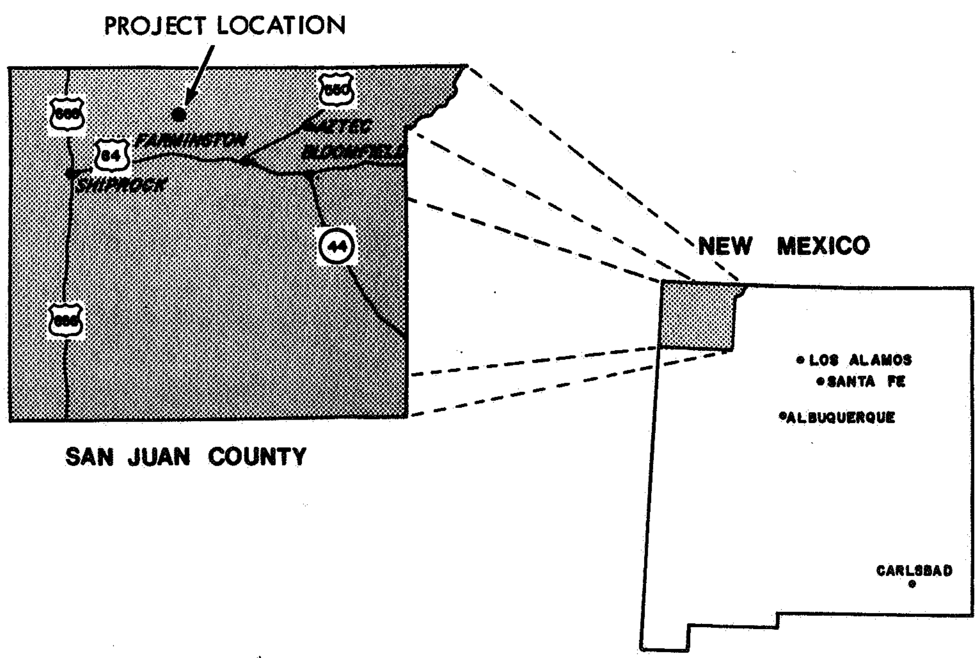
Cooperating Company:
Western Coal Company
Albuquerque, New Mexico

Status:
Active

Field Work Performance Period: June, 1978
Principal Investigator: C.T. Rightmire (TRW)
DOE Technical Project Officer: H.D. Shoemaker

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.



SITE LOCATION

Western Coal Company, well in Section 22, Township 30N, and Range 15W, San Juan County, New Mexico.

SCOPE OF WORK

An agreement was established for the purpose of obtaining coal samples in the outcrop area of the Upper Fruitland Formation or Lower Kutland Shale, on the western flank of the San Juan Basin.

Field activities - Single well drilling, coring.

Analysis - Gas desorption, laboratory analysis.

PROGRESS PRIOR TO APRIL 1979

Field work was performed during June of 1978.

Conventional Coring

A 12.2 foot thick coal seam was encountered during coring between 370 and 413.5 feet.

Gas Desorption

Two samples were desorbed through August, 1978. At that time the indicated gas contents were:

Sample	Desorbed Gas
#1	1.4 cc/g or 45 cf/ton
#2	0.3 cc/g or 10 cf/ton

PROGRESS THIS REPORTING PERIOD

The coal samples were submitted to the USBM for residual gas determination. The combined desorbed and residual gas data indicate the following range in specific gas content of the coal seam:

Sample	Desorbed Gas cc/g	Residual Gas cc/g	Total Gas cc/g	Total Gas cf/ton
#1	1.4 cc/g	0.9 cc/g	2.3	73
#2	0.3	0.2 cc/g	0.5	16

Analysis

Proximate/ultimate analyses were completed.

2.2.16 SOUTHERN APPALACHIAN/WARRIOR BASIN (ALABAMA AND MISSISSIPPI)

Coal resources in the southern Appalachians, Figure 2-10, are found in sequences of shale, siltstone, sandstone, and conglomerate in the Pottsville group of Pennsylvanian age. There are approximately 25 minable coal seams with a total thickness ranging from 15 to 50 feet. The estimated coal resource for the area is approximately 40 billion tons. Individual seams range in thickness from a few inches to 7 feet, average 3 to 5 feet, and are continuous over fairly large areas. The coal rank is from low to high volatile bituminous. Mine emission data suggest that at least 4 seams contain significant quantities of methane. The coal seams and their adjacent formations are nearly horizontal within the Warrior Basin proper, but are gently to tightly folded and faulted along the basin's eastern margin. Overburden thickness varies from 0 to greater than 6,000 feet with all current mining less than 3,000 feet deep.

The current target area of interest within the southern Appalachians is shown in Figure 2-10. As of the end of the reporting period, one site had been investigated in the southern Appalachians. Results of this field test are summarized in the following paragraphs.

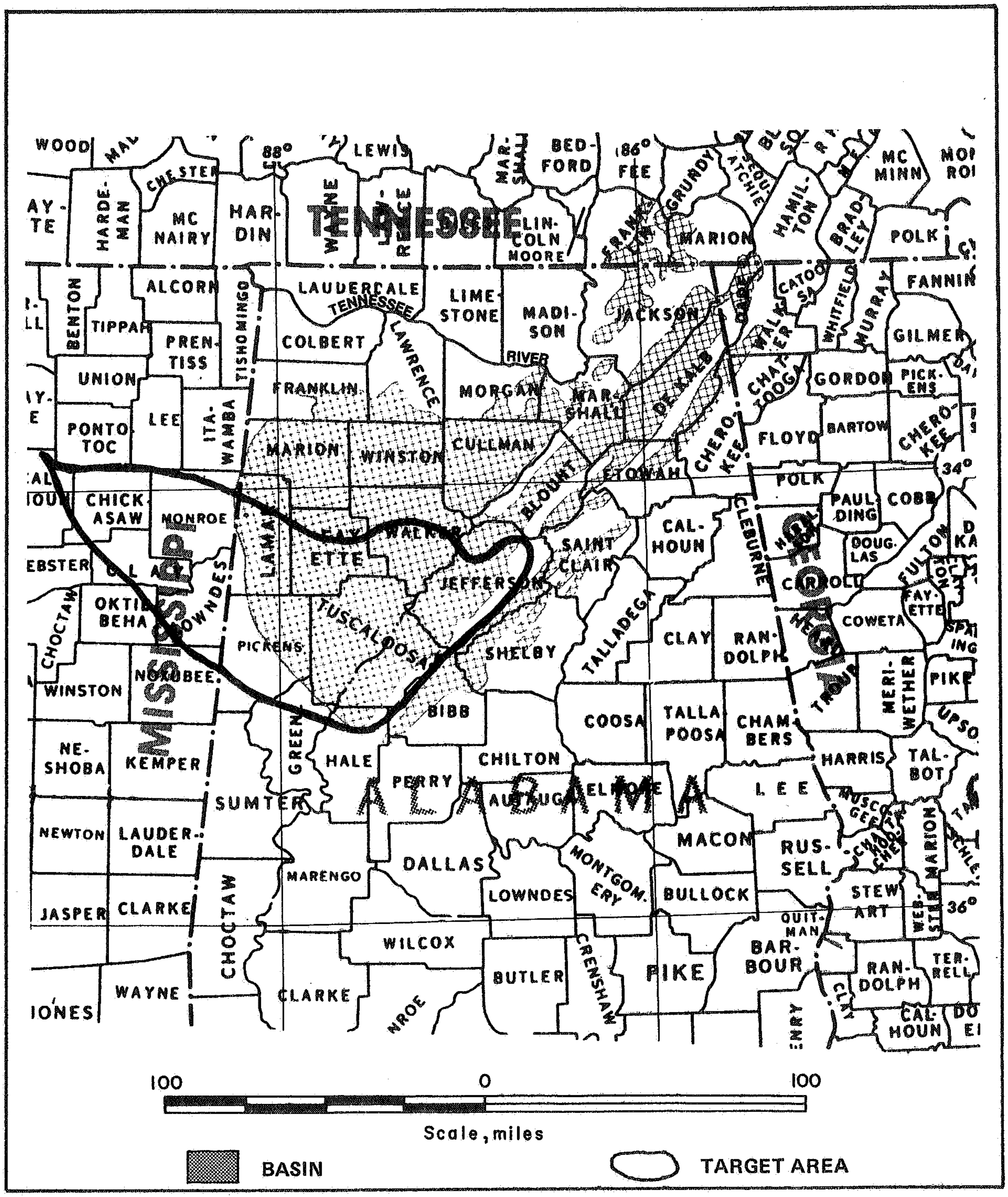


Figure 2-10. Southern Appalachian/Warrior Basin Target Area.

WARRIOR BASIN, SITE AA
FAYETTE COUNTY, ALABAMA

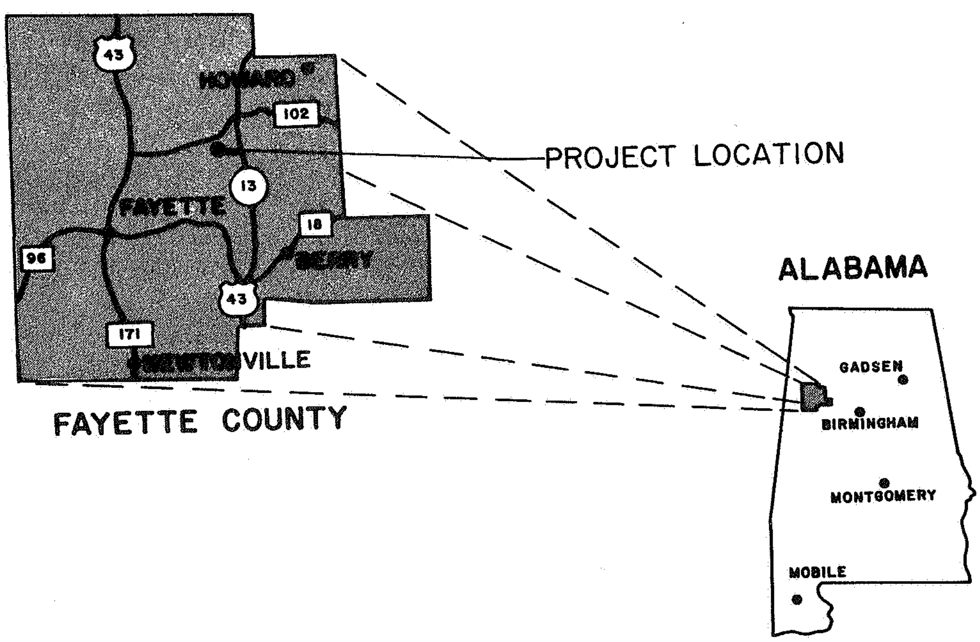
Cooperating Company:
Grace Petroleum Corporation
Denver, Colorado

Status:
Field Work Complete
Analysis Active

Field Work Performance Period: July, 1979
Principal Investigator: C.T. Rightmire (TRW)
DOE Technical Project Officer: H.D. Shoemaker

OBJECTIVE

To determine the quantity and quality of the coal, the methane content of the coal, and some reservoir properties of several coal seams in the Pottsville Formation. This effort will help determine the potential productivity of coalbed methane from this resource area.



SITE LOCATION

Grace Petroleum Corporation Well No. 1, Grimsley 35-15, located in Section 34, Township 14S, Range 11W , in Fayette County, Alabama.

SCOPE OF WORK

The geologic target of this investigation is several coal seams in the Pottsville Formation in the Warrior Basin.

Field Activity - Single well drilling, conventional coring and logging.

Analysis - Gas desorption and laboratory analysis.

PROGRESS THIS REPORTING PERIOD

Field activities were performed in July, 1979 during the original drilling of the well.

Conventional Coring

Conentional coring was performed between July 11 and 17; the following coals were intercepted:

Seam	Interval (ft)	Thickness (ft)
Blue Creek	593-597	4
Unnamed "H"	1100-1102	2
Roosa	1675-1676	1
Tidemore "B"	1880-1882	2

Gas Desorption

In process.

Laboratory Analysis

In process.

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 coalbed methane extraction and utilization. As of the end of the reporting period, several R&D projects were underway or planned.

Projects continuing from the last reporting period involved testing of a 5-3/8 inch downhole turbodrill motor and evaluation of the feasibility of explosive fracturing of coal to increase productivity:

- Turbodrill - Maurer Engineering, Inc.
- Coalfrac - Physics International Company

During this reporting period planning and associated activities were initiated for the following new R&D projects:

- Investigation of Water Jet Drilling for Methane Drainage - Sandia Laboratories

- Studies of Fracture Mechanics of Coal - West Virginia University

- Effectiveness of Using Carbon Dioxide to Increase Methane Production - University of Pittsburgh

Information pertaining to these R&D projects are discussed in Sections 2.3.2 through 2.3.6.

2.3.2 TURBODRILL

Maurer Engineering, Inc.
Houston, Texas

Status:
Active

Contract:	DE-AC21-78MC08380
Contract Date:	September 15, 1978
Anticipated Completion Date:	April 30, 1980
Principal Investigator:	W.C. Maurer
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 design and construction of the turbodrill. The testing aspect focuses on three areas: (1) a horizontal, above-ground bench test mode to generate baseline performance data; (2) controlled, straight-hole and directional field test drilling into formations that are a priori well-known; and (3) a directional field test, drilling a well from vertical at the surface to horizontal in a coal seam.

TURBODRILL DESIGN

The motor consists of a turbine section and a bearing package. A schematic diagram of the 5-3/8 inch Maurer turbodrill is presented in Figure 2-11. The driving fluid is drilling mud or water. All blades and vanes are contained in the turbine section, and all bearings (thrust and radial) are in the bearing package. The turbine section contains 50 stages of blades and vanes. The uppermost stage is used for tachometer pulse generation.

There are two bearing package designs: (1) the sealed bearing package shown in Figure 2-11, for use in drilling with mud through abrasive formations, and (2) the flow-through package shown in Figure 2-12, for

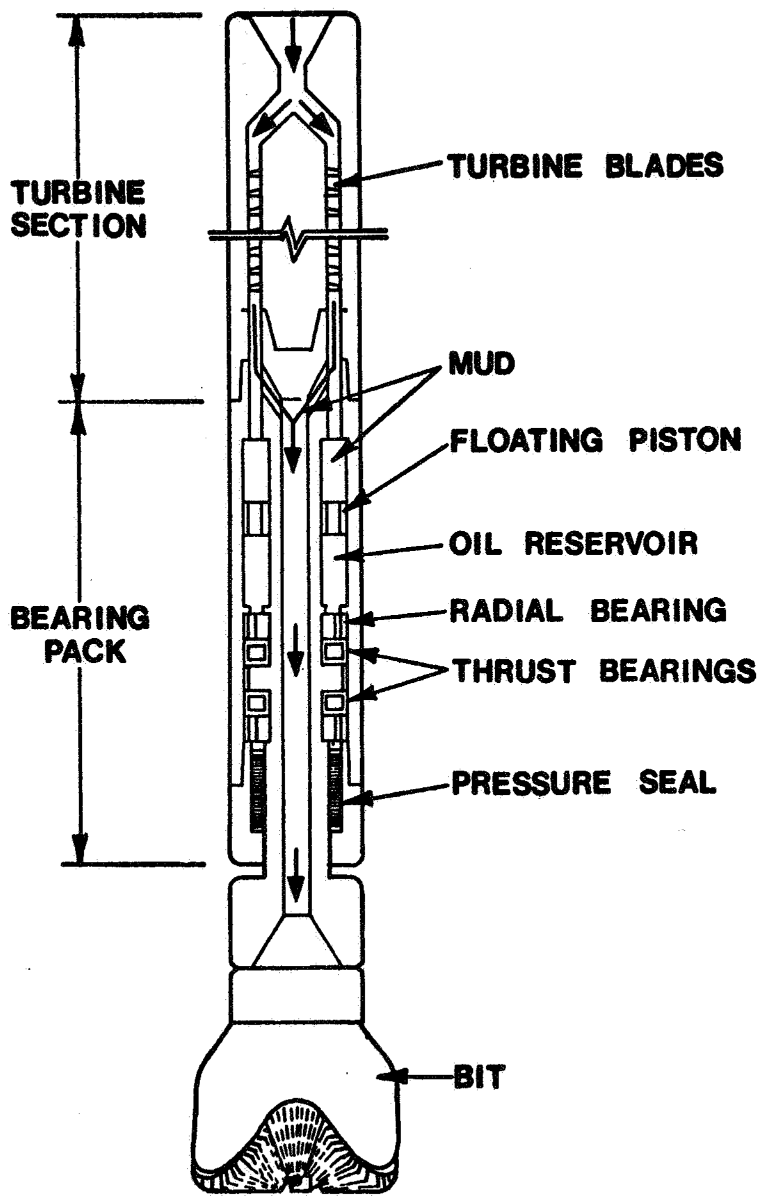


Figure 2-11. Turbodrill Schematic - Sealed Bearing Pack.

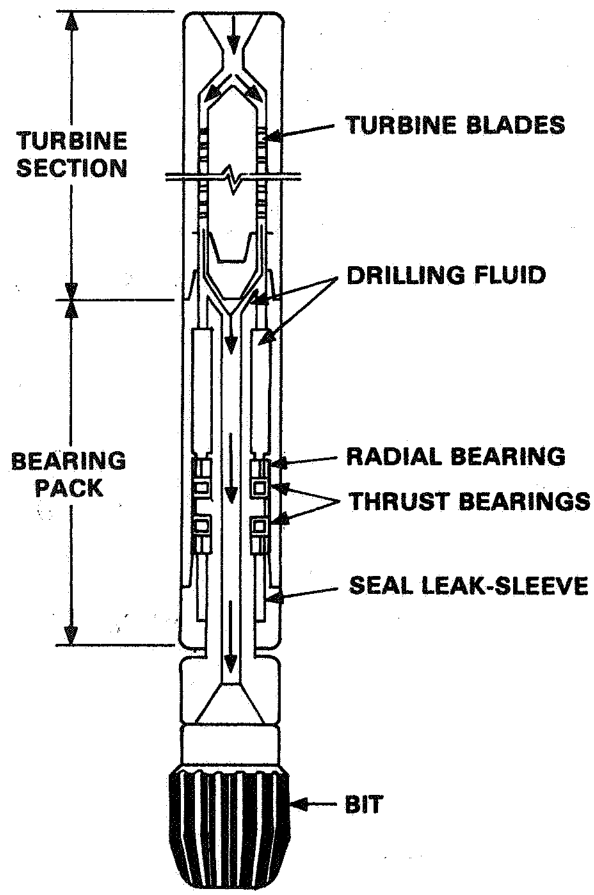


Figure 2-12. Turbodrill Schematic - Flow-Through Bearing Pack

use with less abrasive muds and water (in softer formations). The sealed bearing package has application for directional and straight-hole drilling in conventional oil and gas fields. The flow-through bearing package 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 package pressurizes the oil reservoir (containing a synthetic bearing lubricant) and prevents the intrusion of drilling mud into the roller bearings (Figure 2-11). The bearing package 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. There are two major pressure drops in the turbodrill: one across the stage assembly of blades and vanes in the turbine section and the other across the pressure-seal assembly at the front-end of the bearing package. The bit pressure drop, which strongly influences penetration rates, is supported by the pressure seal assembly.

PROGRESS PRIOR TO APRIL 1979

Short-duration, shakedown tests of the 5-3/8 inch turbodrill were completed in December 1978, during which baseline performance data (with water as the driving fluid) were obtained. Teardown and inspection of the drill motor indicated a problem area in the pressure seal in the bearing package. Maurer Engineering incorporated design modifications to the floating piston seal assembly in preparation for subsequent formal Phase I testing. An option was exercised to proceed into a modified testing period using the flow-through bearing package. The flow-through bearing package is used with drilling mud in Phase I and Phase II testing.

Formal Phase I testing was conducted at TRW Mission Manufacturing in February 1979. Analysis and comparison of the preliminary shakedown test data with Phase I data demonstrate correlation for torque, power, efficiency, and rotary speed relationships, see Figure 2-13. However, pressure drops between various portions of the turbine appeared to be considerably higher than design values.

PROGRESS THIS REPORTING PERIOD

Performance testing of the 5-3/8 inch motor was completed at TerraTek in April 1979. Penetration rates in the range of 30 to 50 feet per hour were achieved drilling in granite, as shown in Figure 2-14.

Preliminary field testing was conducted at the Los Alamos Hot Dry Rock field site in June and July 1979 using a larger 7-7/8 inch turbodrill. Average penetration rates of 20 feet per hour and above were observed. The prototype tachometer unit to be used in Phase II was also tested in the larger drill motor.

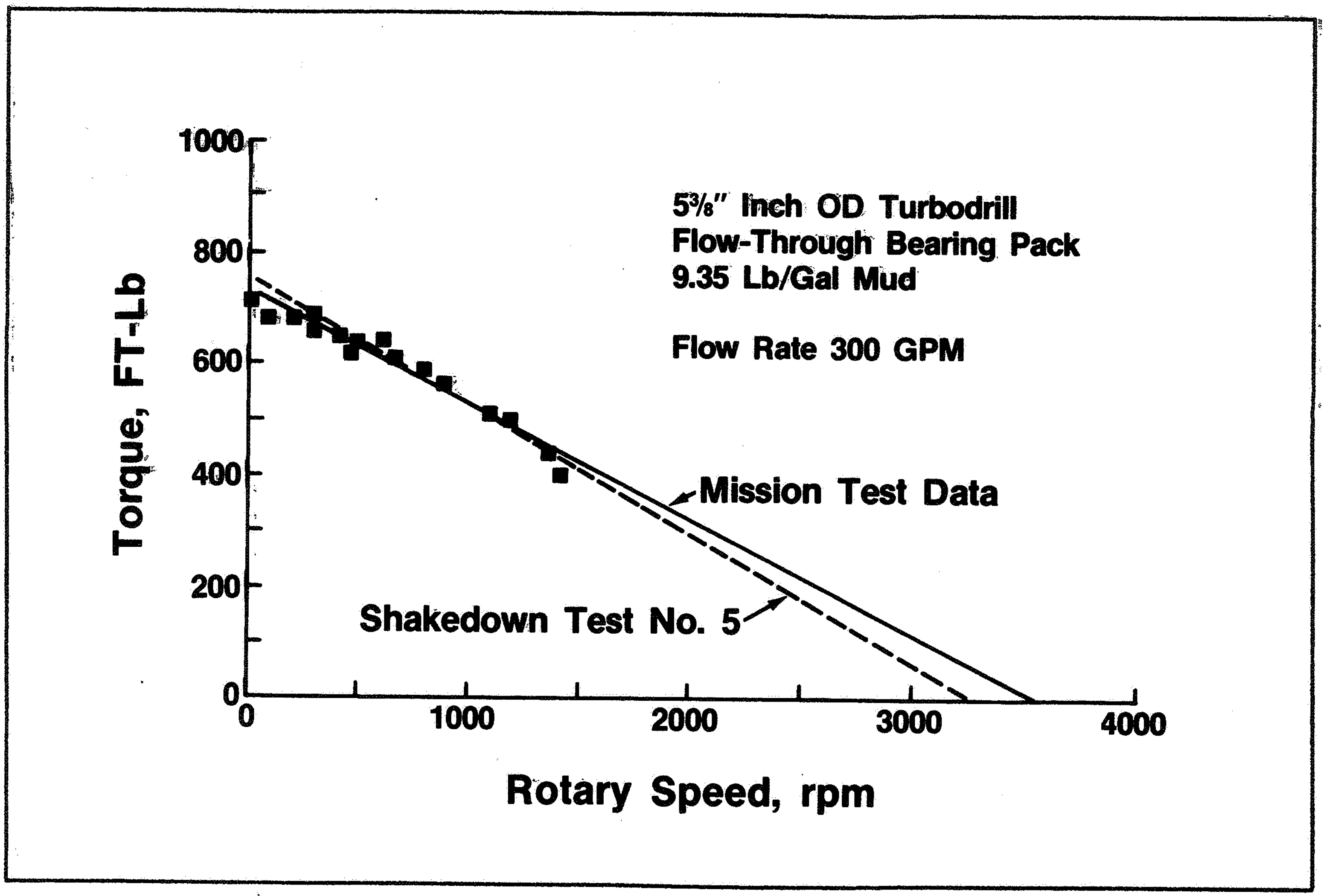


Figure 2-13. Turbodrill Phase I Test, 300 gpm Performance.

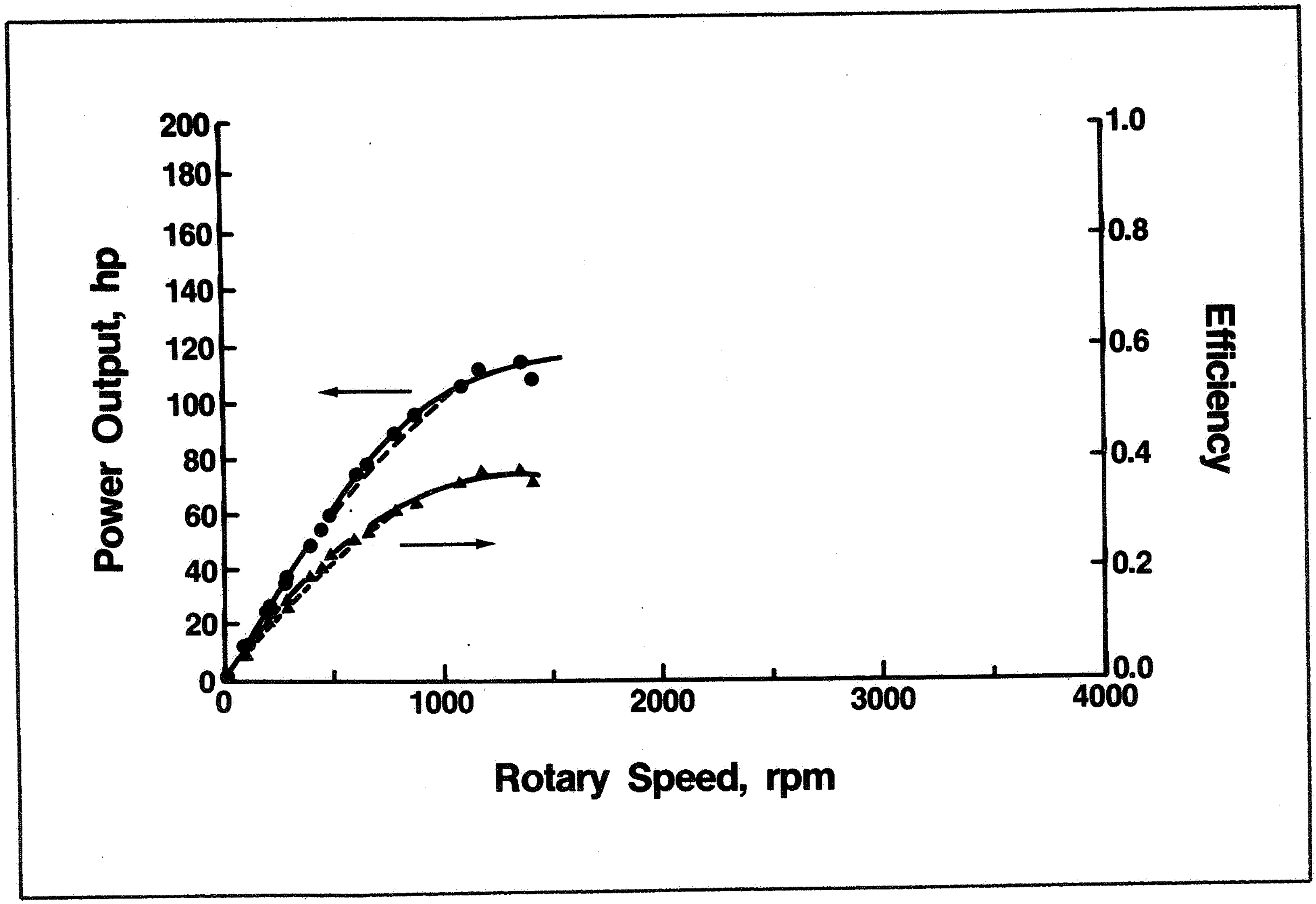


Figure 2-13. Turbodrill Phase I Test, 300 gpm Performance. (Continued)

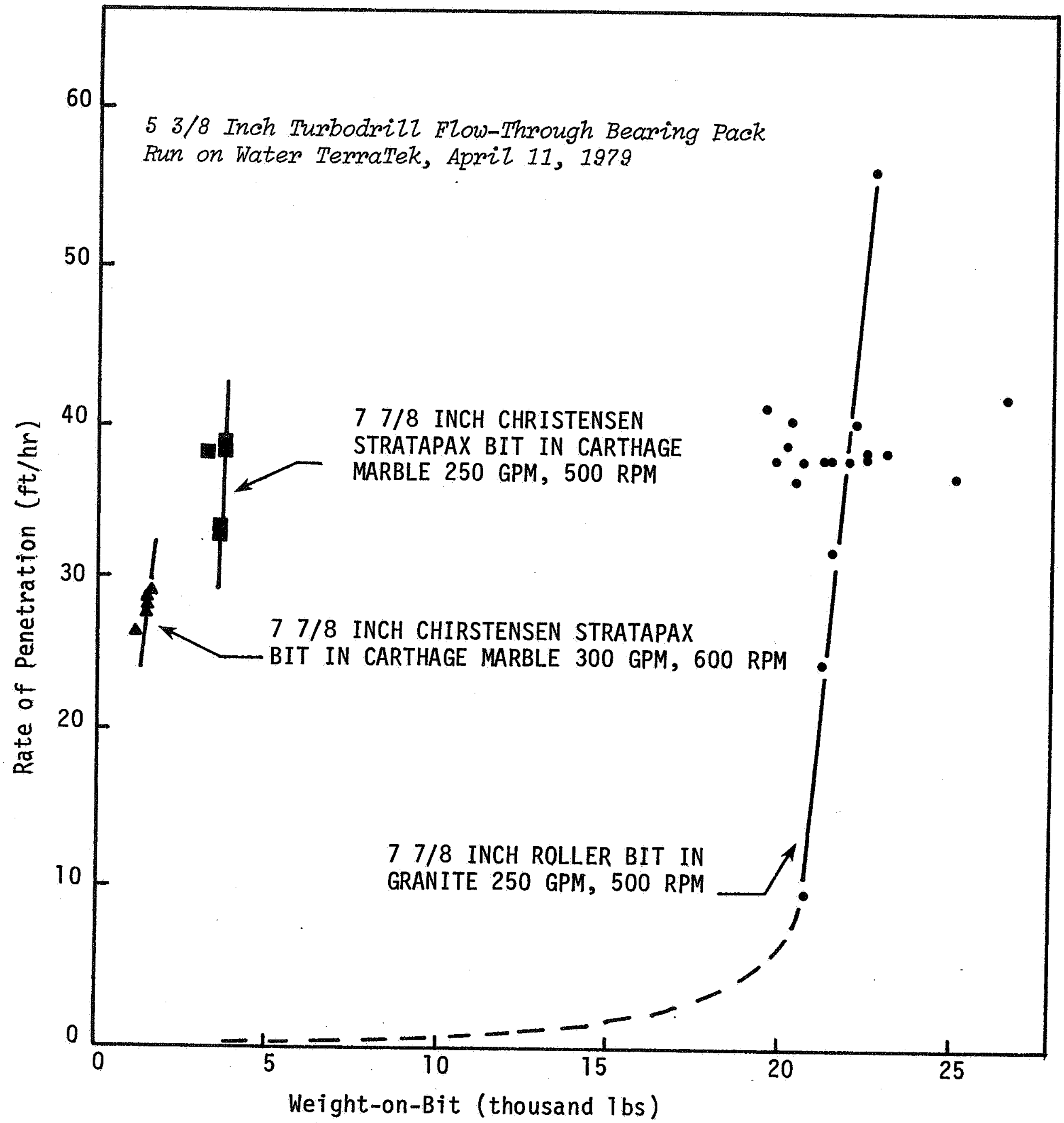


Figure 2-14. Drilling Performance of METC Turbodrill at TerraTek.

The 5-3/8 inch drill motor is ready to proceed into formal Phase II testing at Gearhart-Owen in Fort Worth, Texas. Results will be presented in subsequent reports.

2.3.3 COALFRAC

Physics International Company
San Leandro, California

Status:
Active

Contract:	DE-AC-21-79MC10642
Contract Date:	March 22, 1979
Anticipated Completion Date:	March 31, 1980
Principal Investigator:	J.L. KNOWLES
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 mixure 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:

- Modification of an existing test chamber for use in: (1) determining the permeability of coal samples before detonatable 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.

- 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, to determine the effects of initial pressure, gas composition, mixture, and multiple shots.

PROGRESS THIS REPORTING PERIOD

Contracted work was initiated in April, 1979. Major technical activities involve (1) fabrication, modification and installation of coal test systems, (2) fabrication and preparation of coal samples, (3) experimental work, and (4) analyses and reporting.

Two systems have been identified for experimental study: a coal permeability test system designed and fabricated during this effort and an available COALFRAC detonatable gas filled system, including a coal sample detonation chamber, previously used in 1977 studies. The coal permeability test system was completed and used at the San Leandro facility to measure the permeability of several different sample coals. Water and gaseous nitrogen were used as the flow media. This system was then installed in the existing COALFRAC fill systems at the explosive test facility. The fill system permits local control of selected gases which are delivered to a remote mixing chamber containing a coal sample. This enables measurement of coal sample permeability by passing selected gases (N_2, CH_4, O_2) through the sample before and after detonation.

Six coal samples were prepared in July and mounted in appropriate detonation chamber sleeves. All of the samples were oriented with their face cleats parallel to the chamber axis except one which was butt cleat oriented. Permeability measurements were obtained for these coal samples using nitrogen gas and water as the test medium. The following general observations were made:

- The nitrogen permeabilities measured in the "as received" state are typically greater than any subsequent nitrogen flow measurements. This may be related to the sample exposure to water flow through the cleats following the first "as received" experiments. No causal relationship is advanced at this time.

- The apparent gaseous permeabilities typically follow a linearly decreasing relationship with decreasing reciprocal mean pressure, as is to be expected.

- The "fluid state" permeabilities as measured by gas flow are typical of reported values for Pittsburg seam coal, i.e., $<$10 md.

- Samples 1 and 2 were cored from a single block and samples 3 and 4 from another block. The pairs were cored in the same direction from their original blocks. The permeability results reveal no commonality in the pairs — paternal, not identical twins.

- The "wet sample" permeability with nitrogen is typically less than or equal to the water permeability.

- A tendency toward reduction in coal permeability values with subsequent flow testing correlates with data obtained in 1976-1977.

During preliminary detonation experiment activities to evaluate the system and instrumentation, a need was identified to equalize pressures in the two test chambers to preclude or minimize the flow of hot detonation products through the coal. A technique to accomplish this will be incorporated in future experimentation involving gas detonation.

A coal sample having a permeability intermediate to the other samples was selected for the first detonation study. Although a significant increase in permeability was observed for each increase in test pressure, the results of this initial test were considered inclusive for the following reasons:

- The permeabilities are nearly identical to those obtained on wet samples, and
- A prior experiment utilized methane which represents the first time the sample had been exposed to methane following its removal from the mine.

In continuing permeability experiments the effect, if any, on coal adsorption of methane will be addressed. The final results of this study and detonation experiments with other samples will be presented in subsequent reports.

2.3.4 WATER JET DRILLING

Sandia Laboratories
Albuquerque, New Mexico

Status:
Active

Contract:	MR-11098
Contract Date:	April 9, 1979
Anticipated Completion Date:	December 31, 1980
Principal Investigator:	K.M. Timmerman
DOE Technical Project Officer	H.D. Shoemaker

OBJECTIVE

To develop required technology for deep horizontal penetration of coal seams from vertical borehole 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. The project is a phased effort involving comprehensive investigation and application of water jet drilling to the problem of economical methane drainage. Phase I consists of project initiation tasks and the development of a water jet drilling system design. Phase II consists of construction of a prototype water jet drilling system, selection of a specific site, and field evaluation of the drilling system.

PROGRESS THIS REPORTING PERIOD

Work began on this project in March 1979 and early activities were concerned with development of a detailed project plan, further definition/sequencing of Phase I and II activities, and resolution of early identified problem areas:

- Need for additional development of the water jet drilling head (University of Missouri—Rolla). Specific requirements include (1) nozzle arrangement for hole gauge control and optimum drilling rate, (2) cuttings removal, and (3) submerged drilling; and

- Need for coal seam sensor development, to provide reliable means to keep the drill within the seam.

System hardware design and one quarter-scale model drawings were prepared during mid 1979. A significant advance was made in the design of the rotation and advance assembly. This is the portion of the drilling system that carries the water jet drilling head assembly down the vertical borehole, rotates it 90 degrees, and advances it horizontally into the coal seam. Drilling performance is often degraded and gauge control made difficult by differences between the constant string velocity "in" and constant string, and head, velocity "out" when the drill string moves on a circular path from a vertical borehole to a horizontal borehole. The improved design, providing a theoretical non-circular path, is expected to provide a steady head velocity.

The results of these activities will be discussed in subsequent semi-annual reports.

2.3.5 FRACTURE MECHANICS

West Virginia University Morgantown, West Virginia	Status: Active
Contract:	DE-AT21-79MC11284
Contract Date:	June 1, 1979
Anticipated Completion Date:	November 30, 1980
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 the fracture patterns developed and understanding of when fractures will cross stratigraphic features such as bedding planes, fault cleats and other fractures.

This work includes the following tasks:

1. Quantifying the fracture toughness of coal.
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.

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

PROGRESS THIS REPORTING PERIOD

A contract was negotiated with West Virginia University for the work required to accomplish this project. The effort began in June 1979 and activities during the initial three months period have included design and fabrication of required experiment apparatus and preliminary tests of coal specimens (10 fracture toughness tests and approximately 15 tension tests). Results of these activities and others scheduled to start at later times will be presented in subsequent reports.

2.3.6 CARBON DIOXIDE FOR METHANE PRODUCTION

University of Pittsburgh Pittsburgh, Pennsylvania	Status: Active
Contract:	DE-FG21-79MC10831
Contract Date:	March 1, 1979
Anticipated Completion Date:	December 31, 1979
Principal Investigator:	P.F. Fulton
DOE Technical Project Officer:	H.D. Shoemaker

OBJECTIVE

To determine the effectiveness of the use of carbon dioxide to increase methane production from coal.

SCOPE OF WORK

This project consists of a study of the effectiveness of using carbon dioxide (CO_2) to enhance production of methane from coals. Natural and prepared coal specimens will be subjected to a series of experiments designed to determine the extent that CO_2 may be used to increase the amount of methane that can be extracted from various coal types.

PROGRESS THIS REPORTING PERIOD

This project was initiated early in the reporting period. Redesign and calibration of required experiment equipment was completed before the summer period of inactivity. Preliminary information from two experiment tests completed since resumption of project activity is described below.

A clean, dry coal sample was evacuated and pressurized in steps until 3500 cc (equivalent to 52.8 cf/ton) of methane was adsorbed. The sample was then placed in water and subjected to a pressure of approximately 200 psia for five weeks. When the pressure was reduced to atmospheric, this sample produced 1008 cc (25 cf/ton) of methane (about 29% of the original gas) during the next 9 days. No gas was produced during the following two days. Two cycles of CO_2 injection and methane-CO_2 production were then performed, and an additional 53 percent of the original gas was produced. However, CO_2 production increased significantly compared with the production history of prior tests with dry cores.

A second coal sample, mined from the Pittsburgh seam eight months previously, was stored under water from the time of receipt to minimize loss of methane. No methane was added and a test was initiated with what remained of the in-situ gas. CO_2 was injected and after five days of production a total of 565 cc (8.2 cf/ton) of methane and 7930 cc (110 cf/ton) of CO_2 was collected. After 15 days of production, the composition of the produced gas changed to 62% methane and 26% CO_2. The rest of the produced gas was nitrogen.

Additional information concerning the composition of the produced gases and analyses of these and other CO_2 injection tests will be discussed in subsequent reports.

2.4 TECHNOLOGY SYSTEMS TESTS

2.4.1 GENERAL

The following Technology Test projects were underway at the close of the reporting period:

- Utilization of methane from coalbeds for on-site power generation (Cambria County, Pennsylvania) - Westinghouse Electric Corporation
- Methane extraction from virgin coal and space heating/fuel cell application (Westmoreland County, Pennsylvania) - Westinghouse Electric Corporation
- Methane recovery from unminable coal and Book Cliffs field production test (Carbon County, Utah) - Mountain Fuel Supply Company
- Methane recovery from unminable coal and Piceance Basin production test (Rio Blanco County, Colorado) - Intercomp, Inc./COSEKA
- Long horizontal holes active mine test project (Buchanan County, Virginia) - Occidental Research Corporation/Island Creek Coal Company
- Multiple completion test project (Greene County, Pennsylvania) - Waynesburg College
- Anthracite coal drainage test project (Luzerne County, Pennsylvania) - Pennsylvania Energy Resources, Inc.
- Multiple vertical borehole degasification test project (Jefferson County, Alabama) - United States Steel Corporation
- Directional drilling degasification test project (Greene County, Pennsylvania) - J & L Emerald Mine Corporation
- Vertical drilling Jawbone Coalbed degasification test project (Dickenson County, Virginia) - Clinchfield Coal Company

Information pertaining to these projects is discussed in Sections 2.4.2 through 2.4.11.

2.4.2 ON-SITE POWER GENERATION TEST PROJECT

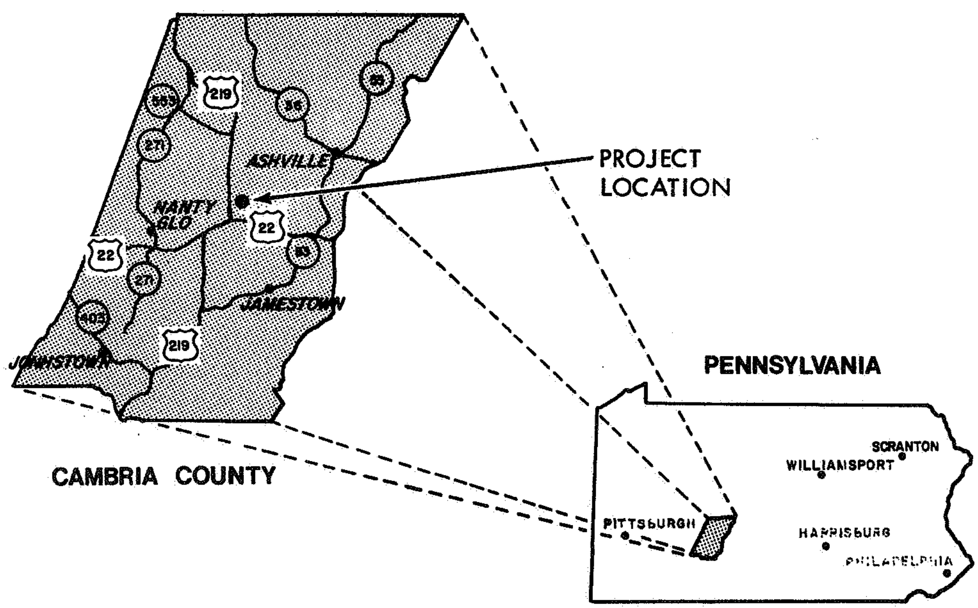
Westinghouse Electric Corporation
Pittsburgh, Pennsylvania

Status:
Active

Contract:	DE-AC21-77MC08098
Contract Date:	September 1, 1977
Anticipated Completion Date:	December 1, 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 the 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 three years ago and subsequent mine flooding, Well 32-10 production became too erratic for consideration. As an alternative, it is planned to provide a gas source for the turbine by predraining virgin coal through a vertical borehole until mining progresses and makes sufficient gob gas available.

A goal of this project is to provide wells with gas production rates sufficient to sustain operation of a turbine which could supply power directly to the local mine power grid. The design gas 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.

The contract is being 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.

PROGRESS PRIOR TO APRIL 1979

A vertical borehole, Revloc 32-13, was drilled in the virgin coal area through seams leased by the Bethlehem Mines Corporation, Ebensburg Division, to just above the "A" seam at 825 feet. Six coal seams were 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.

PROGRESS THIS REPORTING PERIOD

Initial testing of the Revloc 32-13 well was completed in July and the gas flow rate stabilized at approximately 40 Mcfd in August with an unmeasurable quantity of water. A minimum of 150 Mcfd is required for turbine operation at 25 percent electrical power output. 300 Mcfd is desired. No improvement in gas flow rate is expected from the Revloc 32-13 well and consideration of a second alternate site became necessary.

The project location is being moved to a site at the Bethlehem Mines, Ellsworth Division, Marianna No. 58 Mine located near Washington, Pennsylvania. This site should provide an adequate gas supply (250 Mcfd was being predrained from horizontal boreholes in this mine in July), but a pipeline approximately 6,000 feet in length will be required to transport the gas to a location near the power substation where the turbine generator can be connected to the mine power distribution system. The results of activity at the new location will be discussed in subsequent reports.

2.4.3 SPACE HEATING/FUEL CELL TEST PROJECT

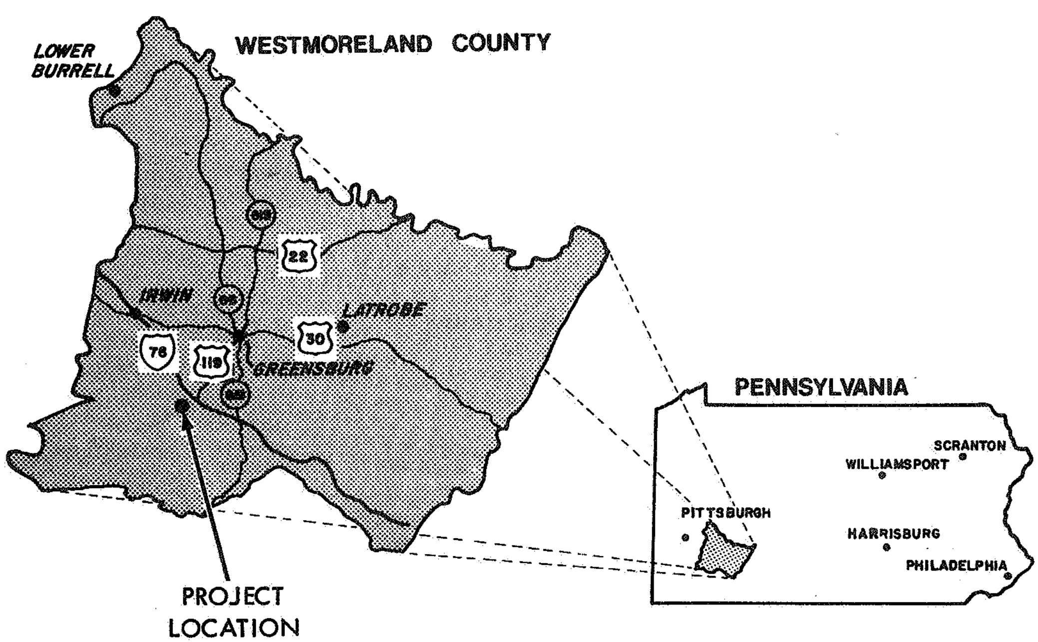
Westinghouse Electric Corporation
Pittsburgh, Pennsylvania

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 cooperative agreement between DOE and Westinghouse consists of a methane drainage and 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 to use the methane for process heat generation (steam, hot water and space heating). The data obtained will be used to assist in determining optimum well spacing for methane drainage operations. Drainage will be accomplished with multiple vertically drilled boreholes 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. The project is being 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

Two wells were planned for Phase I - a production well and an observation well. Phase II consists of evaluation of the work performed during Phase I and planning for Phase III. Phase III consists 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) was designed by Intercomp. It was planned to core and log this well both before and after casing. The purpose of the observation well #5 is to monitor water and pressure levels during gas production.

PROGRESS PRIOR TO APRIL 1979

The Phase I production well (#4) was completed in December 1978 in four zones using a Kiel fracture. An electric downhole pump was used to dewater the well. The frac water was recovered, but the well continued to produce a large amount of water. The water has an acceptable pH value 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.

Free gas flow (flared) over four or five days was 32 to 33 Mcfd initially. The shut-in pressure ranged from 12 to 25 psi. This low production was consistent with the low 37 cf/ton average methane content of the coal.

However, a gas flow of 40 to 45 Mcfd was observed later. Analysis of the production well indicates that with a 160 acre well spacing the Waltz Mill site would be 40 to 50 percent drained in 9 or 10 years at an average daily drainage rate of 20 to 25 Mcfd.

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

PROGRESS THIS REPORTING PERIOD

Three wells (#6, 7 and 8), an addition to Phase II, were drilled and cored to determine the methane content of the coal and to establish the production potential of the site before proceeding into the Phase III methane production demonstration. The gas-in-place and production from the three new wells appears to be 2 or 3 times that of well #4. Further information concerning these wells, and additional wells if Phase III is implemented and the demonstration portion of the project becomes operational, will be discussed in subsequent semi-annual reports.

2.4.4 BOOK CLIFFS COALFIELD PRODUCTION TEST PROJECT

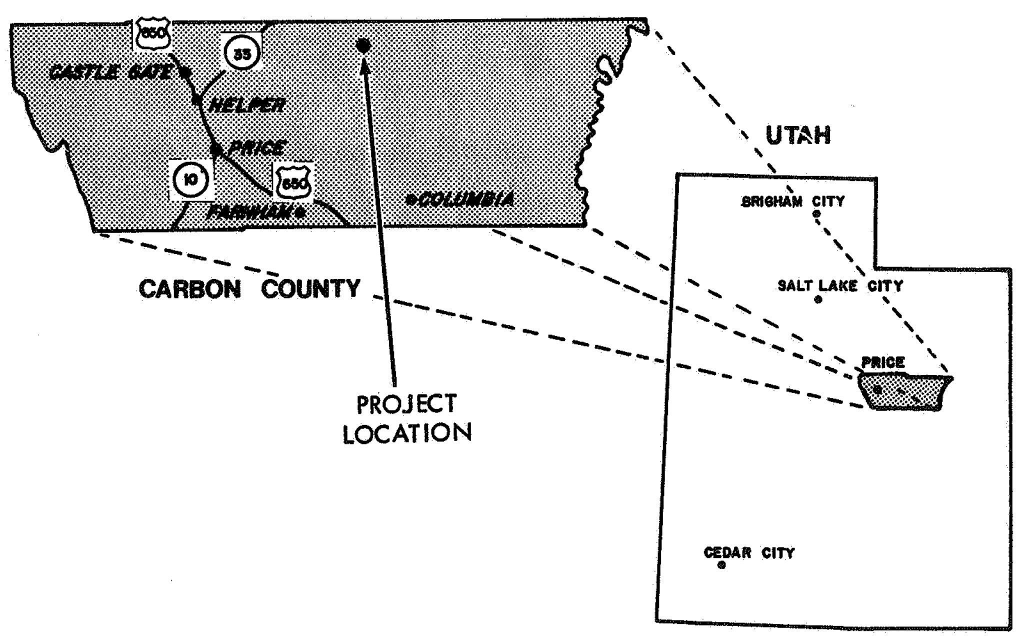
Mountain Fuel Supply Company
Salt Lake City, Utah

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 Investigator:	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 provides for 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 consists 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 demonstration project is planned in which these 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).

PROGRESS PRIOR TO APRIL 1979

Results of activities prior to 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 100 and 200 cf/ton of 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 are located in the Whitmore Park area of the Book Cliffs region (Section 34, T12S, R12E, Carbon County, Utah). Well No. 3 is located in the Castle Gate area of the Book Cliffs region (Section 15, T12S, R10E, Carbon County, Utah), about 12 miles west of Wells No. 1 and No. 2.

- A tentative drilling and completion plan was developed, and a preliminary environmental assessment was made of the three demonstration well locations.

PROGRESS THIS REPORTING PERIOD

Phases I and II were completed and Phase III was initiated in September 1979.

Well site plans for all three wells were completed, and USGS and State of Utah approvals to drill were received for the Whitmore Park Wells No. 1 and 2. The USGS denied the drilling permit application for the Castle Gate Well No. 3 because of questions concerning gas ownership and "minability" of the coal. The application was resubmitted in September without hydraulic stimulation and an appeal of the application, including hydraulic stimulation, is being prepared by Mountain Fuel.

A detailed environmental analysis was completed for each site, and surface and subsurface protection plans were filed with the USGS. The No. 3 well site is on Federal land; No. 1 and 2 on fee land.

Drill sites and access roads for the Whitmore Park Wells No. 1 and 2 were completed and final preparations were ready as of the end of the reporting period to begin drilling the first well pending availability of personnel and equipment. It is expected that a drilling rig can be moved on site early in October.

2.4.5 PICEANCE BASIN PRODUCTION TEST PROJECT

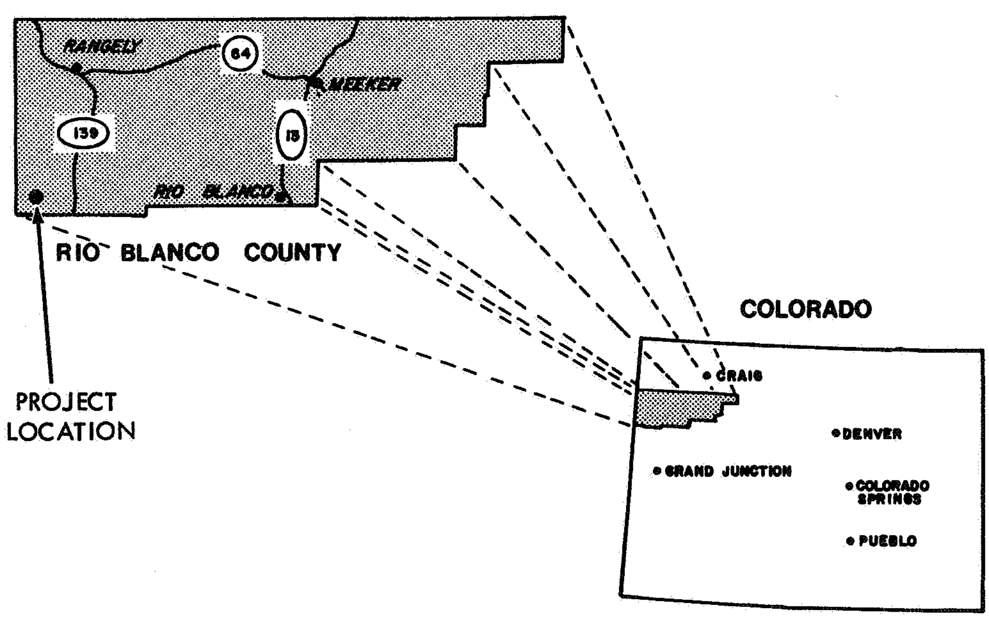
Intercomp, Inc.
Houston, Texas

Status:
Active

Contract:	DE-AC21-78MC08384
Contract Date:	September 29, 1978
Completion Date:	February 29, 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 approximately 10 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 consists 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.

PROGRESS PRIOR TO APRIL 1979

Field activities were not possible during the 1978-79 winter months because of adverse weather conditions which rendered the well site inaccessable. Because of this delay, the original contract was extended four months. Test procedures were prepared and equipment requirements determined.

PROGRESS THIS REPORTING PERIOD

The COSEKA Federal well 1-16 remained shut in all winter and well site activity was not resumed until April. The static bottom hole pressure was determined using a bottom hole pressure bomb. Results were reported as 490 psi at 1479 feet, 2 psi surface pressure, 100°F bottom hole temperature, and fluid level at 200 feet, indicating fresh water in the hole and adequate pressure to produce gas after the fluid level was lowered. A pumping jack was installed and operating by June 8. The well was swabbed in May and an adequate gas flow was observed. As a result, it was decided that an injection test to determine permeability of coal seam would not be performed.

The initial gas production generated a 6 to 7 foot flare; subsequent production, a 1 to 3 foot flare. A 1/8 inch orifice meter installed on June 20 prior to flaring indicated a 10 Mcfd gas flow with 11 psi on the casing side. The well continued to produce from 9.5 to 10 Mcfd of gas and 6 to 9 barrels per day (bpd) of water through June 28. In July and August, the production ranged from 6 to 10.5 Mcfd of gas and 0 to 25 bpd of water.

The well was shut in August 21. During the 75 day production period the well produced a total of 686 Mcf of gas and 642 barrels of water. The average calculated rates are 9.2 Mcfd of gas and 8.6 bpd of water.

Drilling plans were prepared for a second well, Federal 12-15. However, it was determined that this well may not clearly fall into the category of an unminable coalbed. Resolution of this potential resource conflict is pending; however, fracture treatment planning (foam or Kiel) continues.

Analysis of the results of the Federal well 1-16, and Federal well 12-15 if drilled, will be discussed in subsequent semi-annual reports.

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

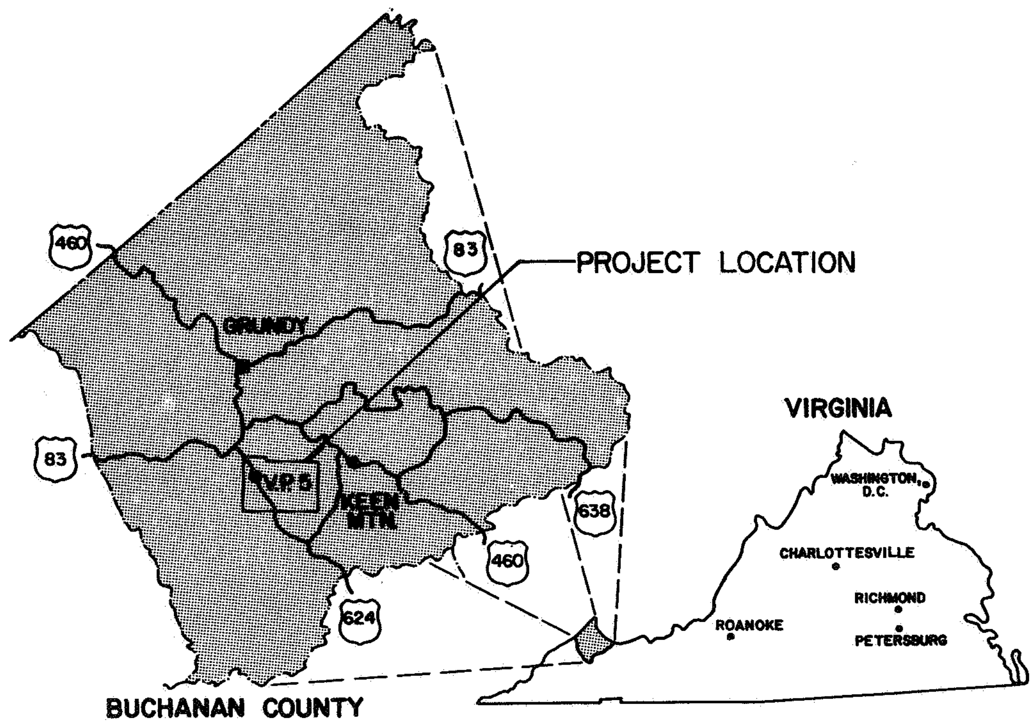
Occidental Research Corp.
Irvine, California

Status:
Active

Contract:	DE-AC21-78MC08089
Contract Date:	April 1, 1979
Completion Date:	July 1, 1981
Principal Investigator:	A.Gillies (TRW)
DOE Technical Project Officer:	H.D. Shoemaker

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 concerned with methane drainage using multiple horizontal boreholes in a mine under development. The site selected for field tests is the Island Creek Coal Company Virginia Pocahontas No. 5 Mine located in Buchanan County in the western part of Virginia.

A predrainage technique for longwall mining is desirable to reduce drilling costs and to avoid adverse surface ownership problems. The project selected to develop this technique was proposed by a team consisting of Occidental Research Corporation (ORC) and Island Creek Coal. The project includes several technology improvements including the development of a drilling technique for long boreholes (greater than 2000 feet) to drain the entire length of a longwall panel and development of a bit guidance technique to keep the borehole within the coal seam.

The project also includes the development of an in-mine piping system with an integrated safety system. Plastic pipe is used to reduce costs. During the design and 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 during the design validation phase may be used 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 utilization systems will be evaluated.

PROGRESS PRIOR TO APRIL 1979

This project was initiated by ORC prior to entering the cost-sharing agreement with the Government effective April 1979. ORC purchased a new in-mine drill, the "Big John" model from Acker Drill Company, Scranton, Pennsylvania, and installed the drill in the mine. The drill has been checked out by drilling several short holes (Nos. 1, 2, and 3). The methane produced during these shakedown operations was piped to a vent using a polyethylene piping system. The piping installation and safety equipment was approved by MSHA.

After the shakedown period, a 505 foot hole (#4) was drilled into a section of the mine not being worked. Gas production was approximately 200 cubic feet per day per foot of hole. Modifications to the drill were made to strengthen several elements.

PROGRESS THIS REPORTING PERIOD

Two long holes were completed with the modified Acker drill during the reporting period. The first hole was drilled in the face cleat direction to a distance of 1550 feet. This was the first of two long holes to validate techniques and equipment. The hole was drilled at the top of the seam and was kept within the seam easily by varying the drill/collar. stabilizer configuration, the drill speed, and the load on the bit. Drilling of this developmental hole was stopped at 1550 feet because large amounts of methane and high pressures were encountered.

The second long hole was drilled in a direction generally perpendicular to the face cleat to determine if hole productivity would be increased by a hole that intersects a greater number of fractures. The hole reached 1730 feet before high gas flow and pressure made further drilling difficult. Additional gas production did not appear to warrant the risk of further drilling in this hole. A post drilling survey showed that the hole deviates approximately 30 degrees in azimuth from the intended direction. General dip of the coalbed in the same direction is a possible cause of the deviation.

2.4.7 MULTIPLE COMPLETION DEVELOPMENT TEST PROJECT GREENE COUNTY, PENNSYLVANIA

Waynesburg College
Waynesburg, Pennsylvania

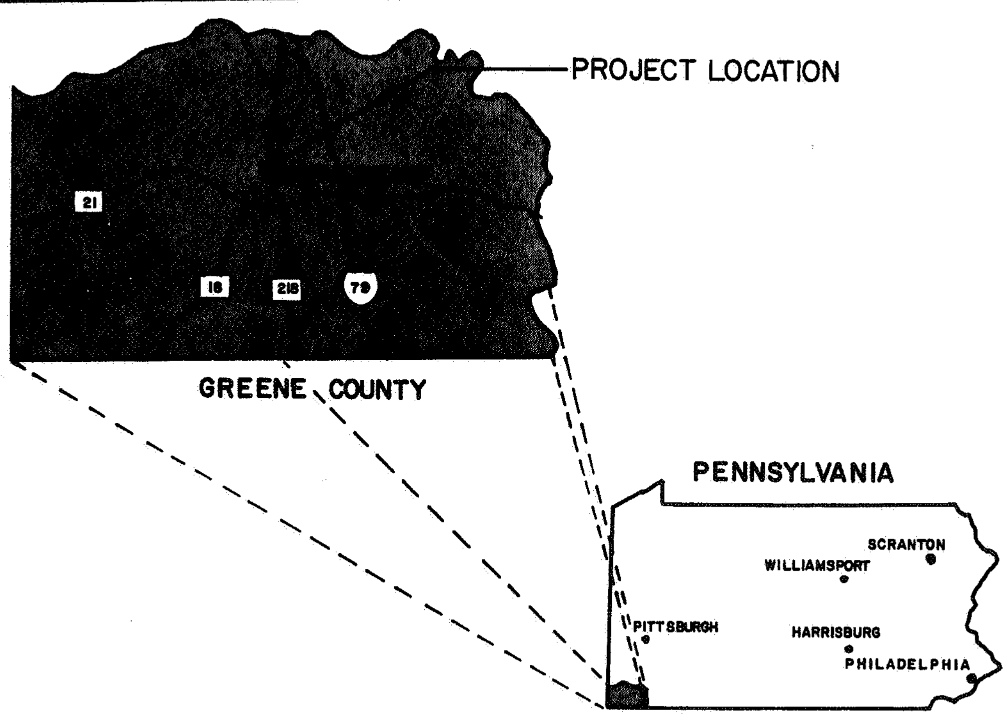
Status:
Active

Contract: DE-AC2178MC08089
Contract Date: July, 1979
Completion Date: March 31, 1980

Principal Investigator: N.F. McGinnis (TRW)
DOE Technical Project Officer: H.D. Shoemaker

OBJECTIVE

To develop and demonstrate a multiple completion technique system considering a variable need for dewatering each zone and utlilizing 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 existing natural gas supply to the college.

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. 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.

PROGRESS THIS REPORTING PERIOD

The following activities were conducted during the reporting period:

- A subcontract with Waynesburg College was negotiated and signed on July 25, 1979.
- The well site was selected so that its location will be convenient to an existing gas pipeline route. This site was surveyed in and the survey data will be included in the well drilling permit application.
- A preliminary well plan was devised and all available drilling data for this area were collected. These data include considerable geological information.
- Preparation of the project environmental assessment was initiated after briefing the college staff and identifying all requirements. Data collection was started and site environmental factors were identified.

It is anticipated that the well will be drilled in the fall of 1979.

2.4.8 ANTHRACITE COAL DRAINAGE TEST PROJECT LUZERNE COUNTY, PENNSYLVANIA

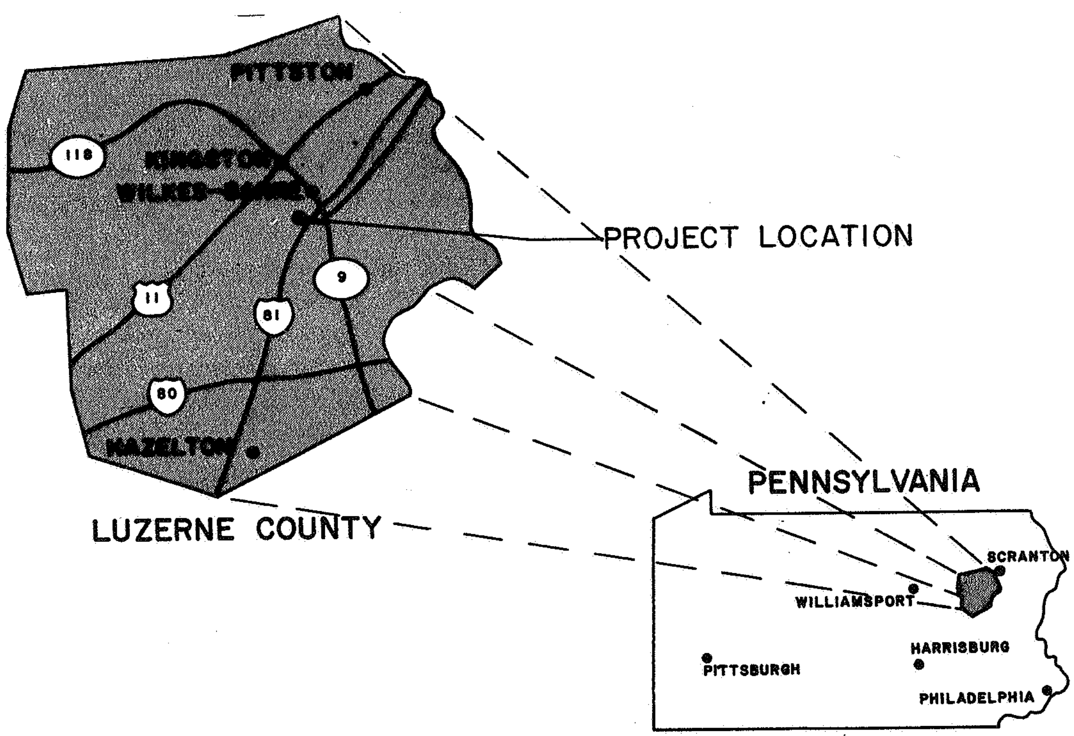
Pennsylvania Energy Resources, Inc. (PERI)
Wilkes Barre, Pennsylvania

Status:
Deferred

Contract:	DE-AC21-78MC08089
Contract Date:	To be determined
Completion Date:	To be determined
Principal Investigator:	H.R. Takamatsu (TRW)
DOE Technical Project Officer:	H.D. Shoemaker

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 completion 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 project 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 obviously communicating with the nearby Susquehanna River. Surface or pit mining is not deemed practical due to the depth of the coal (2000 feet). The concept provides for the geological characterization of the test area, the selection of stimulation techniques, and the drilling and completion of three production wells. The proposed utilization is to tie the wells into a local pipeline owned bv the Pennsylvania Gas and Water Company, a company associated with PERI.

PROGRESS PRIOR TO THIS PERIOD

In conjunction with the preparation of the proposal, PERI prepared a conceptual design, obtained gas rights to the leased land, selected sites for four wells, and obtained coal samples.

PROGRESS DURING THIS PERIOD

PERI started work on the environmental assessment and the detailed design of the methane recovery system. However, because of funding constraints, further work on this project has been postponed.

2.4.9 MULTIPLE VERTICAL BOREHOLE DEGASIFICATION TEST PROJECT JEFFERSON COUNTY, ALABAMA

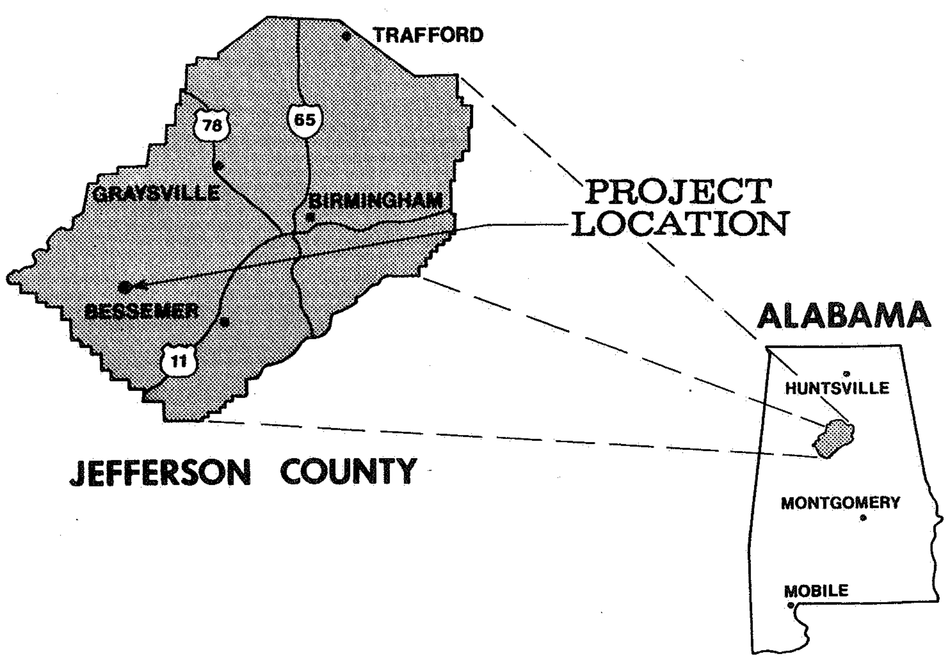
United States Steel Corporation

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 the U.S. Steel 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 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 mined ventilation costs using large-scale application of vertical borehole methane drainage techniques designed to be minimumly disruptive to the coal mining process.

PROGRESS PRIOR TO APRIL 1979

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. Seventeen boreholes were 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 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 Mcf with individual borehole gas flows ranging from 6 Mcf to 200 Mcf daily. The entire pattern of boreholes removed about 400 barrels of water daily.

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

PROGRESS THIS REPORTING PERIOD

Coalbed methane degasification was continued from the producing boreholes of the 17 hole grid at the Oak Grove project site. The total gas produced, average flow rate per borehole, and average flow rate for all boreholes are tabulated below for several months of this reporting period:

	Total Gas (cf)	Average Rate/ Borehole (cfd)	Average Rate All Boreholes (cfd)
May	32,158,000	75,800	1,072,000
June	32,569,000	75,200	1,086,000
July	33,943,000	77,100	1,095,000
August	35,574,000	87,600	1,048,000

In May, 13 of the 17 boreholes produced gas 28 or more days; two produced no gas. After a year of steady increase, total gas production decreased that month. This was a result of maintenance and repair problems that reduced the number of wells in operation. Water pumps were removed from six boreholes for maintenance/repair. Nylon rod guides were installed 100 feet apart to control whipping of the rods and to thereby minimize wear on the inner walls of the water tubing and extend pump cup life. The average daily water production per borehole continued to decrease, as in preceeding months (3200 gallons/day in June 1978 to 1100 gallons/day in May 1979), which indicated the water head on the coal seam was being reduced. Accordingly, the pumps were lowered in several boreholes.

In June, 13 boreholes produced gas every day; two produced on at least 24 days; and two produced no gas. Total gas production for the month increased. Maintenance/repair was required on five holes, with pump work dominating. No significant increase in water production resulted from the lowering of several pumps in May.

In July, 12 boreholes produced gas every day, two produced at least one half of the time, and two produced no gas. This was a result of maintenance and repair problems that reduced the number of wells in operation. Maintenance was performed on four boreholes and at the end of the month four were not operating. Analysis of gas samples indicated that the methane content continued to be high, averaging more than 96 percent. There are very little higher hydrocarbons or CO_2 and the nitrogen content remains 2 to 4 percent. No sulfur has been found and the heating value of the gas is consistently greater than 970 Btu/cf.

In August, 12 boreholes produced gas every day, two produced on at least 22 days, and one produced no gas. Maintenance was performed on five boreholes. Float switch activated sump pumps with electrically operated 20 gallon cycle counters, installed on two boreholes in June, operated successfully over a two month test period. Additional units will be installed on the remaining boreholes to provide more accurate measurement of water production, particularly from the holes with low water flow. Gas was produced from Borehole 9 for the first time since February 1978, but only for six days before downhole problems required shutdown of the hole.

The average daily gas production from all boreholes in the Oak Grove test grid is shown in Figure 2-15 for the 20 month period ending August 1979. Daily gas and water production and detailed maintenance/repair records are maintained for each individual borehole. Additional information resulting from this project will be discussed in subsequent semi-annual reports.

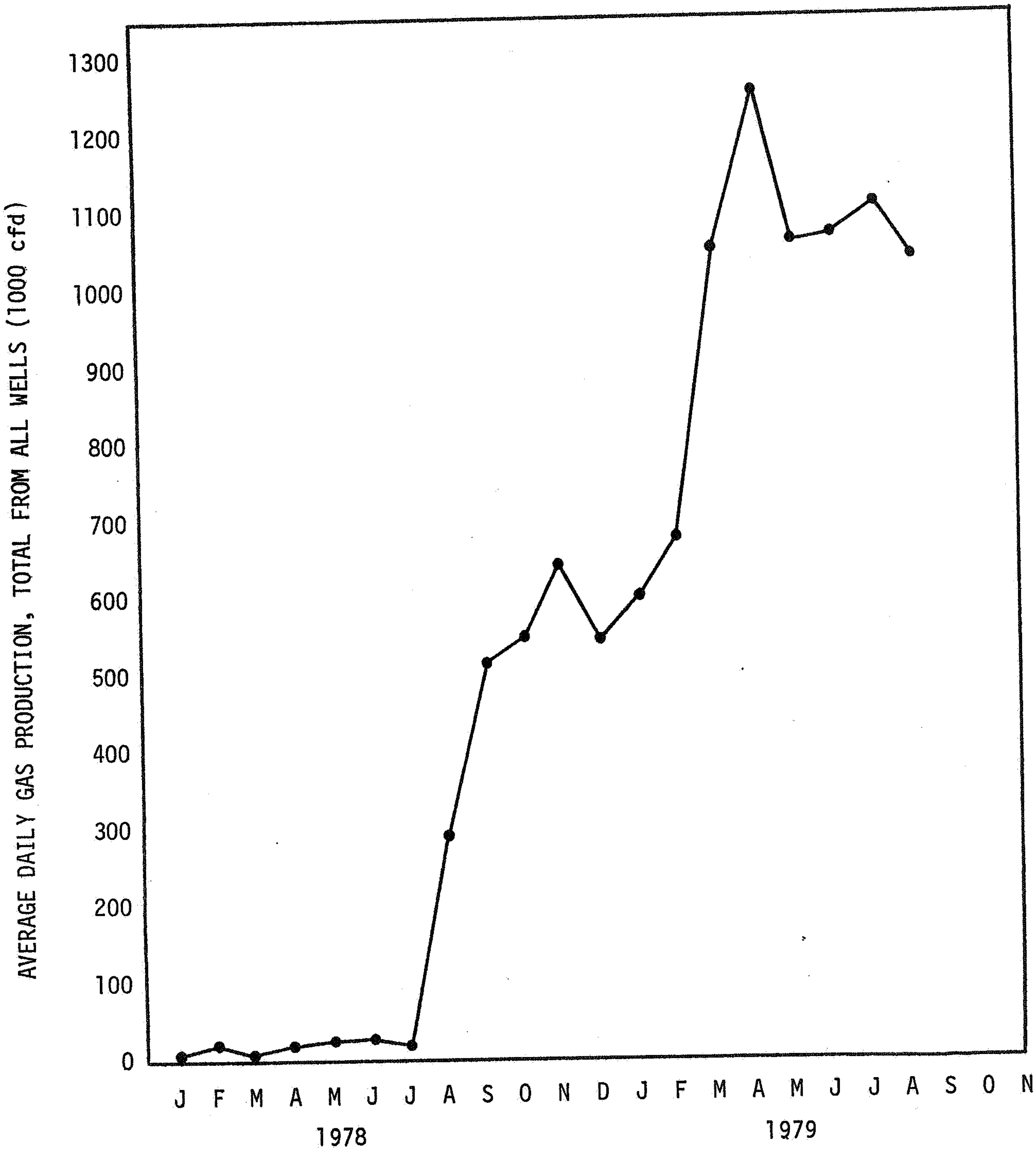


Figure 2-15. Average Daily Gas Production from All Boreholes in Test Grid at the U.S. Steel Corporation Oak Grove Mine, Alabama.

2.4.10 DIRECTIONAL DRILLING DEGASIFICATION TEST PROJECT GREENE COUNTY, PENNSYLVANIA

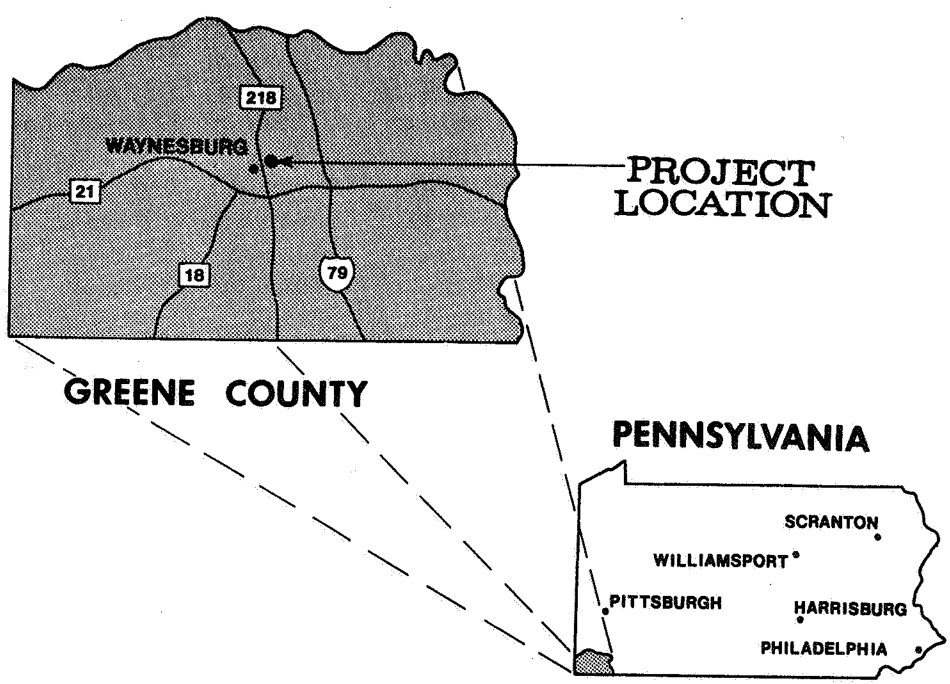
J & L Emerald Mine Corporation

Status: **Active**

Contract:	**ET-77-C-01-8891**
Contract Date:	**September 27, 1977**
Completion Date:	**May 26, 1980**
Principal Investigator:	
DOE Technical Project Officer:	**W.P. Diamond (USBM)**

OBJECTIVE

To develop Coalbed methane degasification capability using directional drilling techniques.



SCOPE OF WORK

This project is comprised of activities designed to develop and demonstrate capability for the degasification of coal seams using directional drilling techniques prior to mining. The Pittsburgh seam is of particular interest in this effort. Existing technologies for drilling vertical boreholes from the surface and horizontal boreholes from underground locations are being combined to improve/develop methods and equipment for directional drilling. The intent is to provide means to extract methane from unmined coalbeds where the surface topography or other barriers make the use of vertical boreholes undesirable or impossible. A directionally drilled, or slanted, borehole is desired in a "birdfoot" pattern, from a single vertical borehole at the surface to multiple horizontal boreholes which intercept and penetrate the coal seam significant distances in several directions. For this developmental project, an array of vertical boreholes are drilled in the vicinity of the directionally drilled borehole. These vertical holes are used to monitor variations in the coalbed pressure at several points, to aid dewatering efforts, and to determine geologic characteristics and parameter values needed for reservoir modeling and the design of future degasification procedures.

PROGRESS PRIOR TO APRIL 1979

Search for a new drilling site was initiated by the U. S. Bureau of Mines early in 1976 after termination of a prior directional drilling project. Procurement activities (RFP released in March 1977) resulted in a cooperative agreement with Emerald Mine and a drilling contract award in September, 1977; however, problems with gas rights prevented use of the site originally selected. On October 1, 1977, the project was transferred to the DOE, with USBM continuing to provide technical management. Final site selection and drilling plans were completed in mid 1978 after long term delays which included a labor strike and modifications to the drilling contract. Provisions were made for directional drilling control and the addition of several vertical boreholes. The vertical holes are used to monitor underground conditions and to support other developmental aspects of the project such as coring, dewatering, and coalbed pressure measurements.

A plan view of the project site is shown in Figure 2-16. A vertical core hole, EM 78-1, was completed in September 1978, after drilling 759 feet to the anticipated interception point of the coal seam and the directionally drilled hole. A vertical dewatering hole, EM 20 (located near core hole EM 78-1), was completed to 900 feet in October. Seven vertical monitoring boreholes, EM-21 through EM-27, were completed in January, 1979.

A directionally drilled 3-inch diameter pilot borehole was completed in December 1978 to a total measured depth (or length) of 1649 feet (999 feet true vertical depth).

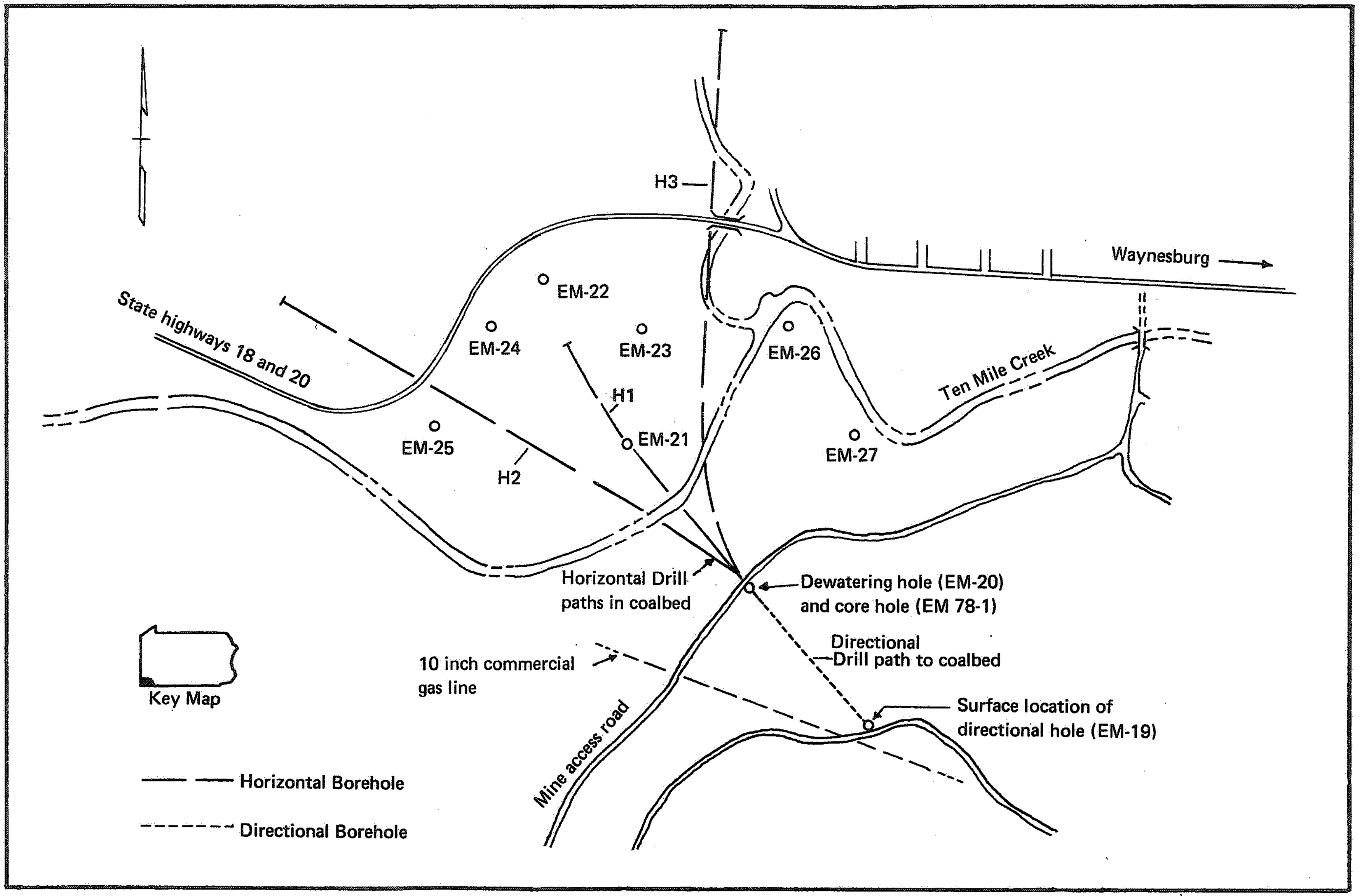


Figure 2-16. Plan View of Directionally Drilled Boreholes and Vertical Monitoring Holes, DOE/USBM Test Project at J & L Emerald Mine.

Reaming of this borehole to 8 3/4-inches diameter was started in January, but severe lost circulation was experienced after proceeding approximately 190 feet. This required larger diameter reaming and placement of casing to 110 feet. The casing parted and recovery operations continued through March of 1979. During this period of time cores were obtained from the vertical monitoring holes EM-21 through EM-25.

PROGRESS THIS REPORTING PERIOD

Reaming of the directionally drilled borehole was completed to 1612 feet in May 1979, and 5 1/2-inch diameter casing was run in 1595 feet.

A 3-inch diameter borehole was drilled horizontally to a length of 90 feet and vertical monitoring hole EM-20 was hydraulically stimulated using a 21,000 gallon foam treatment. Horizontal borehole H-1 (Figure 2-16) was drilled to a total depth (length) of 3,362 feet and drilling operations were terminated in July when the Dyna-drill was pulled and replaced, but could not be run back into the borehole. Horizontal boreholes H-2, H-3, and H-4 were drilled in August and September to total depths (lengths) of 4,802, 4,588, and 2,642 feet, respectively. All of the horizontal holes were drilled using the common directionally drilled hole as a starting entry. The total length of the horizontal portions of these boreholes is 8,837 feet. The length in feet of the individual holes are H1 1767, H2 3207, H3 2993, and H4 870.

After an additional planned horizontal hole (H5) is drilled, the entire "birdfoot" pattern of boreholes will be prepared for the production of gas. Gas flow data and other information will be discussed in subsequent semi-annual reports.

2.4.11 VERTICAL DRILLING JAWBONE COALBED DEGASIFICATION TEST PROJECT DICKENSON COUNTY, VIRGINIA

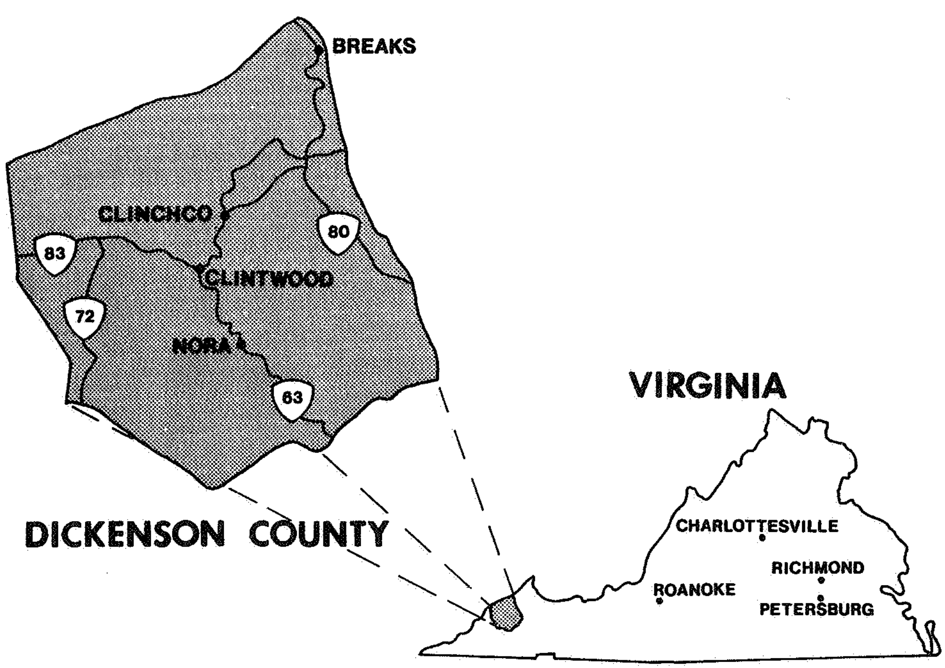
Clinchfield Coal Company

Status:
Active

Contract:	**ET-77-C-01-9151**
Contract Date:	**September 29, 1977**
Completion Date:	**September 28, 1982**
Principal Investigator:	**T. Wallace (Clinchfield Coal)**
DOE Technical Project Officer:	**P.F. Steidl (USBM)**

OBJECTIVE

To determine the feasibility of degasifying the Jawbone Coalbed using vertical boreholes.



SCOPE OF WORK

Conventional drilling methods are being used as the basis for developing and demonstrating the feasibility of Jawbone Coalbed degasification. Wells drilled vertically to the coal seam in areas ahead of advancing mining operations will be fractured and dewatered as required and prepared for the production of gas. Gas flow rates and total gas production of each well will be observed over long term periods to acquire experience and information applicable to specific methane extraction techniques and equipment.

PROGRESS PRIOR TO APRIL 1979

Drilling operations for the first Jawbone Coalbed degasification well, designated DG-1A, began May 30, 1978. The desorption of gas from two core samples was approximately 150 and 280 cf/ton of coal, and the well was stimulated using 30,000 gallons of foam and 27,000 pounds of sand proppet. A number of dewatering pump problems prevented steady gas production; the average rate for 20 days ending October 20 was 24.3 Mcfd of gas and 28 bpd of water. The highest daily gas production was recorded on December 18, 1978 at 43.5 Mcfd with 1 gal/min of water.

PROGRESS THIS REPORTING PERIOD

Gas production from well DG-1A continued throughout the reporting period. The cumulative production through May 1979 was 5.5 MMcf. By the end of the reporting period, production had increased to 26 Mcfd from a low of 23 Mcfd in July. Mining has advanced to approximately 550 feet of the well, lowering the coalbed pressure and allowing more gas to desorb from the coal.

It is planned to continue gas production testing of well DG-1A and to drill additional wells. Additional information resulting from these activities will be discussed in subsequent semi-annual reports.

2.5 PROJECT INTEGRATION

2.5.1 GENERAL

In addition to coordination of the Resource Engineering, Research and Development, and Technology Systems Tests efforts, a draft version of the MRCP Project Plan Document (PPD) for FY1980 was prepared. The primary purposes of this plan are to establish project objectives and to provide planning for the technical work and supporting activities that must be performed to achieve the objectives.

The contents of the document are summarized below:

- Summary - States current problems and issues, accomplishments expected in FY 1980, and long term accomplishments; and describes project activity flow and document organization.
- Introduction - Identifies the MRCP goals, objectives and strategy, states the federal role, describes the coalbed methane resource, and provides background information of coalbed methane technology.
- Project Description and Structure - Presents (1) a description of the MRCP, its major elements and planned activities; (2) the project work breakdown structure (WBS); and (3) a matrix correlation of the MRCP activities with overall Unconventional Gas Resource (UGR) activities.
- Detailed Implementation Plan for FY 1980 - Presents technical activity and budget planning for the current fiscal year. WBS elements are developed to the specific task level with individual contractors and budget allocations identified.
- Management - Describes the roles and responsibilities of project participants and identifies features and requirements with respect to information management and project control.
- Five Year Budget Projection - Presents the MRCP 5-year budget projection through FY 1984.

2.5.2 INFORMATION MANAGEMENT

Significant quantities of information of many types, in various formats, and from diverse sources will be developed through the four elements of the MRCP. Rapid transfer of developed technology to industries active in this field is essential to early commercialization of methane from coalbeds. This requires appropriate Information Management and a draft information management plan was developed to identify and structure for implementation all of the activities necessary to provide for efficient, effective, and economic management of information acquired and developed through the Methane Recovery from Coalbeds Project (MRCP). The document consists of a summary, introduction, information management system description, technical approach for implementing the information management system, management description, and proposed schedule and funding requirements for the initial phase of the information management activity.

The MRCP information management system is currently implemented as a manual open-file. However, as the MRCP matures, the information processed and the user requirements are expected to increase both in volume and complexity. To provide for rapid dissemination of information the requirements will be reviewed at intervals of 3 to 6 months and the information management system will be modified as needed.

2.5.3 TECHNOLOGY TRANSFER (INCL. SYMPOSIA)

A Methane Recovery from Coalbeds symposium was held in Pittsburgh, Pennsylvania on April 18, 19, and 20, 1979. The symposium was sponsored by the U. S. DOE Morgantown Energy Technology Center and featured 17 technical papers. The symposium proceedings are being published separately as a METC special publication. The titles and authors of the papers are as follows:

Methane Recovery from Coalbeds - METC
R. L. Wise, Morgantown Energy Technology Center

Commercialization of Coalbed Methane
Troyt L. York, U.S. Department of Energy

The U.S. Bureau of Mines Program for Methane Drainage to Reduce Safety Hazards in Coal Mines
Maurice Deul, U.S. Bureau of Mines

The Controlling Production Mechanism of Gas in Methane from Coalbeds
Vello A. Kuuskraa, Lewin and Associates, Inc.

The Vagarious Nature of Methane Gas from Coalbeds
Robert Stefanko, Pennsylvania State University

A Review of the State-of-the-Art of Methane Drainage Utilization in the United Kingdom
William L. Hole, National Coal Board, Limited

Degasification Parameters and Well Completion Procedures for the Mary Lee/Blue Creek Coalbeds in Tuscaloosa County, Alabama
K. L. Ancell, Intercomp and J. W. Stevenson, Jim Walter Resources

The Extraction, Collection and Utilization of Coalbed Methane
Carl L. Sturgill, Westinghouse Electric Corporation

Degasification of the Blue Creek Coal Seam at U.S. Steel's Oak Grove Mine
P. B. Stubbs, F. X. Dobscha, and J. V. Mahoney, United States Steel Corporation

The Pricetown Project, Snodgrass #2 Well Methane Production/Performance
H. D. Shoemaker, G. E. Rennick, R. L. Wise and D. W. Gilmore, Morgantown Energy Technology Center

Methane Recovery from Deep Seams
Hilmar von Schonfeldt, Occidental Research Corporation

Hydraulic Stimulation of the Pittsburgh Coal Seam - A Case Study
Raymond L. Mazza, Continental Oil Company

Directional Drilling for Coalbed Degasification in Advance of Mining
William P. Diamond and David C. Oyler, U.S. Department of the Interior, Bureau of Mines

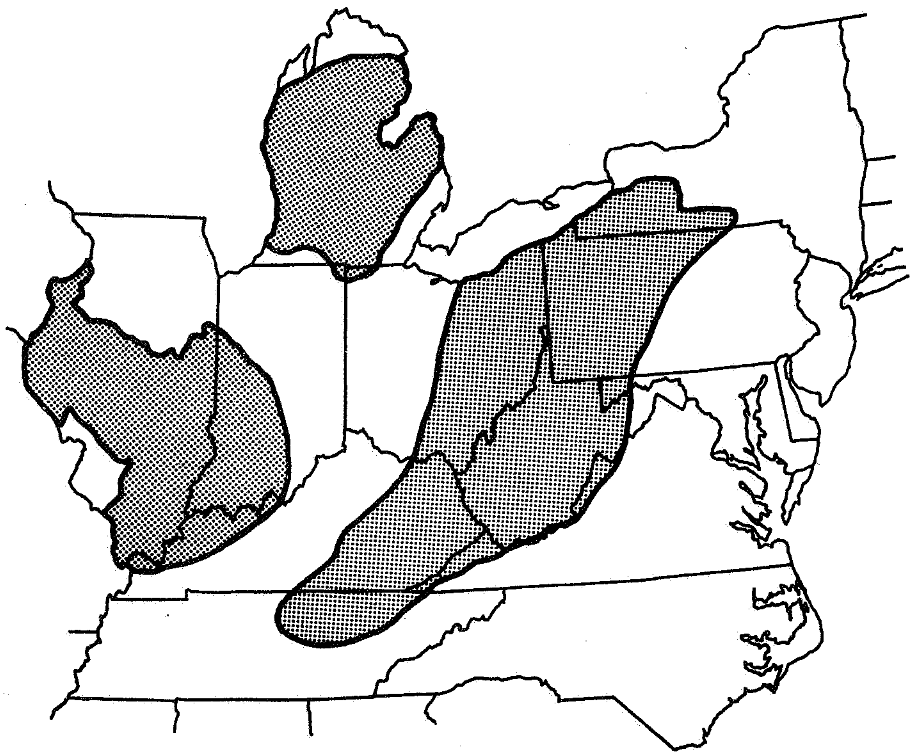
Methane Drainage Turbodrill
William C. Maurer, Maurer Engineering Inc.

Design of a Mobile Horizontal Drill
Pramod C. Thakur and Emrys H. Jones, Continental Oil Company

The Delineation of Methane Resources in Unminable and Minable Coalbeds
A. A. Lee, TRW Energy Systems Group

Evaluation of the Methane Content and Resources of Colorado Coals
D. Keith Murray and Carol Morgans Tremain, Colorado Geological Survey

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.

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 shallow depths 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 is 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.

Based on over 20,000 feet of Devonian Shale core collected by the EGSP, almost all the planned formation characterization work required to update the resource knowledge base has been completed. A computerized information retrieval system has been established to provide access to this data.

The geological evaluation work required to ascertain basin limits and stratigraphic targets as potential gas sources, are essentially complete. Large areas of the Devonian Shale have been determined as geologic provinces exhibiting certain characteristics that require particular technological developments for extraction (Figure 3-1).

EGSP research has identified the nature of producible gas containment to be the micro- and macro-fractures of the shale formation. Knowledge of these fractures, their directionality, and density has enabled the development and testing of effective techniques to connect the gas-bearing natural fractures to the borehole. Field tests and demonstration projects have shown that advanced stimulation technology will produce considerably more gas than conventional wellbore explosive fracturing in historic shale production areas. Directional deviated well technology is achievable but additional demonstrations are warranted in other regions to complete an economic assessment.

Predictive codes for evaluation of stimulation techniques in specific geologic provinces have been developed, as well as a production performance model for the shale gas reservoir.

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

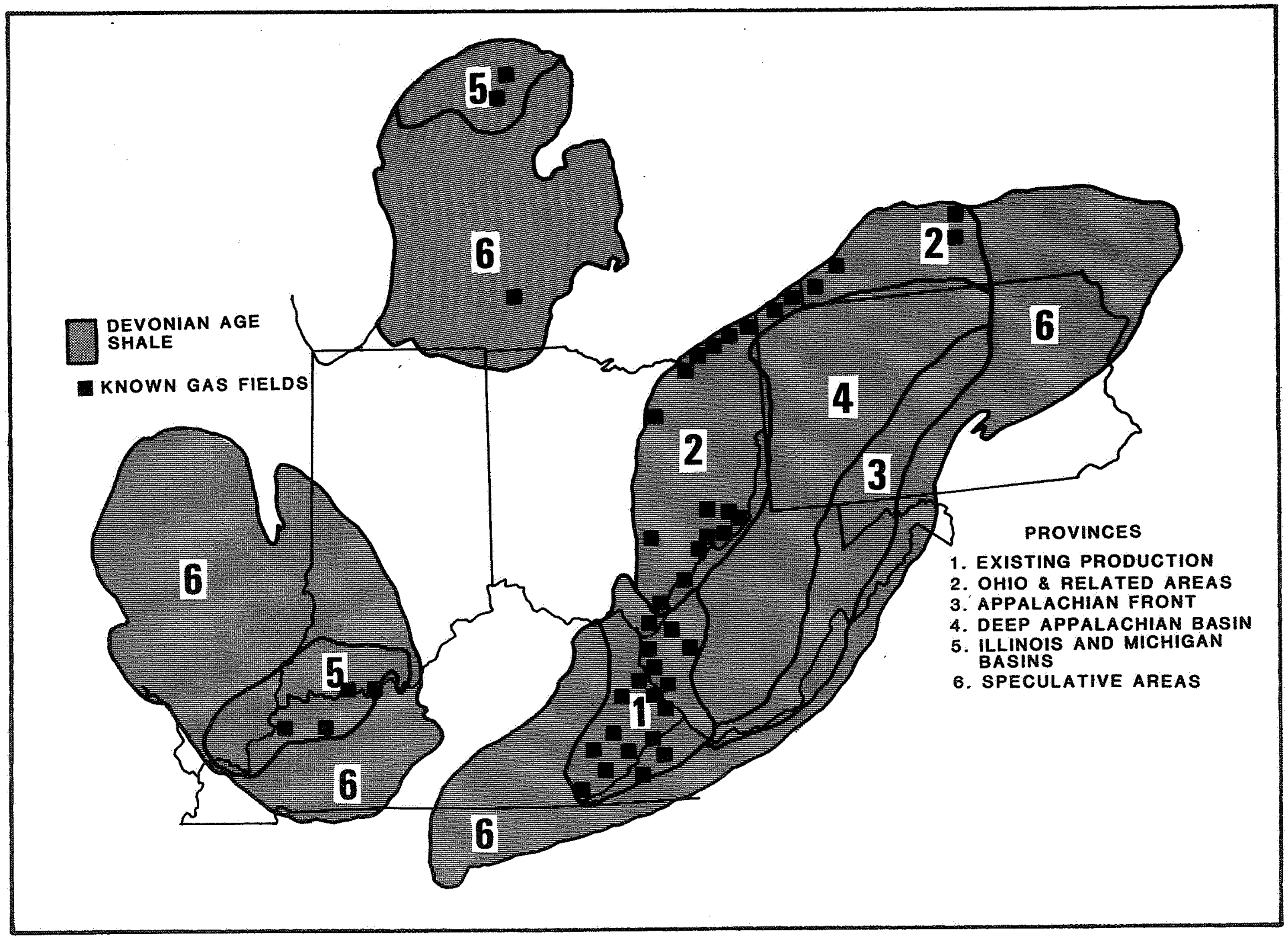


Figure 3-1 Location of Eastern Gas Shales Geologic Provinces

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

The interrelationships between these Elements are shown in Figure 3-2. The goals, objectives and activities of these Elements are described below.

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.

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.

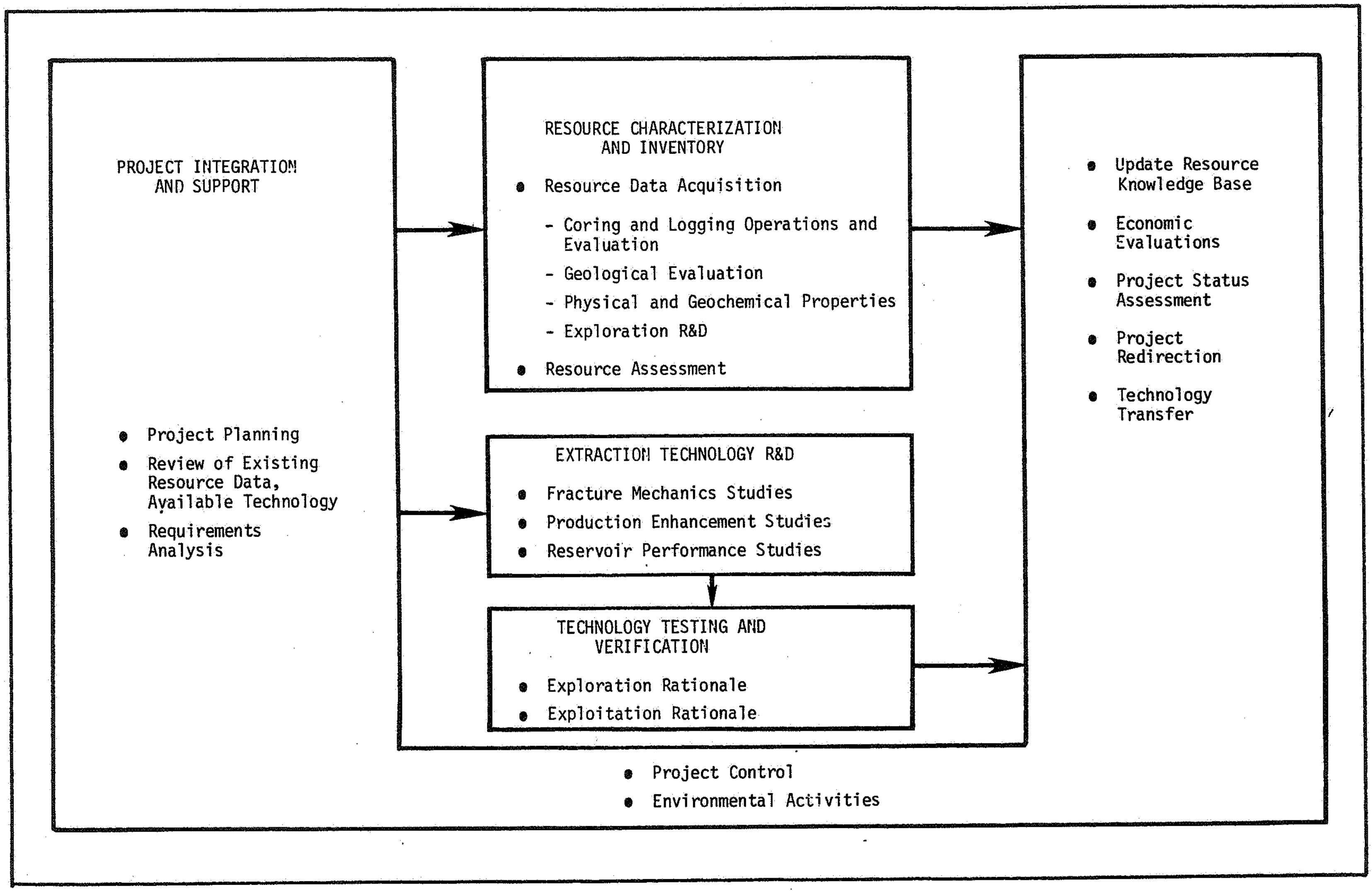


Figure 3-2 Eastern Gas Shales Project Description

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 in the EGSP 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.

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 impact 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

The contractors active in the EGSP during this reporting period, and contractors for core wells for which analyses were performed during the period, 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	
	Resource Data Acquisition & Analysis	Resource Assessment	Fracture Mechanics	Production Enhancement	Reservoir Performance	Exploration Rationale	Exploitation Rationale
Ashland Exploration, Inc.	X						X
Battelle Columbus Laboratories	X						
Cliffs Minerals, Inc.	X						
Columbia Gas System Service Corp.	X						X
Combustion Engineering	X						X
Donohue, Anstey & Morrill (2)						X	
E. I. DuPont DeNemours & Co.				X			
Environmental Research Institute of Michigan	X						
Gruy Federal, Inc. (2)	X				X		
Houghton College							X
Illinois Geological Survey (2)	X						
Indiana Geological Survey	X						
Intercomp					X		
Juniata College	X						
Lawrence Livermore Laboratory			X				
Los Alamos Scientific Laboratory			X				
Minard Run Oil Company	X						X
Mitchell Energy Corporation (2)	X					X	X
Mobay Chemical	X						
Mound Facility	X						
National Fuel	X						
New York Geological Survey	X						
Ohio Geological Survey	X						
Ohio State University			X				
Pennsylvania Geological Survey	X						
Petroleum Technology Corp. (3)				X			
Rector & Stone Drilling Co.	X						
Sandia Laboratories			X				
Science Applications, Inc.	X	X	X		X		
Stanford Research Institute (2)			X				
Tennessee Geological Survey	X						
Terra Tek (2)			X				
Tetra Tech, Inc.				X			
United States Department of Energy							X
United States Geological Survey	X	X					
University of Cincinnati	X						
University of Kentucky RF (2)	X						
University of Maryland			X				
University of North Carolina	X						
J. T. Waggoner							X
Thurlow Weed & Associates							X
West Virginia Geological & Economic Survey	X						
West Virginia University (3)	X		X				

3.2 RESOURCE CHARACTERIZATION AND INVENTORY

3.2.1 INTEGRATION

The goals of this Element are to characterize the Devonian Shales, and to estimate the total gas resource and producible reserves.

Two advances were made in the state-of-the-art of EGSP offgassing studies which provide the basic data for estimating gas-in-place. The first involves the application of controlled offgassing at the well site, and the second, the recovery of pressurized core material. Both techniques are an improvement over the normal offgassing method, in that the measured values of cu ft gas/cu ft shale more closely reflect in situ conditions, by allowing a correction for gas lost prior to encapsulation. During controlled offgassing studies, a sample is encapsulated at the well site in a special, tapped container. Instead of waiting several weeks to measure the offgas volume (the normal EGSP method) the can is periodically tapped and composition determined beginning shortly after encapsulation. The data obtained in this way allows an extrapolation of the matrix gas content to time zero; i.e. when the core sample was first cut from the formation by the coring bit.

The pressurized core barrel technique is a further improvement. In this technique, the downhole pressure is maintained by the core barrel during coring and when the core is brought to the surface. The core is frozen with dry ice and samples taken and analyzed for gas volume and composition. Preliminary work indicates that, using the gas in the pressure core as 100%, controlled offgassing yields 70% of in situ values and the normal canning technique yields 40%. Thus, a larger and more realistic value for the EGSP Resource Assessment is possible due to the obtaining of better offgas data.

The EGSP Pilot Resource Study is nearing completion. The data generated by numerous EGSP contractors are being used to determine the total gas-in-place of a five-county area in southwestern West Virginia. The types of EGSP data being input into the resource assessment are as follows:

- Geological - Isopach (thickness) maps of identifiable black shale units in the study area; Stratigraphic cross-sections which show the correlation and stratigraphic relationships of these units; Maps showing the relation of natural fracture patterns, lineation trends, joint swarms, faults, and folds to these black shale units.

- Physical - Shale porosity and permeability.

- Geochemical - Offgas values, obtained from the samples encapsulated at the wellsite, supplemented by shale gas chromatography and pyrolysis analyses; Maps showing the degree of thermal maturity of the Devonian Shale formations.

Methane adsorption isotherms of shale samples are being used for calculating the total gas resource as well as an input into EGSP reservoir modeling studies. After completion of the Pilot Study, the shale gas resource of the remainder of the Appalachian Basin will be assessed.

A nineteen-county area in southeastern Illinois has been determined to contain the only appreciable shale gas resource in the State. Another study will be completed on November 1, 1979 outlining the high potential gas areas for the remainder of the Illinois Basin.

A contractor has begun examining the utility of remote sensing techniques to locate fractured, gas-filled shale reservoirs in the western Kentucky portion of the Illinois Basin, using the results of two previous EGSP studies covering remote sensing and the geology of western Kentucky.

Core and geologic data generated by the EGSP for the Devonian Shale of eastern Tennessee have been used to site an exploratory well in the Greendale Syncline. The well will test the exploration rationale that fracturing of the organic-rich shales should have resulted from thin-skinned tectonic deformation of the over-and underlying strata. The well is scheduled to be drilled in early 1980.

3.2.2 APPALACHIAN BASIN

The Appalachian Basin extends for over 1500 miles from southern New York to northern Alabama and Georgia. All of the State of West Virginia and portions of New York, Pennsylvania, Ohio, Maryland, Virginia, Kentucky, Tennessee, North Carolina, South Carolina, Georgia and Alabama are included. The total area of the Devonian Shale formations is over 90,000 square miles. The rock formations of the Devonian Geologic Period were deposited in inland seas over 350 million years ago. The Devonian Shales outcrop in the eastern, northern, and western portions of the Basin and reach a thickness of over 3000 feet in south-central West Virginia. The rock facies become coarser-grained and thicken to the east of this area.

RESOURCE DATA ACQUISITION AND ANALYSIS

A summary of the work performed in the Appalachian Basin by 17 contractors in this Work Package of the EGSP is presented in the following pages.

CHEMICAL AND PHYSICAL ANALYSIS OF EASTERN SHALE

Battelle Columbus Laboratories
Columbus, Ohio

Status: Completed

Contract:	DE-AC21-76MC05205
Contract Date:	July 1, 1976
Anticipated Completion Date:	September 30, 1979
Principal Investigator:	J. Synder
Technical Project Officer:	S. Bialobok Morgantown Energy Technology Center

OBJECTIVE

To determine the relationship between shale characteristics, hydrocarbon gas content, and well location so as 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 849 samples of core encapsulated at the well sites. During this reporting period, the following samples were collected:

Location	EGSP Well No.	No. of Samples
Knox County, OH	OH-3	36

All analytical work has been completed on the Knox County, Ohio core and on the samples from Johnson County, Kentucky; McKean County, Pennsylvania; Allegheny County, Pennsylvania; and Hardin County, Illinois collected during the previous reporting period. This completes analytical work for 19 cores in the Appalachian and Illinois Basins. These 19 cores total 885 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.

Gas volume averages for the wells analyzed during this reporting period are listed below:

Location	EGSP Well No.	ft^3 gas/ft^3 shale
Knox County, OH	OH-3	0.29
Johnson County, KY	KY-4	0.55
McKean County, PA	PA-1	0.50
Allegheny County, PA	PA-2	0.30
Hardin County, IL	IL-4	0.00

Results of the other analyses for each well are presented elsewhere in this report, under the individual well contracts.

COLLECTION, DESCRIPTION, AND LOGGING OF EGSP DEVONIAN SHALE CORES

Cliff Minerals, Inc.
Granville, West Virginia

Status: Active

Contract:	**DE-AC21-78MC08199**
Contract Date:	**August 16, 1978**
Anticipated Completion Date:	**November 30, 1981**
Principal Investigator:	**H.J. Leach**
Technical Project Officer:	**C. W. Byrer** **Morgantown Energy Technology Center**

OBJECTIVE

To collect, describe lithology/fractures, fractures, physical properties, and log oriented Devonian shale core for all EGSP core wells. All data generated will be compared with geophysical logs from the cored 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 7795 feet of Devonian Shale core from eleven 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 analysis. Included in the core extraction are approximately thirty feet of oriented pressurized core. The pressurized cores were the first to be taken in the EGSP. The data from these cores will be used to verify or revise off-gassing calculations.

Certain aspects of the directional tensile testing program (subcontracted to Michigan Technological University) will have to be modified as the result of a high percentage of the samples failing parallel to bedding. For these tests to yield useful information, the samples must fail normal to bedding in the diametral direction dictated by the line-loading condition. These modifications should be completed early in the next reporting period.

REMOTE SENSING APPLIED TO THE INCREASE OF NATURAL GAS RESERVES IN THE DEVONIAN SHALE

Environmental Research Institute of Michigan
Ann Arbor, Michigan

Status: Active

Contract:	**DE-AC05-77ET12137**
Contract Date:	**August 4, 1977**
Anticipated Completion Date:	**September 30, 1980**
Principal Investigator:	**P.L. Jackson**
Technical Project Officer:	**C.S. Dean** **Morgantown Energy Technology Center**

OBJECTIVE

To develop remote sensing as an exploration technique for natural gas from the Devonian Shales of the Appalachian, Illinois , and Michigan basins. The technique presumes that certain linear and arcuate features observable in remote sensing imagery are expressions of geologic fracture zones that extend down into the subsurface where the shales occur.

SCOPE OF WORK

This is the second year of a two-year study. The Scope of Work for the first year's effort may be found in the Semi-Annual Report for the Unconventional Gas Recovery Program, METC/SP-79/8, for the period ending March 31, 1979.

The work to be performed during the second year consists of the following tasks:

- Collect and analyze geological, geophysical and remote sensing data in a geologically complex area of western Kentucky (Figure 3-3).
- Select an area or areas for lineament enhancement, based on a study of the raw remote sensing imagery.
- Process and interpret the selected imagery in consultation with geologic photo interpreters who are knowledgeable of the study area.
- Evaluate the utility of the various types of remote sensing data and the effectiveness of the various techniques employed to enhance remote sensing lineaments and bring them across the threshold of perception.

- Prepare a report describing the investigation and its results, evaluating the current status of remote sensing lineament enhancement research and its future potential, especially with regard to locating fractured Devonian Shale reservoirs.

SUMMARY OF PROGRESS

During the initial contract period, the contractor focused his attention on the Cottageville gas field, actively producing from the Devonian Shales in Jackson County, WV. High resolution synthetic apperture radar (SAR) and a 12-channel multispectral scanner (MSS) data were obtained over two 7 1/2- by 21-mile rectangular areas that intersect orthogonally over the field. The data were processed into viewing form and examined for geologic lineaments. Following this preliminary interpretation of the raw imagery, a number of optical analysis and digital processing techniques were used in an attempt to enhance geologic lineaments and suppress extraneous features. Most of the techniques attempted were conventional, but had never before been applied to the problem of detecting fractured reservoirs in the Devonian Shales. One result of the study was the development of gradient filtering, a digital processing technique that was an important advance in the state-of-the-art. 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.

Contract work for the second year was initiated during the last month of this reporting period. Geologic, geophysical and remote sensing data are being obtained and analyzed from the western Kentucky study area. Western Kentucky was chosen for study due to the large number of surface geologic structural features which have been identified in the study area. These features should be identifiable on the ERIM imagery.

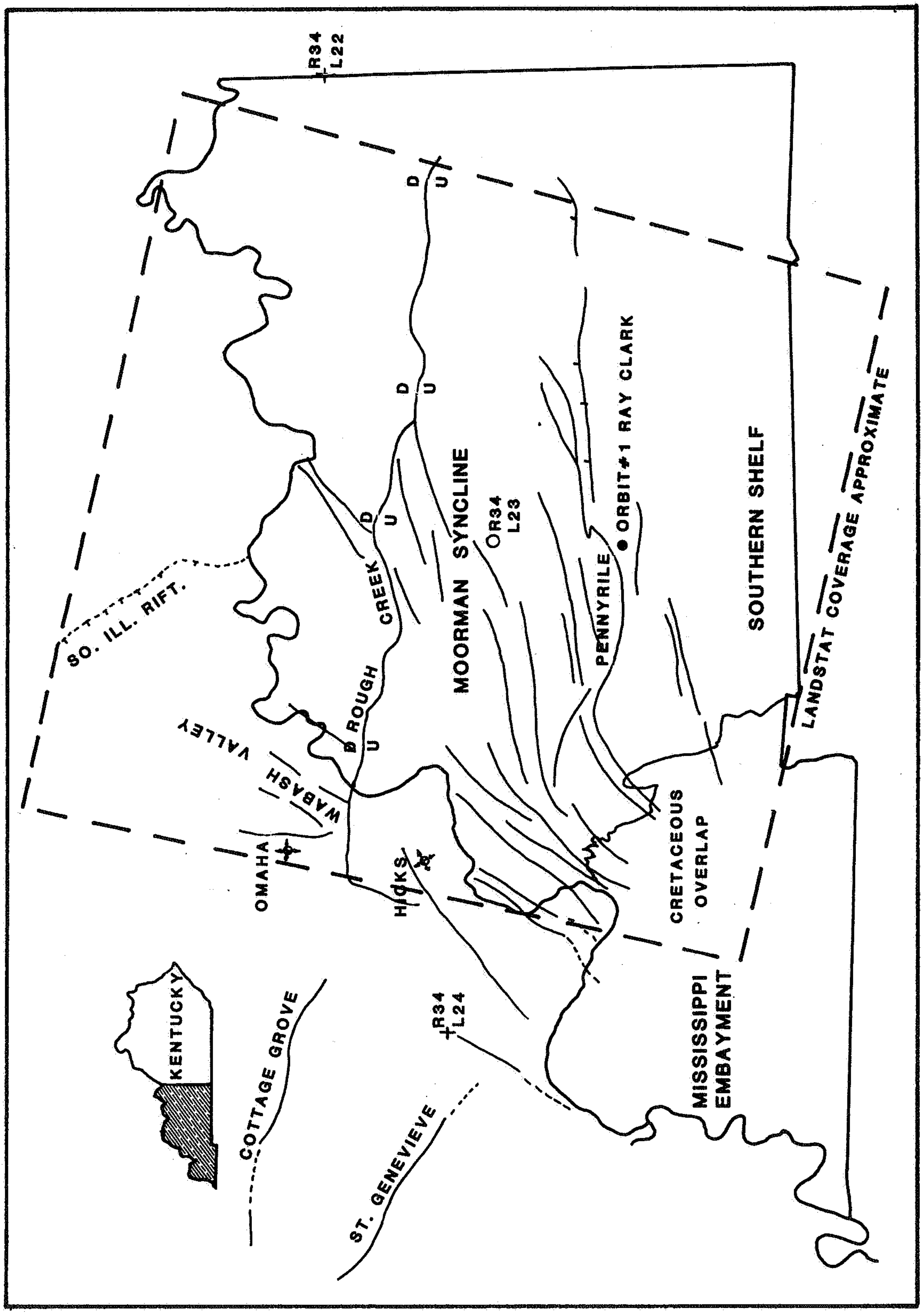


Figure 3-3 ERIM Study Area in Western Kentucky

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

Status: Active

Gruy Federal, Inc.
Houston, Texas

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

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 two year contract, Gruy Federal will contract, collect, consolidate, organize, and prepare for delivery to DOE core material and data extracted from 22 new wells. 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.

SUMMARY OF PROGRESS

The contractor has completed a preliminary assessment of possible drill sites which are to be considered as suitable core locations for the retrieval of Devonian Shale samples from each of the basins. Tentative county locations were initially chosen based on structural and shale thickness criteria. Site-specific locations are based on detailed petrographic and physical properties of the shales.

The first well to be drilled under the contractor's program, is located in Wayne County, Illinois (Figure 3-4). The well was still being drilled at the end of this reporting period. Six additional wells are scheduled for coring during the next six months. These wells are located in Indiana and Lawrence Counties, Pennsylvania; Grainger County, Tennessee: Allegany County, New York; Otsego and Isabella Counties, Michigan (Figure 3-5). Other well locations will be added to the program as they are identified.

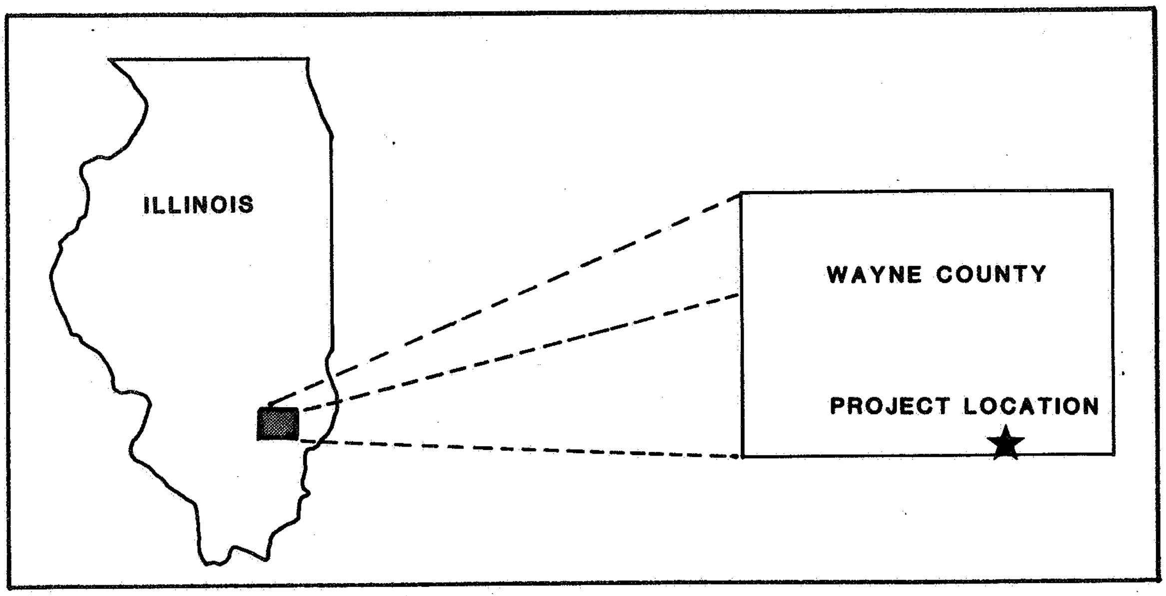


Figure 3-4 Location of Wayne County, Illinois Core Well

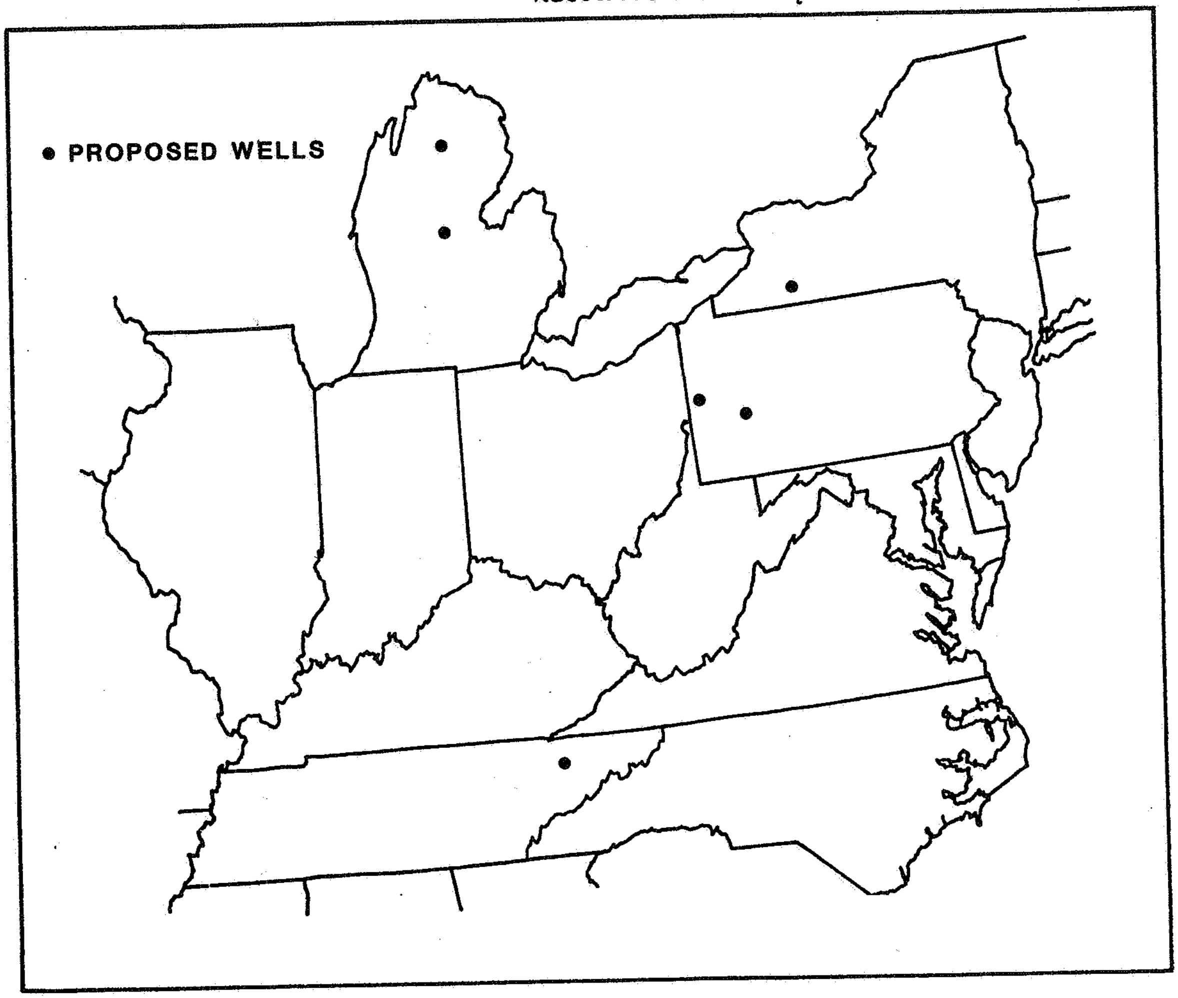


Figure 3-5 Proposed Core Wells During First Half of FY80

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

Juniata College
Huntingdon, Pennsylvania

Status: Active

Contract:	DE-AS05-76MC05197
Contract Date:	July 1, 1976
Anticipated Completion Date:	September 30, 1980
Principal Investigator:	P. Schettler
Technical Project Officer:	S. Bialobok Morgantown Energy Technology Center

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

The repair and calibration of the high pressure isotherm apparatus was completed during this reporting period. A linear isotherm has been obtained for a Devonian Shale sample, consistent with the isotherms obtained at low pressure. The isotherm data being generated by Juniata College are being used in the EGSP reservoir modeling and resource assessment studies.

Other analyses completed during the reporting period were 19 low temperature isotherm/degasibility measurements and 50 CH_4, N_2, O_2, CO_2, C_2H_6 and C_3H_8 gas chromatographic analyses.

CONCEPT FOR EVALUATING THE RESOURCE POTENTIAL OF THE UPPER DEVONIAN SHALE OF WESTERN WEST VIRGINIA

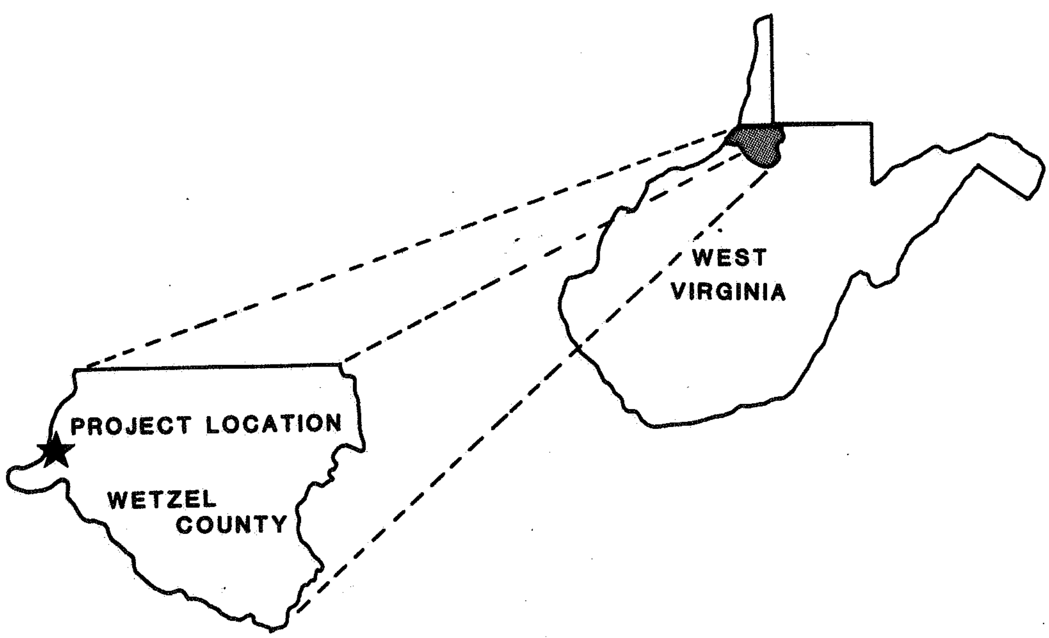
Status: Completed

Mobay Chemical
New Martinsville, West Virginia

Contract:	EW-78-C-21-8428
Contract Date:	May 29, 1978
Anticipated Completion Date:	March 19, 1979
Principal Investigator:	R. L. Harris
Technical Project Officer:	G. W. Byrer Morgantown Energy Technology Center

OBJECTIVE

To drill, core, log and possibly stimulate a well in the Devonian Shale in Wetzel County, West Virginia.



SCOPE OF WORK

Mobay Chemical will drill, core, and log a deep well into the Devonian Shale in Wetzel County, West Virginia. The well will be drilled to a depth of about 7100 feet and approximately 510 feet of oriented core will be retrieved. A comprehensive suite of wet-hole and dry-hole well logs will be run.

If stimulation of the shale is warranted, Mobay will then design a treatment to test the potential of the Devonian Shale in this portion of the Appalachian Basin. Upon completion of any stimulation, Mobay will perform post frac testing and long range monitoring of production history.

SUMMARY OF PROGRESS

As reported in previous Semi-Annual reports, the Wetzel County well (WV-7) was drilled, cored, and logged in September 1978. Approximately 535 feet of oriented core were retrieved. Because of the low production potential of the Devonian Shale in this well, it was decided not to stimulate the well.

During this reporting period, the coring analyses on this well were completed. The results of these analyses are presented in Table 3-2.

Table 3-2 Results of Wetzel County Core Analysis

WETZEL COUNTY, WEST VIRGINIA (WV-7)	
ANALYSIS	MEAN
Gas Volume	0.38 ft^3 gas/ft^3 shale
Organic Carbon	1.64 %
Total Carbon	3.56 %
Bulk Density	2.610
True Density	2.760
Porosity (Calculation)	6.853 %
Porosity (Hg Intrusion)	6.33 %
Surface Area	2.880 m^2/g
Extractable C_{15+}	1,538 ppm
Thermal Alteration Index	Predominant TAI = 3
Vitrinite Reflectance	Ro = 1.58
H/C (Kerogen)	0.72
O/C Kerogen	0.37
Sulfur (whole rock)	1.46 %
H/C (whole rock)	11.91
O/C (whole rock)	11.09

PHYSICAL AND CHEMICAL CHARACTERIZATION OF DEVONIAN SHALE GAS

Mound Facility
Miamisburg, Ohio

Status: Active

Contract:	DE-AC04-76-DP00053
Contract Date:	February 15, 1977
Anticipated Completion Date:	September, 1980
Principal Investigator:	R. E. Zielinski
Technical Project Officer:	S. Bialobok Morgantown Energy Technology Center

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.	ft^3 gas/ft^3 shale
Clark County, IN	IND-2	0.18
Wetzel County, WV	WV-7	0.43
Allegany County, NY	NY-1	0.30
Hardin County, IL	ILL-4	<0.01
Johnson County, KY	KY-4	0.51
McKean County, PA	PA-1	0.46
Knox County, OH	OH-3	0.42
Allegheny County, PA	PA-2	0.23

Fifty-one KY-4 samples were generally medium to dark gray, tabular, hard, and noncalcareous shales. The average organic carbon content was 3.91 wt % comprised primarily of herbaceous and, to a lesser extent, woody-coaly debris. These shales were mildly thermally altered (mean vitrinite reflectance, 0.57 R_o). They yielded an average bitumen concentration of 1704 ppm and a C_1-C_4 concentration of 0.540 standard cubic feet of gas per cubic foot of shale (SCF/ft^3).

The thirty-four OH-3 samples were generally slightly to noncalcareous, hard, medium to dark gray shales. The average organic carbon content was 2.23 wt %. This organic matter was primarily herbaceous and to a lesser extent woody-coaly material. These mildly thermally altered samples (average R_o = 0.56) yielded 934 ppm of C_{15+} extractable material and had a mean C_1-C_4 gas content of 0.406 SCF/ft^3.

One hundred and sixty-one samples were analyzed from the NY-1 well. These samples had a relatively low average organic carbon content of 0.56 wt %. The organic matter of these samples was primarily comprised of woody-coaly debris that was thermally mature (average R_o = 1.29). The average bitumen yield was 1293 ppm.

The forty-five WV-7 samples were from the middle to upper Devonian and contained organic material primarily sourced from a non-marine environment with the exception of three samples which contained a significant amount of _Tasmanites_ (restricted marine) material. The average bitumen yield was 1538 ppm.

The thirty-five samples from the PA-1 well were generally dark gray to grayish black, tabular and hard shales. The average organic carbon content was 1.43 wt % comprised of primarily herbaceous material. These samples were thermally mature (average R_o equal 1.12) and yielded an average of 587 ppm of extractable C_{15+} material. The average total gas content was 0.409 SCF/ft^3.

Twenty-three PA-2 samples were dark gray, tabular to hard shales with a mean organic carbon content of 1.74 wt %. This organic material was primarily of a woody-coaly type and very mature (mean R_o = 2.40). The mean C_1-C_4 gas content was relatively low (0.226 SCF/ft^3) as was the concentration of extractable material (85 ppm).

The Ill-4 samples were very hard, dark gray, massive noncalcareous argillites. The mean organic carbon content was 1.95 wt %. The organic matter is mature (1.44 R_o) and derived from terrestrial sources (woody-coaly and herbaceous). The samples contained minor amounts of hydrocarbon gas and an average C_{15+} content of 474 ppm.

The IND-2 samples were Upper Devonian in age with an average extractable C_{15+} content of 3216 ppm.

Kerogen elemental analysis was completed for samples from the NY-1, PA-1, PA-2, WV-7 and IND-2 wells. The results were presented as H/C versus O/C atomic ratio plots and confirm that the organic matter of the NY-1, PA-1, PA-2 and WV-7 samples are generally from a non-marine source while the IND-2 samples are of marine to intermediate (marine/non-marine) character.

The pyrolysis-gas chromatographic analysis of samples from Appalachian Basin wells indicates that the more eastern wells (NY-1, WV-7 and PA-2) are more thermally mature (i.e., higher Peak II temperatures, and higher Peak I/Peak II ratios) than the western (OH-3 and KY-4) wells. Similarly the samples from the ILL-4 well are significantly more mature than samples from the IND-2 wells.

The bulk density generally decreases with the increasing of the organic carbon content of these well samples. This relationship holds for the results from each well and for a comparison of the cumulative results of all wells.

The effect of increasing maturation on the hydrocarbon generation of NY-1 samples was examined. There was a noticeable increase in the conversion rate of this primarily land derived organic debris to volatile hydrocarbons in samples with a mean vitrinite reflectance of 1.0 R_o.

The total hydrocarbon gas potentials of non-marine, marine and restricted marine shales were compared. Upon intense thermal degradation, the hydrocarbon gas volume yielded by the restricted marine shales was significantly larger.

The comparison was made between the organic carbon content of samples with both the density and gamma-ray borehole log responses of select Appalachian Basin wells. The results suggest an independent or weak negative relationship between the organic carbon content and the density log response.

A preliminary comparison between the gamma-ray log response and total C_1-C_4 sample gas contents suggests no relationship between these properties.

The uranium, thorium and potassium distributions of samples from Illinois and Appalachian Basin wells were characterized and compared to the sample organic carbon content. The potassium content is either independent or weakly negatively related to the organic carbon content. The thorium content is weakly negatively related to the organic carbon content. The uranium content has a general positive correlation with the organic carbon content, however, the ratio U/Th has stronger positive correlation with organic carbon content. The results indicate that the gamma-ray log response will not be an effective indicator of organic carbon content.

Methane permeability of samples from NY-1, KY-2 and KY-4 were determined. The range of values for samples without visible fractures (either natural or induced) for wells NY-1, KY-2 and KY-4 were: 10^{-4} to 10^{-8}, 10^{-9} to $<10^{-12}$ and 10^{-7} to 10^{-10} darcys, respectively.

Methane sorption testing was completed on four NY-1 samples at 1200 and 800 psia. Preliminary results suggest a relationship between desorbed gas volume and sample density.

Formation testing includes the point load testing of 13, NY-1 samples and the study of the dilation effect of four, NY-1 samples subjected to four different fluids (H_2O, H_2O + 2% KCl, kerosene and H_2CO_3 + 2% KCl) at four different pressures (atmospheric, 500, 1000 and 1500 psia). The dilatometry results indicate that the addition of an electrolyte to the solution and increasing pressure inhibit shale expansion.

A statistical analysis was completed of open flow and completion data from wells in the Kentucky and West Virginia area. The results indicate that gas production is concentrated in well intervals containing the restricted marine facies.

In order to obtain better estimates of gas-in-place through offgassing measurements, Mound is tasked to obtain pressurized cores from two wells in Ohio (Figure 3-6).

Four hundred and fifteen feet of oriented core was recovered from the Ashtabula County, Ohio well (OH-4). Two pressure cores were taken at reservoir pressures of approximately 360 and approximately 510 psi. Initial open flow rates were approximately 5-10 MCFD. Subsequent core analysis indicates some of the shales within this well have high gas contents (0.4 cm^3/g).

Samples from OH-4 well were collected for a comparison test of the current methods of determining the volume of gas in shale samples. Preliminary results, using the pressure core samples as standards, suggests that controlled off-gassing gives approximately 70% of the total gas, while, the conventional method (samples placed in cannisters for a fixed time interval) gives approximately 40% of the total gas.

Coring was initiated on the Erie County, Pennsylvania well (PA-3) and was ongoing at the end of the reporting period. The top of the first cored interval was 375 feet. One pressure core was obtained between 375 feet to 385 feet. By September 30, 1979 the well was drilling at 970 feet (Rhinestreet interval). One hundred feet of oriented core had been recovered from the Dunkirk interval; 40 feet from the Pipe Creek interval, and 40 feet from the Rhinestreet interval.

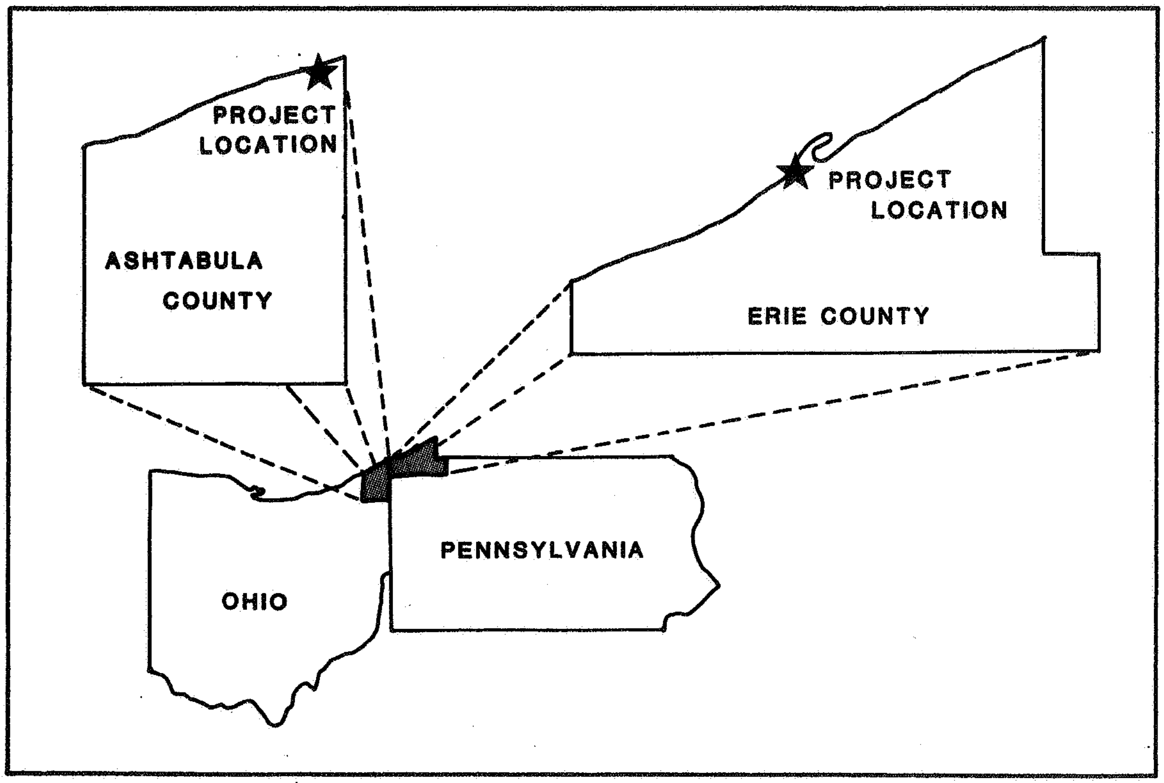


Figure 3-6 Location Map of Pressurized Core Wells

CONCEPT FOR EVALUATING THE RESOURCE POTENTIAL OF THE UPPER DEVONIAN SHALE OF WESTERN NEW YORK STATE

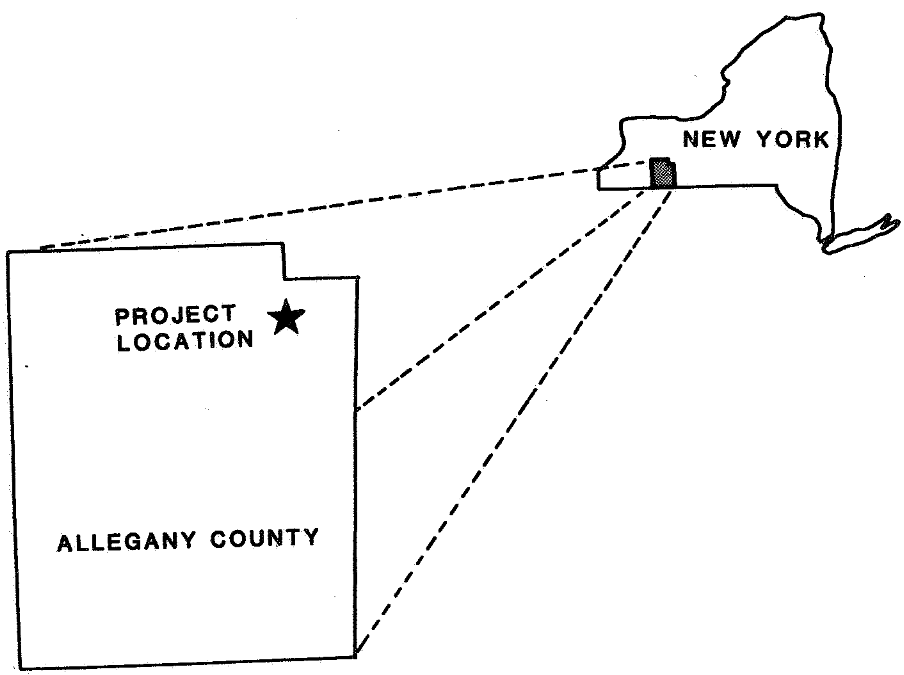
Status: Completed

National Fuel
Wellsville, New York

Contract:	EW-78-C-21-8419
Contract Date:	August 16, 1978
Anticipated Completion Date:	January 31, 1979
Principal Investigator:	W. S. Leeper
Technical Project Officer:	C. W. Byrer Morgantown Energy Technology Center

OBJECTIVE

To drill, core and log a gas well in the Devonian Shale of Allegany County, New York.



SCOPE OF WORK

This contract includes the drilling of a Devonian Shale well, the recovery of approximately 1,500 feet of oriented core, and the logging of the well with a comprehensive suite of dry-hole and wet-hole logs.

SUMMARY OF PROGRESS

One thousand six hundred and forty eight feet of oriented Devonian Shale core were recovered in September, 1978.

During this reporting period the coring analyses on this well were completed. The results of these analyses are presented in Table 3-3.

Table 3-3 Results of Allegany County Core Analysis

ALLEGANY COUNTY, NEW YORK (NY-1)	
ANALYSIS	MEAN
Gas Volume	0.30 ft^3 gas/ft^3 shale
Organic Carbon	0.56 %
Total Carbon	0.94 %
Bulk Density	2.618
True Density	2.767
Porosity (Calculation)	5.502 %
Porosity (Hg Intrusion)	5.97 %
Surface Area	2.405 m^2/g
Extractable C_{15+}	1,293 ppm
Thermal Alteration Index	Predominant TAI = 2- to 3
Vitrinite Reflectance	Ro = 1.29
H/C (Kerogen)	0.75
O/C Kerogen	0.29
Sulfur (whole rock)	0.94 %
H/C (whole rock)	12.97
O/C (whole rock)	9.65

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:	DE-AS21-76MC05206
Contract Date:	July 1, 1976
Anticipated Completion Date:	May 1, 1980
Principal Investigators:	A.M. Van Tyne L.V. Rickard
Technical Project Officer:	P.Y. Williams Morgantown Energy Technology Center

OBJECTIVE

To perform major stratigraphic and structural geological investigations using well cuttings, core data, production data, geophysical logs, aerial photography, 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

Major Devonian Shale correlation problems in west-central New York were resolved by detailed structural mapping. Final structure contour maps on all six major shale units in New York were completed.
Total shale isopach maps of five major shale units were constructed using gamma ray log data. Also, isopach maps of the amount of black shale present in the six major shale units in New York were completed.

The structure contour and isopach maps will be used to determine which areas in west-central New York have the most potential for Devonian Shale gas production.

The contractor also aided a New York operator with the drilling of a shale well in Allegany County, New York. Through the recommendation of the contractor, the Marcellus Shale was stimulated and flowed at a rate of 500 MCFD.

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

Status: Active

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

Contract: DE-AS05-76MC05200
Contract Date: April 15, 1977
Anticipated Completion Date: September 30, 1980

Principal Investigator: R. A. Struble
Technical Project Officer: P. Y. Williams
Morgantown Energy Technology Center

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

Work in the stratigraphic phase of the project is nearing completion. The identification, correlation, and shale thickness determinations of selected Devonian Shale units have been completed for the 49 counties in the study. The interlocking cross-sections are completed, reviewed, and are now being modified to incorporate the suggestions of the review committee. Isopach maps have been completed on the requested shale members and they are now in the final drafting stages. The Division has started work on lithofacies mapping of the Devonian Shale sequence. The first map, a ratio of radioactive shale to total shale, has been completed.

Regional structure maps have been completed on all shale members which have a wide lateral distribution over eastern Ohio. Detailed structure contour maps were completed on the Big Lime datum for Columbiana, Mahoning, Tuscarawas, Coshocton, and Holmes Counties. The top of the Berea Land and Packer Shell were compiled and posted for Holmes County.

The remote sensing fracture analysis is progressing according to projections. The 1:80,000 scale interpretation is approximately 85 percent complete. Completion of this phase of the remote sensing proposal is projected for November 30, 1979.

The analytical phase of the mineralogy and petrology studies is completed and work is underway on the compilation of data, data interpretation, and reports on the findings. These data and interpretations will be incorporated into the final integrated report.

The geochemical phase will also terminate on November 30, 1979. Work has been continuing on projections on the analysis of major and minor and trace elements and carbon and sulfur determinations.

Gas shows were monitored on twenty-four wells during the reporting period. This brings the total number of monitored wells to fifty-one since initiation of the program. Gas profiles have been developed for all fifty-one wells.

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: November 30, 1979

Principal Investigator: R.G. Piotrowski
Technical Project Officer: P.Y. Williams
Morgantown Energy Technology Center

OBJECTIVE

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

SCOPE OF WORK

Specific tasks include the following:

- To provide detailed stratigraphic sections of the Perrysburg Fm, Huron shale member of Ohio Shale, 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 Perrysburg Fm, Huron shale member of Ohio Shale and the Java Formation.
- To generate detailed structure contour maps and lithofacies maps of the above mentioned units and related rocks in Pennsylvania.
- To maintain a storage site for data and cores obtained in Pennsylvania for the EGSP.

SUMMARY OF PROGRESS

The Pennsylvania Geological Survey is completing the second phase of the geologic mapping of the Devonian Shales in Pennsylvania. The first phase was completed with the construction of regional scale cross sections, structure maps, isopach maps, and lithofacies maps. The second phase is intended to provide detailed maps and cross sections of the best potential gas producing units within the Devonian Shale - Perrysburg Fm, Huron shale member of Ohio Shale, and the Java Formation.

Ten stratigraphic cross sections of the Perrysburg, Huron, and Java Formations have been completed. Two isopach maps were completed - Java Formation and Perrysburg - Huron isopachs. Two structure contour maps were completed, one on the base of the Java Formation and one on the base of Perrysburg - Huron. Additionally, lithofacies maps of these shale units will be constructed.

With the completion of these maps, a detailed stratigraphic and structural framework will be available for use in exploration for Devonian Shale gas in northwestern Pennsylvania.

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

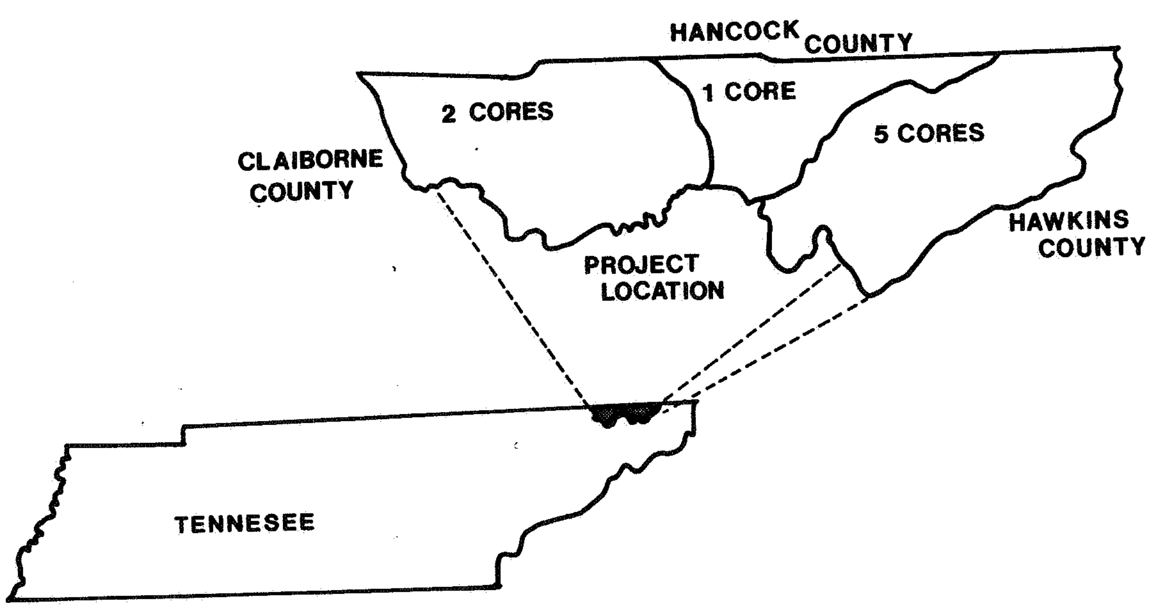
Status: Active

Tennessee Department of Conservation
Nashville, Tennessee

Contract:	EY-76-C-05-5196
Contract Date:	October 1, 1977
Anticipated Completion Date:	November 30, 1979
Principal Investigator:	C. Ferguson
Technical Project Officer:	C.S. Dean Morgantown Energy Technology Center

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

The eighth and final Chattanooga Shale core has been recovered from the eight stratigraphic test wells adjacent to Clinch Mountain and Newman Ridge in eastern Tennessee. Lithologic and fracture descriptions of the cores and stratigraphic cross sections are being completed. The final report of the Tennessee EGSP studies will be completed during the next reporting period and summarized in the October 1, 1979-March 31, 1980 UGR Semi-Annual Report.

The subsurface information derived from the TNGS study has been used to site an exploratory shale gas well in the Greendale Syncline of eastern Tennessee. The well will test the exploration rationale that fracturing of the organic-rich shales should have resulted from thin-skinned tectonic deformation of the over- and underlying strata. The well is scheduled to be spudded in 1980.

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
Technical Project Officer:	C. S. Dean Morgantown Energy Technology Center

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 for the proposed paleocurrent study has been completed and the study indicates a homogenous sediment source located to the east provided most of the Devonian Shale sediment. An additional rate on the paleocurrents in the Allegany County, New York core is being added to the study. The studies of this core and previous samples show that even in the black shale, low variance westward bottom currents were the rule.

The Pine Mountain Overthrust Block study is almost completed. The structure and isopach maps are completed as is a cross section that runs north of the Pine Mountain Fault.

The Braillier Study has been prepared for publication. This study was completed during the previous reporting period and covers the stratigraphy, petrology, and geochemistry of the Braillier Formation.

The study of the Geology of the Ohio Shale along Lake Erie has been completed and the manuscript sent out for review. This report correlates gas shows and production to stratigraphy in the Ohio and Chagrin Shales. The Three Lick Bed shows a concentration of gas shows. This report also includes a comprehensive petrologic study, x-ray diffraction mineralogical analyses and some analyses for carbon, hydrogen, and nitrogen in the shale. The petrologic relationship to gas shows is indicated by the appearance of numerous gas shows where the silt laminations are plentiful.

All of the published lines of cross sections have been compiled on a single map for inclusion in the Basin analysis. Several basin-wide cross sections, both parallel and perpendicular to strike have been prepared. Block diagrams have also been completed for the Basin analysis.

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: May 31, 1980

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

Technical Project Officer: C.W. Byrer, Morgantown Energy Technology Center

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

All the analytical work is complete for the EGSP studies in Kentucky. The main effort is now to compile all chemical data for the black shales of Kentucky and to prepare a set of geochemical maps to show the variation of geochemical parameters across the eastern part of the State.

Radioactive shale isopach maps have been completed for the Cleveland Shale, Huron Shale, Java and West Falls Formations. These maps will add data to the total gas resource determination of the shales in the Appalachian Basin.

The following summary and significant conclusions were presented by the University of Kentucky concerning geochemical study of the Devonian black shales in eastern Kentucky.

(1) The concentration of most of the elements in the Chattanooga-Ohio-New Albany shale of eastern Kentucky are typical of the abundances of these elements in black shales in general.

(2) The mechanisms by which elements are incorporated into the shales are poorly understood. Basically, the elements can be concentrated by chemical precipitation, adsorption, and/or organic processes. In many cases, these processes are intimately associated and many of the elements are probably concentrated by more than one of these mechanisms: which may change in importance through time or location in the basin of deposition.

(3) The carbonate in the Chattanooga Shale, particularly near the basal sections of Powell, Estill, and Madison Counties, is commonly observed to be present as vein and vug fillings. This carbonate, therefore, is post deposition in origin, possibly representing a hydrothermal event.

(4) The distribution of the copper in the Chattanooga Shale and its lack of association with the typical chalcophile elements in the shale may have two origins:

   1) copper sulfides may be precipitating out in shallow, nearshore, less reducing zones in association with upwelling currents (due to the higher redox potential of the copper sulfides compared to the sulfides of iron, lead and associated elements).

   2) postdepositional, possibly hydrothermal, introduction of the copper along with cadmium, sulfur, calcium, magnesium, and manganese.

(5) Trend surface analysis, geochemical logs, and the raw data reveal a sharp discontinuity between the lower and upper units of the Lewis to Rowan sections, indicating a change in the environment of

deposition. Increasing clastic abundance and decreasing boron concentration toward the top of these sections suggest an approaching source and perhaps less marine waters.

(6) An increase in clastic material (normative quartz, zirconium, and the clastic factor in general) toward the southwest terminus of the outcrop belt, particularly near the top of the sections (Pulaski to Cumberland sections) indicates a clastic source to the north-northwest. Whether the Cincinnati Arch was a feature of positive relief, above the air-water interface, in the southwestern area of the outcrop belt or a lobe of the Bedford-Berea delta supplied the sediment is not known.

SUMMARY OF TIOGA BENTONITE MARKER HORIZON IN APPALACHIAN BASIN DEVONIAN SHALES

Status: Active

University of North Carolina
Chapel Hill, North Carolina

Contract: EY-76-C-05-5195
Contract Date: July 1, 1976
Anticipated Completion Date: March 31, 1980

Principal Investigator: J. Dennison
Technical Project Officer: C.S. Dean, Morgantown Energy Technology Center

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

Detailed cross sections and maps of the Tioga Bentonite are being prepared, and the final report is being written.

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, 1980**
Principal Investigators:	**L. Woodfork** **D. Patchen** **M. Behling** **J. Renton**
Technical Project Officer:	**C.S. Dean** **Morgantown Energy Technology Center**

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

During the reporting period, work concentrated on the detailed geologic, geochemical and petrologic characterization of the Devonian Shales in outcrops and in the subsurface of West Virginia. Isopach and structure maps of the organic-rich black shale were completed for use in the EGSP Resource Assessment study.

Nine isopach maps and two cross sections in western West Virginia were completed. An outcrop study of the Middle and Upper Devonian units in the Eastern Panhandle and a subsurface study in southern West Virginia were also completed.

One thousand, eight hundred and forty-two (1842) XRD and 2232 XRF samples have been analyzed and data interpretation initiated. Shale samples from 56 wells in southern West Virginia have been analyzed. The data from these wells are now being used to generate isocompositional maps of individual elements.

Detailed petrologic reports for the Wise County, Virginia and the two Jackson County, West Virginia cores have been completed. These reports will form the basis of the final, interpretative report of the EGSP petrologic characterization in West Virginia, due December 31, 1979.

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

West Virginia University
Morgantown, West Virginia

Status: Active

Contract:	DE-AC21-76MC05194
Contract Date:	July 1, 1976
Anticipated Completion Date:	September 30, 1980
Principal Investigator:	R.C. Shumaker
Technical Project Officer:	C.S. Dean Morgantown Energy Technology Center

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 structures, 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.

SUMMARY OF PROGRESS

The following is a summary of several independent studies that were reported on during this period.

Numerous extension faults and extension fractures may form in the steep limbs of detached anticlines. In the Wills Mountain anticline, eastern West Virginia, the Devonian Brallier Formation has undergone the greatest amount of extension faulting and fracturing. In the subsurface, given a dark shale source and a capping seal, this formation may contain gas in a fractured reservoir.

Analysis of fractures found in a Devonian Shale core, located in Monongalia County, West Virginia, indicate two major subvertical to vertical fracture sets, N80°E and N70°W. The major trend of the slickensides is N70°W, the direction of regional tectonic transport. Based on the highest density of slickenside surface, decollement horizons are indicated near the base of the Mahantango Formation and Marcellus Shale.

Preliminary interpretations of the relationship of gas occurrence to various geologic parameters in the eastern Kentucky Gas Fields (Big Sandy) are being developed. Initial results indicate that production from the fields are related to preferential fracture directions. The preferential fracture directions suggest that they could be related to tensional stresses associated with folding and thrust faulting in the basement rocks.

Based on a study of outcrop fractures in the Devonian Shale along the Pine Mountain Thrust, eastern Kentucky, two zones of movement were found within the shales. The major fault occurs at the base of the shale, and the shales near the fault show the most deformation. A second zone of lesser faulting occurs in the upper part of the shale. These two zones may match the productive zones in the eastern Kentucky Gas Fields (Big Sandy) to the west. Results from this study and others will be presented as an integrated regional analysis of Devonian Shale fractures.

RESOURCE ASSESSMENT

Resource Assessment for the Appalachian Basin is being performed by the United States Geological Survey. A summary of their work in this and other areas of the EGSP follows.

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, 1980

Principal Investigator: W. de Witt, Jr.
Technical Project Officer: S. Bialobok
Morgantown Energy Technology Center

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 and dark brown Devonian Shales of the Appalachian Basin.

SUMMARY OF PROGRESS

A pilot resource study of five counties in south-western West Virginia is nearing completion. The basic geological, physical and geochemical data used for the pilot study were generated by the EGSP. These data have been supplemented by well production histories. Monte Carlo techniques which utilize probability distributions for the analyzed data are being applied to the study area. The total Devonian Shale gas-in-place estimate for the five county area will be available early in the next reporting period. Much of the work performed by the USGS during this reporting period is being used as input parameters to the pilot study.

The final printing of forty-one maps and nine cross sections have been completed by the USGS Bureau of Printing for the EGSP. These products were submitted by the Pennsylvania Geological Survey (PAGS) and are available through the METC UGR File and PAGS. The EGSP Series Numbers and titles are as follows:

Cross section titles: Preliminary Stratigraphic Cross Section ( ) Showing Radioactive Black Shale Zones and Sandstones in the Middle and Upper Devonian, Western Pennsylvania. (for first nine numbers only)

METC/EGSP Series Number	Cross Section
1	(C_1-C_3) E-W
2	(A^1_3-D^3_3) N-S
3	(A^3_2-D^3_2) N-S
4	(A^2_1-D^2_1) N-S
5	(C^1_4-D^1_4) E-W
6	(D^4_3-D^4_4) E-W
7	(B^3_1-B^4_4) E-W
8	(D^1_1-D^4_3) E-W
9	(A^1_1-A^3_4) E-W

Map Titles:

10 Drilling Depth Map to the top of the Middle Devonian Onondaga Group

11 Gas Show and Production Map from Middle and Upper Devonian Organic Rich Shales in Western and Northern Pennsylvania

13 (Package of 39 maps and text) Black Shale and Sandstone Facies of the Devonian "Catskill" Clastic Wedge in the Subsurface of Western Pennsylvania

3.2.3 ILLINOIS BASIN

The Illinois Basin encompasses portions of the States of Illinois, Indiana, Kentucky, Wisconsin, Iowa and Missouri. The total area of the Devonian Shale formations is over 24,000 square miles. The Devonian Shales outcrop in the northern and eastern portions of the Basin, and reach a thickness of over 450 feet in southeastern Illinois.

RESOURCE DATA ACQUISITION AND ANALYSIS

RESOURCE ASSESSMENT

The summary of progress of five contracts dealing with the Resource Characterization and Inventory of the Illinois Basin are presented below.

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-AC21-76MC05203**
Contract Date:	**June 1, 1976**
Anticipated Completion Date:	**September 30, 1979**
Principal Investigators:	**N. Shimp** **R. Bergstrom**
Technical Project Officer:	**C. W. Byrer** **Morgantown Energy Technology Center**

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, directional 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 approximately 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 learned of twelve gas shows reported in the Devonian Shale, all within the nineteen county area in southeastern Illinois previously delineated as the area which may have significant gas resources (Figure 3-7).

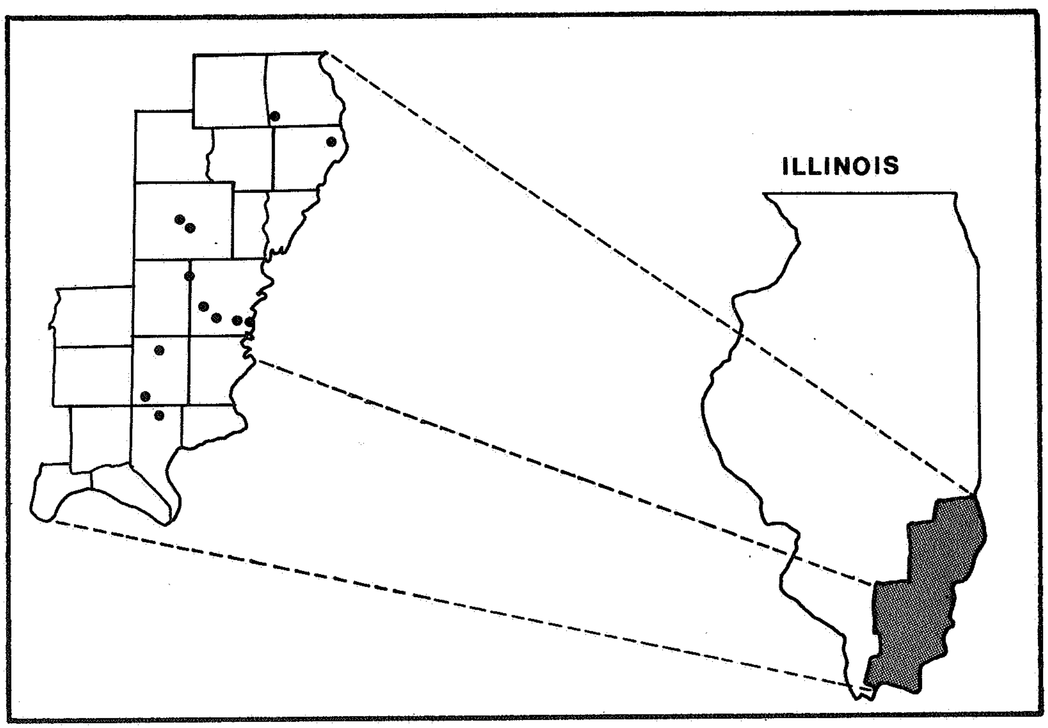


Figure 3-7 Reported Gas Shows in Southern Illinois

The lithofacies maps of the "radioactive" shale zones within the New Albany Shale have been completed. The patterns shown by these maps strengthen the earlier conclusions that the delineated nineteen county area in southeastern Illinois offers the best possibilities for shale gas resources. The "radioactive" zones are thickest in this area and closely resemble the pattern of total thickness for the New Albany Shale.

The scanning electron microscope study has been completed. This study provided useful information on clay orientation and its relationship to shale fabric, data on the different forms of pyrite and organic matter and their relationship to the shale matrix.

Sample preparation for radiographic analysis has been completed and thin section analysis is underway on samples from Fayette, Hardin, and Wayne Counties, Illinois. X-ray diffraction analysis (clay mineralogy, clay orientation indices, and whole rock mineralogy) has been completed on all samples collected through FY79. Vitrinite reflectance data has been compiled on all samples collected through FY79.

Elemental analysis has been completed on 325 of the 355 samples collected to date.

Outgassing analysis has been completed on four samples from the Wayne County, Illinois core. Data indicate that there may be some potential for Devonian Shale gas production in this area.

Internal surface area measurements from samples of the Wayne County, Illinois core show that N_2 and CO_2 values are significantly lower at greater depth reflecting the greater compaction. The rate of gas release is quite low in these samples.

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

Illinois State Geological Survey
Urbana, Illinois

Status: Active

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

OBJECTIVE

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

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 liaison 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.

In addition , the Illinois State Geological Survey will collect, assemble, mark and describe approximately 220 feet of Devonian Shale core from a well in Wayne County, Illinois. Samples for geochemical analyses will be provided and a wet-hole suite of logs will be run upon completion of drilling/coring operations.

SUMMARY OF PROGRESS

Coring was initiated in September on a New Albany Shale well in Wayne County, Illinois. This core will be extensively sampled and tested for off-gassing to evaluate the gas volume of the nineteen county area in southeastern Illinois previously designated as the area of the Illinois Basin most likely to contain gas resources.

A report summarizing stratigraphy and lithofacies studies in the Illinois section of the Illinois Basin is nearly completed.

The following lithofacies maps were completed during the reporting period:

- Map of the cumulative thickness of radioactive shale within the New Albany Group in Illinois.

- Map showing the percentage of New Albany Shale in Illinois with a gamma ray value of more than 60 units above a normal shale base line.

- Map showing thickness of New Albany Shale in Illinois.

Nearly all problems of correlation of stratigraphic units between Illinois and Indiana have been resolved. It has been determined that the Indiana nomenclature should be used in the deeper part of the Basin with some nomenclature revision.

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

Indiana Geological Survey
Department of Natural Resources
Bloomington, Indiana

Status: Active

Contract:	**DE-AC21-76MC05204**
Contract Date:	**September 21, 1976**
Anticipated Completion Date:	**December 31, 1979**
Principal Investigators:	**J.B. Patton** **D.D. Carr** **R.K. Leininger** **G. Carpenter**
Technical Project Officer:	**P.Y. Williams** **Morgantown Energy Technology Center**

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 outcrop 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. A series of detailed stratigraphic cross sections, isopach maps, lithofacies maps, lineament maps, and regional structure maps, will be constructed.

- To perform detailed physical, mineralogical, 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

Work completed during this reporting period consisted of completion of the majority of the remaining geologic mapping and the solving of stratigraphic problems as well as the completion of analysis on EGSP and INGS shale core samples. Specifically the following items were completed.

Isopach maps of the Blocher, Hannibal and Selmier Members of the New Albany in Indiana were completed, as well as isopach maps of the Antrim, Ellsworth and Sunbury Shales in the Indiana portion of the Michigan Basin. The final copies of the oil and gas show maps for the 100 feet of strata overlying the New Albany Shale, the New Albany Shale, and the Middle Devonian Limestone underlying the New Albany Shale were also completed.

Twelve samples from the Citizens Gas #1 Dennis, Greene County, IN, were canned for gas yield studies. Analysis of the gas content has not been completed. An average value of 0.62 cu ft gas/cu ft shale was calculated for the New Albany in Indiana. The value is based on four cores and excludes a six-county area which apparently has negligible gas potential. The definitive resource assessment for the New Albany will be completed by the USGS.

A summary of the analyses of the Clark County core is given in Table 3-4. The location of the core is shown in Figure 3-8.

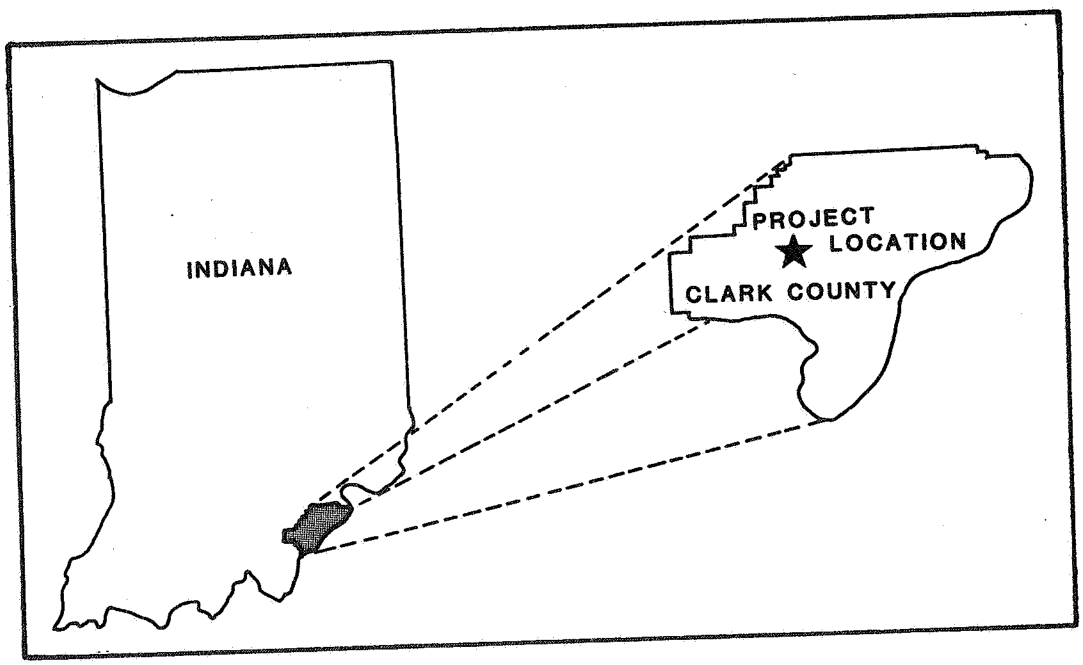


Figure 3-8 Location of Clark County, Indiana Core

Table 3-4 Results of Clark County Core Analysis

CLARK COUNTY, INDIANA (IN-2)	
ANALYSIS	MEAN
Gas Volume	0.13ft^{3}gas/ft^3 shale
Organic Carbon	7.56%
Total Carbon	Not Reported
Bulk Density	Not Reported
True Density	Not Reported
Porosity (Calculation)	Not Reported
Porosity (Hg Intrusion)	Not Reported
Surface Area	Not Reported
Extractable C_{15+}	3216 ppm
Thermal Alteration Index	Predominant TAI=1+
Vitrinite Reflectance	Ro = 0.48
H/C (Kerogen)	1.26
O/C Kerogen	0.20
Sulfur (whole rock)	Not Reported
H/C (whole rock)	Not Reported
O/C (whole rock)	Not Reported

CORING AND LOGGING IN HARDIN COUNTY, ILLINOIS

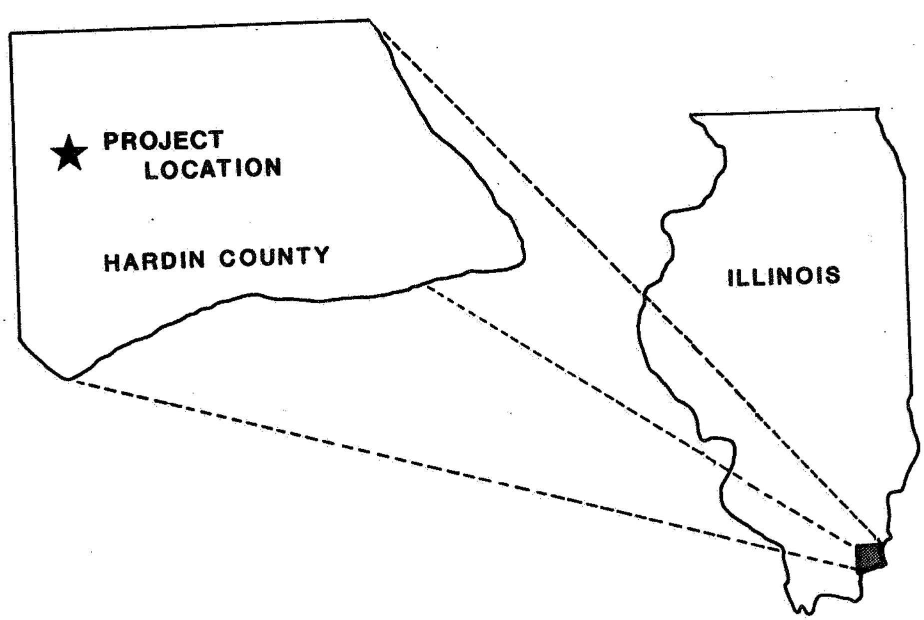
Status: Completed

Rector & Stone Drilling Company
Carmi, Illinois

Contract:	DE-AC21-78MC08467
Contract Date:	September 20, 1978
Anticipated Completion Date:	March, 1979
Principal Investigator:	S. Stone
Technical Project Officer:	C. W. Byrer Morgantown Energy Technology Center

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, Illinois. 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. Two hundred and thirty seven feet of oriented core were retrieved and a suite of wet-hole and dry-hole logs was run. The results of the core analyses are presented in Table 3-5.

Table 3-5 Results of Hardin County Core Analysis

HARDIN COUNTY, ILLINOIS (IL-4)	
ANALYSIS	MEAN
Gas Volume	<0.01 ft^3 gas/ft^3 shale
Organic Carbon	1.95 %
Total Carbon	3.92 %
Bulk Density	2.618
True Density	2.632
Porosity (Calculation)	1.997 %
Porosity (Hg Intrusion)	4.69 %
Surface Area	1.631 m^2/g
Extractable C_{15+}	474 ppm
Thermal Alteration Index	Predominant TAI = 3 to 3+
Vitrinite Reflectance	Ro = 1.44
H/C (Kerogen)	0.66
O/C Kerogen	0.24
Sulfur (whole rock)	1.46 %
H/C (whole rock)	0.92 %
O/C (whole rock)	1.33 %

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

Status: Active

University of Kentucky Research Foundation
Henderson, Kentucky

Contract: EW-78-S-21-8215
Contract Date: December 1, 1977
Anticipated Completion Date: November 30, 1979

Principal Investigator: J. Beard
Technical Project Officer: C.W. Byrer
Morgantown Energy Technology Center

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

The final report for the first contract year has been completed. The report details the subsurface structure and isopach mapping and cross section construction work for western Kentucky. An appendix to the report includes the reported gas shows and known producing wells in the Devonian Shale.

The coring program has also been completed. Five cores were recovered near the eastern outcrop belt in the Kentucky portion of the Illinois Basin. The cores have been described and samples taken for petrographic and geochemical analysis.

All analyses and the final report on the western Kentucky EGSP study will be completed by November 30, 1979.

3.2.4. MICHIGAN BASIN

The Michigan Basin is a subcircular feature which lies northwest of the Appalachian Basin and north of the Illinois Basin. The Basin encompases all of the State of Michigan and portions of Indiana, Ohio, Wisconsin and the Province of Ontario. The total area of the Devonian Shale formations is over 32,000 square miles. The Devonian Shales outcrop around the rim of the Basin and reach a thickness of over 660 feet near the central part of the Basin.

Based on an EGSP study of Devonian Shale characterization activities and progress (Laramie Energy Technology Center) in the Michigan Basin, EGSP activities will include coring of the Devonian Shale and development of suitable exploration rationales applicable to the geologic characteristics of the area. Oriented Devonian Shale cores are scheduled to be taken from a well in Otsego County, Michigan (north portion of the Basin) during the next reporting period. Based on recent drilling, the Devonian Shale appears as a potential source of gas in this area. Additional cores may be taken in the central part of Michigan to obtain stratigraphic and lithologic data in the deepest portion of the Basin.

3.3 EXTRACTION TECHNOLOGY R & D

3.3.1 INTEGRATION

The goal of this Element has been 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.

All of the specific activities described below in subsections 3.3.2 through 3.3.5 can be thought of and discussed in terms of the three main Work Packages: Fracture Mechanics Studies, Production Enhancement Studies, and Reservoir Performance Studies.

By the end of the reporting period, more than a dozen contractors were investigating one or another of the interrelated aspects that deal with the theory and practice of stimulation treatments. Many of these studies have to do with understanding the mechanics of breaking rock apart, and how to make use of this information in the design of field applications. Specific activities have dealt with testing the feasibility of producing from two horizons simultaneously; demonstrating the technical and economic feasibility of chemical explosive fracturing technology; testing DuPont's El-836 explosive; determining in situ stresses in Devonian Shales; forecasting the possibilities for fracture control in explosive/propellant stimulation of shale wells; designing a wireline in situ stress measurement tool; the question of skin damage; proppant/fracture interactions; modeling the effect of stress fields on fracturing; the tailored pulse-loading concept; and related subjects. Integration of all of these activities is provided to some extent by the concurrent work at the National Laboratories (Sandia, LASL and LLL).

In addition, during this reporting period work continued to be sponsored in the general area of simulation of reservoir and individual well performance data. These studies are necessary in order to provide a methodology for evaluating the production enhancement achieved by particular well stimulations, and to provide a method for designing offset well tests.

3.3.2 FRACTURE MECHANICS

Eight contracts currently active in this Work Package of the EGSP are presented in the following pages.

HYDRAULIC FRACTURE AND ASSOCIATED STRESS MODELING FOR THE EGSP

Status: Active

Ohio State University
Columbus, Ohio

Contract:	DE-AC21-79MC10514
Contract Date:	January 1, 1979
Anticipated Completion Date:	January 1, 1980
Principal Investigator:	S. Advani
Technical Project Officer:	C. A. Komar Morgantown Energy Technology Center

OBJECTIVE

To model and evaluate hydraulic fracturing and associated stress field effects for the EGSP.

SCOPE OF WORK

The contractor will utilize finite-element numerical modeling simulations to study the role of in situ stresses, pore pressure and shale material and geometric properties in terms of fracture treatment selection. Formulae will be developed for predicting the width, height, length and orientation of hydraulic fractures in terms of structural, fracture mechanics and fluid response behavior.

SUMMARY OF PROGRESS

Numerical results revealing the fracture response at a bi-material interface, fracture widths, fluid leak-offs and predicted fracture lengths have been obtained and compared with the results of earlier models. The effects of multilayering, variable in situ stress and fracturing fluid properties on induced vertical fractures have been evaluated. Rationale for the selection and application of foam fracture and dendritic fracture treatments have been developed for consideration, evaluation and review in stimulation strategy development.

SMALL SCALE FIELD TEST OF EXPLOSIVE EXPERIMENTS

SRI, International
Menlo Park, California

Status: Active

Contract:	DE-AC21-79MC11577
Contract Date:	September 29, 1979
Anticipated Completion Date:	June 10, 1981
Principal Investigator:	S. L. McHugh
Technical Project Officer:	C. A. Komar Morgantown Energy Technology Center

OBJECTIVE

To conduct small-scale experiments to evaluate the fracture propagation and permeability enhancement effects of tailored-pulse-loading.

SCOPE OF WORK

The evaluation of the tailored-pulse-loading concept being conducted by SRI will involve both laboratory and computational efforts as follows:

- Conduct small-scale wellbore springing experiments to develop rock fracture parameters and make measurements of post-shot permeability modifications.
- Conduct pulse-shape sensitivity calculations utilizing a finite-difference wave propagation code including improvements and extensions of the SRI NAG/FRAG fracture model based on the experimental data.
- Initiate development of a permeability model based on NAG/FRAG crack density and linkage calculations.

SUMMARY OF PROGRESS

As these efforts were contracted very late in the six-month reporting period, efforts have been limited to the execution of a few parameter sensitivity one-dimensional calculations to predict stresses and accelerations for the design of instrumentation in the Sandia NTS mineback experiments.

PROPPANT FRACTURE MECHANICS INTERACTION STUDY OF THE FLOW TREATMENT PROCESS

Status: Active

SRI International
Menlo Park, California

Contract:	DE-AC21-79MC11597
Contract Date:	September 28, 1979
Anticipated Completion Date:	September, 1981
Principal Investigator:	S. L. McHugh
Technical Project Officer:	C. A. Komar Morgantown Energy Technology Center

OBJECTIVE

To evaluate proppant/fracture interactions in hydraulic fracture treatments.

SCOPE OF WORK

The efforts on this program are experimental in nature and will be applied to two specific study areas:

- Utilize a small-scale laboratory hydraulic fracture pressure chamber to study fluid penetration and crack propagation characteristics in simulated rock media as functions of fluid viscosity and pumping rate.
- Conduct experiments in which proppants have been added so as to provide cases: a) in which proppant motion is dominated by fluid viscous behavior, and (b) in which proppant transport is dominated by simulated gravitational settling.

SUMMARY OF PROGRESS

As this contract was negotiated very late in the reporting period, no significant technical efforts have been carried out to date. Progress will be reported in future Semi-Annual Reports.

DESIGN OF A WIRELINE TOOL FOR IN SITU STRESS MEASUREMENTS

Terra Tek, Inc.
Salt Lake City, Utah

Status: Active

Contract:	DE-AC21-79MC11047
Contract Date:	February 15, 1979
Anticipated Completion Date:	September 30, 1979
Principal Investigator:	A. Jones
Technical Project Officer:	C. A. Komar Morgantown Energy Technology Center

OBJECTIVE

To design, build and bench test a prototype wireline straddle packer tool for making *in situ* stress measurements.

SCOPE OF WORK

This design and fabrication program is directed toward achieving the following objectives:

- Determine the availability of off-the-shelf components which can be utilized in the fabrication of an *in situ* stress measuring tool.
- Design a wireline *in situ* stress measuring tool utilizing as many off-the-shelf components as possible.
- Fabricate a prototype wireline stress measuring tool which can be utilized for both bench testing the reliability of the various components and eventually utilized for downhole *in situ* stress measurements.
- Bench test the *in situ* stress measuring tool so as to establish its suitability for downhole measurements and make any necessary modifications in tool design and function.
- Field test the wireline *in situ* stress measuring tool so as to demonstrate the applicability of this tool for making such measurements and to provide some basic data on *in situ* stress values in areas of interest to the EGSP.

Only the efforts related to component availability and tool design are funded under the inplace contract.

SUMMARY OF PROGRESS

A careful review of available valves, seals, downhole motors and electronic components has indicated that nearly all of the components required for the fabrication of a reliable wireline in situ stress measuring tool are currently available. Efforts are now being concentrated upon the detailed design of a tool based upon the utilization of as many commercially available components as possible.

FRACTURE MECHANICS TESTS ON SELECTED SHALE CORES

Terra Tek, Inc.
Salt Lake City, Utah

Status: Active

Contract: DE-AC21-80MC12093
Contract Date: December 1, 1979
Anticipated Completion Date: November 30, 1980

Principal Investigator: A. Jones
Technical Project Officer: C. A. Komar
Morgantown Energy Technology Center

OBJECTIVE

To better understand the interactions between fracturing fluid, proppants and the shale mineral components as they relate to the development of skin damage in hydraulic stimulation treatments.

SCOPE OF WORK

This laboratory program will encompass several efforts related to fluid/rock compatibility in hydraulic stimulation treatments as follows:

- Measurement of matrix permeability after contact with selected fracturing fluids.
- Measurement of crack closure versus confining pressure for selected fracturing fluids.
- Measurement of flow capacity versus proppant pack for selected fracturing fluids.

SUMMARY OF PROGRESS

As this contract was signed after the end of this reporting period, efforts have been limited to the design of the tests to be conducted, and no data are available. Progress will be reported in future Semi-Annual Reports.

FRACTURE CONTROL FOR UTILIZATION IN GAS SHALE STIMULATION

Status: Active

University of Maryland
College Park, Maryland

Contract:	DE-AC21-79MC12010
Contract Date:	September 28, 1979
Anticipated Completion Date:	March, 1981
Principal Investigator:	W. Fourney
Technical Project Officer:	C. A. Komar Morgantown Energy Technology Center

OBJECTIVE

To conduct an experimental and theoretical research program to understand and predict the possibilities for fracture control in the explosive/propellant stimulation of shale wells.

SCOPE OF WORK

This combined experimental theoretical program will be directed towards achieving the following objectives:

- Conduct experiments to determine the optimum pressure pulse shape for explosive/propellant well stimulation.
- Conduct experiments and finite-difference calculations to evaluate the importance and control of crack pressurization in fracture propagation.
- Conduct experiments to study the effects of in situ stress on fracture propagation.
- Conduct experiments utilizing a fluid filled borehole around an explosive/propellant energy source so as to determine the benefits/detriments of a fluid pad buffering media.
- Conduct experiments to determine the desirability of controlling fracture initiation sites.
- Conduct some three-dimensional rock model experiments so as to evaluate three-dimensional effects not observable in the previously mentioned two-dimensional experiments.

- Experimentally determine stress intensity factor versus fracture velocity for Devonian shale.

SUMMARY OF PROGRESS

Although the primary contract for this work was not negotiated until late in the reporting period, some experiments were executed under preceding purchase order agreements and have yielded some preliminary data on the phenomenology of explosive/propellant well stimulation. The experimental results indicate that very large crack opening displacements are associated with dynamic explosive stimulation fracturing operations. In the case of very lightly coupled charges, fracture pressurization is seen to play a very important role in fracture propagation. The experimental results have also revealed that better fracturing, in terms of fracture length, is realized near the stem or tamp in the wellbore rather than in the immediate vicinity of the explosive charge. Further work will be required to differentiate whether this phenomena is due to the reflection of the explosive shock wave off the stem or due to the development of a skip zone (stress cage) around the borehole adjacent to the explosive charge due to permanent yielding of the material.

IN SITU STRESS DETERMINATION BASED ON FRACTURE RESPONSES ASSOCIATED WITH CORING OPERATIONS

West Virginia University
Morgantown, West Virginia

Status: Active

Contract:	DE-AT21-78MC11284
Contract Date:	October 1, 1979
Anticipated Completion Date:	April 1, 1981
Principal Investigator:	H. V. S. GangaRao
Technical Project Officer:	C. A. Komar Morgantown Energy Technology Center

OBJECTIVE

To determine accurately and economically the magnitude of in situ stresses in Devonian Shales from the fracture patterns observed in extracted cores.

SCOPE OF WORK

Fracture Response of Devonian Shales will be characterized by conducting: crack opening displacement controlled (notched beam) three point bending tests; uniaxial compression tests; split cylinder (tension) tests; simple shear tests; extensive measurements of initial and final fracture angles; stress-strain relations determinations; frequency and shape of disc fractures determinations; and studies of the effects of sample size, anisotropy, and notch/crack configurations.

Finite element codes previously developed will be specifically applied to study detailed stress computations. Design charts for determining in situ stresses will be developed on the basis of the previous experimental and analytical studies.

Computations will be made for specific cores. In situ stress will be computed for specified shale fracture thresholds. The results obtained will be applied over the length of a specific oriented core to be selected by METC. Quantitative assessments for this core, from fracture mechanics and stress analysis vantage points will be made.

SUMMARY OF PROGRESS

This contract was signed at the close of this reporting period. Progress will be reported in future Semi-Annual Reports.

DEVELOPMENT OF ULTRASONIC TECHNIQUES FOR MEASURING IN SITU STRESSES

West Virginia University
Morgantown, West Virginia

Status: Active

Contract:	EY-77-C-21-8087
Contract Date:	July 1, 1978
Anticipated Completion Date:	March 31, 1980
Principal Investigator:	S. Peng
Technical Project Officer:	C. A. Komar Morgantown Energy Technology Center

OBJECTIVE

To determine the feasibility of an ultrasonic technique as a method of measuring in situ stress.

SCOPE OF WORK

This contract includes: laboratory testing on sandstone under uniaxial compression; design of a biaxial compression testing system; the testing of sandstone and shale under biaxial compression to determine the effect of anisotropy on the velocity distribution around a borehole; and development of a method for data interpretation.

SUMMARY OF PROGRESS

The studies of sandstone under uniaxial compression have been completed. The results showed that under these conditions, the ultrasonic technique is applicable in measuring the in situ stress. The technique should be checked out under more complicated conditions before it can be applied.

3.3.3 PRODUCTION ENHANCEMENT

The summary of five contracts in this Work Package of the EGSP are presented in the following pages.

STUDY OF EXPLOSIVE STIMULATION IN DEVONIAN SHALE GAS WELLS

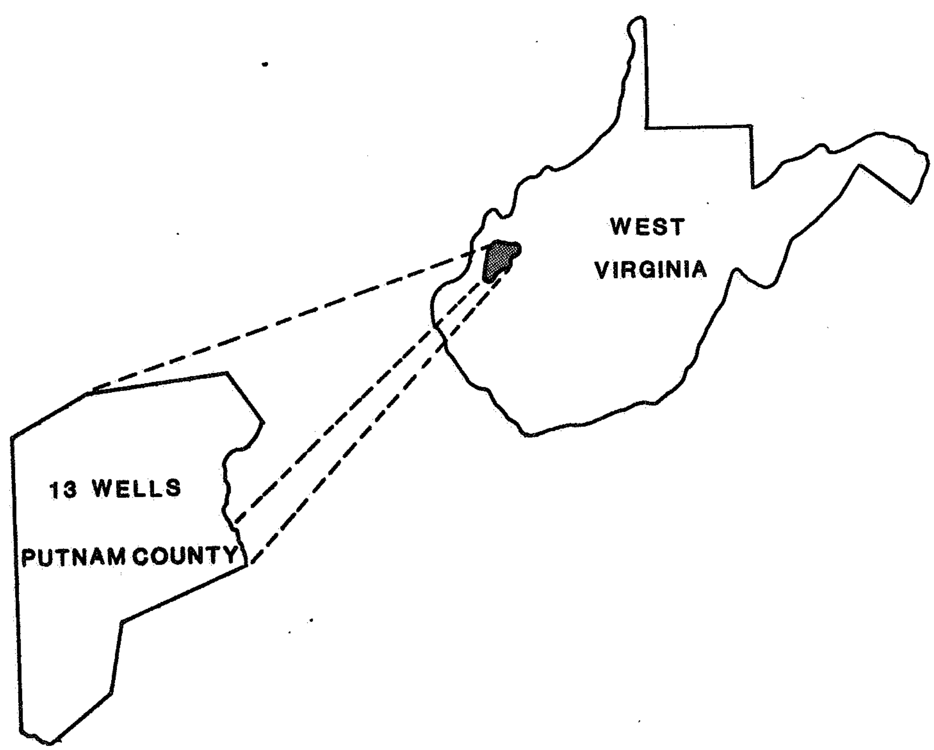
E. I. Dupont DeNemours and Company
Wilmington, Delaware

Status: Active

Contract:	DE-AC21-79MC11843
Contract Date:	September 30, 1979
Anticipated Completion Date:	June 30, 1980
Principal Investigator:	C. E. Coffey
Technical Project Officer:	C. A. Komar Morgantown Energy Technology Center

OBJECTIVE

To achieve a direct comparison of a novel gas well stimulation technique with conventional explosive stimulation in a fractured shale reservoir.



SCOPE OF WORK

This contract provides for the stimulation of 13 wells in Putnam County, West Virginia. Five of the wells will be stimulated by conventional explosives, and the other eight will be stimulated with DuPont's El-836 explosive.

SUMMARY OF PROGRESS

Work on this contract was initiated after the reporting period. Results will be reported in future Semi-Annual reports.

CHEMICAL EXPLOSIVE FRACTURING DEMONSTRATION

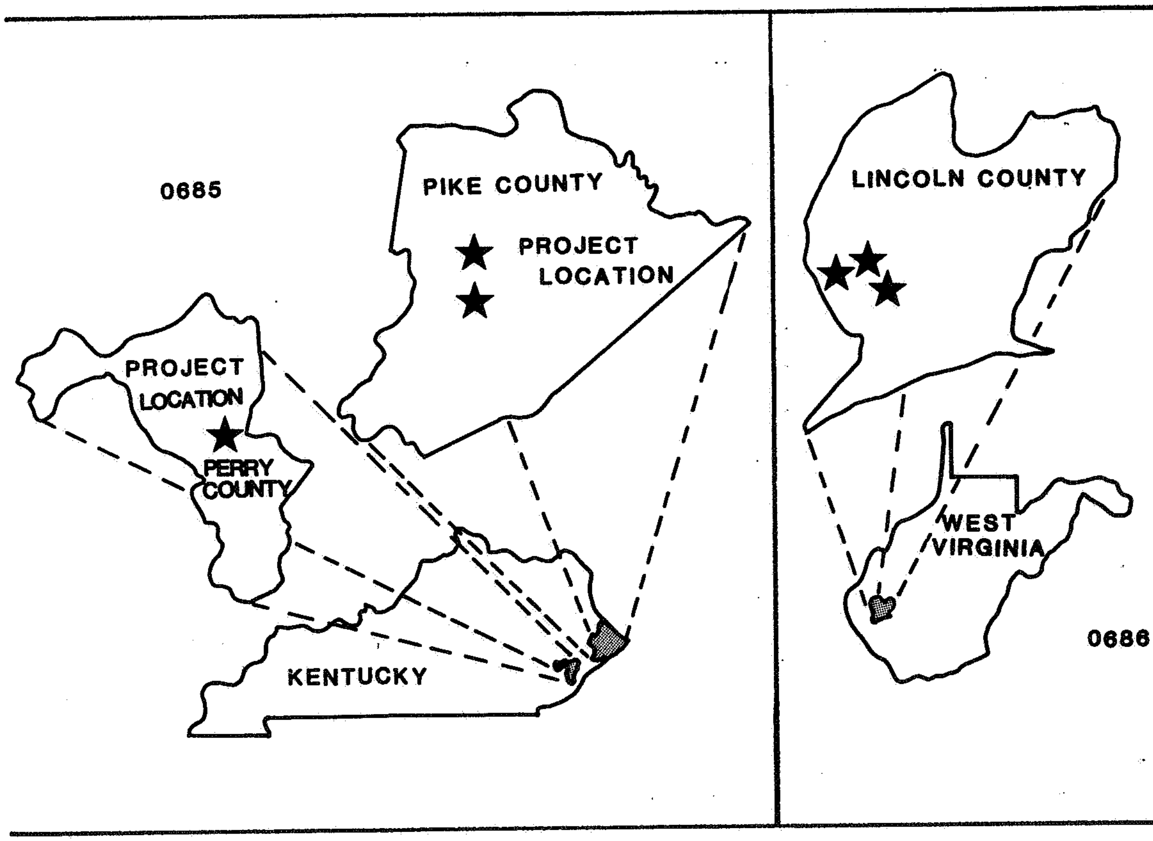
Petroleum Technology Corporation
Columbia Gas Transmission Corporation
Redmond, Washington

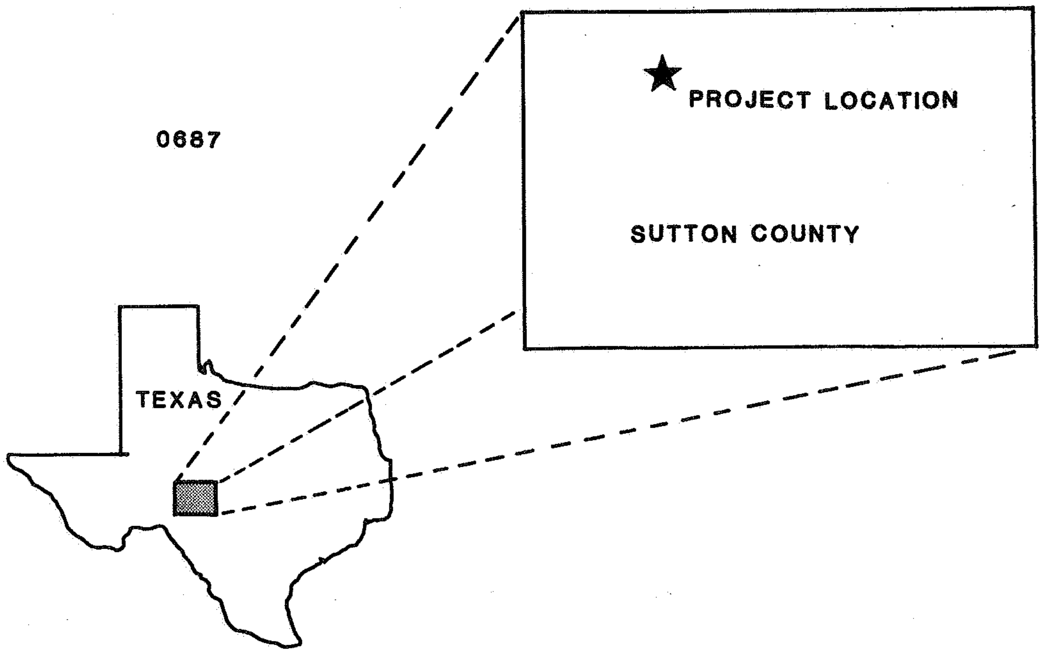
Status: Completed

Contract:	EY-76-C-08-0685, 0686, 0687
Contract Date:	July 1, 1976
Anticipated Completion Date:	December, 1979
Principal Investigator:	B. Beckelman
Technical Project Officer:	C. A. Komar Morgantown Energy Technology Center

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 and tight gas sands.





SCOPE OF WORK

CEF field test stimulation of seven wells in West Virginia, Kentucky and Texas will be conducted. Technical feasibility will be based on production tests and logs. Economic feasibility will be determined from production figures before and after treatment.

SUMMARY OF PROGRESS

All field activities have been completed on the projects. Results of the displaced liquid explosive tests in the shale are encouraging based on initial open flow but further demonstrations will be required for verification. Premature detonation in the Canyon Sand of Texas precluded any assessment in the tight gas sands. DOE is awaiting the submission of a final report from PTC before conclusions are offered.

A preliminary review by a team of DOE, National Lab, University and subcontract specialists in explosive fracturing technology identified results which indicate that the displaced explosive method or some modification to it might yield attractive stimulation effects. Nearly all of the problems associated with the application of the displaced explosive approach can be related to engineering implementation difficulties rather than to basic inadequacies of the concept.

ASSESSMENT OF SHALE PRODUCTION IN DUAL COMPLETED WELLS

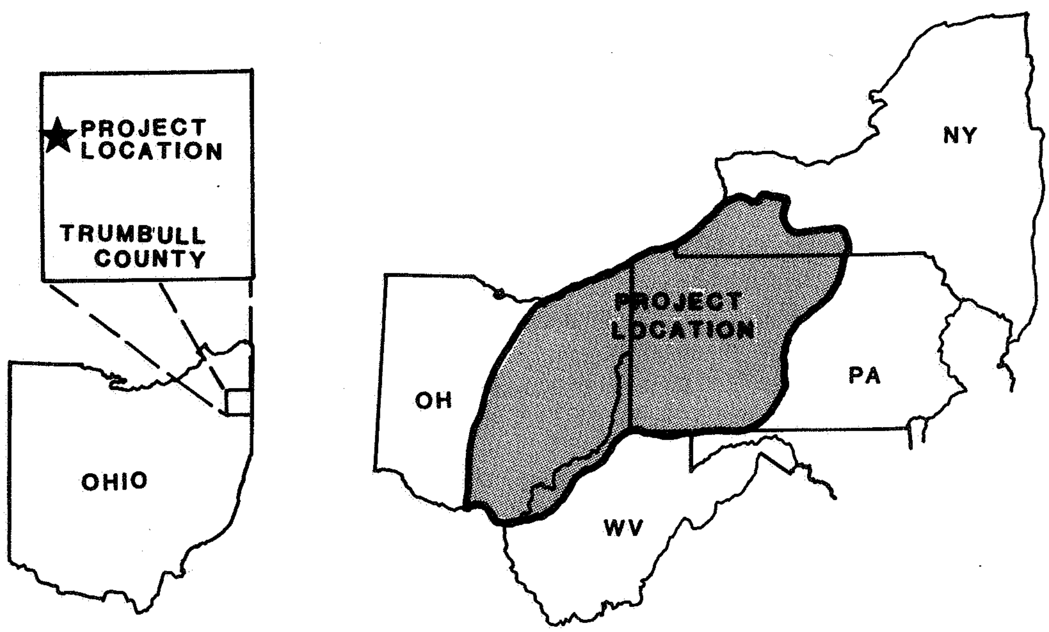
Status: Active

Tetra Tech, Inc.
Houston, Texas

Contract:	DE-AC21-78MC10389
Contract Date:	February 5, 1979
Anticipated Completion Date:	March, 1980
Principal Investigator:	J. P. Trunz
Technical Project Officer:	C. A. Komar Morgantown Energy Technology Center

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 and to evaluate the productive potential of the Devonian Shale in a four state region comprising the northern portion of the Appalachian Basin.



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 determined using cost benefit analysis and industry payout criteria. Regional and sub-regional studies will be conducted to identify and classify Devonian Shale reservoirs that exist under differing kinds of geological conditions throughout the area of interest. Prospects that are favorable for Devonian Shale production will be tested later by wells that are subject to dual completion in the Devonian Shale and in another reservoir. Extraction techniques will be used that are particularly suited to each type or trend that is defined.

SUMMARY OF PROGRESS

Two wells (Berg #1 and Shafer) were drilled during the last reporting period. During this period the Devonian Shale section of Berg #1 between 2010-2070 feet (twelve 0.56 inch holes) were stimulated using 1000 bbl 75 quality foam frac. The formation broke down at 3000 psi with an average displacement pressure of 2550 psi. The well was shut in for two days and the pressure built up to 2000 psi which on opening through a two inch L-pipe blew down in three minutes. Subsequent shut in and blow down experiments indicated that the shale reservoir had low volume and low pressure indicating that stimulation did not connect the borehole with a natural fracture system. Subsequent injection of radioactive pellets and logging indicated that the lower (2060-2070 feet) and upper (2010-2030 feet) zones responded to treatment. It was decided to abandon the zone and produce from the Clinton sandstone formation.

The program was re-evaluated and the contract was modified to develop another area in the eastern Devonian Shale province to drill three new wells and continue with the program. Phase I of the modified program which includes data acquisition has been initiated.

3.3.4 RESERVOIR PERFORMANCE

A summary of two contracts in this Work Package of the EGSP are presented in the following pages.

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, 1980
Principal Investigator:	J. Hartsock
Technical Project Officer:	K-H. Frohne Morgantown Energy Technology Center

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

During this reporting period, the MERC #1 and The C E POWER wells were tested. Results of the MERC #1 tests have been evaluated and the C E Power well is still in the evaluation stage.

The MERC #1 well was stimulated earlier with a cryogenic frac. At 7:30 p.m. September 14, 1979 the well was opened for 133.5 hours. The rate varied considerably during this flow period. At 9:00 a.m. on September 20, 1979 buildup period was started and continued until 5:00 p.m. on September 25, 1979 for the second drawdown period. The production history for this second period is presented in Figure 3-9.

Fracture length was calculated at 607 feet using a fracture height of 48 feet and fracture width of 0.2 inch. The results were analyzed by plotting log m (p) against time (t). In this case, a variable rate log n (p) was plotted versus $q_n t_n$. Well bore stage effects corresponded to t = 11 hours.

The following is a summary of results using both conventional analysis and a reservoir simulator. The results include a presentation of a sensitivity study (Figure 3-10) and a deliverability projection for five years based on 160 acres of spacing (Figure 3-11).

1. Estimation of Matrix Permeability and Fracture Half-Length From Conventional Analyses

	Permeability	Fracture Half-Length*
First drawdown	0.0034 md	36 ft.
Buildup	0.0021	20
Second drawdown	0.005	29
Arithmetic mean	0.0037 md	28.3 ft.
Log mean	0.0034 md	27.5 ft.

*Calculations are based on an average permeability value of 0.0037 md.

2. Reservoir Properties Used in History Match

Reservoir	
Effective Porosity	0.7%
Effective Permeability	0.0014 md
Pay Thickness	48
Fracture	
Fracture Half-Length	35 ft
Fracture Porosity	33%
Fracture Permeability	5000-500,000 md*
Fracture Height	48 ft
Fracture Width	0.1-0.2 in*

*Based on sensitivity runs, the reservoir simulator is not sensitive to calculated pressures in these ranges.

The conclusions of this study are presented as follows:

Analysis of the transient test data on the Morgantown Energy Research Center No. 1 well leads to the following conclusions:

- Most of the sand did not go to the desired zone. The frac job created a very small fracture (about 35 feet) in the perforated interval.
- Maximum storage was seen during the buildup because of the large pressure drop during the proceeding drawdown. Storage was more dominant in the first drawdown than in the second because of widely fluctuating flow rates.
- On the basis of the sensitivity analyses, it is obvious that the match obtained is extremely sensitive to changes in reservoir and fracture properties.
- Turbulence effects were negligible.
- Type-curve techniques could not be used because of extremely variable flow rates during drawdown and short shut-in periods during buildup.

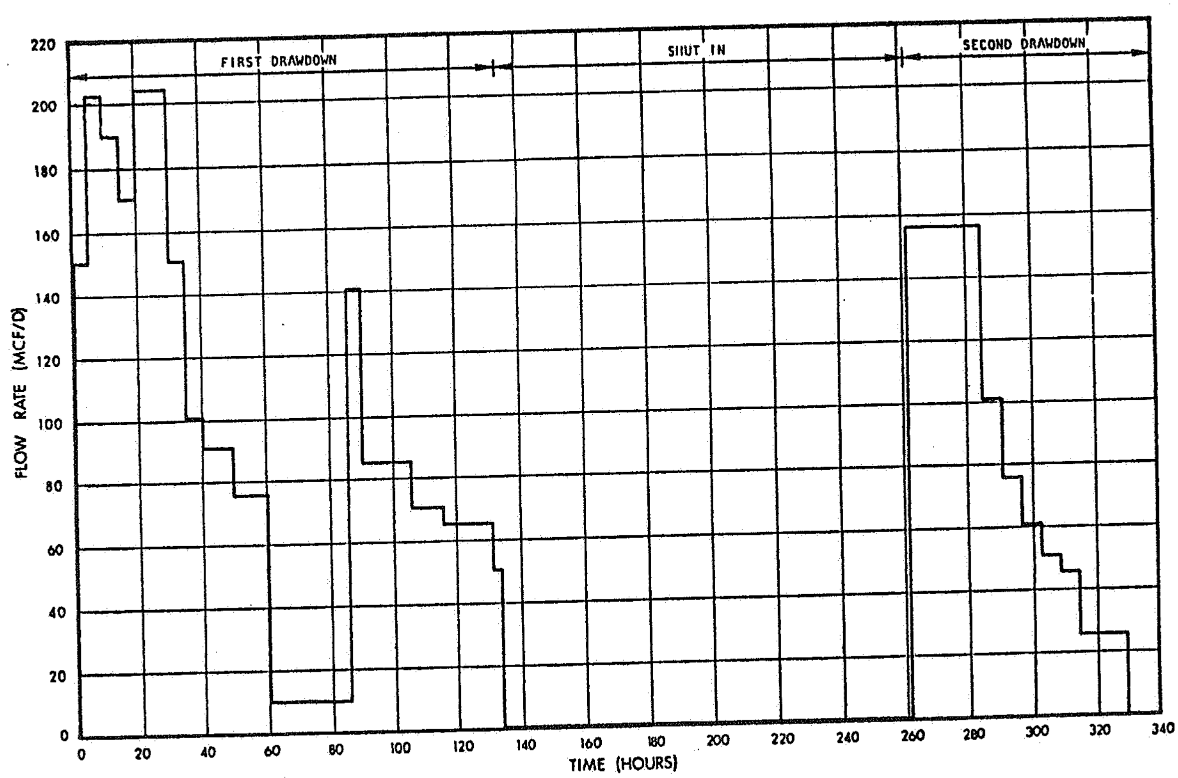


Figure 3-9 Production History of the MERC #1 Well

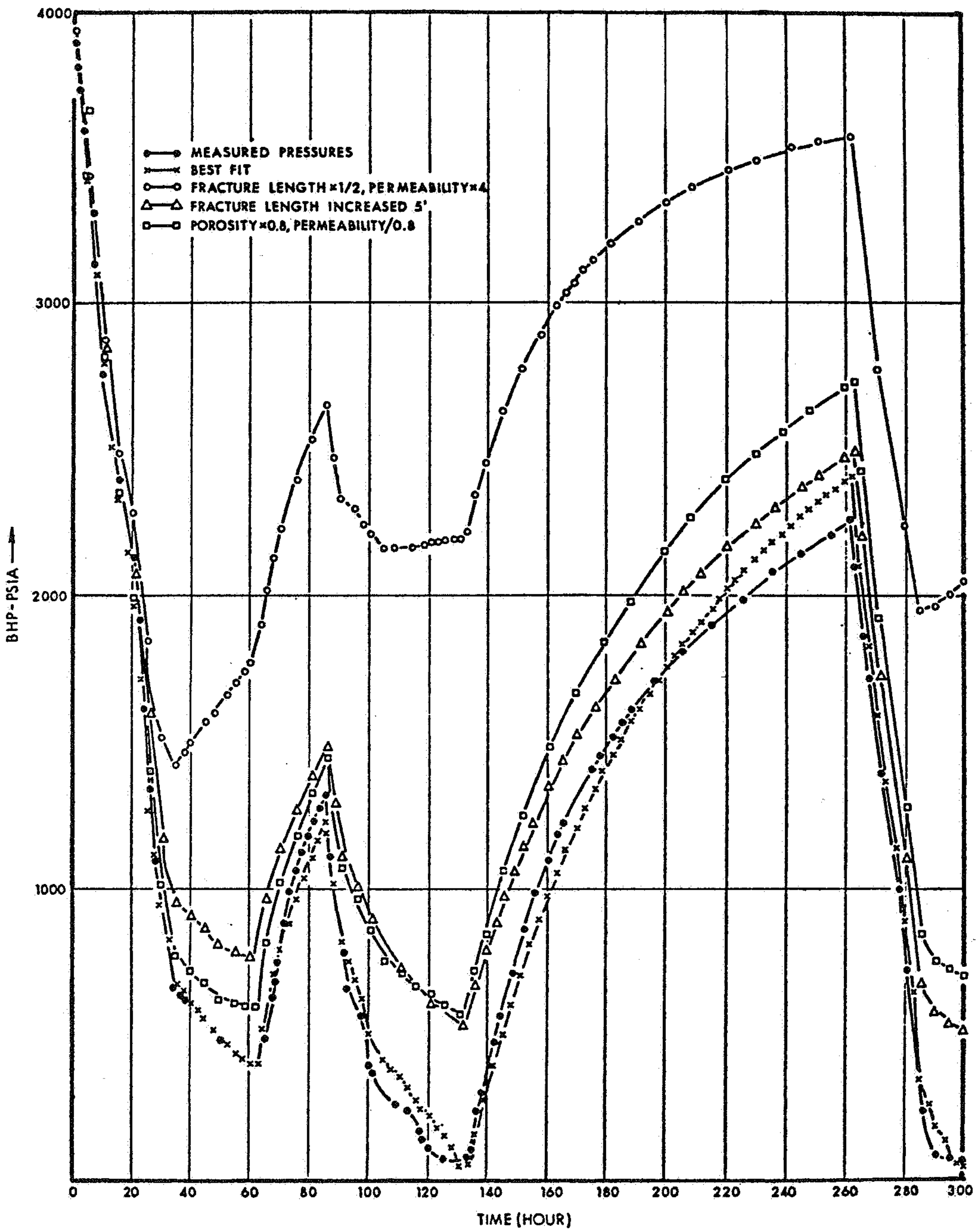


Figure 3-10 Sensitivity Analysis

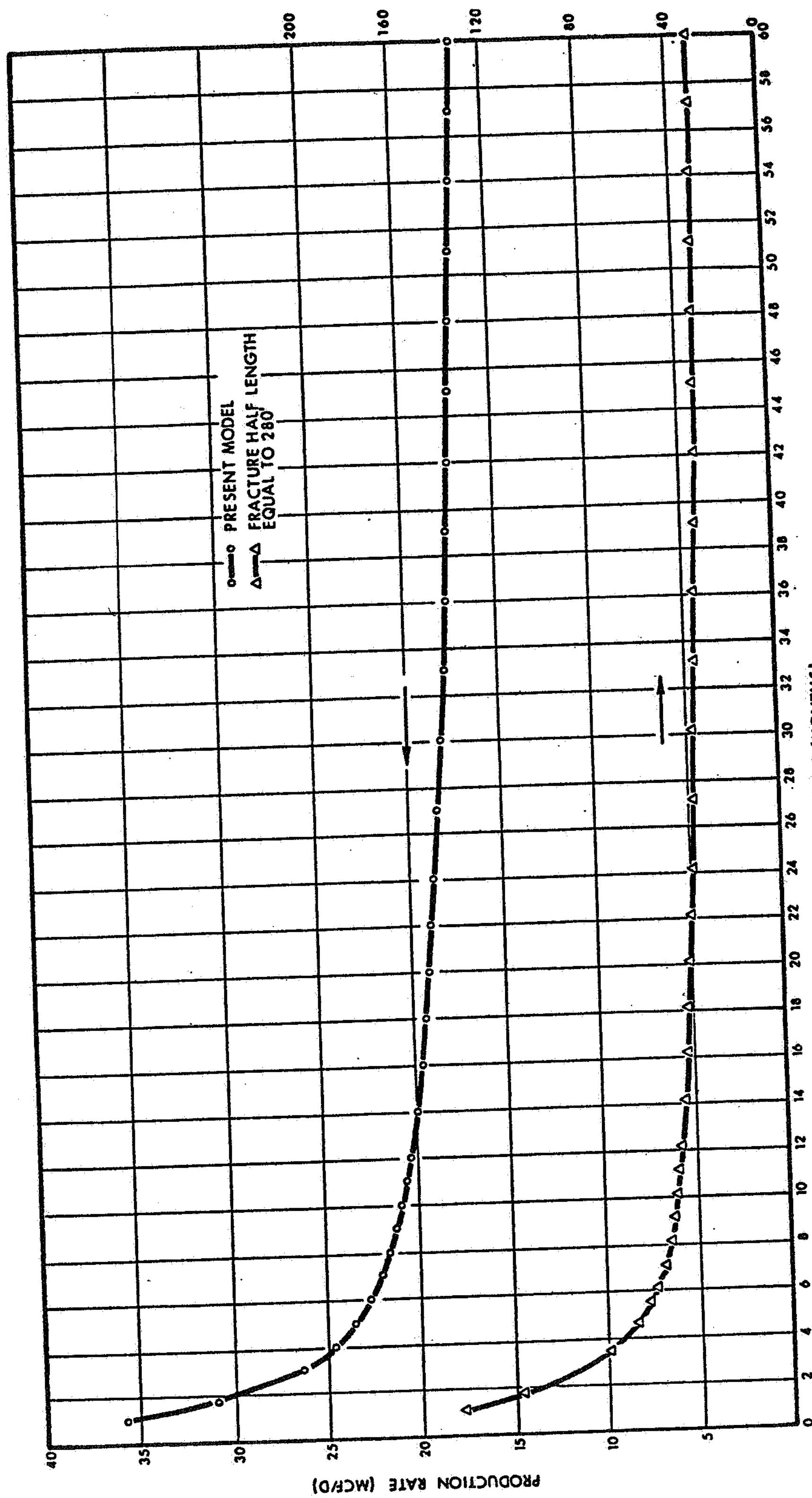


Figure 3-11 Deliverability Projection

ANALYSIS OF GAS PRODUCTION FROM EASTERN GAS SHALES

Intercomp Resource Development and
Engineering, Inc.
Houston, Texas

Status: Completed

Contract:	EW-78-C-21-8485
Contract Date:	October 1, 1978
Anticipated Completion Date:	November, 1979
Principal Investigator:	H. Price
Technical Project Officer:	C. A. Komar Morgantown Energy Technology Center

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.
- 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

A comprehensive final report has been submitted. The study included a characterization of Devonian Shales, core and log analyses, fracture analysis, model validation, production characterization using both a single radial model and an areal model, sensitivity analysis, pressure testing and economics of in fill drilling. The conclusions of the study are presented below.

Geological

The conclusions reached during this study of the petrophysical data on the Devonian Shale are as follows:

- Organic carbon content can be quantitatively determined from uranium content, a quantity which is measurable with wireline tools.
- Gas productivity appears primarily dependent on the organic carbon content and the fracture porosity system.
- The determination of fracture porosity is presently only a qualitative technique.
- Porosity log values can be quantitatively determined by the use of only a gamma-ray log in the Devonian Shales.

Engineering

The following conclusions can be made from the results of the study of production from the Devonian Shale.

- The presence and importance of an adsorbed gas phase in the Devonian shale is more difficult to conclusively identify than was first thought.
- Although it probably exists, as evidenced by laboratory and outgassing studies, the dual porosity system is important to the present production characteristics only in that it extends the life of a well beyond that of a well with only a free gas phase.
- The adsorbed gas phase becomes increasingly important as the drainage volume is significantly depleted.
- At the present level of technology, there is apparently little that can be done to increase the rate of production of this adsorbed gas.
- Well production characteristics are most sensitive to reservoir permeability and fracture half-length. The adsorption diffusion

constant becomes increasingly important as pressure is reduced in the drainage volume.

- Conventional transient pressure analysis techniques are valid in the adsorption/desorption environment of the Devonian Shale, except for those designed to determine drainage volume (reservoir limit tests).

- Economics of closer spacing indicates that at current costs and a gas price of $4.00/MCF, it would be economical to drill on a spacing as small as 10 acres.

The study suggested that the major unanswered question is what can be done to significantly increase the recovery, particularly from the adsorbed phase, of gas from Devonian Shales. The study also concluded that the reservoir could be treated as a naturally fractured tight gas sand.

3.3.5 TECHNICAL SUPPORT

Three national laboratories (Lawrence Livermore, Los Alamos and Sandia) are providing technical support to the EGSP as part of their overall support to the Unconventional Gas Recovery Program of DOE.

In addition, there is a technical and management support contractor specifically for the EGSP (Science Applications, Inc.). A summary of the work of these four contractors is presented in the following pages.

LAWRENCE LIVERMORE LABORATORY

OBJECTIVE

To provide fundamental research and development support to the Eastern Gas Shales Project and other DOE programs on unconventional gas recovery

SCOPE OF WORK

The research and development support efforts being conducted at Lawrence Livermore Laboratory involve both theoretical and experimental efforts directed in the following technical areas:

- Two- and three-dimensional modeling of hydraulic fracturing.
- Small-scale laboratory modeling.
- Basic rock mechanics measurements.
- Reservoir analysis.
- Conventional log evaluation.
- Dry-hole sonic log development and application.
- Environmental reports.

SUMMARY OF PROGRESS

Two-dimensional numerical models of hydraulic fracture propagation have been used to study and predict fracture propagation across interfaces with varying frictional properties. The models show that a fracture blunting effect will occur across an interface where frictional slippage is allowed. Slippage on the interface will tend to draw the fracture to the interface but will inhibit propagation of the fracture across the interface. The analyses also indicate that the existence of natural fractures in the two rocks bounding the interface will reduce the effects of mechanical changes across well-bonded interfaces. The results of theoretical dynamic analyses agree with the equilibrium calculations. However, inertial effects, seen as fracture propagation overshoot, can serve to draw a fracture across an interface that it would not traverse under static loading conditions.

Small-scale laboratory experiments have been utilized to evaluate friction thresholds for fracture penetration of interfaces and to study the effects of fluid modification of the coefficients of frictions on interfaces. All of the laboratory data obtained to date verify the effects of fracture behavior near interfaces predicted by the theoretical studies discussed above. It has been observed that aqueous fluids reduce the effective coefficient of friction in siliceous rocks but serve to increase the coefficient of friction in limestone and possibly argillaceous rocks.

Data on the fundamental mechanical properties of Devonian Shale have been generated and a report summarizing these data and their significance is being prepared.

The basic equations for studying the flow characteristics in hydraulic fractures have been formulated. These equations will be utilized to construct numerical models to study both fluid flow in hydraulic fracture propagation and the fluid flow associated with well production in hydraulically fractured wells.

Three-dimensional sonic log data have been analyzed in detail for the applicability of this type of data to the evaluation of in situ formation fracture logging. Color coding the 3-D sonic log data with respect to amplitude provides an unusually clear presentation of the data.

The LLL dry-hole sonic logger previously developed on the UGR support contracts has been tested in a Devonian Shale well in Ohio. Although the tool functioned well during these tests, tool vibrational modes generated noise which tended to mask the data on in situ fracture characteristics being sought.

LOS ALAMOS SCIENTIFIC LABORATORY

OBJECTIVE

To provide fundamental research and development support to the Eastern Gas Shales Project and other DOE programs on unconventional gas recovery.

SCOPE OF WORK

The research and development efforts being conducted at LASL involve both theoretical and experimental efforts directed in the following technical areas:

- Technical studies of heat and mass transport in reservoir rocks.
- Consideration of fluid/formation interactions.
- Development of laser pyrolysis techniques for determining organic content of shales.
- Computer generation of geological and reservoir maps.
- Development of an NMR focused logging capability.
- Theoretical study of dynamic rock fracture and explosive well stimulation methodologies.

SUMMARY OF PROGRESS

A laboratory laser pyrolysis apparatus has been constructed and put into successful operation. This equipment has been successfully utilized to obtain data on EGSP core material which can be reduced to determine the organic content of the rock.

A numerical computer based model for the fractured Devonian gas shale reservoir in Cottageville, West Virginia has been developed. This model has integrated into it all of the available geological, geophysical and gas production data and will provide a self-consistant representation of the observed flows and pressures in the field. A single phase Darcy flow simulator and a data-base management code provide capabilities for selecting, ranking, rotating, mapping, meshing, and plotting various attributes of wells in the field. Correlation studies that have been conducted utilizing the model illustrate that producing wells occur in narrower structural ranges than do the non-producing wells. Some correlation, but with weak confidence, was observed when only wells of a particular type of decline curve are compared.

Efforts on the development of an NMR focused logging tool have been concentrated on the evaluation of formation penetration characteristics of potential down-hole tools and an evaluation of the potential for distinguishing between free and bound water within formations of interest.

An in-depth technical review of the Petroleum Technology Corporation (PTC) Astrofrac displaced explosive stimulation technique has been completed. This review involves the establishment of a working group which included numerous non-LASL specialists. The review identifies results which indicate that the displaced explosive method or some modifications to it might yield attractive stimulation effects. Nearly all of the problems associated with the application of the displaced explosive approach can be related to engineering implementation difficulties rather than to basic inadequacies of the concept.

SANDIA LABORATORIES

OBJECTIVE

To provide research and development to improve well-shooting technology for stimulating Devonian Shale reservoirs with dynamic fracturing techniques. These techniques are aimed at producing multiple fractures radiating from a wellbore.

SCOPE OF WORK

The work performed for the Eastern Gas Shale Project involves primarily a field test at the Nevada Test Site and associated modeling efforts for the specific tests and for tailored-pulse stimulation in general. The field and modeling efforts can be further defined as follows:

(1) Field tests with mineback for direct observation of results:

- Evaluate and compare five tailored-pulse concepts
- Evaluate existing modeling capabilities by acquisition of specific data
- Define phenomenology and mechanisms not adequately modeled at present

(2) Modeling and Analysis

- Determine material properties of test bed and provide core to other labs
- Model tailored-pulse loading using empirical, analytical, and numerical techniques
- Coordinate modeling efforts with Stanford Research Institute, University of Maryland, Los Alamos Scientific Laboratory, and Science Applications, Inc.

SUMMARY OF PROGRESS

Progress through September, 1979 focused on the field test. This test series involves the shooting of five cased horizontal holes with the following devices: 1) Dynafrac - a decoupled explosive, 2) Augmented Dynafrac - a decoupled explosive with propellant booster, 3) Kinefrac - a small-diameter propellant charge with pressurized water pad, 4) Multiple Kinefrac - three successive shots of Kinefrac, and 5) Gas Frac - a full-diameter charge of propellant.

A complete test design was achieved that includes test hole configuration (Figure 3-12), instrumentation selection and layout (formation and cavity measurements), tunnel layout with mineback plan (Figure 3-13), etc. Design of the Gas Frac shot (Sandia's tailored-pulse concept) was completed and a new initiating device was tested. Orders were placed for all hardware, such as casing and transducers, and most of the machining was completed. Tunnel operations were begun by the drilling and reaming of the casing sections. Electrical feedthroughs for cavity pressure and detonator connections were obtained and proof tested.

Modeling work was focused in two areas: A permeability analysis was performed that provides the capability to measure in situ the effective pre-test and post-test permeability. A closed-form linear-elastic analysis of previous Gas Frac experiments suggested that rates of loading should not exceed those that give initial compressive hoop stress at the wellbore wall.

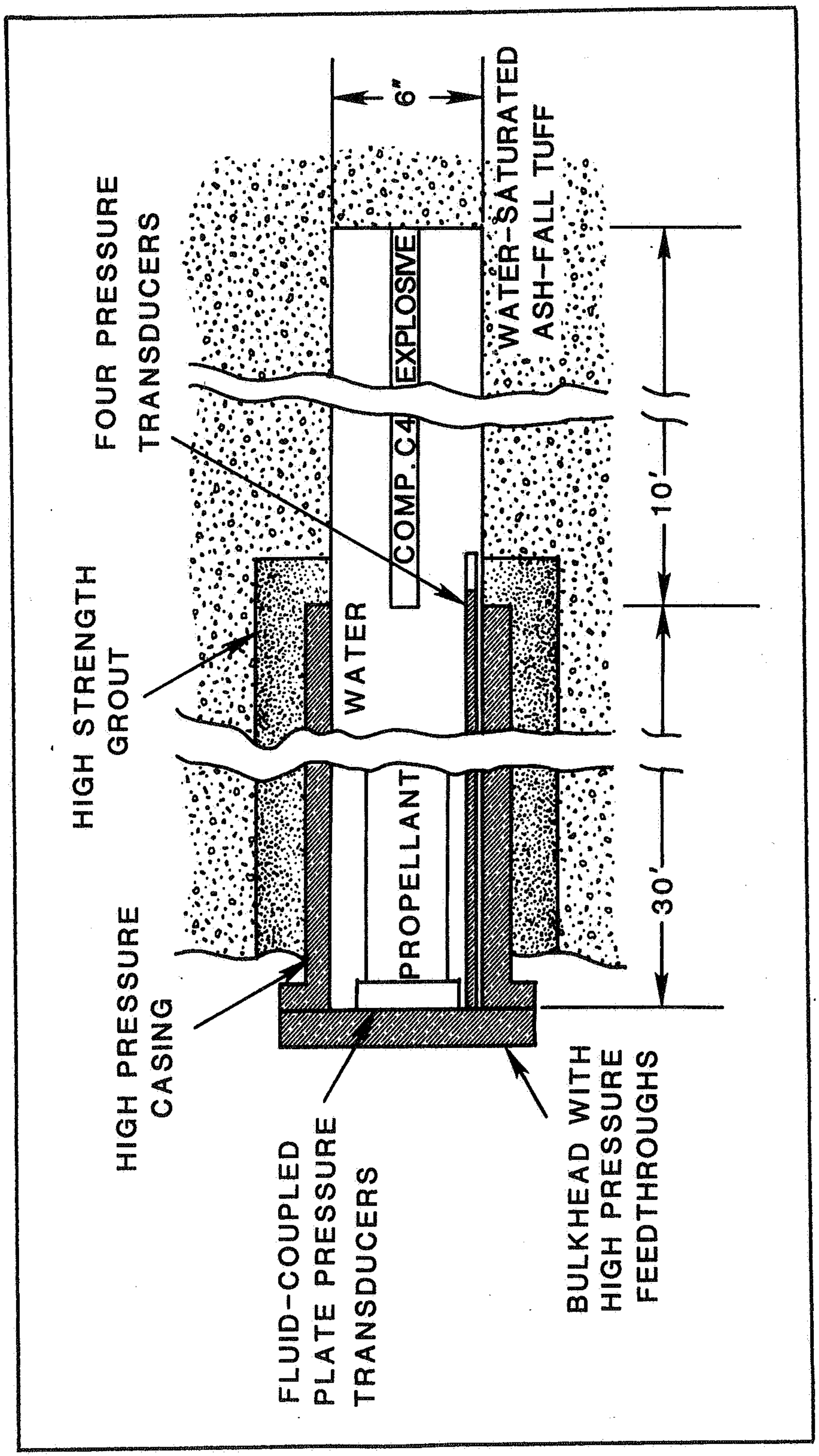


Figure 3-12 Test Configuration for Augmented Dynafrac

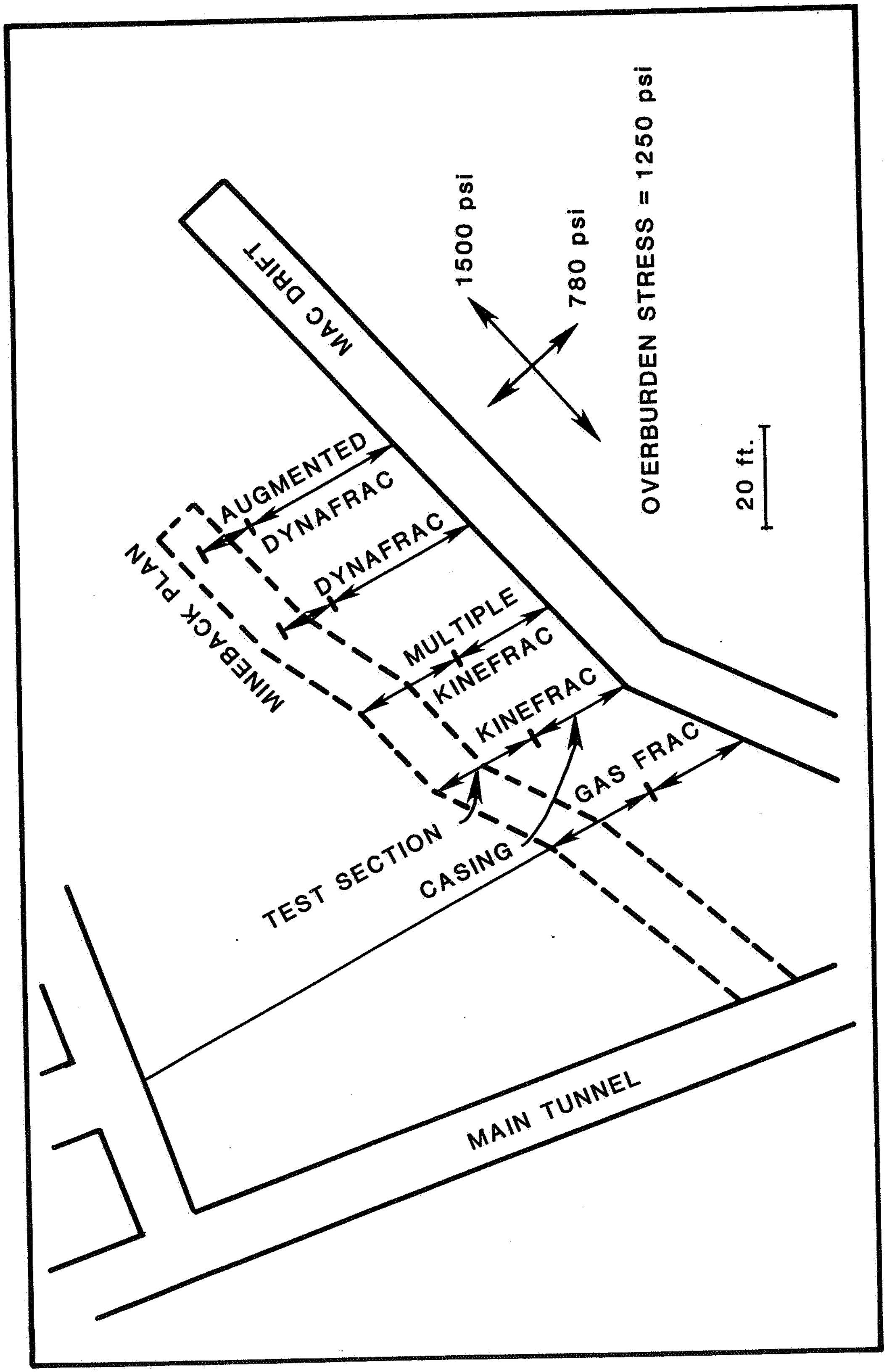


Figure 3-13 Tunnel Plan for Multi-Frac Test Series with Proposed Mineback Route

TECHNICAL AND MANAGEMENT SUPPORT SERVICES

Science Applications, Inc.
Morgantown, West Virginia

Status: Active

Contract: DE-AT21-78MC08216
Contract Date: August 1, 1978
Anticipated Completion Date: July 31, 1981

Principal Investigator:
Technical Project Officer: C. A. Komar
Morgantown Energy Technology Center

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

In addition to providing general support to METC in all four Elements of the EGSP, SAI also undertook specific tasks. Progress on these is summarized below:

1. A reservoir model for the Devonian Shales was developed. The following conclusions were made:

   a. The sensitivity analysis showed that early performance of shale reservoirs is dominated by fracture system parameters, while later performance is primarily controlled by shale matrix and desorption parameters.

   b. Gas slippage, or Klinkenberg effects, are pronounced in Devonian Shales; however, to date no experimental data are available for validation.

c. Fracture system permeability, shale matrix permeability and size, and desorption isotherms are key determining factors of reservoir performance. However, data for these parameters are scarce.

The sensitivity studies indicated that reservoir performance is strongly dependent on shale matrix parameters. This conclusion must be validated through laboratory experiments since assumptions were made about the transport and gas holding mechanism of the shale matrix.

2. All available data on 20 well stimulation treatments performed under the EGSP were compiled. This included all drilling and stimulation details, and core and log analyses where available.

3. Efforts to quantify a stimulation rationale for shale wells have provided some basic reservoir production criteria which should exist if explosive stimulation treatments are to be preferred over conventional hydraulic treatments. As these criteria relate to the density, heterogenity and anisotropy of the natural <u>in situ</u> fracture system and the consequent importance of this fracture system in controlling production, well testing programs designed to better delineate the importance of <u>in situ</u> fractures in Devonian Shale well production are strongly recommended.

4. Theoretical efforts to evaluate explosive stimulation treatments have been concentrated upon the development of a rock fracture model representative of explosive wellbore fracturing. A detailed study of the fracturing developed by the Dynafrac stimulation technique and an evaluation of the various explosive/propellant stimulation treatments in the Sandia NTS mineback experiments in tuff have been made.

5. SAI geologists assisted METC in evaluating seven proposed well sites in eastern Tennessee. A site was chosen in the Greendale Syncline. The well will test the exploration rationale that natural fracturing, necessary for economic shale gas production, should occur as a result of regional thin-skinned tectonic deformation. The well is scheduled to be spudded in early January 1980.

   A study has been initiated to determine the applicability of the cross-strike structural discontinuity (CSD) exploration rationale to the EGSP. The current state of knowledge has been assessed and recommendations are being made to develop the rationale for field testing. If successful, such testing could extend Devonian Shale gas production eastward from the current producing area. The study will be completed in mid-October, 1979.

   METC and SAI have undertaken the screening of the Appalachian, Illinois and Michigan Basins to identify areas which have a high potential for Devonian Shale gas production. The screening of the States of Pennsylvania, and West Virginia has been completed. The screening of Indiana, Illinois, and western Kentucky will be completed in mid-October, 1979.

The screening and ranking of areas is based on the analysis of stratigraphic, structural and shale gas production/show data.

6. A study of off-gassing data produced by EGSP contractors concluded:

   a. The stratigraphic horizons, characterized by dark shales with high organic and high carbon content and a relatively high gamma ray intensity of 200 + API units also have high gas contents (relative to other units within the same well). The Lower Huron, Rhinestreet, and Marcellus Shales are high in gas content relative to other stratigraphic units at the same sites.

   b. The difference in gas content of the same stratigraphic horizon between well sites appears to be controlled by the thermal maturity of the shale. Although undoubtedly a simplification, shales with a high organic content and a high thermal maturity have a high gas content. Thermal maturity in the Appalachian Basin is determined by basin position and proximity to structural features. Depth of burial has little effect on thermal maturity of the shale in the Appalachian Basin.

   c. The correlation of gas volume to total carbon content is weak on a sample by sample basis. If organic carbon values are substituted to eliminate the effect of mineral carbon, the correlation coefficient increases only slightly (with exceptions) and could not be classed as a strong correlation. If average gas contents and average carbon volumes are used for each stratigraphic unit, the correlation between the two variables is strong with high carbon units consistently having high gas volumes. Averaging could be expected to increase the correlation coefficient, but not to the degree observed.

   d. Kinetic studies have shown that in some samples, significant amounts of gas are released after the time when the gas volume would be initially measured. Additional work needs to be performed to determine why the rates of gas release and the volume of gas released varies between samples.

7. Efforts were completed to assess the shale characterization being performed in the Michigan Basin (Laramie Energy Technology Center and Dow Chemical Corporation) and how it relates to EGSP goals and objectives.

   Based on initial results of geochemical, physical, and lithological analyses of the Antrim Shale, it appears to be quite similar in its character to the Devonian Shale in the Appalachian and Illinois

Basins. The critical item yet to be determined is how much gas is contained in the Antrim Shale. With additional cores and the analytical test results from these cores, this question can be answered.

The gas resource values of the Antrim Shale in the Michigan Basin may be similar to that of the New Albany Shale in the Illinois Basin because of similarities in their lithofacies types, thickness of radioactive black shale, and tectonic activity.

3.4 TECHNOLOGY TESTING AND VERIFICATION

3.4.1 INTEGRATION

Economic Devonian Shale gas production is dependent on both exploration and exploitation rationales and techniques. While it is difficult to completely separate the contributions of exploration and exploitation for individual wells, core analysis and well testing does allow individual evaluation of exploration and exploitation rationales. Of the eleven contracts in this Element, three are primarily to test exploration rationales, while the other eight are designed primarily to test stimulation techniques.

The two exploration rationales currently being tested are one based on seismic velocity analysis (one contract in Ohio and one in New York), and one based on the theory that the development of natural fracture systems is related to the structure at the time of deposition (one contract in Ohio).

The stimulation treatments to be tested in the other eight contracts are primarily foam and cryogenic treatments, as previous EGSP research has indicated that these are the most promising techniques for further development.

3.4.2 EXPLORATION RATIONALE

Three contractors are currently active in this Work Package of the EGSP. A summary of their work appears on the following pages.

NEW EXPLORATION CONCEPT FOR LOCATING FRACTURE ZONES IN THE DEVONIAN SHALE

Donohue, Anstey and Morrill
Boston, Massachesetts

Status: Active

Contract: DE-AC21-78MC08339
Contract Date: February 23, 1979
Anticipated Completion Date: March 1, 1980

Principal Investigator: D. A. Donohue
Technical Project Officer: C. A. Komar
Morgantown Energy Technology Center

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 two or 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 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 the wells.

SUMMARY OF PROGRESS

The velocity analysis data have been processed and interpreted. Two well sites have been proposed by the contractor along the velocity traverse and approved by METC.

Drilling of the wells was scheduled to begin in November, 1979. Leasing problems have forced a rescheduling until after the first of the year.

SHALE TEST WELLS IN SOUTHERN TIER COUNTIES OF NEW YORK

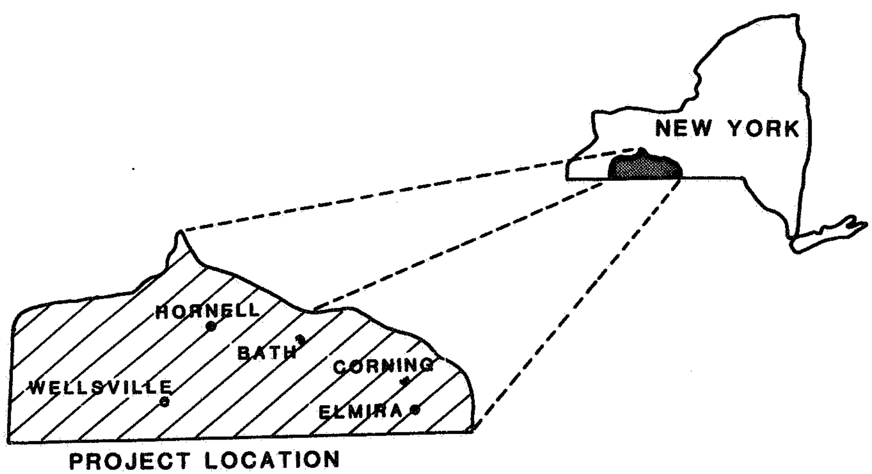
Status: Active

Donohue, Anstey and Morrill
Boston, Massachesetts

Contract:	DE-AC21-79MC12697
Contract Date:	September 28, 1979
Anticipated Completion Date:	August 31, 1981
Principal Investigator:	D. A. Donohue
Technical Project Officer:	C. A. Komar Morgantown Energy Technology Center

OBJECTIVE

To locate, drill and test by stimulation methods the production potential of 10 wells in the Rhinestreet/Marcellus Facies of the Devonian Shale in the Southern tier Counties of New York.



SCOPE OF WORK

The contractor will provide a project site within the designated area (Figure 3-14) which will be a candidate area for drilling, coring, logging, testing, stimulating and re-testing 1-10 Devonian Shale wells. The wells will be sited using seismic and geologic exploration techniques. A complete core of the Upper Devonian Shale will be obtained from the first well for detailed resource and reservoir characterization work. Selected intervals may be cored and analyzed from the second well. All wells will be logged with a research suite of logs. The decision to continue drilling up to 10 wells will be based on the results of the stimulation and testing of the initial wells.

SUMMARY OF PROGRESS

This contract was signed in the last week of the reporting period. Progress will be reported in future Semi-Annual Reports.

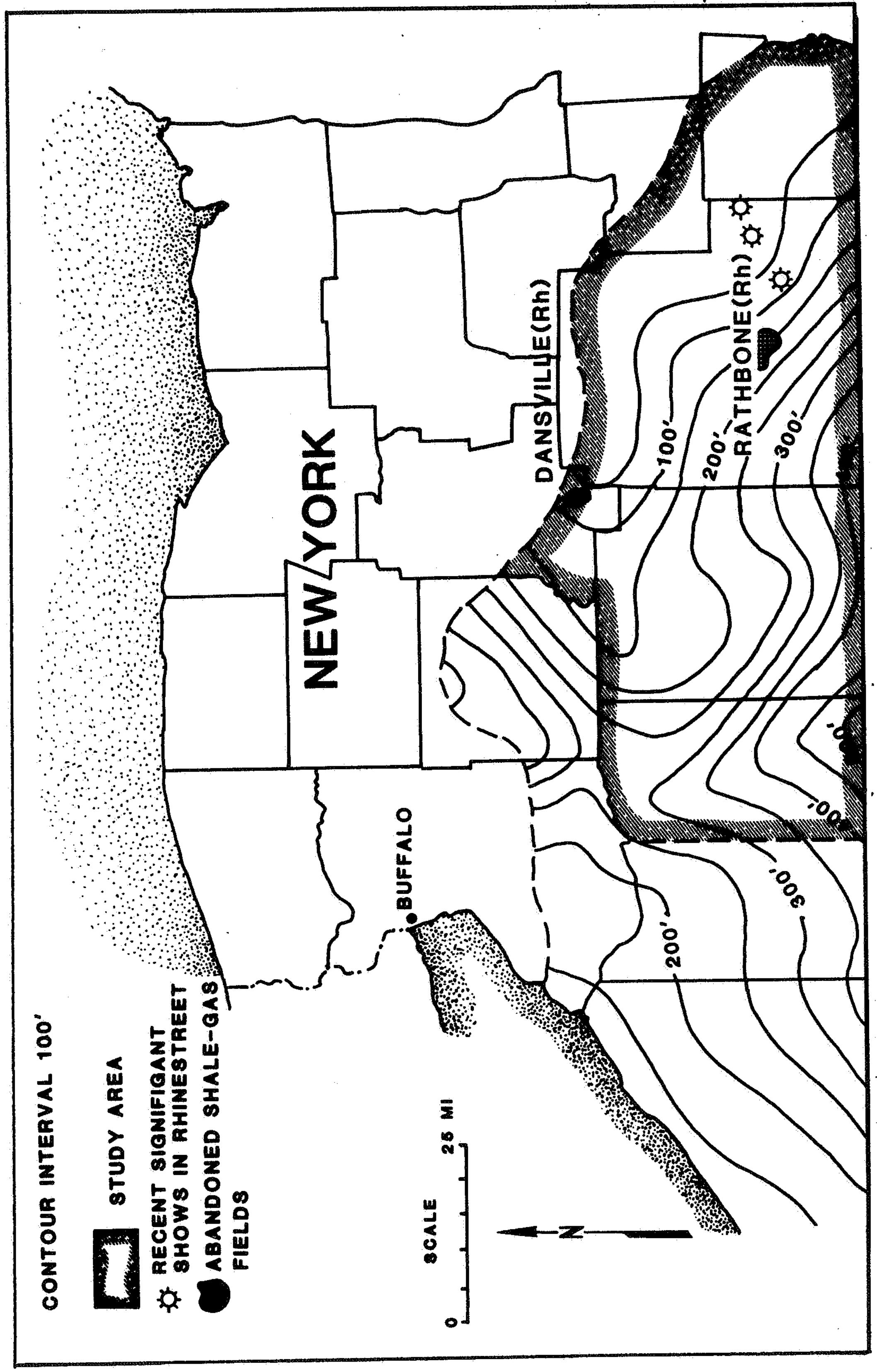


Figure 3-14 Southern Tier Counties of New York Showing Radioactive Shale Isopach of West Falls Formation

SUPPORT DEVELOPMENT OF AN UNCONVENTIONAL EXPLORATION TECHNIQUE TO SELECTIVELY LOCATE NATURAL FRACTURE SYSTEMS IN THE DEVONIAN-OHIO SHALE

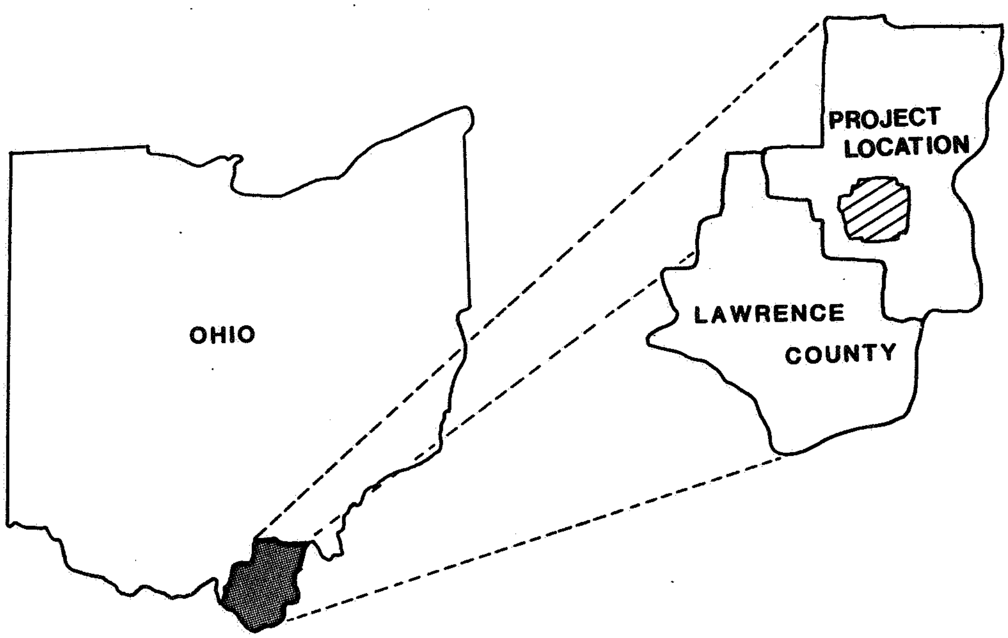
Status: Active

Mitchell Energy Corporation
Houston, Texas

Contract:	DE-AC21-78MC08387
Contract Date:	September, 1978
Anticipated Completion Date:	September, 1980
Principal Investigator:	W.M. Hennington
Technical Project Officer:	A.B. Yost Morgantown Energy Technology Center

OBJECTIVE

To establish: An unconventional technique to selectively locate naturally fractured shale reservoirs; the presence and orientation of natural fractures; 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 are designed to determine 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

Since this project was initiated one year ago, work has been concentrated in the planning, exploration and temporary test line tasks. Considerable time has also been spent in obtaining the necessary approvals.

Efforts to collect geological and production data for the old (pre-1930) shale fields in the vicinity of this project were, for the most part, unsuccessful. Such information for many wells was not retained, was never released or was not suitable. Enough data was collected to conduct a fairly detailed study of the Cottageville Field in Jackson and Mason Counties, West Virginia (15 miles east of the project area).

A 65-point spot correlation seismic survey was conducted to detail the structure in the project area.

From the above studies and information, the approximate depositional structure of the Devonian Shale in the project area was reconstructed. The locations of the natural fracture reservoirs were then proposed with the locations for the PHASE I wells selected to test the various depositional structure positions. Based on this interpretation the #1-5 S. Carpenter, #1-8 Straight-Wisemandle Unit and #1-9 M. Carter should encounter more natural fractures than either the #1-6 L. McCombs or the #1-7 White-Price-Newberry Unit.

The archaeological approval proved to be very time consuming. Twenty-one locations were submitted in order to obtain approval for five which would satisfy the main PHASE I objective and test various depositional structural positions. These locations have been given final approval by the Ohio Historical Preservation Officer, the USDOE Technical Project Officer and the Ohio Division of Oil & Gas.

The project area received a positive environmental assessment.

All available remotely sensed imagery (Landsat, SLAR, Aerial Mapping Photography) has been analyzed and mapped. The ground truth field check of fractures in outcrops has been completed. Based on this interpretation, the #1-5 S. Carpenter, #1-7 White-Price-Newberry Unit and #1-9 M. Carter should have more natural fractures than either the #1-8 Straight-Wisemandle Unit or the #1-6 L. McCombs.

Equipment to preserve core samples and both wet and dry well cuttings has been received. The well cuttings gas analyzer has been received and is being repaired. The chart recorder has been ordered.

The 4" test line and 2" well line systems have been planned and surveyed. All regulations have been checked. Right-of-way has been obtained along with archaeological approval. Extreme and unusually wet ground conditions, the resulting large backlog of work for pipeline contractors and construction during unfavorable late fall-early winter conditions are felt to be mainly responsible for the bids received for this work. In order to minimize the effects of these problems and, therefore, increase the possibility for substantially lower construction costs, this work will be delayed until spring 1980. Formal USDOE approval has been requested for this program modification.

Delays resulting from regulations, data deficiencies, subcontractor scheduling conflicts, poor weather conditions, and archaeological problems have caused an estimated three month setback in the program.

Lease, title, unitization and survey work have been completed. Environmental, archaeological, USDOE and Ohio drilling permit approvals have been received for all five locations. USDOE approval of subcontractors, subcontracts, and cost estimates have been received for the drilling, coring, logging and casing stages.

The #1-5 S. Carpenter has been drilled, cored, logged and cased. Preliminary indications are that the structure was as predicted and fractures were encountered as predicted in the lower two zones cored. Due to lack of adequate control in this area, the first 60 feet core was started 50 feet below the proposed core point. Log, sample and core analyses are continuing.

The #1-6 L. McCombs location has been prepared and the lease problems recently encountered have been corrected.

The #1-7 White-Price-Newberry Unit well is currently being cored at 1697 feet (CORE #1).

3.4.3 EXPLOITATION RATIONALE

A summary of the work of the contractors in this Work Package of the EGSP follows.

HYDRAULIC FRACTURING EXPERIMENT IN JOHNSON COUNTY, KENTUCKY

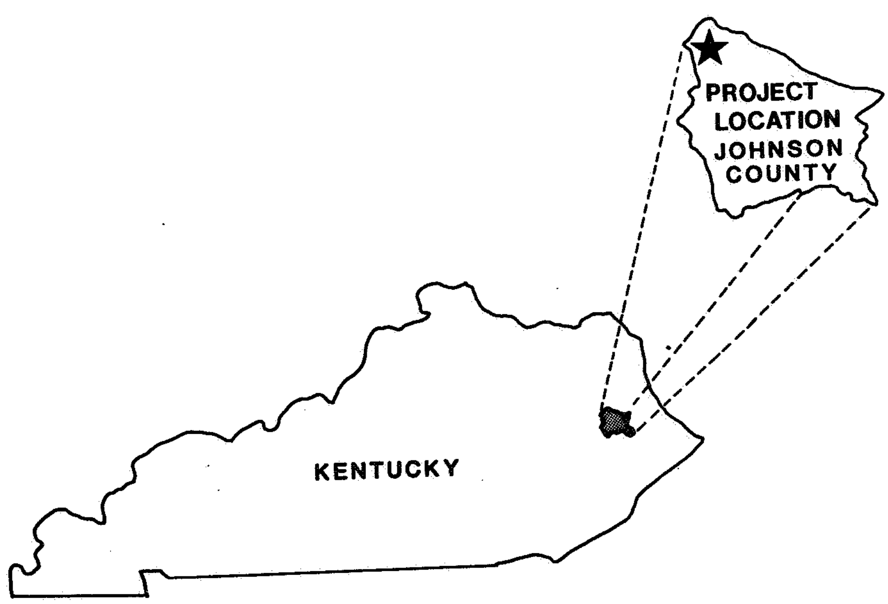
Status: Completed

Ashland Exploration, Inc.
Ashland, Kentucky

Contract:	DE-AC21-78MC008444
Contract Date:	September 26, 1978
Anticipated Completion Date:	March, 1979
Principal Investigator:	J. Avila
Technical Project Officer:	C. W. Byrer Morgantown Energy Technology Center

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, Kentucky. 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

As reported in the last Semi-Annual report, the well in Johnson County, Kentucky was drilled, logged, and cored in October, 1978. Five hundred and forty three (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 53,000 gal of foam 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 43,600 gal of foam 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.

During this reporting period the core analyses on this well were completed. The results of these analysis are presented in Table 3-6.

Table 3-6 Results of Johnson County Core Analysis

JOHNSON COUNTY, KENTUCKY (KY-4)	
ANALYSIS	MEAN
Gas Volume	0.53 ft^3 gas/ft^3 shale
Organic Carbon	2.91 %
Total Carbon	3.6 %
Bulk Density	2.572
True Density	2.666
Porosity (Calculation)	4.069 %
Porosity (Hg Intrusion)	5.43 %
Surface Area	2.200 m^2/g
Extractable C_{15+}	1.704 ppm
Thermal Alteration Index	Predominant TAI = 1+ to -2
Vitrinite Reflectance	Ro = 0.57
H/C (Kerogen)	Not Reported
O/C Kerogen	Not Reported
Sulfur (whole rock)	1.28 %
H/C (whole rock)	4.62
O/C (whole rock)	3.27

ASSESSMENT OF THE ECONOMIC POTENTIAL OF DEVONIAN SHALE GAS PRODUCTION

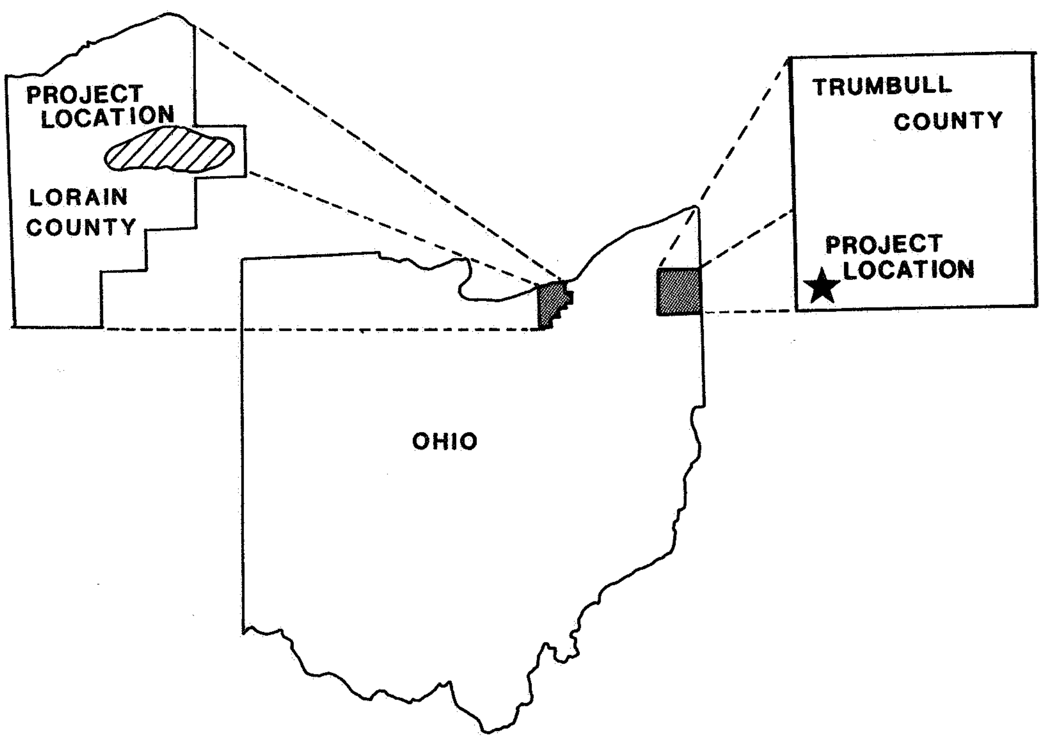
Columbia Gas System Service Corporation
Columbus, Ohio

Status: Active

Contract:	EW-78-C-21-8385
Contract Date:	September 27, 1978
Anticipated Completion Date:	September, 1980
Principal Investigator:	W.F. Morse
Technical Project Officer:	C. A. Komar Morgantown Energy Technology Center

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, Ohio. 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

During this reporting period work consisted of planning and initiating field activities.

Sites were identified during the reporting period for both Trumbull and Lorain Counties, Ohio. Archaeological survey work was completed during June and July, and drilling was initiated in August, 1979. By the end of this reporting period three wells had been drilled. Well #20149 in Lorain County, Ohio has been drilled, cored, logged, and cased with 4 1/2" pipe at 1340 feet. A total of 879 feet of 3 1/2" core was retrieved. The well measured an initial open flow of 7.6 MCFD prior to casing. Offgas measurements on core material were initiated in the field and are continuing in the laboratory. Preliminary results suggest that high offgas concentrations are between approximately 870 feet and 1080 feet. The logging program consisted of a full Coriband suite, a fracture identification log, sibilation log, temperature log, 3-D velocity log, and Schlumberger's experimental noise log. Sibilation and temperature logs indicated gas entry at or near the depths of 470, 620, 727, 752, 792 and 874 feet. Mud log gas analysis showed concentrated gas entry between 620 feet and 910 feet. Drilling of the second well (#20148) was continuing at the end of this reporting period and was close to total depth (TD). This well was not scheduled for coring. Eight core barrels had been retrieved for a total of 524 feet of core in the third well (#20143 in Trumbull County, Ohio). Additional core is being recovered. Stiff foam was used for coring and an air rotary rig was used to drill the wells.

HYDRUALIC FRACTURING EXPERIMENT IN ALLEGHENY COUNTY, PENNSYLVANIA

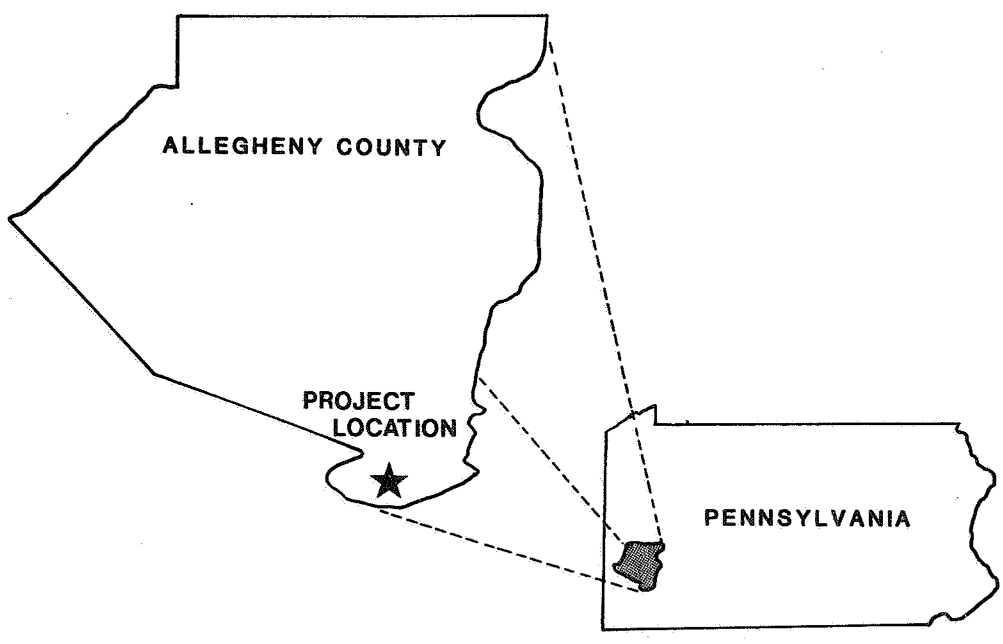
Combustion Engineering, Inc.
Windsor, Connecticut

Status: Active

Contract:	DE-AC21-79MC10374
Contract Date:	February 12, 1979
Anticipated Completion Date:	June, 1979
Principal Investigator:	P. Murphy
Technical Project Officer:	K-H. Frohne Morgantown Energy Technology Center

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, Pennsylvania. 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 Combustion Engineering well was drilled and cored during the last reporting period. During this reporting period two zones, the "Marcellus" and "Burkett" were treated using cryogenic treatments.

The Marcellus Zone was stimulated during May 1979 using 40 lbs. gel with 20% CO_2. The treatment consisted of 102,000 gallons of fluid with 880 sacks of 20/40 mesh sand and 880 sacks of 80/100 mesh sand. Instantaneous shut-in pressure was 3600 psi. Average treating pressure was 4957 psi with a rate of 26.9 BPM. After flow back, the well was shut-in pending stimulation of the second zone.

The Burkett zone was stimulated during August, 1979, using Versagel 1400 with 20% CO_2. The treatment consisted of 62,500 gallons of fluid with 370 sacks of 20/40 mesh sand and 370 sacks of 80/100 mesh sand. The average injection pressure was 3637 psi with a fluid rate of 11.9 BPM, and 14.9 BPM including CO_2. Instantaneous shut-in pressure was 3200 psi. After flowback, the well was shut in to run pressure buildup and drawdown tests. During this reporting period the field tests were performed and are presently being evaluated. Results of the tests will be reported in the next Semi-Annual Report.

During this reporting period the core analyses on this well were completed. The results of these analyses are presented in Table 3-7.

Table 3-7 Results of Allegheny County Core Analysis

ALLEGHENY COUNTY, PENNSYLVANIA (PA-2)	
ANALYSIS	MEAN
Gas Volume	0.28 ft^3 gas/ft^3 shale
Organic Carbon	1.74 %
Total Carbon	Not Reported
Bulk Density	Not Reported
True Density	Not Reported
Porosity (Calculation)	Not Reported
Porosity (Hg Intrusion)	Not Reported
Surface Area	Not Reported
Extractable C_{15+}	85 ppm
Thermal Alteration Index	Predominant TAI = 3 to 3+
Vitrinite Reflectance	Ro = 2.48
H/C (Kerogen)	0.41
O/C Kerogen	0.24
Sulfur (whole rock)	1.22 %
H/C (whole rock)	Not Reported
O/C (whole rock)	Not Reported

DEVONIAN SHALE TEST WELL/HOUGHTON COLLEGE AREA OF NEW YORK

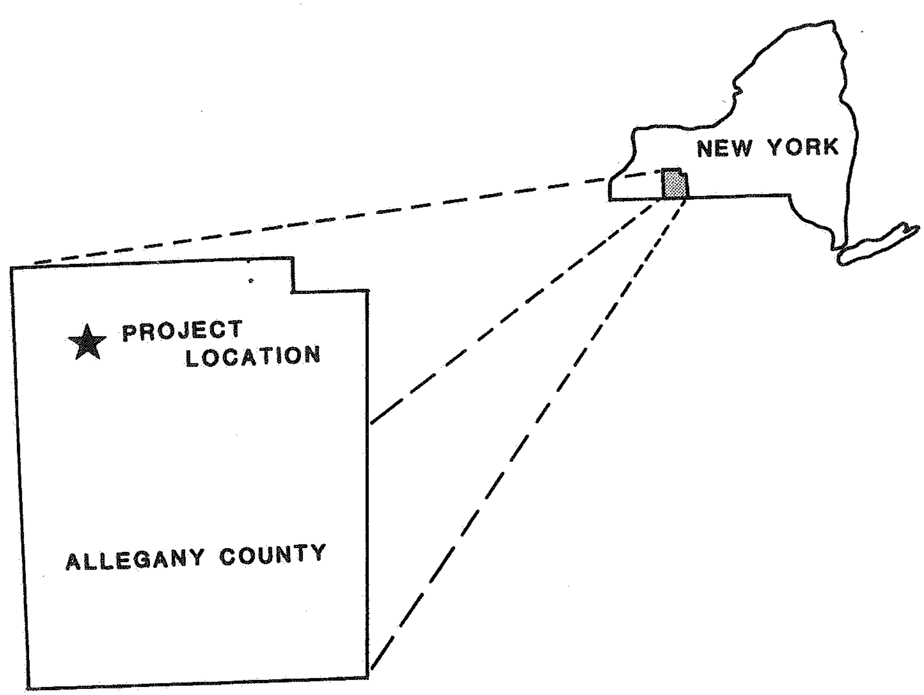
Status: Active

Houghton College
Houghton, New York

Contract:	DE-AC21-79MC10640
Contract Date:	February 26, 1979
Anticipated Completion Date:	December, 1979
Principal Investigator:	R. G. Tighe
Technical Project Officer:	C. A. Komar Morgantown Energy Technology Center

OBJECTIVE

To acquire comprehensive geophysical well log data from the Devonian Shale in Allegany County, New York; and to evaluate the technical and economic feasibility of stimulating natural gas production from the Devonian Shale by hydraulic fracturing.



SCOPE OF WORK

Specific tasks include the following:

- To select a suitable site for the proposed well and to drill, log, and case the well through the Devonian Shale formation in Allegany County, New York. The contractor will run a comprehensive suite of geophysical wet-hole and dry-hole well logs. In addition, field data digitizing, determination of the in situ elastic rock properties, and interpretations of porosity, fracture kerogen content, fluid saturation, and lithology will be performed.

- To design a suitable hydraulic (foam) fracture treatment for the well, to hydraulically fracture the well, and to alter the designed treatment while the treatment is in progress if necessary. 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 if sufficient gas is producible from the well, to put the well on line and monitor its production history on a monthly basis for five years.

SUMMARY OF PROGRESS

The Houghton College #1 well, was drilled, logged and cased during this reporting period. The well was drilled to a total depth of 2332 feet. Cuttings from the well were studied and a description completed.

During September the well was stimulated using a 56,000 gallons foam frac treatment. The formation breakdown pressure was 3000 psi with an average treating pressure of 2810 psi. The well gauged a flow of 300 MCFD at 130 psi on a 18/64 choke. After flow back of frac fluids the well was shut-in in preparation of build-up and drawdown tests to be performed by Gruy Federal. The well testing is to be performed during the next reporting period.

HYDRAULIC FRACTURING EXPERIMENT IN MCKEAN COUNTY, PENNSYLVANIA

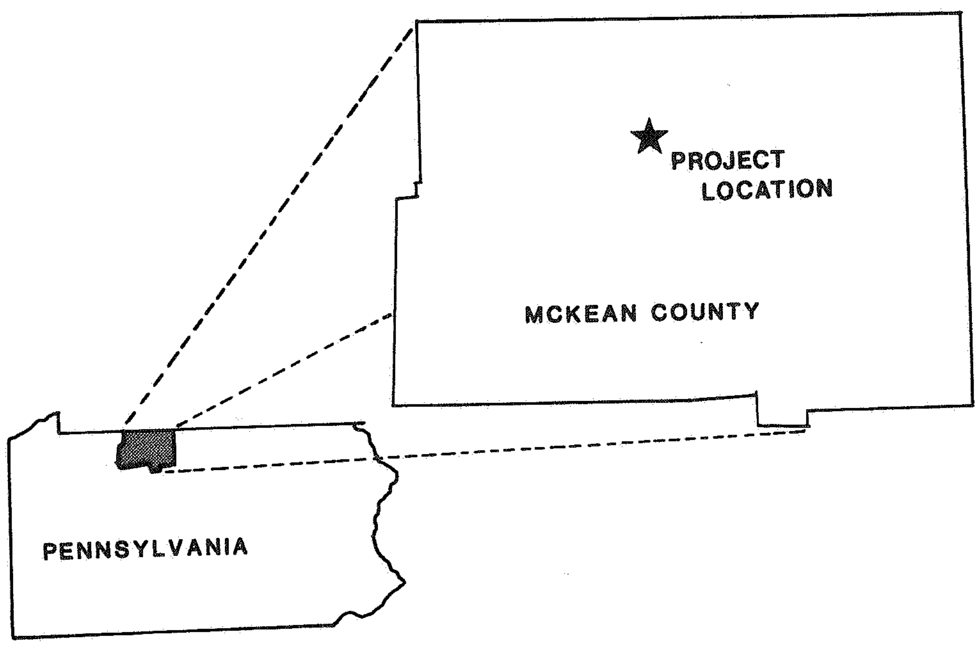
Status: Completed

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
Technical Project Officer:	C. W. Byrer Morgantown Energy Technology Center

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

As reported in the last Semi-Annual Report, the well in McKean County, Pennsylvania was drilled, logged and cored in March, 1979. Seven hundred and twenty five 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.

During this reporting period, the core analyses on this well were completed. The results of these analyses are presented in Table 3-8.

Table 3-8 Results of McKean County Core Analysis

McKEAN COUNTY, PENNSYLVANIA (PA-1)	
ANALYSIS	MEAN
Gas Volume	0.48 ft^3 gas/ft^3 shale
Organic Carbon	1.43 %
Total Carbon	Not Reported
Bulk Density	Not Reported
True Density	Not Reported
Porosity (Calculation)	Not Reported
Porosity (Hg Intrusion)	Not Reported
Surface Area	Not Reported
Extractable C_{15+}	587 ppm
Thermal Alteration Index	Predominant TAI = 3
Vitrinite Reflectance	Ro = 1.12
H/C (Kerogen)	0.55
O/C Kerogen	0.17
Sulfur (whole rock)	1.06%
H/C (whole rock)	Not Reported
O/C (whole rock)	Not Reported

ASSESSMENT OF DEVONIAN SHALE POTENTIAL IN CARROLL COUNTY, OHIO

Mitchell Energy Corporation
Houston, Texas

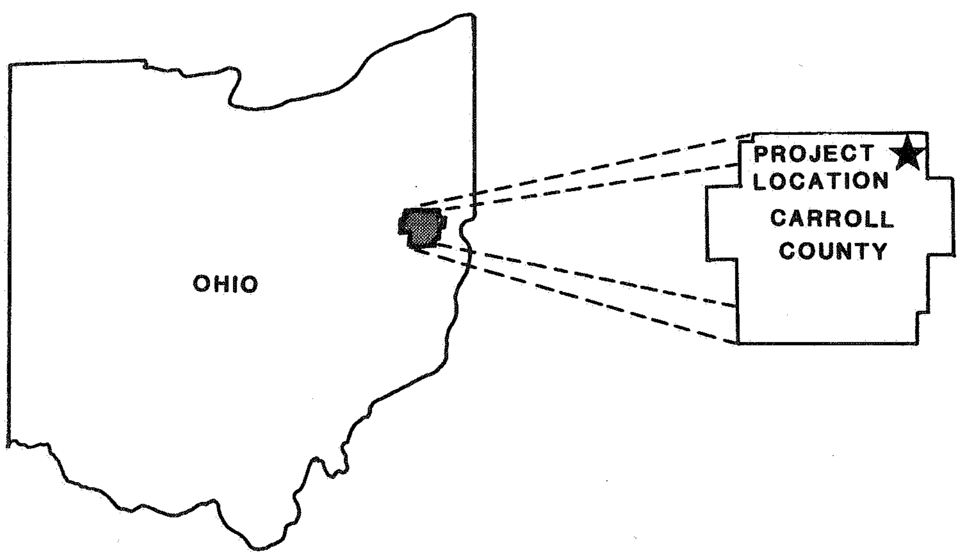
Status: Active

Contract: DE-AC21-78MC12537
Contract Date: September 8, 1979
Anticipated Completion Date: November 9, 1979

Principal Investigator: W. M. Hennington
Technical Project Officer: K–H. Frohne
Morgantown Energy Technology Center

OBJECTIVE

To assess the production potential of the Devonian Shale in Carroll County, Ohio.



SCOPE OF WORK

This contract provides for the logging, stimulation and testing of the Marcellus Shale in Carroll County, Ohio. Optionally, the Burkett Shale will also be stimulated. The well is currently temporarily abandoned in the Clinton Sand, and will be recompleted in the organic portions of the Devonian Shale.

SUMMARY OF PROGRESS

Work on this contract will be initiated after the reporting period. Results will be presented in future Semi-Annual reports.

DEEP DEVONIAN SHALE GAS TEST IN NORTHERN WEST VIRGINIA

U.S. Department of Energy
Morgantown, West Virginia

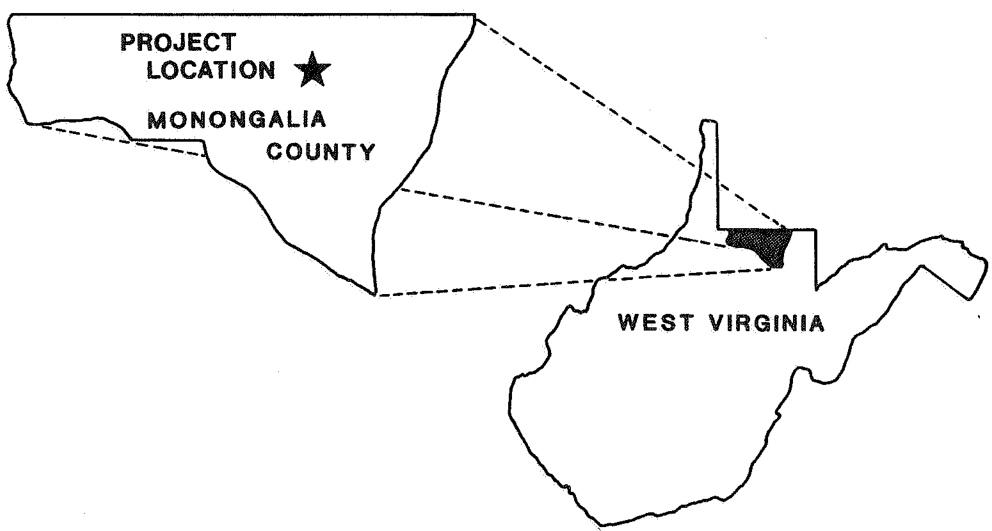
Status: Active

Field Work Performance Period: Spring, 1978 - Fall, 1980

Principal Investigator: K-H. Frohne
Morgantown Energy Technology Center

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 Burkett Shale between 7107 and 7155 feet was treated with a gel/CO_2 treatment during the last reporting period. After treatment the well was producing at a rate of 12 MCFD. The well was kept shut-in.

During this reporting period a fourteen day cycle of two pressure build-up and drawdown tests were conducted. Results were analyzed using a reservoir simulator. Details of results have been presented in the Gruy Federal contract progress.

ASSESSMENT OF DEVONIAN SHALE POTENTIAL IN PRESTON COUNTY, WEST VIRGINIA

Status: Active

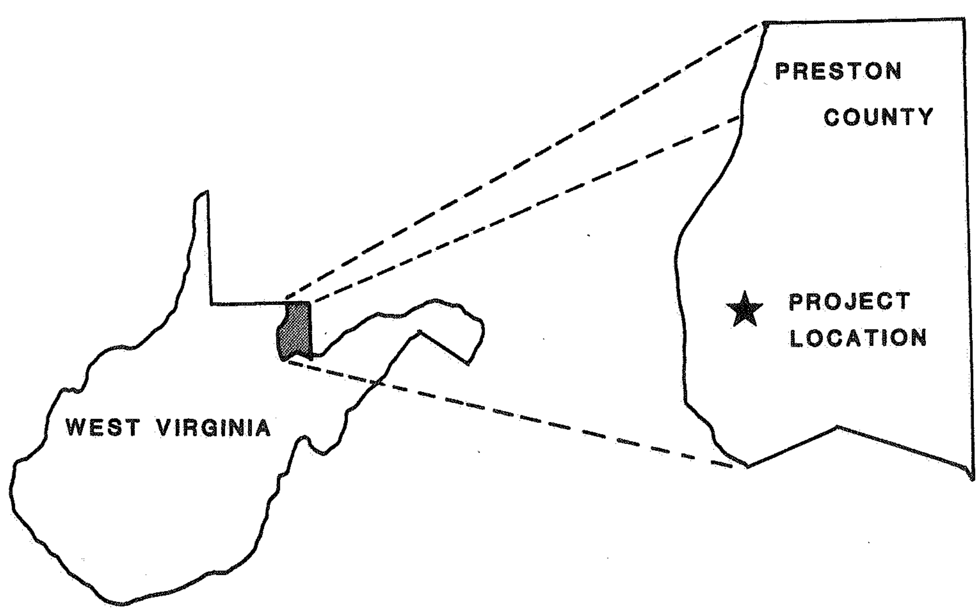
J. T. Waggoner
Silver Spring, Maryland

Contract: DE-AC21-79MC010515
Contract Date: August 8, 1979
Anticipated Completion Date: November 9, 1979

Principal Investigator: J. T. Waggoner
Technical Project Officer: K-H. Frohne
Morgantown Energy Technology Center

OBJECTIVE

To assess the production potential of the Devonian Shale in Preston County, West Virginia.



SCOPE OF WORK

This contract provides for the stimulation and testing of the Devonian Shale by recompleting a currently temporarily abandoned well drilled to the Oriskany sandstone. The Marcellus Shale is scheduled for stimulation with a gel/CO_2 treatment.

SUMMARY OF PROGRESS

Work on this contract will be initiated after the reporting period. Results will be presented in future Semi-Annual reports.

TESTING PROGRAM FOR SHALE GAS PRODUCTION POTENTIAL

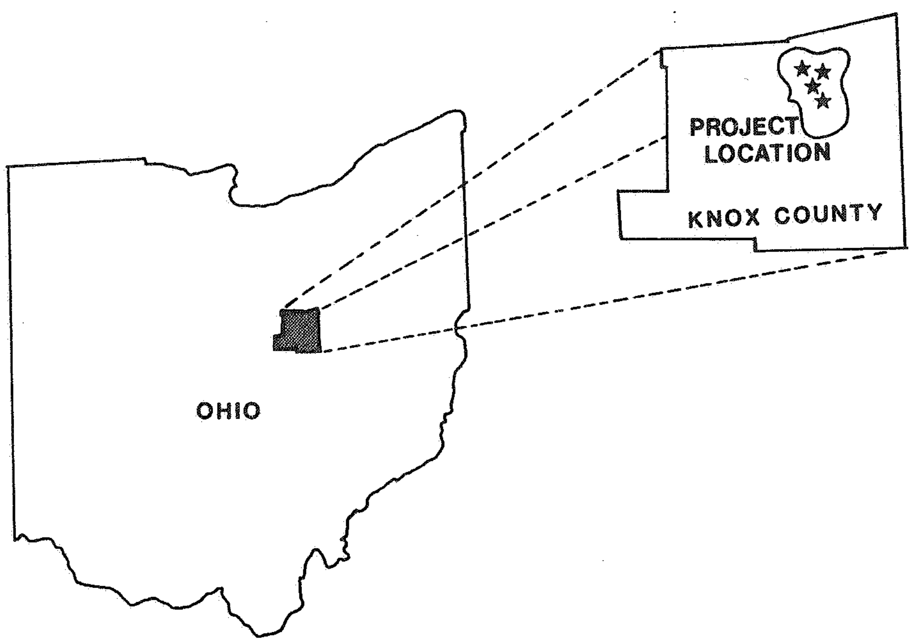
Status: Active

Thurlow Weed and Associates, Inc.
Mount Vernon, Ohio

Contract:	EW-78-C-21-8386
Contract Date:	September, 1978
Anticipated Completion Date:	June 1, 1980
Principal Investigator:	T. Weed
Technical Project Officer:	A. B. Yost, II Morgantown Energy Technology Center

OBJECTIVE

To acquire data on the commercial potential of various stimulation techniques, to evaluate methods of determining 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, Ohio; 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

During this reporting period the Louise Beckholt #1 well (EGSP-OH-3) was drilled, cored, logged, and cased. The Devonian Shale section was left uncased for open hole completion. A total of six hundred and ninty four feet of oriented core were retrieved. There was no natural gas production to test and the well was shut-in pending a decision on a stimulation treatment and the analyses of core. Analyses of core have been performed by Battelle and Mound Laboratories. Initial experiments by Battelle indicate the loss of all existing permeability in shale samples exposed to water and then subjected to one atmosphere of gas pressurization. Additional experiments to determine the pressure required to displace the imbibed water are being conducted. The results of these core analyses are presented in Table 3-9.

The Black #1 well (one of four existing wells) has been selected for the first fracture treatment. This treatment is scheduled for the next reporting period. Plans for stimulation include tiltmeter directional fracture experiments by Sandia and Wood and the use of a down hole television camera to view a section of bore wall before and after fracturing. The following sequence of events are planned: plugback the well, run casing, cement casing, use television camera to record borehole features, stimulate well, run television camera again, and run production test. Plans are to complete this activity in October 1979.

Table 3-9 Results of Knox County Core Analysis

KNOX COUNTY, OHIO (OH-3)	
ANALYSIS	MEAN
Gas Volume	0.36 ft^3 gas/ft^3 shale
Organic Carbon	2.23 %
Total Carbon	3.33 %
Bulk Density	2.614
True Density	2.662
Porosity (Calculation)	2.982 %
Porosity (Hg Intrusion)	7.20 %
Surface Area	3.225 m^2/g
Extractable C_{15+}	934 ppm
Thermal Alteration Index	Predominant TAI = 2
Vitrinite Reflectance	Ro = 0.56
H/C (Kerogen)	1.09
O/C Kerogen	0.12
Sulfur (whole rock)	1.57 %
H/C (whole rock)	6.73
O/C (whole rock)	4.30

3.5 PROJECT INTEGRATION

3.5.1 GENERAL

As well as planning, coordinating and evaluating the Resource Characterization and Inventory, Extraction Technology R&D, and Technology Testing and Verification activities, this Element of the EGSP includes environmental studies, a project database management system, economic analysis, and technology transfer.

3.5.2 ENVIRONMENTAL ACTIVITIES

Environmental assessments were completed for current field activities to ensure proper consideration of all potential problems and to minimize adverse environmental impacts. Site specific studies and archaeological surveys were completed for the 10-well Columbia Gas project in Lorain and Trumbull Counties, Ohio, the 11-well Mitchell Energy project in Gallia County, Ohio and the 4-well Weed/Henry project in Knox County, Ohio. Results were incorporated into EIA reports, submitted to DOE HQ and published as information documents for management use.

Concurrently, an indepth study of the environmental impact that shale development wells might have was prepared for the project as a generic environmental impact statement. Technologies considered for demonstration activities were also identified and evaluated in an Environmental Development Plan for Unconventional Gas Recovery that was prepared for the Assistant Secretary for Environmental and Energy Technology within DOE. The Environmental Development Plan has been published and can be obtained from the Morgantown Energy Technology Center.

3.5.3 PROJECT DATA BASE MANAGEMENT SYSTEM

Developments have been completed on the implementation of an automated data processing system (DBMS-System 2000) for data entry, storage and retrieval in order to satisfy the information needs of people who are interested in developing Devonian Shale gas prospects. Accomplishments to date include the completion of an interim data base and a well history control system. Accessible data include geological, physical and geochemical information from 18 cored wells, sampled from 12 counties in four states.

Current activities are directed at completing the interface with the computer system at Mitre Corporation and the preparation of a status report for potential users. Upon completion, interested users can request computer outputs for particular wells from the file coordinator at METC, namely Jan Downey.

3.5.4 ECONOMIC EVALUATION

A preliminary study on the economic viability of foam fracturing treatments in the Devonian Shale was performed by the Department of Energy's Morgantown Energy Technology Center (DOE-METC) and TRW. Specifically, the objective of the study was to explore the potential benefits of foam fracturing in terms of well productivity and economic feasibility.

It was observed, based on initial open flows, that wells stimulated with foam have better production potential than hydraulically stimulated wells. This conclusion is supported by a mean initial open flow rate of 329 MCFD, obtained from nine conventional size (average volume: 1000 bbls) pilot treatments. These pilot treatments were in the periphery of the Big Sandy region which has a history of relatively good gas production. In a separate case, ten massive foam treatments were performed in four stratigraphic intervals in Lincoln County, West Virginia. The treatments were conducted in three wells, and the average initial open flow per well (adding together all the zones) was 394 MCFD. This, however, is despite the fact that the region contains 75 old wells and is partially depleted.

The economics of the foam treatments were evaluated under two scenarios based on a set of representative conditions, particularly on two different rates of initial open flow and exponential production decline. For the 350 MCFD initial open flow scenario, the required gas prices for profitability are less than the maximum lawful price in October 1979, which is $2.636/MCF. These prices are also competitive when compared to the price of $2.80/MCF for Canadian imports. However, under the 50-250 MCFD scenario, production from shale wells treated with foam were not found to be economical. In both instances a return-on-investment (ROI) of 15% was assumed with a well lifespan of 30 years.

The results are preliminary and further evaluations of stimulation techniques are needed before any firm conclusions can be reached. The study is also limited in that investor attitudes to risk and uncertainty were not formally incorporated in the analysis. Risk and uncertainty are especially important where there is a strong likelihood of economic loss in using foam treatments. This would be the case if the 50-250 MCFD scenario that results in economic loss is realized in practice. Where the degree of uncertainty associated with this scenario is great, risk-averse investors will be inclined to prefer less costly treatments such as borehole shooting.

A second economic evaluation was an engineering-economic study to evaluate stimulation techniques, particularly those of massive hydraulic fracturing, conventional hydraulic fracturing, tailored-pulse techniques, and borehole shooting. The analysis was conditional on a set of engineering assumptions concerning the gas production mechanism. Two significant assumptions deal with fracture spacing and skin factors. The results indicate that stimulation can increase gas production, by a factor of two to three at economic rates, with rates-of-return greater than 15%. Another outcome of the study states that the keys to effective stimulation are: favorable geology (fracture spacing (50 cm), ability to achieve effective fracture lengths in the formation from tens to hundreds of feet, and low skin factors.

However, the question still remains as to the uncertainty associated with different states-of-nature prior to stimulation. Selection of a particular stimulation technique tailored to fit a set of geological and engineering parameters is still under study.

On a very preliminary basis, massive hydraulic and tailored pulse stimulation seem to be economically attractive. In all cases the economics of stimulation is improved by external incentives, such as tax credits. This is obviously the case, and more so, if well productivity is not enhanced by stimulation on a proportional basis.

3.5.5 TECHNOLOGY TRANSFER

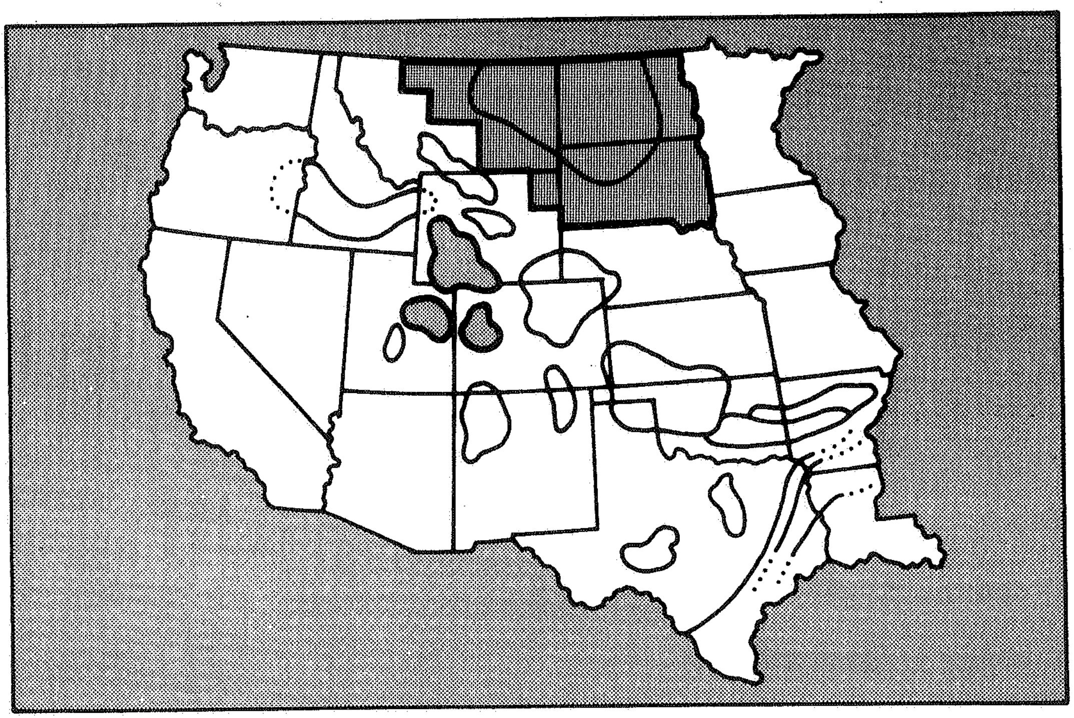
The Third Eastern Gas Shales Symposium was held in Morgantown, West Virginia on October 1-3, 1979. Forty-two papers covering work funded by DOE were presented. The symposium proceedings are published in a Special Publication series (METC/SP-79/6), and can be obtained from DOE's Unconventional Gas Recovery (UGR) Information File located at METC or from the National Technical Information Service (NTIS). Other information generated from the EGSP can also be obtained from the UGR Information File. The file contains approximately 250 publications and 80 maps. A bibliography/accession list of information contained in the File is available upon request.

An exhibit covering all the various elements of the UGR resources has been prepared. The exhibit has been shown at the Oil and Gas Exposition in Tulsa, Oklahoma, METC's Open House, the Third Eastern Gas Shales Symposium, and the Eastern Regional SPE Meeting held in Charleston, West Virginia.

A comprehensive distribution list for the EGSP and other UGR resources has been placed on the METC Computer System for updating, addition of users' names and addresses, and for the purpose of transferring technological information to the users accurately and quickly.

For further information on the EGSP and other UGR resources, please contact R. D. Manilla, USDOE/METC, P.O. Box 880, Morgantown, WV 26505.

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 low permeability reservoirs in a number of geologic basins scattered throughout the western United States (Figure 4-1). Potentially gas productive sands within these intervals thousands of feet thick 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 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 number of known low permeability reservoirs, and have a sizable existing data base (Table 4-1). The Lewin study aslo 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

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 to demonstrate 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.

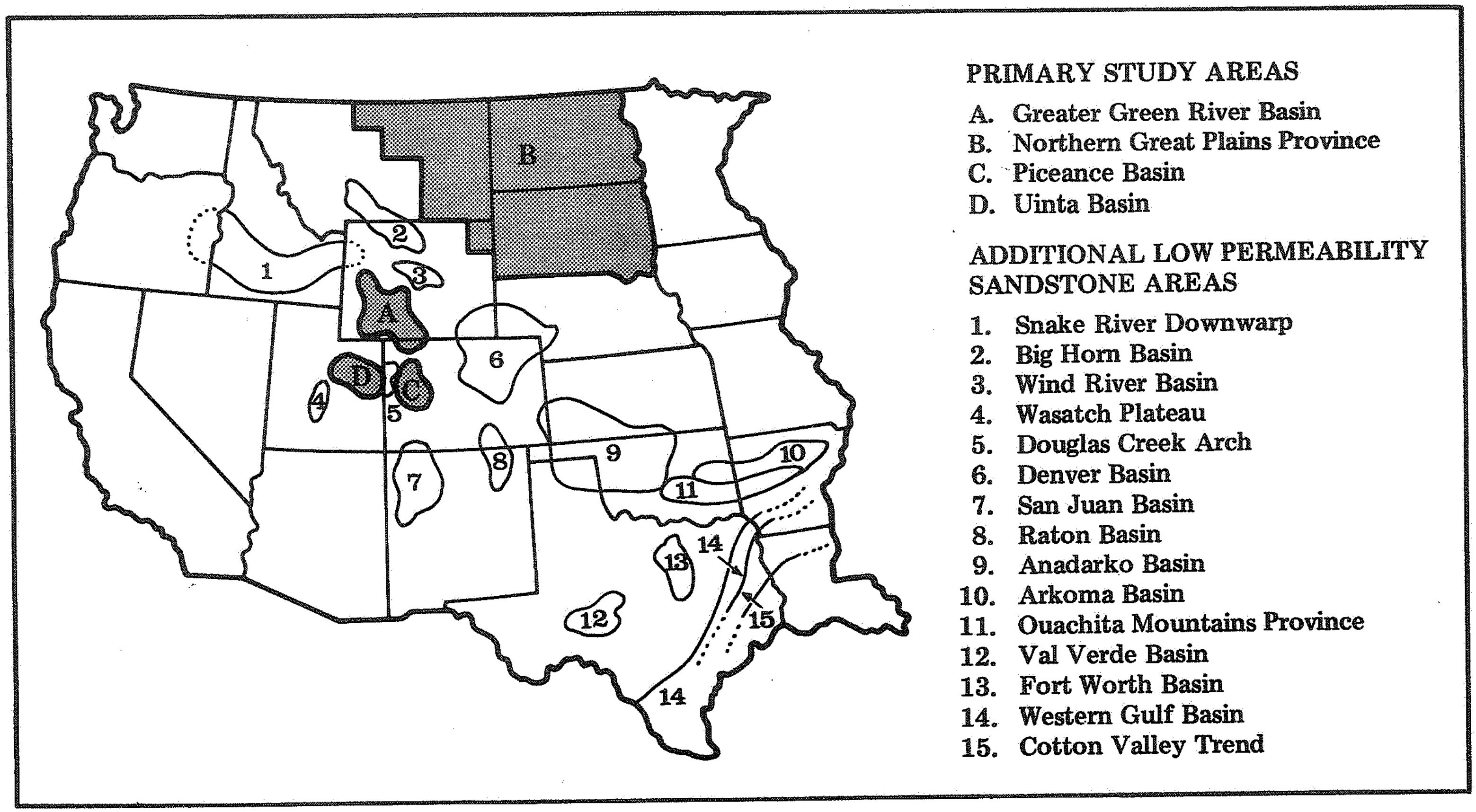

Figure 4-1. Map of Western United States, Showing Areas of Interest (Refer to this figure for the location of WGSP Study Areas)

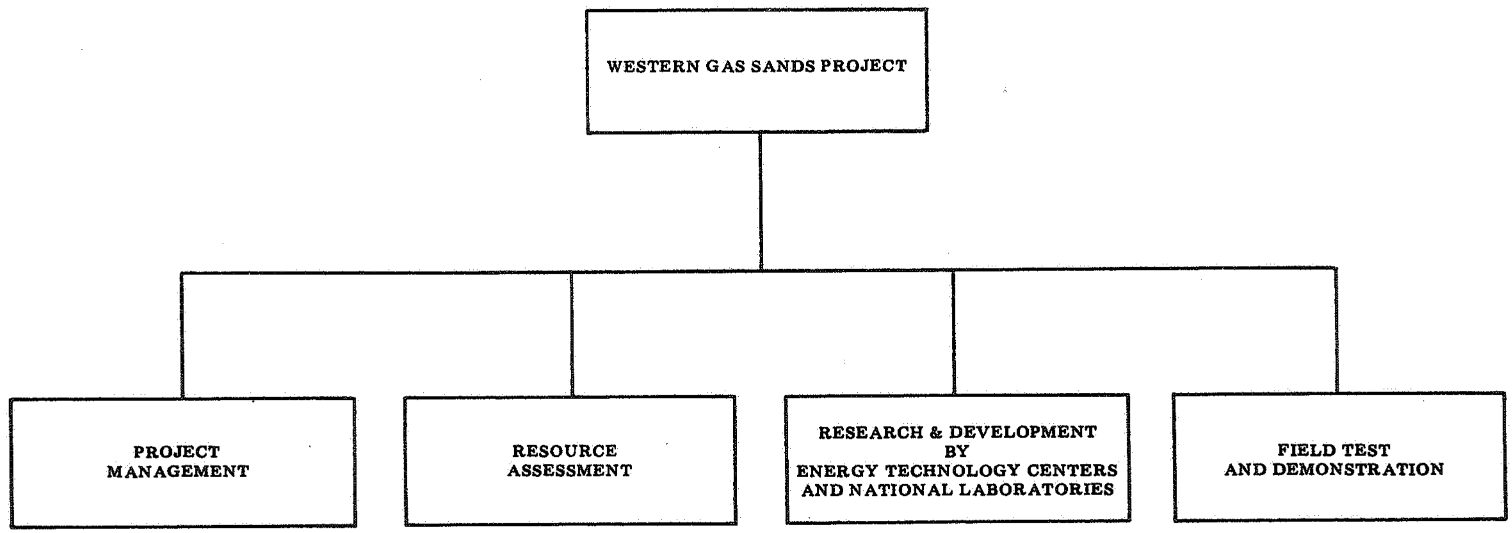

Figure 4-2. Elements of Western Gas Sands Project

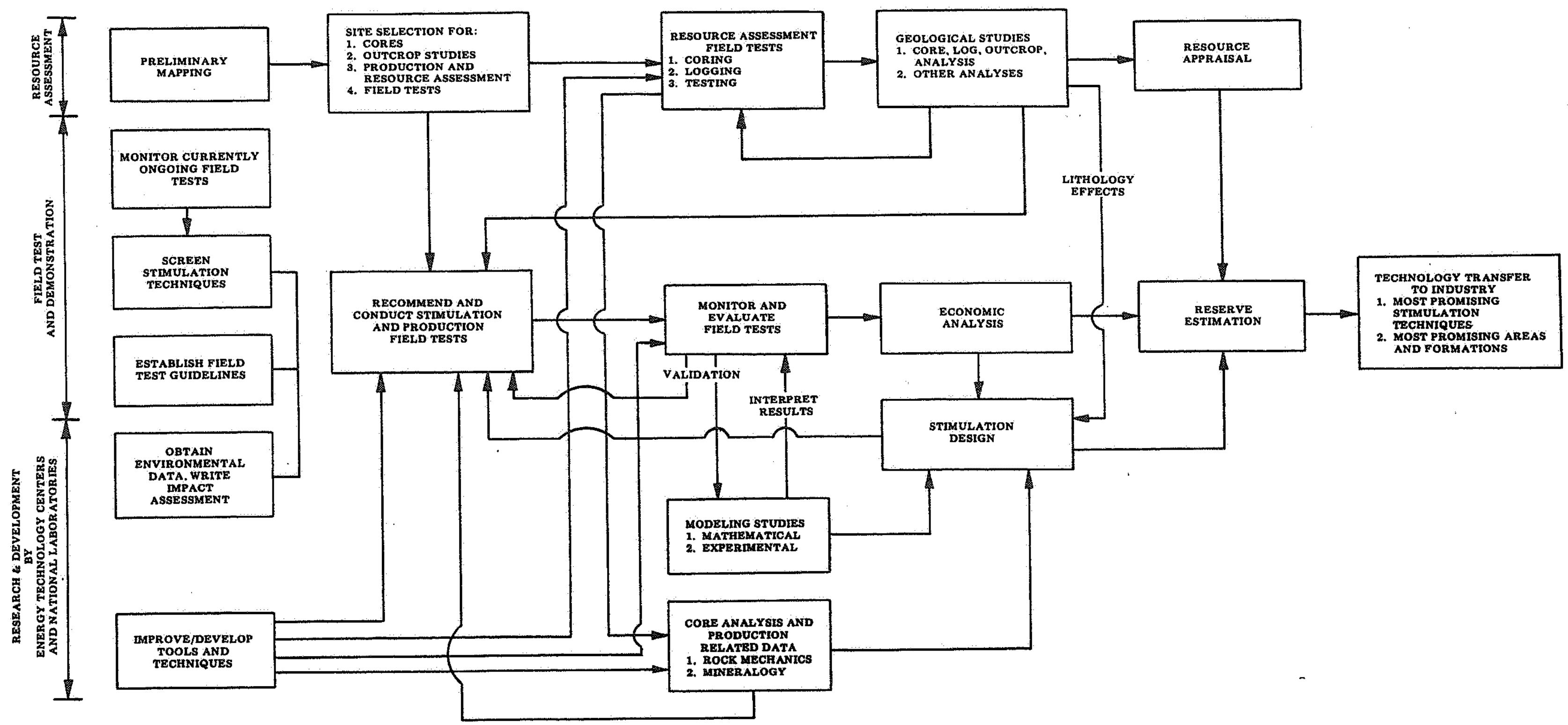

Figure 4-3. Principal Project Activities and Their Interrelationships

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 need from cores, geophysical logs and gas-production tests. Some of these sites will become the location of 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 the 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, Los Alamos Scientific Laboratory and the Gas Research Institute.

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 is primarily 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 is also 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. The Gas Research Institute is funding selected tasks for various field projects in support of DOE objectives.

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.

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 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 Provides reports of project status and accomplishments 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
CONTRACTORS AND AGENCIES	Executes contract work Maintains proper interface with project office and its representatives on technical matters Interface with NV on financial, legal and contract administration matters
NATIONAL LABORATORIES	Performs and directs research and development in various areas of expertise

4.2 RESOURCE ASSESSMENT

The USGS is performing the majority of the geological, geophysical and reservoir evaluation studies necessary to define and characterize the resource base. Support of the USGS activities is provided by field test data and core acquisition and analysis.

4.2.1 U.S. GEOLOGICAL SURVEY ACTIVITIES

During the reporting period, 12 reports were released and 3 drafted. Two maps were released in the open file, 5 papers were drafted and 8 finalized. In addition, 4 presentations were made to professional organization meetings.

USGS activities in the areas of interest are summarized in the following sections.

GREATER GREEN RIVER BASIN

Work continued on the stratigraphic analysis of the Greater Green River Basin. During the last six months, the Washakie and Great Divide Basins lineament study was completed, and geological cross section through these basins were completed.

Cores were described and sampled from two Tierney area wells from the Washakie Basin and the Inexco (Belco) well No. 1-A WASP in Sublette County, Wyoming, Section 28, T36N, R112W.

A map, titled "Wildcat Well Penetration Map Showing Wells Drilled into and through Potentially Gas-Bearing, Low-Permeability Upper Cretaceous and Tertiary Reservoirs, Great Divide Basin, Southwest Wyoming," was completed and added to the USGS open file.

Field work in the Sand Wash Basin was completed and a cross section submitted for review.

Field work was completed in the northern Green River Basin, and continued in the Rawlins, Wyoming area.

NORTHERN GREAT PLAINS PROVINCE

Field work in Montana and North and South Dakota continued through the reporting period. Petrographic analysis of Eagle sandstone equivalent rocks from the Joseph J.C. Paine/DOE cored well was completed. Petrographic and scanning electron microscope analyses of Mesa Petroleum core of Eagle-equivalent shelf sandstone from the Liscomb Creek gas field, southeastern Montana was initiated. X-ray diffraction analysis began on Pierre Shale cores from the Hayes and Turner wells near Pierre, South Dakota. X-ray diffraction analysis of clay minerals from the Joseph J.C. Paine/DOE cored well continued.

Field work on the Eagle sandstone and Mosby (Phillibs) sandstone in central Montana was completed.

PICEANCE BASIN - UINTA BASIN

Field work in the Piceance and Uinta Basins continued.

Analyses of Cretaceous and Paleocene cores from the Price River Canyon area by X-ray diffraction and petrographic methods were compiled.

Preliminary mineralogical investigation of CIGE Natural Buttes No. 21 core samples of the Green River, Wasatch-Colton, Tuscher-Farrer, and Sego Formations, and the Mancos Shale continued. The purpose of this investigation is to describe the rocks and indicate diagenetic features and their effects on reservoir properties of the rocks. Preliminary observations are given below.

- Several samples are more porous than rocks from the same sequence which were reported in the Western Gas Sands Project Status Report, 1 January 1979 - 31 January 1979, p. 21.

- Some samples with very high apparent porosity values have estensive areas of kaolinite. These samples have the appearance of microcrystalline rock fragments under the petrographic microscope. However, SEM analysis of the apparent rock fragments indicates that the grains are felted kaolinite that is very porous but relatively impermeable. This type of occurrence of kaolinite affects the pore geometry of the potential reservoir and may explain the log and core analysis that indicates high porosity but low permeability values for the rock. It is unlikely that this form of porosity will contribute significant volumes of fluid to the borehole with or without stimulation even though log analysis indicates relatively high porosity values.

- Several generations of cementation (principally Fe-Mg carbonates and anhydrite are present in some samples.

- Barium has also been detected in some rocks but its mineralogical form is uncertain.

Carbonate cements, kaolinite, and the element barium are all potentially significant rock constituents that may affect the productive capacity of a reservoir. The depositional, mineralogical, and stratigraphic controls on the occurrence of these constituents are uncertain, but regionally mappable. Although most of the core is thought to be fluvial rocks, limited suitable samples preclude interpretation of the depositional processes responsible for the occurrence of these materials and their areal distribution. These rocks were formed in a variety of depositional settings and have undergone significant subsequent diagenesis. The regional significance of these individual mineralogical and physical features that relate to reservoir and borehole log properties cannot be accurately assessed from the limited and incomplete sample set.

Core from the Green River Formation from the Pariette Bench field was described and sampled and core samples of Tertiary rocks from the eastern Uinta Basin were examined. Petrographic study of selected Cretaceous core samples from CIGE NBU No. 21 well from the Uinta Basin is near completion. A mineralogical investigation was started of core samples from the Upper Cretaceous Sego sandstone, southeastern Uinta Basin, Utah.

Additional core (provided by Amoco Production Company) of Lower Tertiary hydrocarbon bearing rocks from the south-central Uinta Basin was examined. Analyses of mineralogy and diagenesis of the unconventional reservoirs cored in the area have begun. In addition, several hundred feet of core from the Chapita Wells area of the Uinta Basin were examined.

4.2.2 CORE PROGRAM

Many companies were contacted concerning WGSP coing program participation during the six-month period. Several are considering the proposal, and many declined for various reasons. Some expressed interest in coring future wells.

A 6-1/2 in. diameter core hole (DOE/WGS-GC-1) is being drilled by CK GeoEnergy through about 1,200 ft of the non-marine Mesaverde Group in the Westwater Canyon area of the Book Cliffs in eastern Utah (Section 16, T17W, R24E, Grand County, Utah). The core hole is located on a ridge and the section being cored (lower Tucher, Farrer, Upper Neslen) is exposed along the adjacent valley walls. There has been excellent core recovery and 4,400 lb of 3 in. diameter core has been shipped to the USGS in Denver for description. An additional 600 ft of core was cut in early September and logging will commence later.

Sandia Laboratories, DOE and GRI are fielding a three-dimensional geophysical survey covering the area around this well. This project will attempt to define lens size and orientation by geophysical means. Lenses exposed in the outcrops are being mapped at a scale of 1 in. = 400 ft.

If the geophysical work indicates some success in defining the lenses, additional mapping (lens location, height, length, and size and orientation of sedimentary structures) will be done on a larger scale.

In August, phase one of the coring operation began on the Pacific Transmission Supply Co. well, No. 22-12 Federal Barcus Creek, Section 12, T1N, R99W, Rio Blanco County, Colorado. Two hundred eighty one ft of Mesaverde core was cut with 98 percent recovery. The upper 120 ft and lower 100 ft of core was very fine to medium grained, salt and pepper sandstone. The middle 60 ft was predominantly shale and siltstone with small layers of carbonaceous material. Gas was not detected from this Mesaverde section. In October, a 120 ft Mancos B core will be cut at 11,500 ft. Logs will be run over the Mancos B through the Fort Union interval prior to setting intermediate casing. Selected core samples will be sealed in plastic and sent to Bartlesville Energy Technology Center, Los Alamos Scientific Laboratory and Lawrence Livermore Laboratory for analyses.

Discussion continued concerning coring Wasatch and Mesaverde horizons in the Mapco RBU No. 11-17F well, Section 17, T10S, R20E, Uintah County, Utah. Spud in is expected around mid-October, with coring being planned about two weeks later.

Core Laboratories, Inc., performed various special core analysis tests on core material from the Twin Arrow C&K No. 14-14 well, Rio Blanco County, Colorado. These tests included acoustic velocity measurements, capillary pressure tests, formation resistivity factor measurements using several overburden pressure, and formation resistivity index measurements among others.

4.2.3 SURVEY OF BASIN ACTIVITIES

The monitoring of basin activities is an important part of resource assessment and promotes cooperation between industry and government. Certain areas in each study area have been recommended by the USGS for obtaining core. Operators active in these specific areas are located by monitoring new activity in each area and are contacted to negotiate contracts for a joing industry/government coring operation.

The information on each study area summarizes drilling and testing operations of interest and tabulates production figures from horizons of interest. Newly staked and completed wells are listed. Figure 4-1 shows the location of the WGSP study areas.

Drilling information is compiled primarily from The Rocky Mountain Region Report, published daily by Petroleum Information Corporation. Additional sources used are the Montana Oil and Gas Journal, The Oil and Gas Journal and the Western Oil Reporter.

Background and geologic information can be obtained from the Quarterly Basin Activities Reports, dated January 1, 1978, April 1, 1978 and July 21, 1978. Included in these reports are stratigraphic correlation charts, cross sections, a brief account of the geology of each area and information relating to the USGS recommended coring locations. These reports may be obtained from the Technical Information Center, P.O. Box 62, Oak Ridge, Tennessee 37830. Additional information may be obtained from CER Corporation, 4220 South Maryland Parkway, Suite 801, Las Vegas, Nevada 89109.

As shown in Table 4-3, a total of 151 wells of interest were reported drilled in the Northern Great Plains Province. Of this total, 112 were development wells: 82 were producers and 30 were D&A. Of the 39 wildcat wells, 10 were discoveries and 19 were D&A. Initial production from these wells totalled 36,741 MCFD.

In the Greater Green River Basin, 98 wells of interest to the WGSP were reported drilled. Sixty-one development and 13 wildcat wells were reported producers, and 11 development and 13 wildcat wells were reported D&A. Initial production totalled 99,388 MCFD.

In the Piceance Basin, 53 wells of interest were completed. Forty development wells were producers and 2 were reported D&A. Seven wildcat wells were reported discoveries and 4 were D&A. Initial production totalled 29,428 MCFD.

Forty-three wells of interest to the WGSP were completed in the Uinta Basin. Thirty-one were development wells: 29 were reported producers and 2 were D&A. Nine wildcat wells were discoveries and 3 were reported D&A. Initial production totalled 54,104 MCFD.

Table 4-3. Summary of Drilling Activities From April to September 1979

Area of Interest	Wells					Production (MCFD)
	Wildcat		Development		Total	
	D&A	Discovery	D&A	Producer		
Northern Great Plains Province	29	10	30	82	151	36,741
Greater Green River Basin	13	13	11	61	98	99,338
Piceance Creek Basin	4	7	2	40	53	29,428
Uinta Basin	3	9	2	29	43	54,104
Totals	49	39	45	212	345	221,611

4.2.4 C K GEOENERGY CORPORATION

RESERVOIR CHARACTERISTICS OF UINTA BASIN WELLS

After completing arrangements with Diamond Shamrock, log analyses to determine porosity, water saturations and net pay thickness were completed on eight Uinta Basin gas wells. Horner plots were also developed to determine permeability and average reservoir pressures. The results of these analyses and the production data for the wells are being used to check reservoir geometries established by outcrop studies conducted along the edge of the basin. To verify late-time slopes on the Horner plots, additional pressure measurements will be made on most of these wells priom to being put on production.

DEVELOPMENT OF TECHNIQUES FOR OPTIMIZING SELECTION AND COMPLETION OF WESTERN TIGHT GAS SANDS

CK GeoEnergy met with USGS and Sandia Laboratories to select core hole locations. A location was selected that would allow a portion of the Tusher, Farrer and part of the Neslen to be cored at one site. The coring operation was completed in August.

After Diamond Shamrock, Gas Producing Enterprises and Belco Petroleum Corporation made wells available for analysis, pressure buildup data aquisition commenced on four wells. Static reservoir pressure data are being used along with cumulative production figures to determine total reservoir volumes. This analysis will allow the first check on tight gas reservoir lenticular geometry models developed from the outcrop studies.

The Green River Basin outcrop reconnaissance was completed and field work was started on the three selected areas. These are:

- The Hoback Basin, a northwestern extension of the restricted Green River Basin.

- The Cretaceous Mountain/Hogsback Mountain area, outside of the Overthrust Belt located on the western edge of the Green River Basin.

- The northern Rock Springs Uplift, located on the southeastern edge of the Green River Basin.

Preliminary work to obtain representative Paleocene and non-marine Upper Cretaceous coverage in the three areas indicated better continuity than previous studies in the Piceance and Uinta Basins. However, discordant small scale sedimentary structures were more prevalent, especially in the northern Rock Springs Uplift area, and may be an improtant factor in the low permeabilities.

4.3 RESEARCH AND DEVELOPMENT BY ENERGY TECHNOLOGY CENTERS AND NATIONAL LABORATORIES

4.3.1 BARTLESVILLE ENERGY TECHNOLOGY CENTER

IMPROVED PRESSURE CORING SYSTEM (SANDIA LABORATORIES ET AL)

Core Retriever Design and Tests

The Diamond Oil Well Drilling Company (DOWDCO) modified pressure core barrels were used in testing the Sandia low invasion coring fluid in August at Terra Tek Drilling Laboratory in Salt Lake City, Utah. Two-piece and one-piece polycrystalline diamond compax (PDC) bits, and a standard natural diamond core bit were comparatively tested. Initial field tests of the single piece PDC core bit, using the modified pressure core barrels with low invasion coring fluid and standard core barrels without low invasion fluid, were conducted in September in the Wasson Field. Results are shown in Table 4-4.

Core Fluid Tests

Room temperature static mud invasion tests were conducted on various particle size distribution polymer muds in Grey Berea and Brown sandstones.

Five commercially available grades of $CaCO_3$ bridging particles were added in 25 lb/BBL concentration to a base mud consisting of 5 lb/BBL HEC polymer in low-freezing 30 percent $CaCl_2$ brine. The muds were tested for API filtrate loss at 100 psi/72^oF and 500 psi/200^oF and were tested for invasion in the sandstones with a 3,000 psi hydrostatic loading and a 500 psi differential pressure. The results (cc fluid loss in 30 min) are summarized below.

Table 4-4. Static Invasion Test Results of Grey Berea and Brown Sandstone

Additive	Grey Berea 1 Min	Grey Berea 30 Min	Brown Sandstone 1 Min	Brown Sandstone 30 Min	API Filtrate 100 psi/72^oF	API Filtrate 500 psi/200^oF
Wate	21.0	38.2	17.0	27.6	8.4	24.0
Safeseal	0.5	3.7	4.0	15.9	1.4	11.6
Safeseal-X	5.0	8.3	17.0	22.9	3.2	11.0
Sluggit	1.5	7.1	7.0	11.9	2.0	14.4
Sluggit-max	8.2	12.3	5.5	10.2	4.2	18.4

Particle size distributions of five grades of $CaCO_3$ have been measured using a sedigraph. The data indicated that the optimum particle size distribution for minimizing invasion and fluid loss was greatly affected by the presence of the polymer. Safeseal, which was superior in reducing invasion, had the "wrong" size distribution to effectively minimize invasion.

The patented magnesia additive was evaluated by adding 1 gram per liter of MgO to a base mud consisting of 10 lb/BBL HEC polymer and 50 lb/BBL $CaCO_3$ in 30 percent $CaCl_2$ brine. The "stabilized" mud and the base mud were then tested for filtrate loss from 70°F to 300°F, and the magnesia was found to significantly improve the fluid loss properties of the HEC. Similar tests performed with a proprietary polymer additive consisting of various starch derivatives and magnesia showed the starch to be of little value in reducing filtrate loss.

Design work for the dynamic test apparatus which will allow testing of coring fluids under simulated drilling conditions was completed during the reporting period. This system will test low-invasion fluids at pressures up to 1,000 psi and temperatures up to 400°F. Test fluids of various viscosity and solids content can be circulated at controlled rates of up to 30 gal/hr.

Two freeze tests were completed in July to determine the low-temperature properties of the polymer coring fluid. These tests showed that highly viscous HEC polymer muds did not freeze until about -60°F and that they could easily be scraped off a frozen core at -50°F. The 20 lb/BBL HEC mud was too viscous to be practical since it was difficult to remove the frozen core from the core barrel. The 15 lb/BBL HEC mud was clearly superior in mechanical properties and will be used for further low-invasion fluid testing.

Compressibility/air entrainment testing was completed with the same 15 lb/BBL HEC mud. These experiments showed that air entrainment can be a series problem unless preventive measures are taken. The addition of a few drops of "BREAK" per liter of coring fluid increased the density of the mud from 11.4 ppg to 11.6 ppg, which reduced the air entrainment by about 20 ml per liter of fluid. This 11.6 ppg mud was then tested in an autoclave for compressibility at pressures up to 3,000 psi. The procedure was repeated for mud which was de-aerated in a vacuum chamber. The "as-mixed" mud exhibited a 2.73 percent shrinkage at 3,000 psi while the deaerated mud was essentially the same as water (0.95 percent shrinkage at 3,000 psi). The mud column length reduction in the 10 ft-long core barrel would be 3.28 in. for "as-mixed" polymer mud and 1.14 in. for pure water. There should be no major plugging problems while coring if proper care is used to avoid air pockets when filling the inner core barrel with low-invasion fluid and if a 4± in. extension is used on the wiper plug.

Bit Design, Fabrication and Tests

Design and fabrication of 2-1/2 in., 3 in. and 6-1/2 in. pilot core bit bodies were completed during the reporting period.

A laboratory test of a 3 in. pilot bit with cutters attached by low temperature brazing, but similar in design to the 2-1/2 in. pressure core barrel bit, was run using low invasion mud for ship removal and cooling. The mud was extruded by the core entering the drill tube similar to that anticipated in the pressure core barrel assembly. Mud compressibility due to entrained air caused the barrel to plug from lack of mud flow across the cutter faces.

The single piece core bit was used in the laboratory to cut limestone at 128 ft per hour using Sandia's special low-invasion coring fluid.

Based on the laboratory test, a field coring experiment was arranged with Shell Oil Company in the Wasson Field near Denver City, Texas. Coring was conducted at a depth of 5,200 ft into a dolomite/anhydrite formation. Two runs were made the first day with 100 percent core recovery. The first core examined was found to be in perfect condition and completely encapsulated in the low-invasion fluid. The second core was frozen in dry ice and cut into three segments for shipment for analyses. The cut-off flushing head end of the core barrel contained a short segment of frozen core which was used to evaluate the stripping characteristics of the low-invasion fluid. The stripping characteristics were excellent. Core analysis for coring fluid invasion is currently underway. Penetration rates were from 7 to 10 times faster than those normally obtained. No bit wear was observed and 19 cores were recovered.

INTERFACE CONDUCTIVITY EFFECTS ON ELECTRIC LOGGING

Selected core samples from the CIGE Natural Buttes Unit No. 21 and Mobil PCU F31-13G wells were analyzed for mineral and clay composition by X-ray diffraction (see Tables 4-5 and 4-6). The lack of montmorillonite and illite in the NBU No. 21 samples confirmed the relatively low cation exchange capacity (CEC) values. The CEC range was from 0.010 to 0.027 meq/g.

Samples of the same cores were analyzed for surface areas. Initial results indicated that the measured areas were affected by sample outgassing temperatures. For samples outgassed the same length of time, higher outgassing temperatures produced higher surface areas, as shown in Table 4-7.

Table 4-5. X-Ray Diffraction Mineral Percentages for Natural Buttes No. 21 Well

Mineral	Depth (ft) 6475.0	6498.4	6499.4	6499.7
Quartz	67	67	68	63
Microline Feldspar	9	6	7	9
Calcite	3	—	1	3
Dolomite	2	7	5	7
Ankerite	2	2	4	4
Kaolinite	10	8	8	7
Chlorite	2	3	2	2
Illite *	5	7	5	5
Halite	Trace	Trace	Trace	Trace

* No expandable illite found.

Table 4-6. X-Ray Diffraction Mineral Percentages of the PCU F31-13G Core

Mineral	Depth (ft) 8,498	9,946	9,957	9,998
Quartz	55	50	84	68
Feldspar	6	3	4	8
Calcite	18	3	3	3
Dolomite	2	22	2	5
Siderite	—	—	—	2
Kaolinite	6	6	trace	—
Chlorite	3	3	trace	—
Illite	8	11	7	12
Glauconite	—	trace	trace	trace
Mixed layer illite/montmorillonite	2	2	trace	2

Table 4-7. Surface Areas of PCU F31-13G and CIGE No. 21 Cores

Well	Depth in ft	Outgas temperature °C — Measured surface areas m^2/g 150	300
F31-13G	8498.0	3.0	3.9
F31-13G	9946.0	3.3	—
F31-13G	9957.0	4.0	—
F31-13G	9958.0	4.3	5.6
CIGE No. 21	6475.0	2.1	2.2
CIGE No. 21	6499.0	2.0	—
CIGE No. 21	6499.5	1.6	2.2

In Situ Permeability

A series of permeability experiments were conducted on cores from the Pacific Transmission Supply Company well No. 24-19 Federal, the CIGE Natural Buttes Unit No. 21, and the Mobil PCU F31-13G well.

Klinkenberg permeabilities for the PTS No. 24-19 well were measured at low overburden pressures (see Table 4-8). Table 4-9 shows permeabilities at 120 psia net confining pressure using a NaCl solution and methyl alcohol.

Table 4-8. Klinkenberg Permeabilities of Cores from Pacific Transmission Supply No. 24-19 Federal

Depth (ft)	Constant O.B. pressure (225 lbs) microdarcies	Variables O.B. pressure mircrodarcies
5,120.7 A	26.	30.
5,120.7 B	22.	23.
5,122.7 A	448.	—
5,122.7 B	415.	415.
5,172.3 A	133.*	—
5,172.3 B	729.*	831.
5,196.5 A	116.	93.
5,204.8 A	148.	148.
5,210.8 B	185.	177.
5,217.8 A	820.	777.
5,219.1 A	1,202.	1,170.
5,220.4 B	709.	735.
5,220.7 B	1,390.	1,258.
5,221.4 B	647.	563.

* Thin coal beds

Table 4-9. Permeabilities of Pacific Transmission Supply Well No. 24-19 Core

Core Depth (ft)	Permeability (md) NaCl Solution (15g/ℓ)	Methyl Alcohol
8,498	.0014	.0030
9,957	.0057	.0052

Klinkenberg extrapolations were obtained at different net confining pressures for the NBU No. 21 (core No. 6475.5) and Figure 4-4 shows some of the results. Measurement results on cores Nos. 9957 and 8498A from the Mobil PCU F31-13G well are shown in Table 4-10.

For core No. 9957 of the PCU F31-13G well, the permeability values appear to be a function of confining pressure. However, there are two values of permeability which are rather high. The measurements made on core No. 8498A were more erratic. High differential pressure (300 psi) and/or the movement of fines may account for the unsteady flow behavior. Results of measurements made on core No. 9957A at a single confining pressure (4,700 psi) are shown in Table 4-11. As in all liquid permeability measurements reported herein, there is a range of values. The permeability of core No. 9957A to kerosene varied from 3.74×10^{-4} to 2.25×10^{-3} md. The kerosene permeability for core No. 9957 (another plug from the same core) was reported to be between 1.35×10^{-5} and 1.51×10^{-3} md.

The liquid permeability apparatus was modified to enable reversal of flow direction for experimentation using Mobil core Nos. 9998 and 9957A. The flow direction was reversed approximately every 2 hrs. Flows varied from approximately 0.05 to 1.5 pore volumes. The results of these measurements are shown in Table 4-12. The two flow directions are denoted as $X \rightarrow Y$ and $Y \rightarrow X$. Reversal of flow direction was sometimes accompanied by a rather marked alteration in the permeability value, but it was unclear whether this was due to fines movement or to the readjustment of the core to the new stress field imposed by reversal of the direction of differential pressure. The liquid permeability of core No. 9998 ranged from 7.72×10^{-4} to 8.67×10^{-2} md at a confining pressure of 5,000 psi. The gas permeability under similar confining pressure conditions (5,020 psi) was 2.9×10^{-3} md (at 40 psig inlet pressure and 0 psig outlet pressure). For core No. 9957A, the liquid permeability varied between 1.05×10^{-3} md and 1.86×10^{-2} md at a confining pressure of 5,100 psi in these experiments (compared with 3.74×10^{-4} to 2.26×10^{-3} md measured in earlier experiments).

Gas permeability measurements were obtained for core Nos. 8498, 9957, and 9957A from the Mobil PCU F31-13G well. Results of high differential pressure measurements made on core No. 8498 (Figure 4-6) indicate that at high differential pressures, a plot of permeability versus reciprocal mean pressure curves away from the straight line obtained from measurements at low differential pressures. The value of permeability extrapolated to infinite mean pore pressure under a net confining pressure of 4,500 psi was 0.0021 md compared with 0.017 md obtained from measurements made at 120 psi net confining pressure. Figure 4-7 shows the results of measurements made on core Nos. 9957 and 9957A.

Gas permeabilities of core No. 6475.5 from the CIGE NBU No. 21 well were measured at different pore pressures to evaluate the extrapolated Klinkenberg permeability. Results are shown in Figure 4-5.

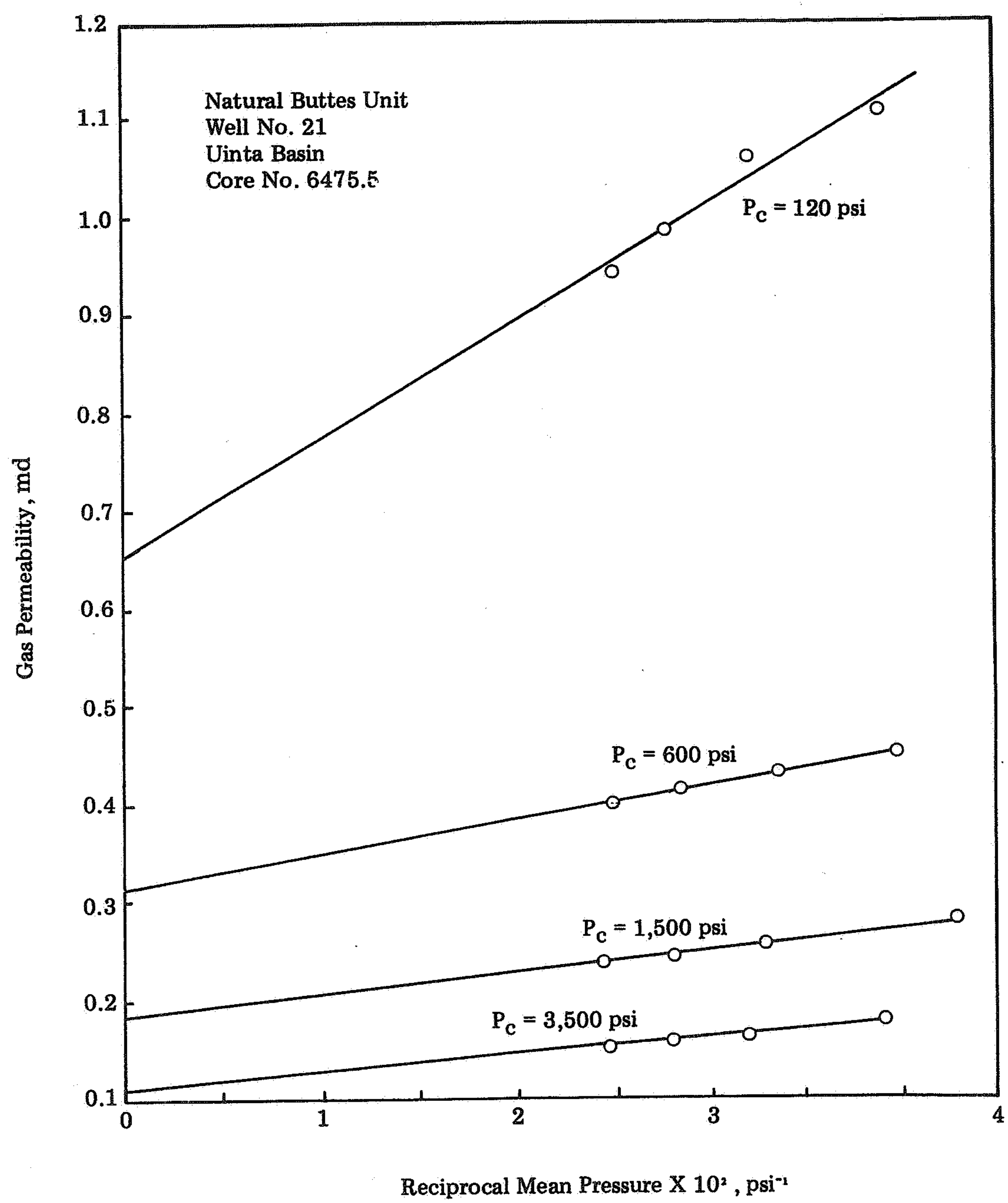

Figure 4-4. Effect of Confining Pressure on Klinkenberg Extrapolations

Table 4-10. Liquid Permeability Measurements on Core from Mobil PCU F31-13G Well

Core Depth: 9,957 feet
Core No. 9957
Differential Pressure: 300 psi

Confining Pressure (psi)	Maximum Permeability (md)	Minimum Permeability (md)
500	6.19×10^{-2}	1.67×10^{-4}
1,000	1.62×10^{-2}	1.40×10^{-2}
1,500	7.36×10^{-3}	3.85×10^{-3}
2,000	9.95×10^{-3}	1.42×10^{-3}
2,500	6.78×10^{-3}	6.46×10^{-4}
3,000	2.83×10^{-2}	5.70×10^{-3}
3,500	5.91×10^{-3}	2.30×10^{-3}
4,000	6.28×10^{-2}	9.11×10^{-4}
4,500	1.13×10^{-3}	8.48×10^{-4}
5,000	1.09×10^{-2}	1.61×10^{-3}

Core Depth: 8,498 feet
Core No. 8498A
Differential Pressure: 300 psi

Confining Pressure (psi)	Maximum Permeability (md)	Minimum Permeability (md)
500	8.02×10^{-3}	2.49×10^{-3}
1,000	6.62×10^{-3}	3.89×10^{-3}
1,500	7.56×10^{-3}	3.85×10^{-3}
2,000	1.11×10^{-2}	5.17×10^{-3}
2,500	9.15×10^{-3}	4.88×10^{-3}
3,000	1.35×10^{-2}	7.98×10^{-3}
4,000	1.94×10^{-2}	4.59×10^{-3}

Table 4-11. Measurements Made at a Single Confining Pressure (4,700 psi) on Core from Mobil PCU F31-13G Well

Core Depth: 9,957 feet
Core No. 9957A
Confining Pressure: 4,700 psi
Differential Pressure: 300 psi

Experiment No.	Time	K (md)
1	0 min	1.85×10^{-3}
	30 min	1.35×10^{-3}
	45 min	1.72×10^{-3}
	1 hr 15 min	1.81×10^{-3}
	1 hr 30 min	1.35×10^{-3}
	1 hr 45 min	1.22×10^{-3}
2	0 min	8.20×10^{-4}
	5 min	1.94×10^{-3}
	20 min	2.26×10^{-3}
	35 min	1.63×10^{-3}
	1 hr 05 min	3.74×10^{-4}
	1 hr 35 min	8.49×10^{-4}

Table 4-12. Liquid Permeability Measurements (With Periodic Reversal of Flow Direction) on Core from Mobil PCU F31-13G Well

Core Depth: 9,998 feet
Core No. 9998
Confining Pressure: 5,000 psi
Differential Pressure: 300 psi

Flow Direction	Time	Permeability (md)
X→Y	15 min	8.67×10^{-2}
	30 min	4.66×10^{-3}
	45 min	1.38×10^{-3}
	1 hr 15 min	3.12×10^{-3}
Y→X	10 min	2.72×10^{-3}
	30 min	2.45×10^{-3}
	1 hr 00 min	2.09×10^{-3}
	1 hr 20 min	1.32×10^{-2}
	1 hr 25 min	1.82×10^{-2}
	1 hr 55 min	2.97×10^{-3}
X→Y	10 min	1.67×10^{-2}
	15 min	2.75×10^{-2}
	30 min	1.55×10^{-2}
	50 min	4.79×10^{-2}
	1 hr 10 min	5.62×10^{-3}
Y→X	15 min	1.42×10^{-3}
	40 min	1.29×10^{-3}
	1 hr 20 min	1.84×10^{-3}
	1 hr 45 min	7.72×10^{-4}
Core Depth: 9,957		
Core No. 9957A		
Confining Pressure: 5,100 psi		
Differential Pressure: 300 psi		
X→Y	5 min	5.40×10^{-3}
	30 min	1.90×10^{-3}
	1 hr 00 min	1.35×10^{-3}
	1 hr 30 min	1.05×10^{-3}
Y→X	10 min	2.88×10^{-3}
	35 min	1.79×10^{-3}
	1 hr 05 min	3.46×10^{-3}
	1 hr 35 min	2.05×10^{-3}
X→Y	10 min	4.47×10^{-3}
	40 min	3.69×10^{-3}
	1 hr 10 min	5.55×10^{-3}
	1 hr 40 min	1.42×10^{-3}
Y→X	15 min	4.15×10^{-3}
	35 min	1.92×10^{-3}
	1 hr 25 min	1.64×10^{-3}
	1 hr 50 min	1.58×10^{-3}
X→Y	5 min	1.86×10^{-2}
	1 hr 15 min	1.89×10^{-3}
	1 hr 45 min	1.35×10^{-3}
	2 hr 30 min	1.03×10^{-3}

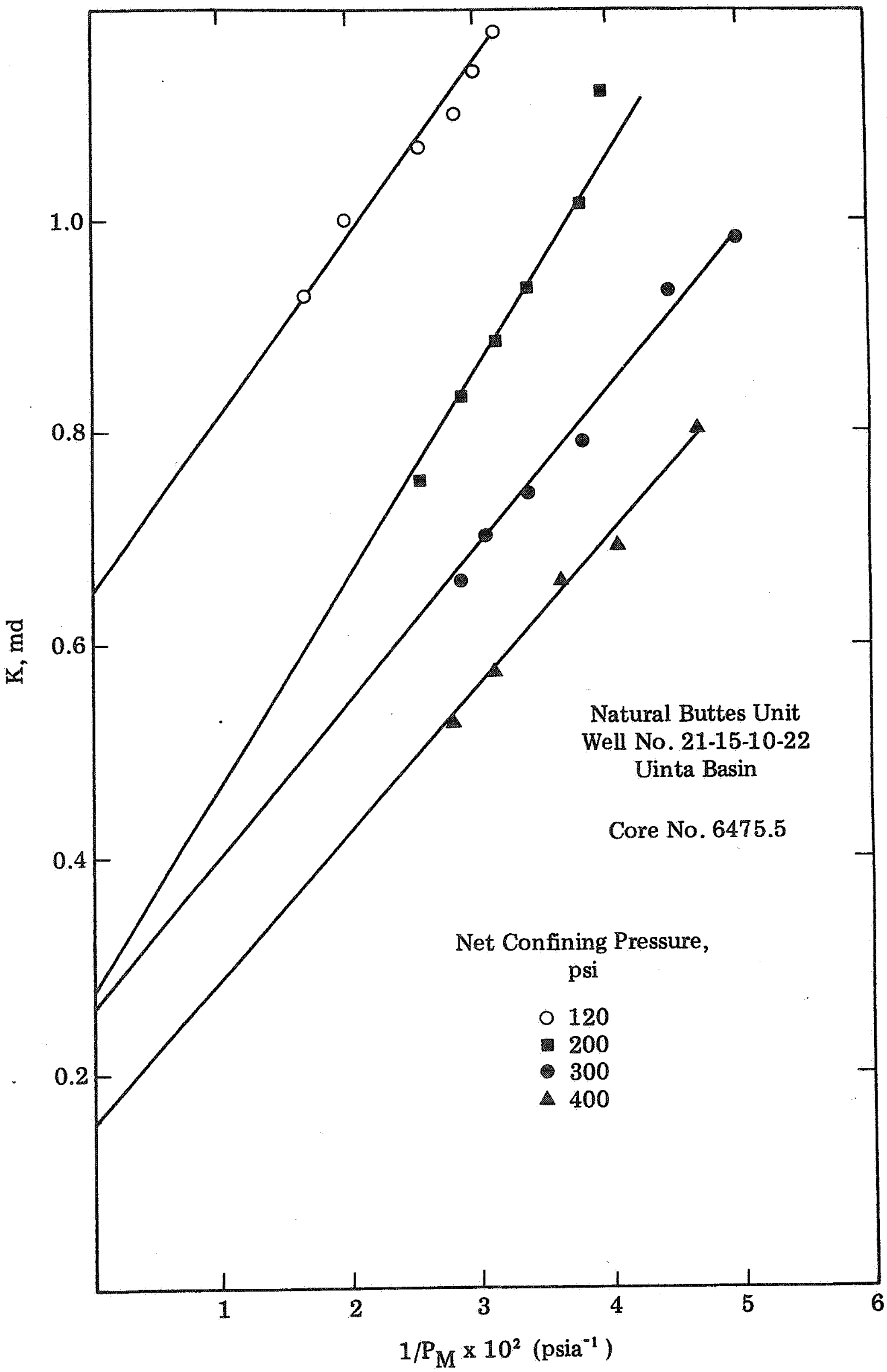

Figure 4-5. Effect of Confining Pressure on Klinkenberg Extrapolations

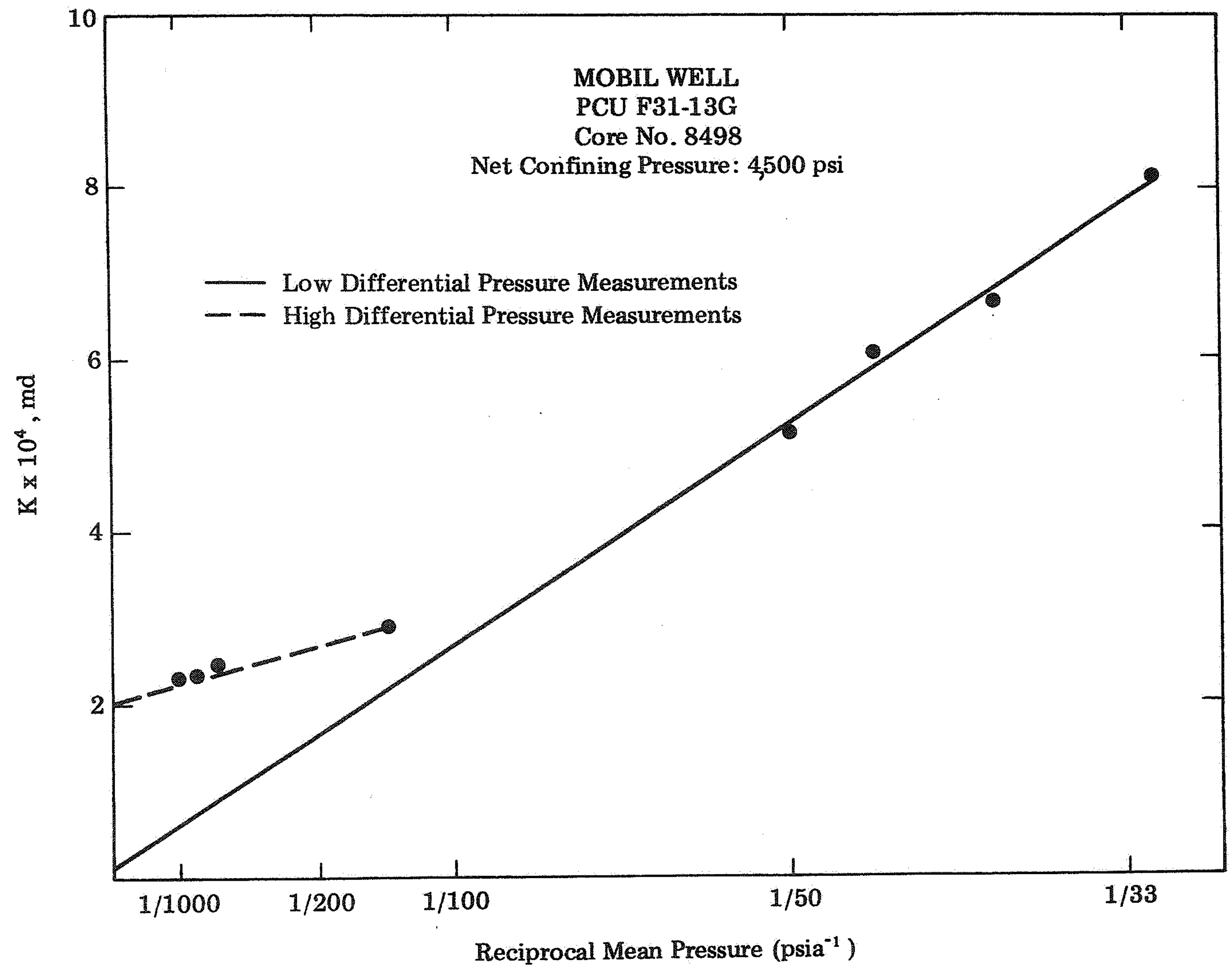

Figure 4-6. Effect of Pore Pressure on Gas Permeability

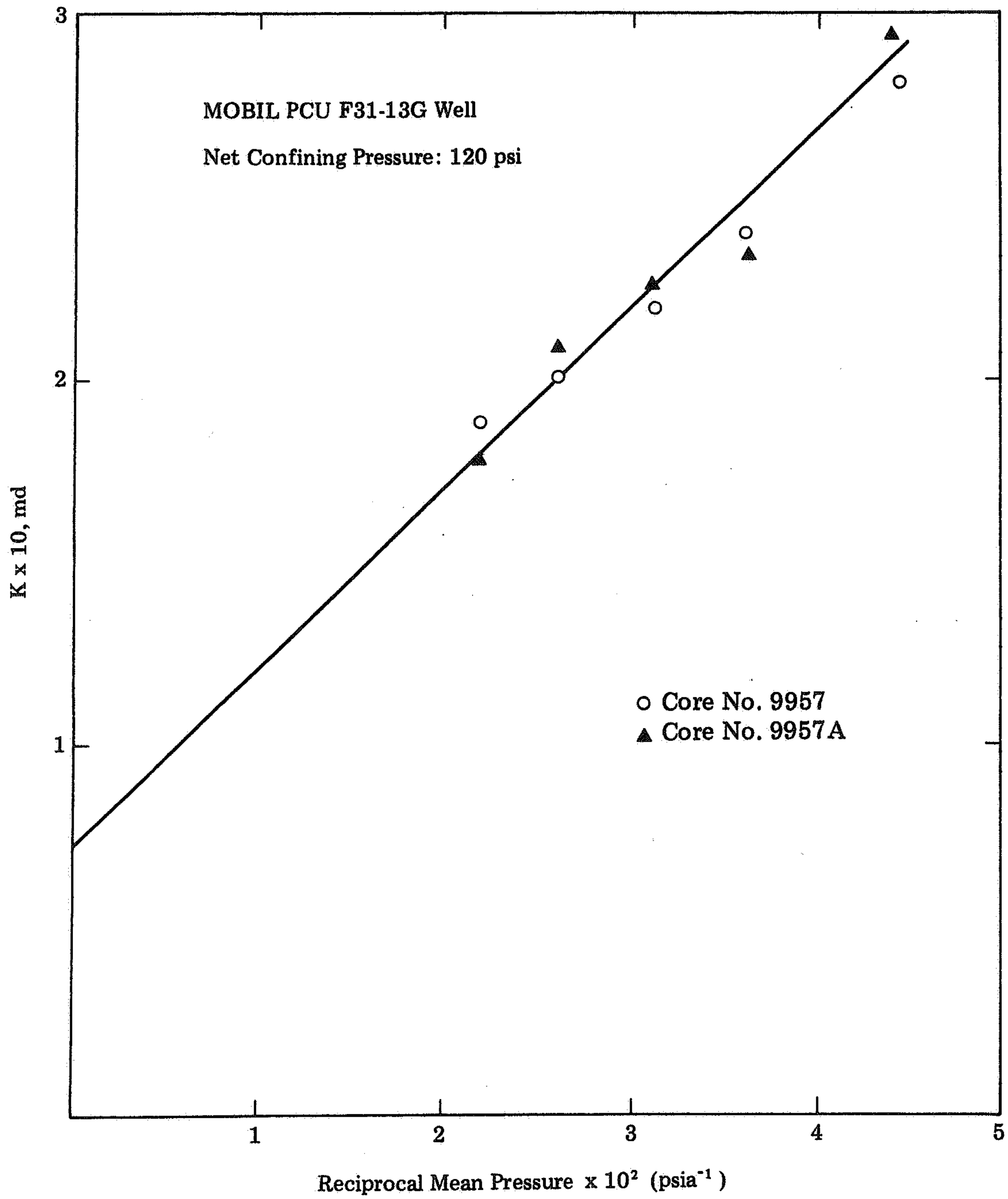

Figure 4-7. Effect of Pore Pressure on Permeability at Low Confining Pressure

Relative Permeability

The relative permeability to gas of cores No. 8498, 9957, and 9998 from the Mobil PCU F31-13G well and core No. 7011 from the Canyon Largo well No. 256 was calculated at different brine saturation levels assuming irreducible water saturation was zero. Results are tabulated in Table 4-13. Relative gas permeability values measured by establishing different water saturation levels by evaporation are also presented for comparison. The absolute permeability (for the measurements) was assumed to be the gas permeability at zero water saturation. The values estimated using capillary pressure data were consistently lower than the measured values, the difference being rather marked at high saturation levels. The difference could be due to the fact that S_{wi} may have a value higher than zero and that the measurements were made by desaturation.

The results of measurements on core No. 9998A from the Mobil PCU F31-13G well are summarized in Figures 4-8 and 4-9. It was noted that at net confining pressures up to about 1,000 psi, the measured permeability values were considerably higher than the initial measurement of permeability. Subsequently, the core was heated to 90^{o}C under a vacuum and maintained at that temperature for 3 days. Permeability measurements were made again, 3 weeks after the first series of measurements. The values had dropped to initial measurement (after the plug has been drilled out of the core).

The core, which was saturated with brine subsequent to initial permeability measurements was also used in the brine flow experiments. In both sets of experiments, Klinkenberg permeabilities decreased with increasing confining pressure. This behavior is consistent with that reported for CIGE NBU No. 6475.5 core from the Uinta Basin.

Figures 4-10 and 4-11 present the results of experiments conducted on core No. 7011 from the Canyon Largo well No. 256, Dakota Formation, Farmington, New Mexico.

Effect of Core Saturation History on Relative Permeabilities to Gas and Water

Welge-type unsteady state relative permeability curves can be obtained only at high differential pressures across the core because of high capillary pressures. An expression for relating flow out of the downstream end to permeability and relative permeability must first be obtained since these high differential pressures produce a large net confining pressure gradient. The general nature of this expression involves integration of flow for an infinitesimal length where the permeability at that point is determined by an equation describing the pressure dependence of permeability as a function of net confining pressure. An expression to evaluate unsteady state measurements is being formulated. This will be compared with the liquid phase stationary method measurements.

Table 4-13. Relative Permeability

Mobil Well PCU F31-13G

Core Depth: 8,498 Feet

	Relative Permeability		Absolute Permeability	
S_L, Percent	K_{rg}/K (calculated)	K_{rg}/K_g^o (measured)	(calculated), md	K_g^o (measured), md
0.1	1.82×10^{-2}	8.70×10^{-1}	7.35×10^{-1}	2.76×10^{-2}
0.2	7.55×10^{-3}	7.43×10^{-1}		
0.3	2.80×10^{-3}	5.80×10^{-1}		
0.4	1.01×10^{-3}	4.35×10^{-1}		
0.5	2.87×10^{-4}	2.97×10^{-1}		
0.6	6.78×10^{-5}	1.81×10^{-1}		
0.7	1.35×10^{-5}	— —		
0.8	1.99×10^{-6}	— —		
0.9	1.25×10^{-7}	— —		
Core Depth: 9,998 Feet				
0.1	1.15×10^{-2}	9.52×10^{-1}	8.31×10^{-1}	3.15×10^{-2}
0.2	4.60×10^{-3}	8.57×10^{-1}		
0.3	1.73×10^{-3}	7.30×10^{-1}		
0.4	4.84×10^{-4}	5.78×10^{-1}		
0.5	1.48×10^{-4}	4.13×10^{-1}		
0.6	4.83×10^{-5}	2.54×10^{-1}		
0.7	1.25×10^{-5}	— —		
0.8	2.01×10^{-6}	— —		
0.9	1.26×10^{-7}	— —		
Core Depth: 9,957 Feet				
0.1	5.56×10^{-2}	8.64×10^{-1}	1.25	1.10×10^{-1}
0.2	2.36×10^{-2}	6.91×10^{-1}		
0.3	9.15×10^{-3}	5.82×10^{-1}		
0.4	2.97×10^{-3}	3.45×10^{-1}		
0.5	6.07×10^{-4}	2.00×10^{-1}		
0.6	7.46×10^{-5}	2.55×10^{-2}		
0.7	1.46×10^{-5}	— —		
0.8	1.74×10^{-6}	— —		
0.9	2.17×10^{-7}	— —		
Canyon Largo Well No. 256, Dakota Formation				
Core Depth: 7,011 Feet				
0.1	2.4045×10^{-2}	7.49×10^{-1}	1.3	6.21×10^{-2}
0.2	1.0355×10^{-2}	5.31×10^{-1}		
0.3	4.7853×10^{-3}	3.62×10^{-1}		
0.4	2.1129×10^{-3}	2.25×10^{-1}		
0.5	7.5635×10^{-4}	1.26×10^{-1}		
0.6	2.0911×10^{-4}	6.12×10^{-2}		
0.7	4.1387×10^{-5}	— —		
0.8	3.3884×10^{-6}	— —		
0.9	1.2102×10^{-7}	— —		

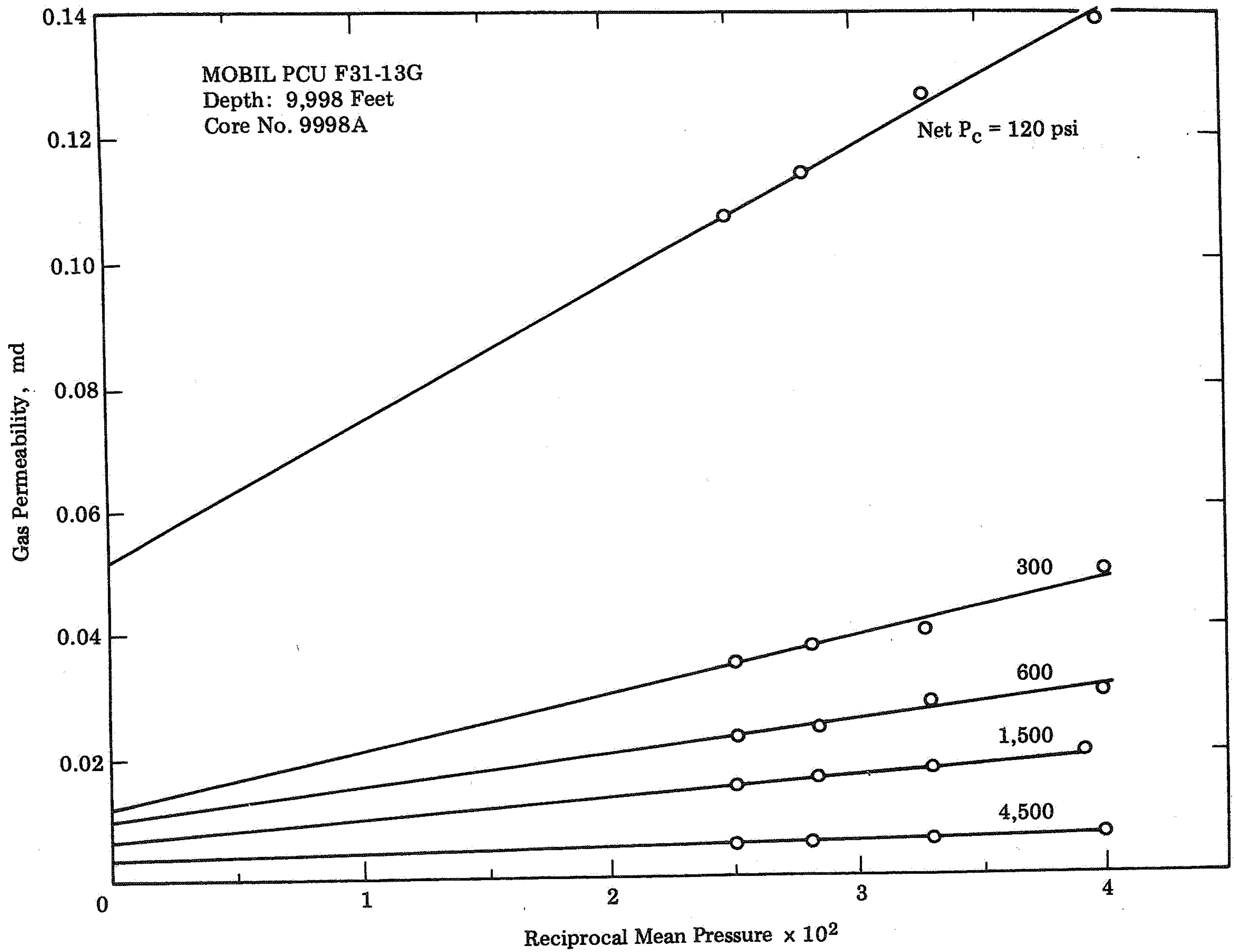

Figure 4-8. Effect of Net Confining Pressure on Klinkenberg Permeabilities: Experiment No. 1

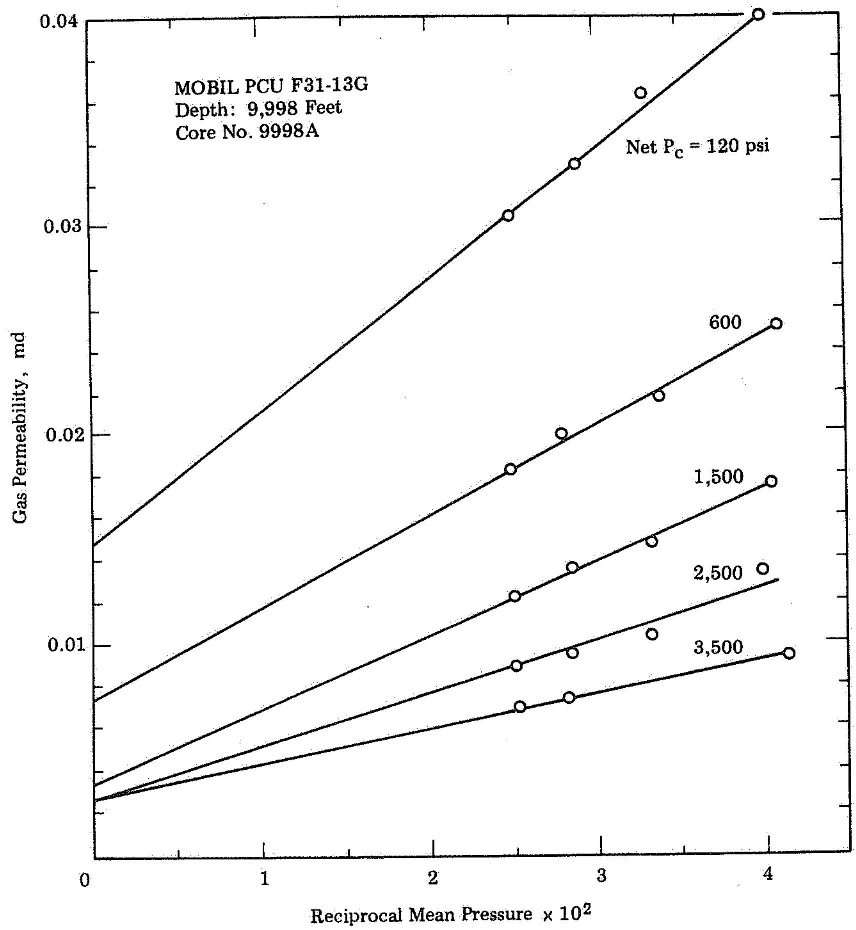

Figure 4-9. Effect of Net Confining Pressure on Klinkenberg Permeabilities: Experiment No. 2

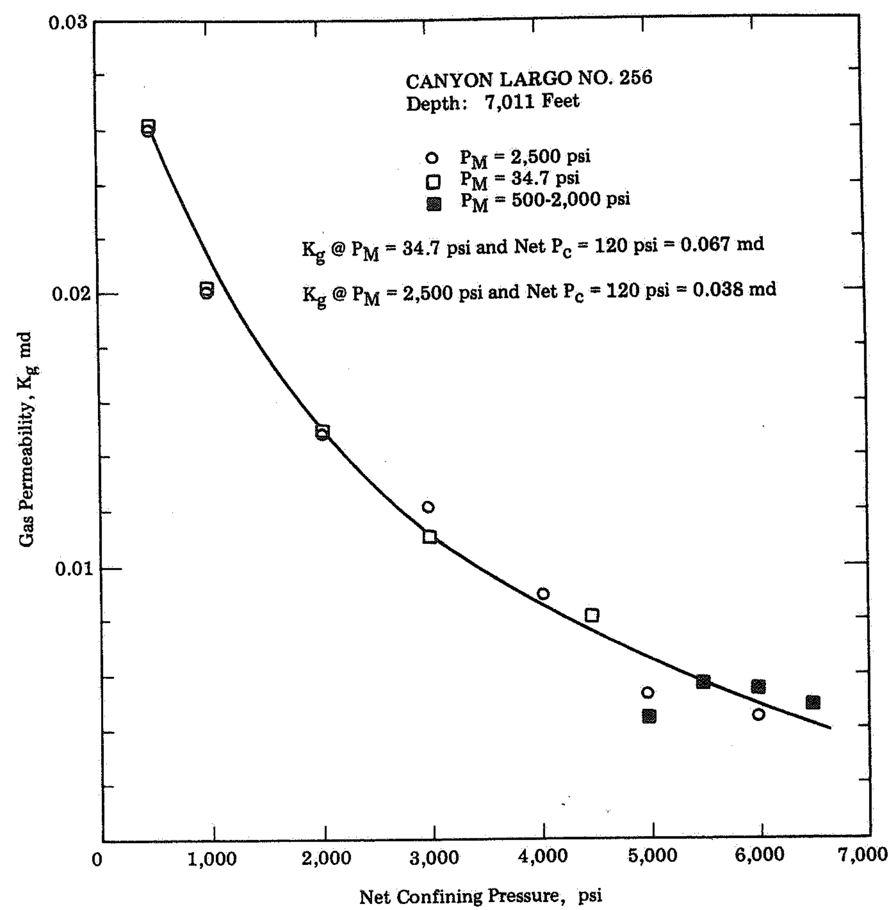

Figure 4-10. Effect of Net Confining Pressure on Gas Permeability at High and Low Pore Pressures

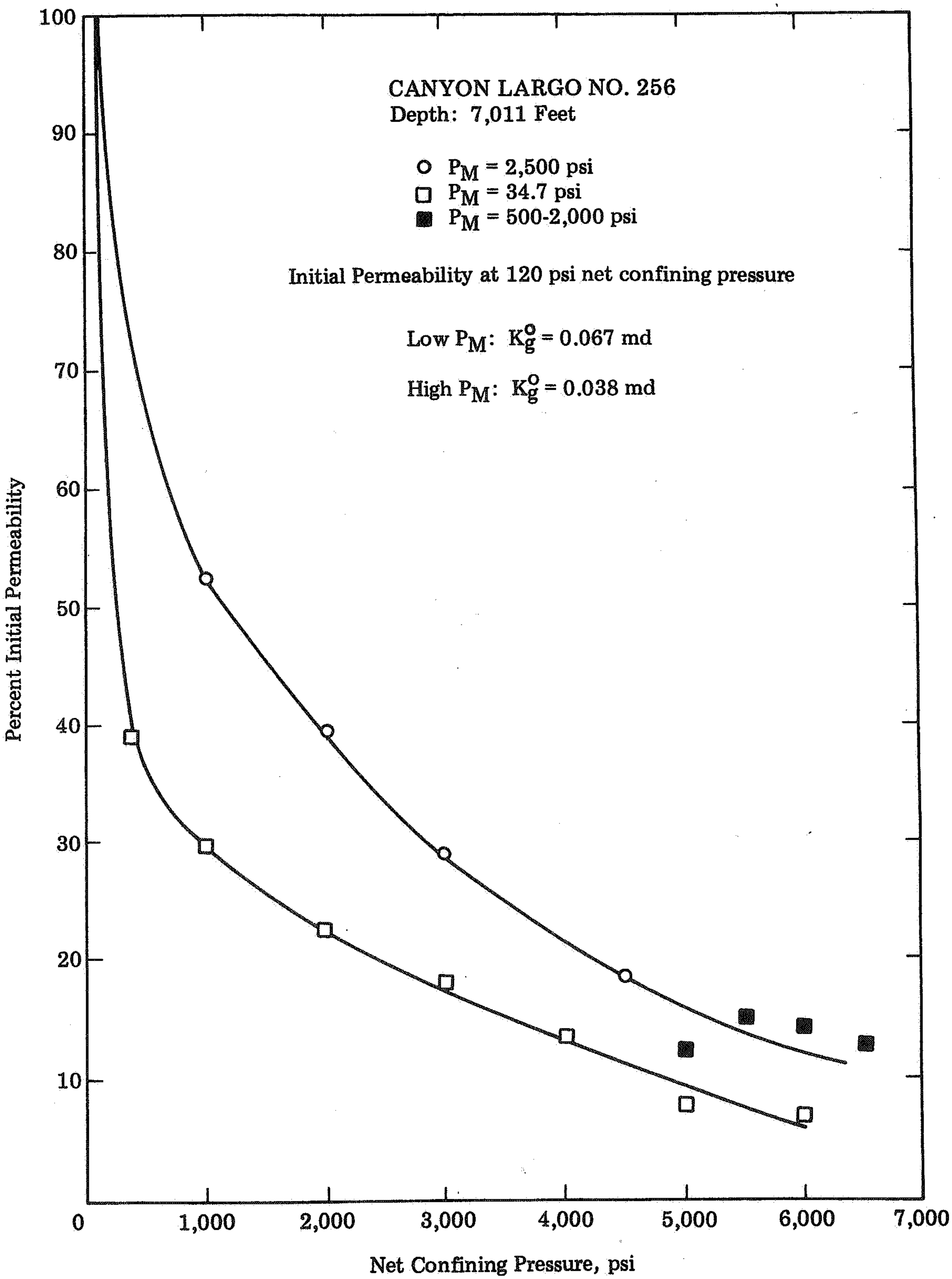

Figure 4-11. Effect of Net Confining Pressure on Reduction in Gas Permeability at High and Low Pressures

RESERVOIR SIMULATION STUDIES

Parametric Analysis of MHF Test Data and Engineering Studies of Western Gas Sands -- Intercomp Incorporated

The post-fracture pressure transient test data from zones 1 and 3 in the Mobil PCU F31-13G well were analyzed. Results of the new analyses are given in Table 4-14, and Figures 4-12 through 4-15. The consistency between reservoir parameters calculated from pre-fracture pressure transient test data and those used in the post-fracture analysis is much better than in earlier analyses. The new analysis gave a much lower fracture permeability than was used earlier. Previously the fracture permeability was assumed to be 50,000 md.

The post-breakdown pressure buildup test data from zones 4A and 4B of the Mobil PCU F31-13G well have been analyzed by computer matching the test data. The analysis showed both zones to be fractured. The fractures may have been naturally occurring or created during the breakdown operation.

The analysis of the buildup test data from zone 4A gives a fracture half-length, x_f, of 24 ft and a fracture flow capacity, $k_f w$, of 11.5 md-ft. The effective p_i, was 4,140 psia. Analysis of the pressure buildup data from zone 4B gives:

$$x_f = 72 \text{ ft}$$
$$k_f w = 5.7 \text{ md-ft}$$
$$k_g = 0.001 \text{ md}$$
$$p_i = 4{,}060 \text{ psia}$$

Pre-fracture pressure buildup data from zones 5 through 9 of Mobil well PCU F31-13G were analyzed using type curve analysis coupled with computer matching. Zones 5 through 7 were fractured with the fracture half length varying from 66 to 121 ft. The fracture permeability ranged from 500 to 3,000 md and the matrix permeability between 0.0034 to 0.016 md.

Analyses of zones 5 through 9 showed that these zones were fractured prior to massive hydraulic fracturing. This may have been due to natural fractures existing in the reservoir or to fractures created during perforation breakdown.

The effective gas permeability of the matrix in zones 8 and 9 is 0.0134 md and 0.0154 md, respectively. The test data indicate a reservoir pressure for zone 8 of 2,825 psia and 2,905 psia for zone 9. This is anomalous since zone 8 is the deeper of the two zones.

Table 4-14. Reservoir Parameters Utilized in Radial Gas Simulator

Parameter	Zone 1 Pre-Frac	Zone 1 Post-Frac	Zone 2 Pre-Frac	Zone 2 Post-Frac
Initial pressure, psia	4,975	4,975	4,070	4,070
Hydrocarbon Porosity	0.036	0.036	0.036	0.036
Permeability, md	0.0109	0.0109	0.0215	0.0215
Thickness, ft	20	20	61	30
Wellbore vol., ft^3	234	1,952	312	312
Fracture half-length, ft	100	504	56	432
Fracture width, in.	0.2	1.0	0.2	1.0
Fracture Permeability, md	738	300	129	1,000
Fracture skin	0.267	0	0	0.25

A post-fracture pressure drawdown test on zone 9 was matched, varying only fracture properties. Reservoir properties determined by matching the pre-fracture pressure buildup data were held constant in matching the post-fracture drawdown pressures. The fracture and reservoir parameters obtained from post-fracture zone 9 were used to predict production rates for an extended flow test taken on the zone. The production rates predicted by the model match well with the rates measured during the test.

Analysis of the post-fracture pressure data from zone 9 gave a fracture half-length, x_f of 1,367 ft and a fracture flow capacity, $k_f w$, of 190 md-ft. The fracture face was damaged. A fracture skin factor of 0.065 was used in matching pressure from the post-fracture drawdown test. Effective gas permeability in the reservoir was 0.021 md.

The analytical development of a two-dimensional reservoir simulator has been completed for a vertically fractured dry gas reservoir. The model considers two-dimensional rectangular flow in the reservoir and one-dimensional flow in the fracture. The model includes the effect of non-Darcy flow in the reservoir and fracture, fracture face formation damage, wellbore and fracture storage effects, and frictional pressure drop effects in the production string. The derived equations are general enough to consider variable rock property data and extension to a three-dimensional case. However, the general equations have been reduced to the case of flow in a homogeneous slab penetrated by a vertical fracture. In addition, a statistical model of discontinuous sand lenses contained in the producing zones of the Western tight sands area is also under development. It is believed that by incorporating the geologic characteristics of these formations into the reservoir simulator, a more representative model of the actual flow processes will be obtained. Such an approach should result in a reservoir simulator which can be used as an exploration tool as well as in pressure transient analysis of a given well.

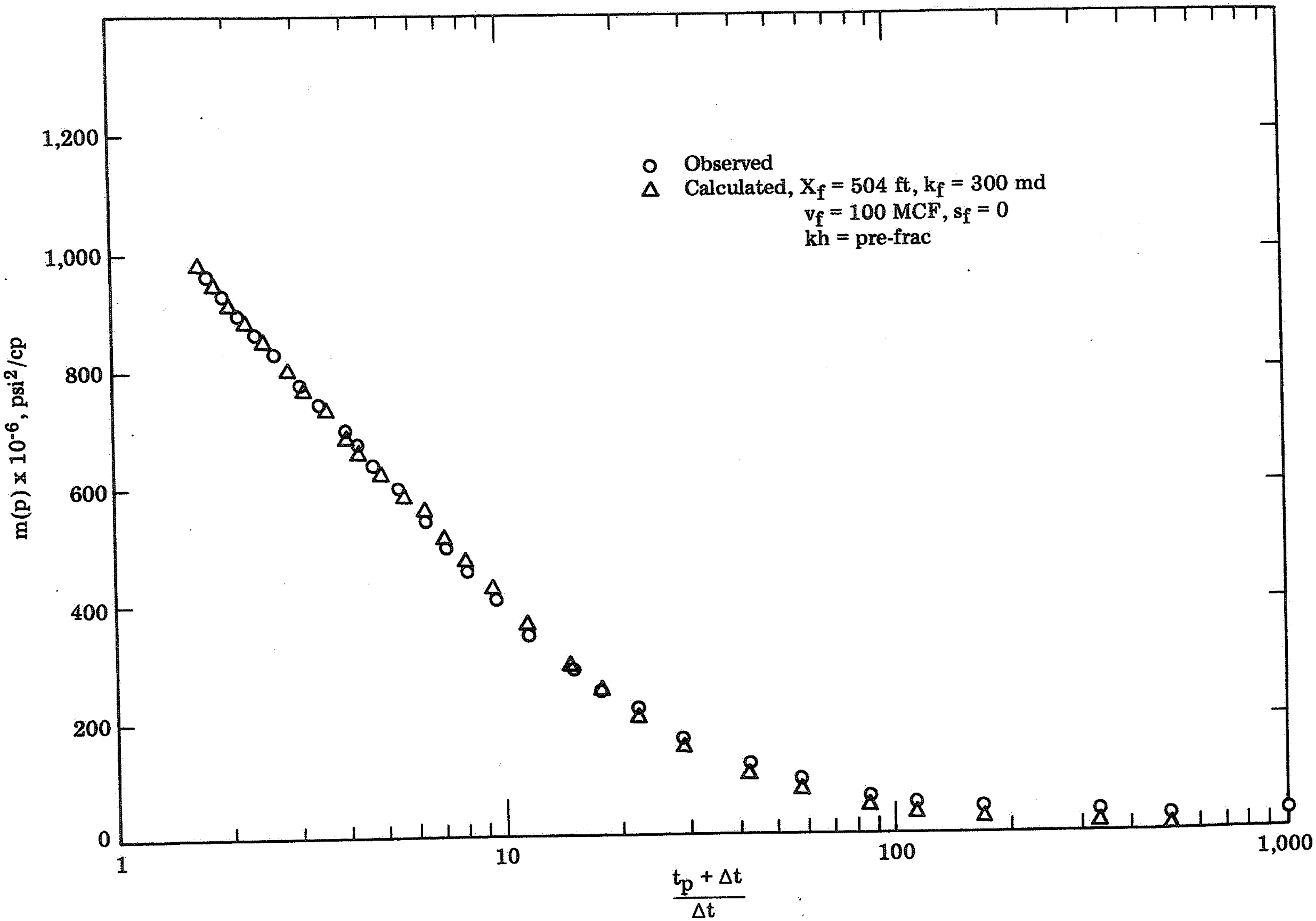

Figure 4-12. Post-Fracture Pressure Buildup Test - Zone No. 1

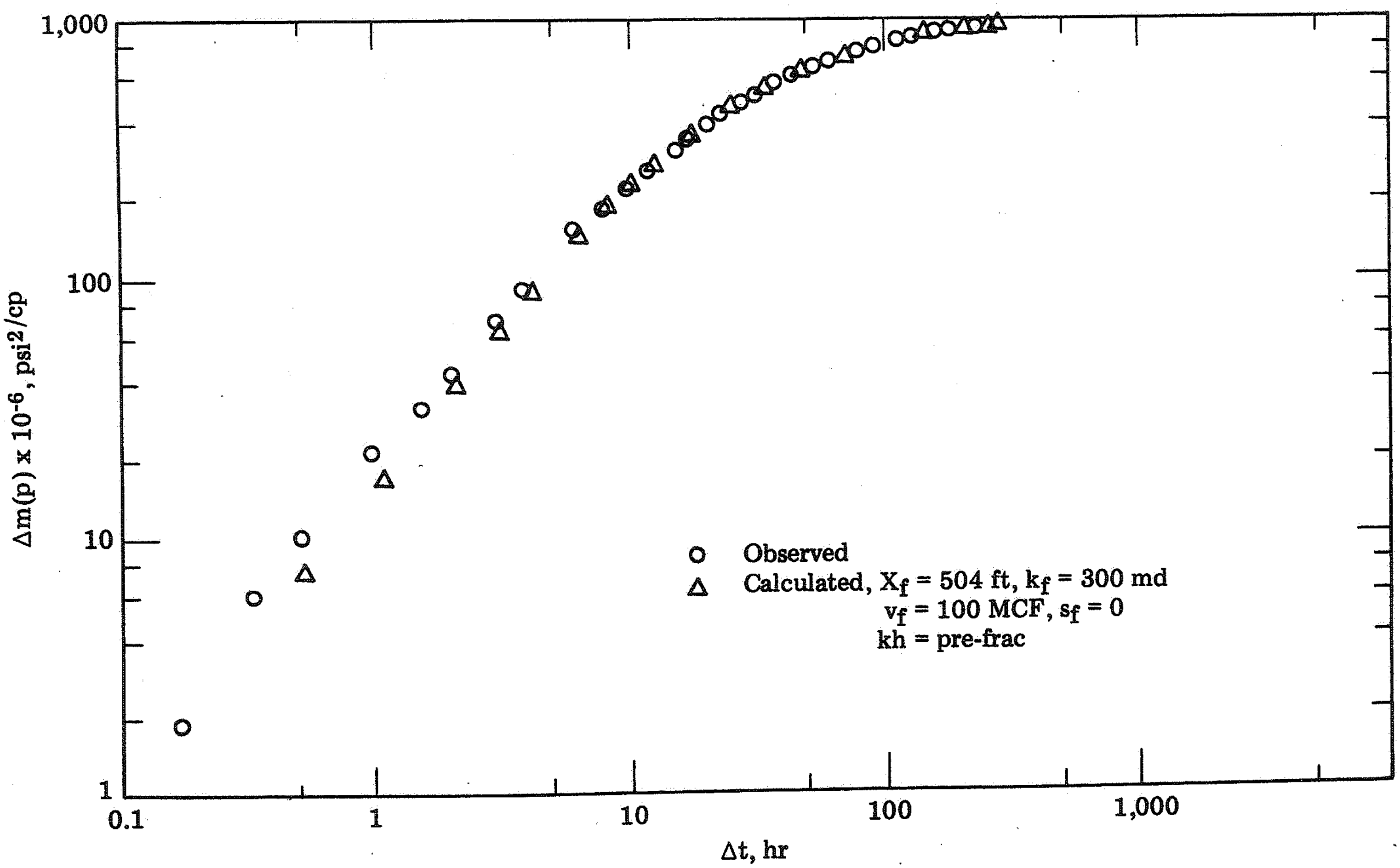

Figure 4-13. Post-Fracture Pressure Buildup Type Curve - Zone No. 1

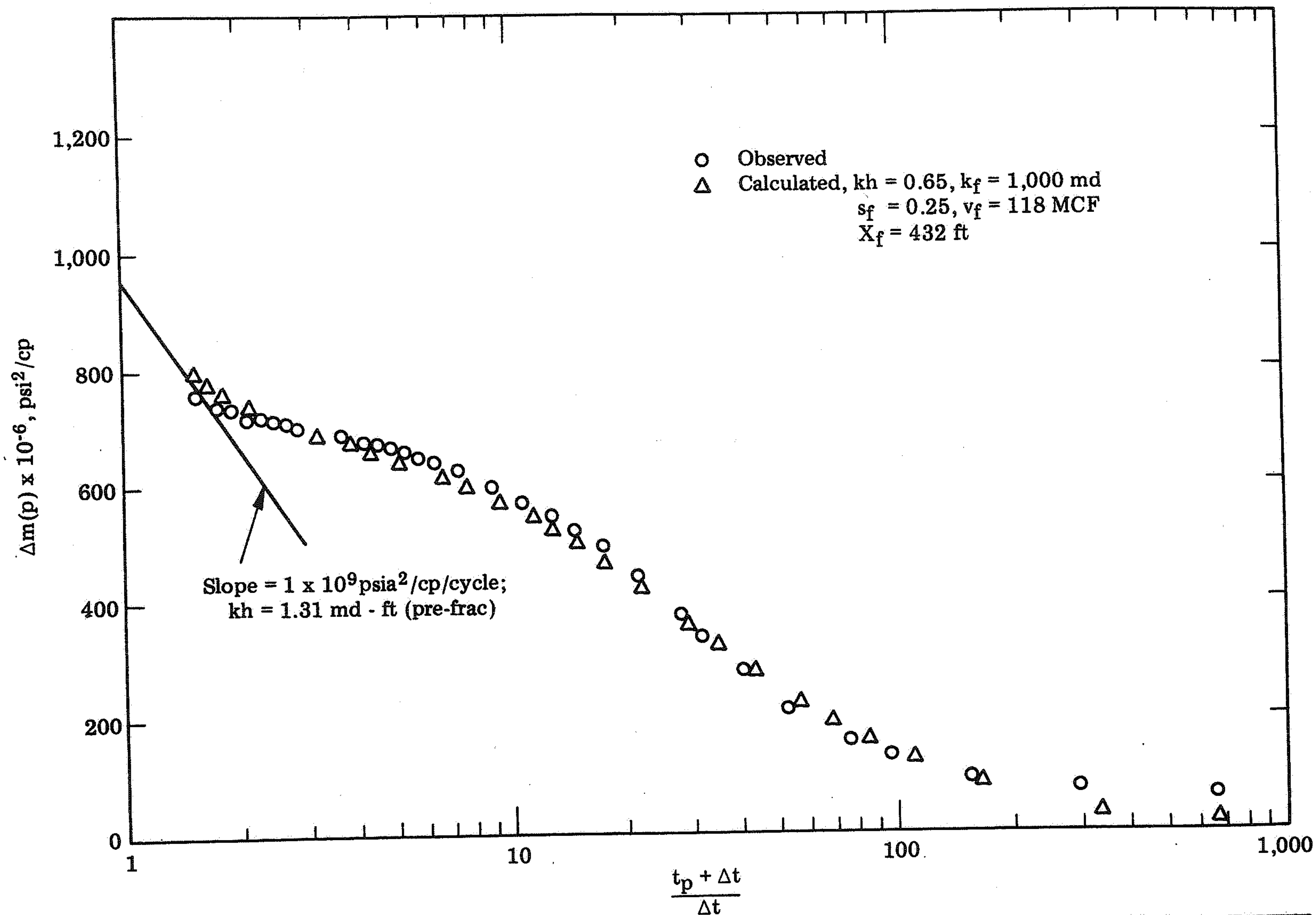

Figure 4-14. Post-Fracture Pressure Buildup Test - Zone No. 3

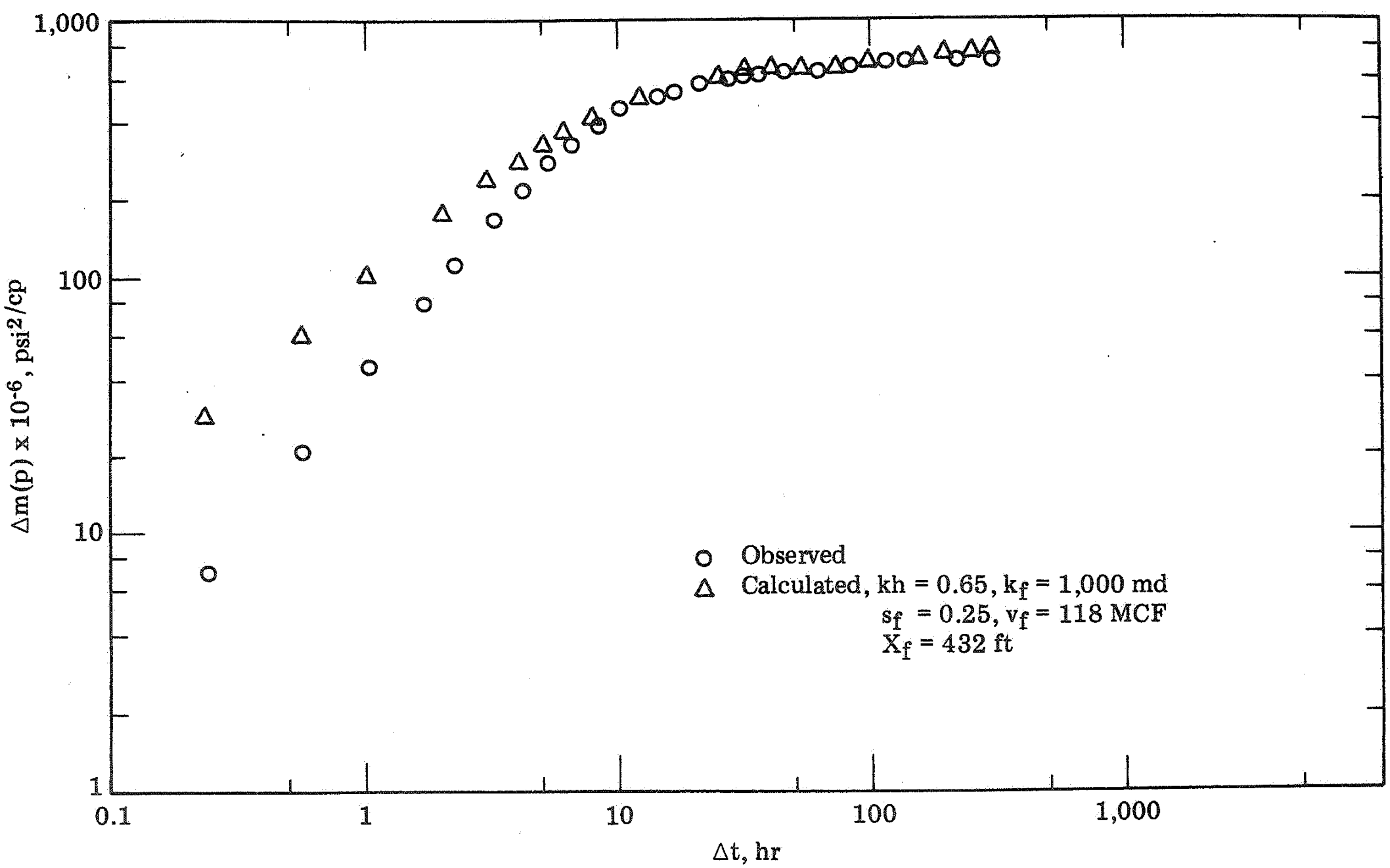

Figure 4-15. Post-Fracture Pressure Buildup Type Curve - Zone No. 3

ROCK-FLUID INTERACTION

Drilling muds were obtained for particle size distribution measurements and to determine the potential of the muds to plug hydraulic fractures. Analyses have not been completed.

A model of fracture propagation is being developed and remaining tasks include using "realistic" parameters to estimate the probability of obtaining a certain fracture length when a spectrum of inhomogeneities in stress (initially) or fracture toughness are imposed. The model will include crack tips which can propagate out of the plane of the fracture.

Work continued in the characterization of sintered bauxite proppant. A 4 in. diameter tight sandstone core from the Pacific Transmission Supply Company well No. 24-19 Federal (5,171 ft) was cut into 1-3/16 in. thick waffers and vacuum saturated with 2 percent KCl solution. Proppant imbedment was tested between two waffers. Hardness of the core material varied randomly from 56 to 93 on the Rockwell B scale with an average of 80.9.

Fifty, 75 and 100 percent of a monolayer of proppant were used with a complete monolayer being 1.72 $\pm$ 0.05 g/in.^{2}. The total proppant area was 3.98 in.^{2} (a 2-1/4 in. diameter circle). In order to facilitate proppant placement, one of each core section pair was coated with silicone grease. Prior to an imbedment test, the proppant-covered core section was soaked in the 2 percent KCl brine, thereby wetting the sintered bauxite. The assembly used for the imbedment measurements is shown in Figure 4-16.

The compression of the hardened steel cylinder, (2), and steel plate, (3), in Figure 4-16 was found to be only 1 to 2 percent of the embedment change. The compressibility of the core itself was measured, but due to the irregular point-like support offered by the proppant, the actual compression of the core sections during an experiment was not known. However, corrections for the core compression (somewhat overestimated) and the compression of the steel members (2) and (3) was attempted. Embedment results are presented in Figures 4-17, 4-18, and 4-19. In these figures, the percent closure was based on a 1.90 mm (0.0739 in.) fracture width, which was the diameter of the largest proppant found in the 12-20 mesh bauxite. The percent closure is the sum of the embedment of proppant into both faces. As in previous work, there was some proppant fracturing. In every experiment, the core sections fractured between 1,000 and 4,000 psi. This was also evident in the Δl's values obtained.

The opinion is that within the limits of this experiment the embedments at 100 percent and 75 percent proppant coverages are indistinguishable, and embedment at 50 percent coverage is somewhat greater. At 7,000 psi, a fracture propped with a 75 percent monolayer or greater with 12-20 mesh bauxite will result in a 40 percent fracture closure based on a 1.90 mm fracture and a formation of average hardness. Reduction to 50

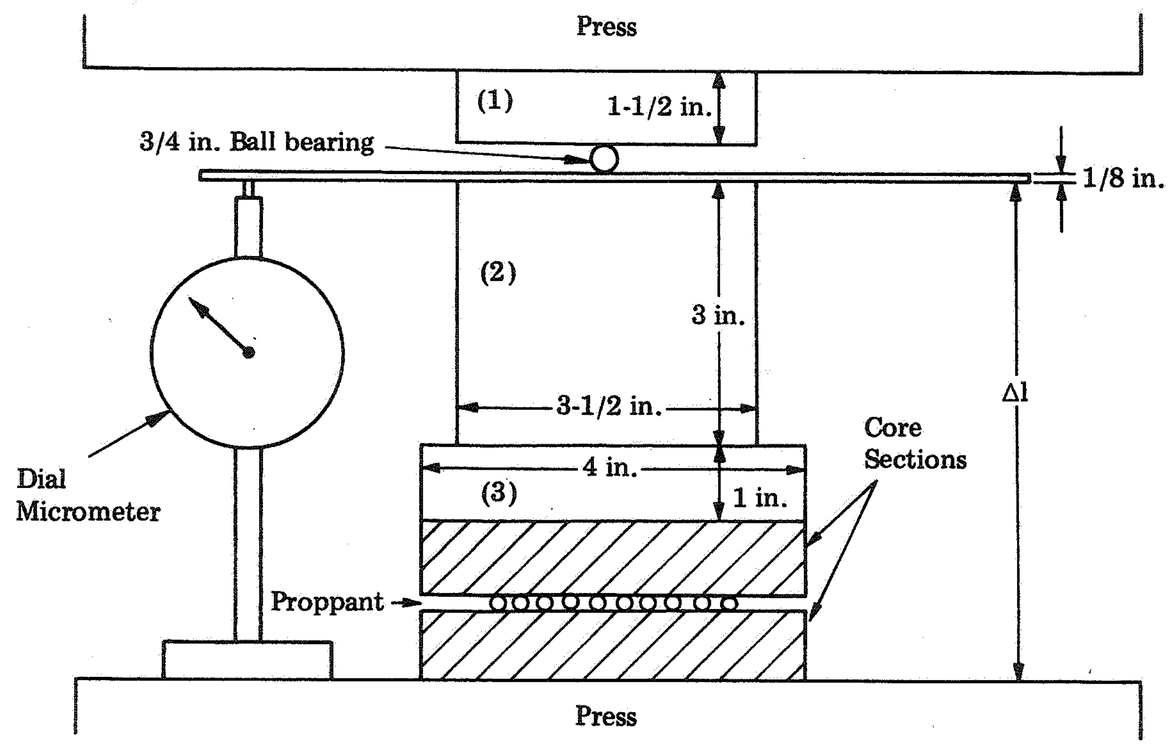

Figure 4-16. Proppant imbedment apparatus. (1), (2) and (3) are of hardened steel. The 1/8 in. steel plate has a 1 in. hole cut in its center to allow clearance for the ball bearing. This steel plate is epoxied onto steel cylinder (2).

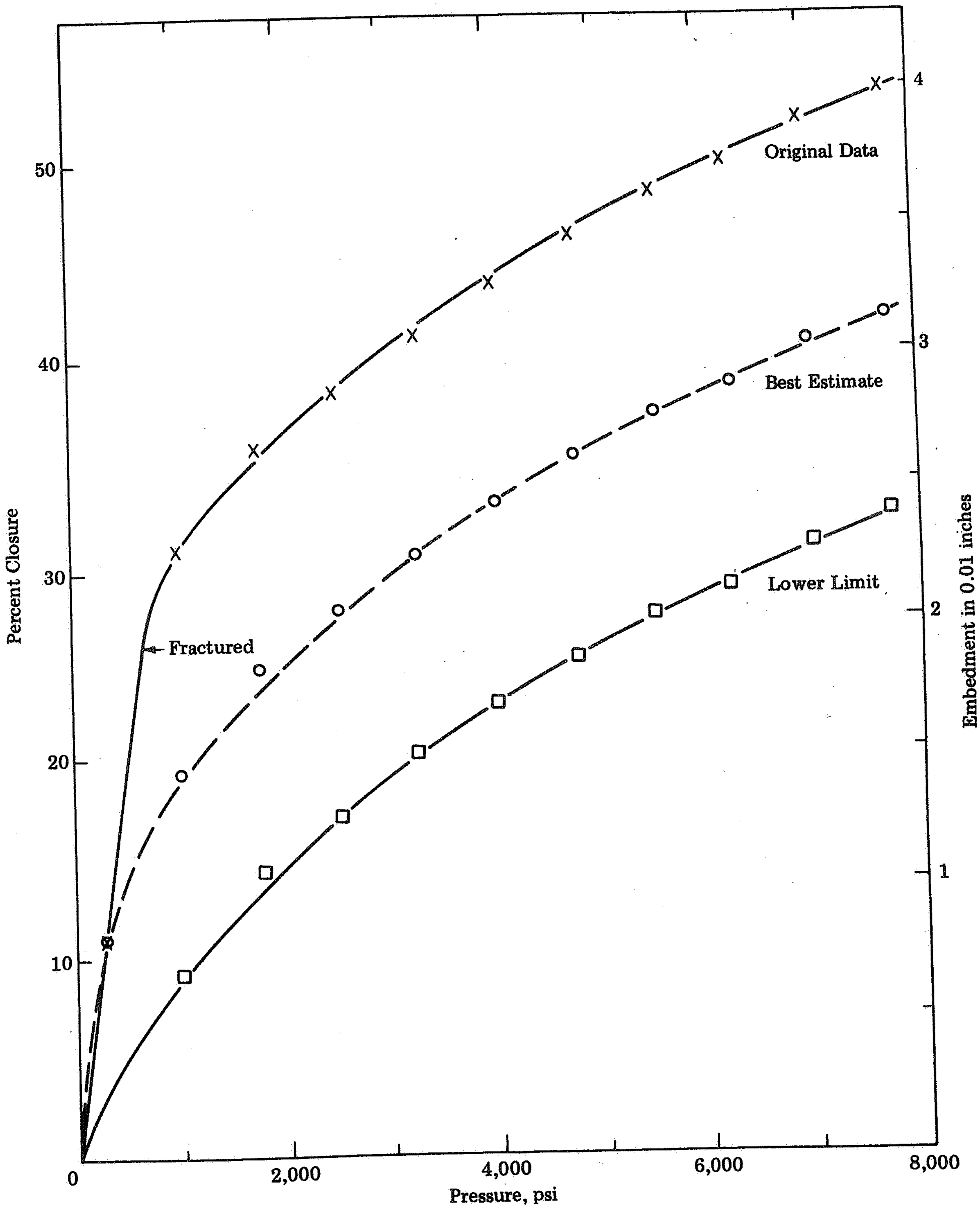

Figure 4-17. Percent closure vs. applied pressure for 100 percent coverage

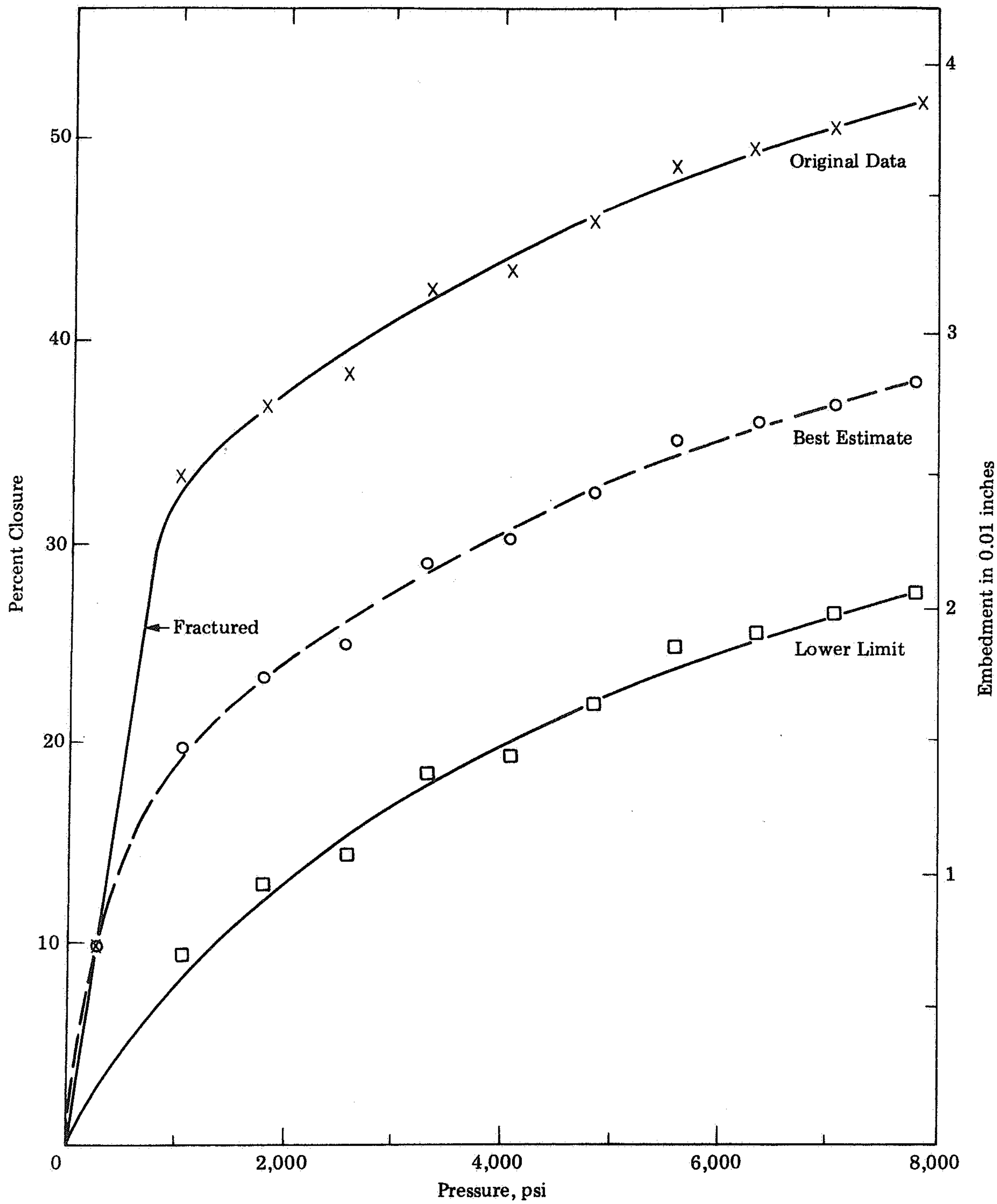

Figure 4-18. Percent closure vs. applied pressure for 75 percent coverage

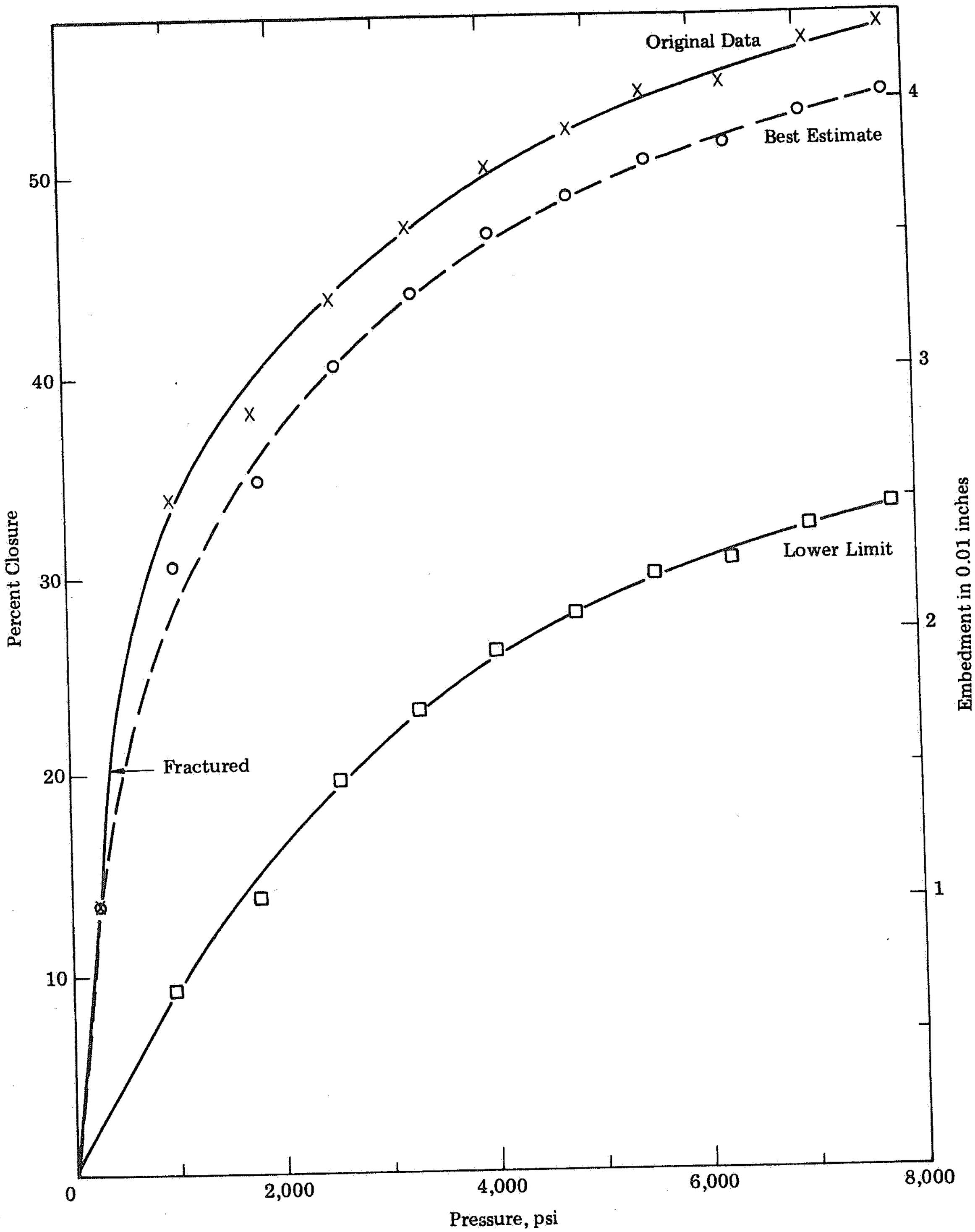

Figure 4-19. Percent closure vs. applied pressure for 50 percent coverage

percent proppant coverage could increase the closure to 65 percent. At 2,500 psi, or at a depth of about 5,000 ft (the depth from which this core was taken), the closure would be 25 to 30 percent at proppant coverages of 75 percent or greater, and 40 percent with a 50 percent coverage. Therefore, although sintered bauxite shows some clear advantages over sand or glass beads, considerations must be given to the fracture closure through imbedment.

Efforts to determine the feasibility of fabricating light weight proppants for application in gas and oil well stimulation continued. Literature review of patent and published works to determine previous work in selecting light weight proppants, properties of porous ceramics, and material properties data bank for selection of a composite proppant was initiated.

Initial review of the papers indicated that for 30 to 50 percent porosity, material strength was reduced by 90 percent. The ceramics remained potentially viable light weight proppants.

ADVANCED LOGGING TECHNIQUES AND INTERPRETATIONS

Study of Sonic, Neutron, and Density Logging of Low Permeability Gas Sands -- Texas A & M University

After the well was located and information obtained, the logs were digitized in terms of sonic (At), density (bulk density), gamma ray (API units), Rt and neutron. Computer runs of the digitized data were made and gathered.

Run 1	4,400 - 4,500 ft
Run 2	6,400 - 6,500 ft
Run 3	7,400 - 7,500 ft
Run 4	8,400 - 8,500 ft

These trials were not final and formation water resistivity (R_W) will be studied. In addition, the values of matrix and "shale" density and travel time must be accurately defined. Core analysis fits the calculated values in the log analysis but there are some areas which are recording porosities that are too high, considering the input parameters. For this reason, zones are not adequately described; shale, sandstone-limestone or sandstone-dolomite, and lignite, must be clearly defined. More core will be required for study.

The porosity of samples from the CIGE Natural Buttes Unit No. 21 well were analyzed using the helium porosimeter and by determining the difference in dry weight and saturated weight using kerosene as a saturating fluid. The porosities obtained by these three methods are presented in Table 4-15.

From these measurements, the matrix density of the reservoir rock samples was calculated. These values are presented in Figure 4-20. The unexpected feature of these measurements is that the matrix density is considerably higher than the 2.65 gm/cc value normally expected for sandstone. However, this may have been due to the presence of carbonates in the matrix. In some cases, the rock contained gypsum. For the higher porosity (about 10 percent), the density of the matrix approaches 2.65 gm/cc. However, for samples with lower porosity, the matrix density was higher.

The cores were grouped to correspond to readings that could be obtained from the log (see Table 4-16). The matrix density of each interval was averaged and used with the bulk density read from the density log to yield a porosity. Figure 4-21 is a plot of the porosity obtained from the density log together with the average porosity for the cores in the interval being analyzed.

Some samples from the CIGE Natural Buttes Unit No. 21 well were extracted before the porosities were determined. Others were placed in an oven, dried, and porosity was subsequently measured. Essentially, there was no difference between the porosity for the samples which were extracted and those that were not.

Dielectric Constant Measurements for Formation Evaluation

The development of an accurate laboratory method for measurement of dielectric constant in rock samples continued. The method will be used to investigate the effects of anisotropy, matrix material, salinity and wetability on dielectric constant measurements. A system which used rock samples as part of a resonant Q meter circuit was tested, but this technique lacked the sensitivity required to investigate dielectric constant properties. The phase shift measurement system, having greater sensitivity, measures dielectric constant in terms of a network phase shift. The system, which has been breadboarded, has been refined by using mixers to convert the rf test frequency signals to 20 kHz signals for a phase shift measurement. An HP 5328A electronic counter operating in the time interval averaging mode was used to accurately measure the phase shift. Preliminary measurements show that a sensitivity of at least 5 counts per picofarad can be obtained with a 2MHz test frequency. Additional components have been ordered to improve the accuracy and frequency range of this system.

A second system for dielectric constant measurement will use digital sampling methods. The analog to digital converters and sample-hold modules has been received and the control and readout circuits are being designed. This system should be more flexible than the present dielectric constant phase shift system.

Table 4-15. Core from Natural Buttes No. 21

Core	Depth in Feet	Porosity - Helium & Matrix Cup (%)	Porosity - Sat. Method (%)	Porosity - Helium Porosimeter (%)
1	4,441 ft 4.5 in.	5.2	2.9	4.6
2	4,441 ft 6.5 in.	4.6	4.2	4.8
3	4,441 ft 9.5 in.	3.0	2.0	3.3
4	4,442 ft	2.7	2.2	3.0
5	4,457 ft	2.8	1.7	3.1
6	4,457 ft 6.0 in.	3.9	3.6	4.5
7	4,453 ft 10 in.	4.4	4.2	5.3
8	4,450 ft 1.0 in.	5.2	4.1	5.2
9	4,460 ft 6.0 in.	5.0	4.4	5.5
10	4,463 ft 8.0 in.	3.6	1.9	3.3
11	4,463 ft 11 in.	3.3	2.9	3.9
12	4,465 ft 10 in.	4.2	3.4	5.0
13	6,405 ft	4.4	4.9	4.8
14	6,405 ft 10 in.	6.4	5.7	7.2
15	6,406 ft	6.2	5.4	5.6
16	6,423 ft 3.0 in.	5.1	4.3	5.5
17	6,472 ft 1.0 in.	8.5	8.0	8.1
18	6,472 ft 9.0 in.	5.5	4.8	5.6
19	6,473 ft 1.0 in.	7.2	6.1	7.1
20	6,473 ft 10 in.	10.8	10.3	10.0
21	7,423 ft	5.2	4.7	5.6
22	7,424 ft	5.9	5.4	6.2
23	7,425 ft 6.0 in.	6.5	5.9	7.1
24	7,426 ft	6.5	6.0	7.1
25	7,426 ft 11 in.	7.5	7.1	7.8
26	7,429 ft	8.7	8.7	8.4
27	7,430 ft	9.0	8.4	8.4
28	7,475 ft 3.0 in.	3.2	—	3.2
29	7,478 ft 1.0 in.	3.2	2.1	2.8
30	7,479 ft 3.0 in.	3.2	2.3	3.1
31	7,479 ft 6.0 in.	3.0	2.5	2.9
32	7,481 ft	5.6	5.6	5.5
33	7,482 ft	6.2	5.7	6.0
34	7,482 ft	5.8	5.4	6.0
35	8,425 ft	4.0	2.9	4.5
36	8,425 ft	3.7	2.8	3.9
37	8,434 ft 6.0 in.	8.7	7.6	8.7
38	8,434 ft 4.0 in.	9.8	9.2	9.2
39	8,436 ft 1.0 in.	9.0	7.4	8.8
40	8,437 ft	9.5	9.0	9.1
41	8,438 ft 2.0 in.	9.3	8.5	9.4
42	8,439 ft	7.2	6.6	6.4
43	8,483 ft	2.6	2.3	3.3
44	8,510 ft	4.1	3.4	3.7
45	8,512 ft 3.0 in.	4.3	3.8	5.0
46	8,513 ft	3.8	2.5	3.4
47	8,514 ft	6.4	5.5	6.3
48	8,515 ft 3.0 in.	10.0	9.1	9.6

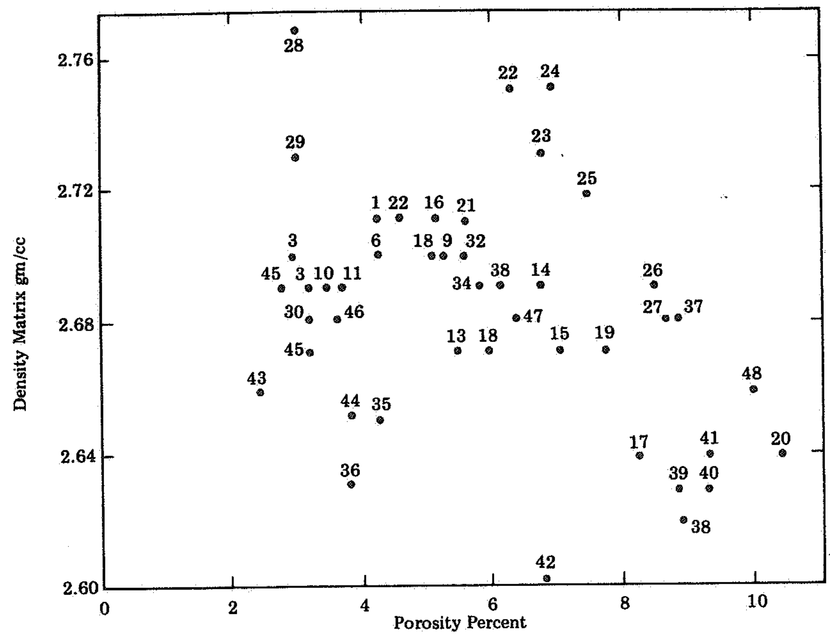

Figure 4-20. Matrix Density versus Porosity for Cores from Natural Buttes No. 21

Table 4-16. Coding samples from Natural Buttes No. 21

Plug No.	Log Depth	Zone	Plug No.	Log Depth	Zone
1	4,441 ft 4.5 in.		28	7,476 ft 3.0 in.	
2	4,441 ft 6.5 in.	A	29	7,478 ft 1.0 in.	
3	4,441 ft 9.5 in.		30	7,479 ft 3.0 in.	
4	4,442 ft		31	7,479 ft 6.0 in.	G
			32	7,481 ft	
5	4,457 ft		33	7,482 ft	
6	4,457 ft 6.0 in.		34	7,482 ft 1.0 in.	
7	4,458 ft 10 in.				
8	4,459 ft 1.0 in.	B	35	8,425 ft	
9	4,460 ft 6.0 in.		36	8,425 ft 11 in.	H
10	4,463 ft 8.0 in.				
11	4,463 ft 11 in.		37	8,434 ft 6.0 in.	
12	4,465 ft 10 in.		38	8,435 ft 4.0 in.	
			39	8,436 ft 1.0 in.	
13	6,405 ft		40	8,437 ft	
14	6,405 ft 10 in.	C	41	8,438 ft 2.0 in.	I
15	6,406 ft		42	8,439 ft	
16	6,423 ft 8.0 in.	D	43	8,483 ft	J
17	6,472 ft 1.0 in.		44	8,510 ft	
18	6,472 ft 9.0 in.		45	8,512 ft 3.0 in.	
19	6,473 ft 1.0 in.	E	46	8,513 ft	K
20	6,473 ft 10 in.		47	8,514 ft	
			48	8,515 ft 3.0 in.	
21	7,423 ft				
22	7,424 ft				
23	7,425 ft 6.0 in.				
24	7,426 ft	F			
25	7,426 ft 11 in.				
26	7,429 ft				
27	7,430 ft				

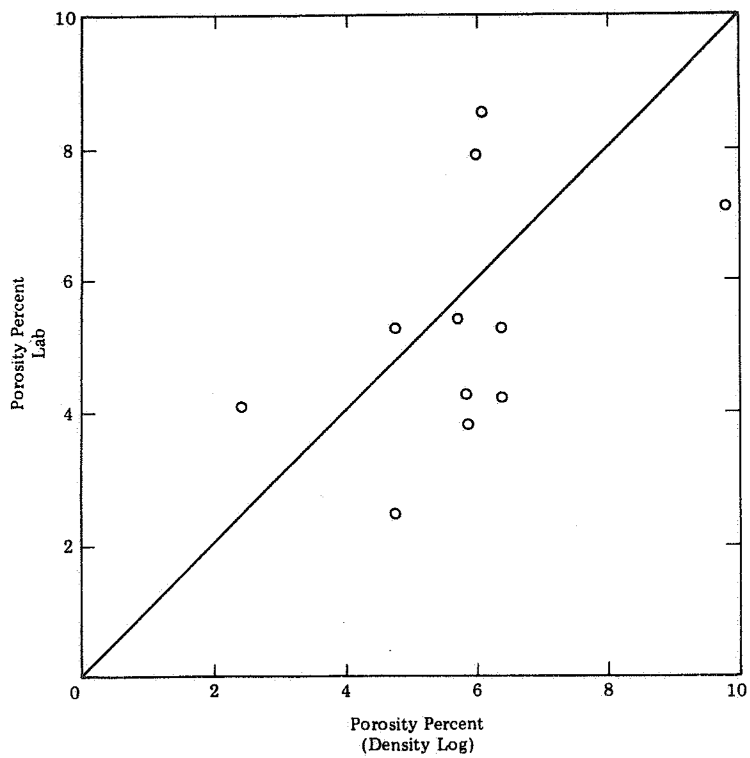

Figure 4-21. Porosity from Density Log and Core Analysis for Natural Buttes No. 21

4.3.2 GAS RESEARCH INSTITUTE

The Gas Research Institute (GRI) initiated a project for evaluations of reservoir fracturing to increase the producibility of tight gas reservoirs by providing essential field data. Three projects, which included hydraulic fracturing and testing of the Rio Blanco Natural Gas Company No. 397-19-1 Government well, evaluation of seismic data for detailed stratigraphic studies of lenticular sands, and coring and logging of Pacific Transmission Supply Company No. 22-12 Federal well, were funded and work has commenced.

HYDRAULIC FRACTURING AND TESTING OF RIO BLANCO NATURAL GAS COMPANY NO. 397-19-1 GOVERNMENT WELL

The reservoir analysis of the Rio Blanco Natural Gas Company well No. 397-19-1 Government was initiated. The well was blown down on September 5 in preparation for a new set of perforations (pre-fracture stimulation was unsuccessful). Prior to perforation, the well was gauged at 1 to 2 psi flowing through a 1/16 in. orifice after approximately two hours of flow (the well had a stabilized flow). The well was then shut-in for a BHP buildup test. The test, conducted from September 13 to September 19, indicated approximately the same flow capacity, kh, as derived from the previous two tests in July. This was postulated from a final flow capacity value of 20 μd-ft.

EVALUATION OF SEISMIC DATA FOR DETAILED STRATIGRAPHIC STUDIES OF LENTICULAR SANDS

A project has been funded to perform seismic research using recently developed techniques to see if the geometry and character of lenticular sands at depth can be determined. Sandia Laboratories plans to obtain data from the Uinta Basin that will complement and extend outcrop and core hole studies being made under contract to DOE.

A contract has been negotiated with Seismic International Research, Inc. to perform a twelve-fold survey in the eastern Uinta Basin. This survey will use an existing core hole and existing outcrop control to delineate sand lenses to a depth of 500 ft.

CORING AND LOGGING OF THE PACIFIC TRANSMISSION SUPPLY COMPANY NO. 22-12 FEDERAL WELL

The PTS No. 22-12 Federal well was spudded July 7, 1979, and is targeted to the Dakota Formation at 14,500 ft. Coring of the Mesaverde commenced August 17 and was completed in four days. (See section 4.2.2, Coring Program, for further details). Coring of the Mancos B should take place in October. Approximately 120 ft of 4 in. core is planned within the interval 10,460 - 11,000 ft, with the exact depths to be determined on the basis of information available at that time.

Logging operations will take place after the completion of all coring activities.

4.3.3 LAWRENCE LIVERMORE LABORATORY

THEORETICAL ANALYSIS

Two-dimensional analyses of the dynamic propagation of fractures near interfaces were performed with the dynamic elastic computer code TEMS.[1] This code has been used extensively to study dynamic fracture propagation and earthquake source mechanics, and is based on Lagrangian techniques to solve equations describing the continuum. It requires the use of a calculational grid over which the response of the continuum is calculated. The number of nodal points (grid blocks) in the calculational grid must be limited since computers are of finite size and calculations must be performed within a reasonable amount of computer time. Hence, the grid is terminated over some finite part of the continuum. Boundaries of the calculational grid then act as reflection surfaces to the dynamic phenomenon which is being studied and, if the grid boundaries do not coincide with physical boundaries, non-physical reflections result. These limitations strongly influence the grid size requirements for a calculation because the calculations are normally terminated before the non-physical boundary reflections cross the areas of interest in the grid.

Techniques have been proposed to remove or significantly reduce reflections from calculated mesh boundaries.[2,3] The Dirichlet and Neumann conditions are summed incrementally at the boundaries of a finite element/finite difference mesh to eliminate reflections. This incremental approach eliminates reflections as soon as they occur. Application of the technique requires a small superposition mesh around the boundary of the regular calculational grid (Lagrangian mesh). Two complete solutions are then possible, one in the regular mesh and the other in the superposition mesh. Reflections at a boundary are then eliminated by adding to solutions incrementally in the two overlapping grids. The two overlapping grids have separate boundary conditions: fixed in the normal direction, free in the tangetial direction, and free in the normal direction and fixed in the tangential direction. All variables in the two grids are then averaged every third and fourth computational cycle.

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[1]Petschek, A. G., and M. E. Hanson, "Difference Equations for Two-Dimensional Elastic Flow," J. Comp. Phys. 3, 307-320 (1968).

[2]Smith, W., "A Non-Reflecting Plane Boundary for Wave Propagation Problems," J. Comp. Phys. 15, 492-503 (1973).

[3]Cundall, P. A., R. R. Komar, P. C. Carpenter and J. Marti, "Solution of Infinite Dynamic Problems by Finite Modeling in the Time Domain," unpublished report (1978).

This technique significantly reduces boundary reflections and is being included in the dynamic fracture code being used to analyze dynamic fracture propagation near interfaces.

Analyses of crack propagation near an interface were completed using quarter-plane symmetry in an finite element model. A material was sandwiched between pieces of another material which was characterized by a different elastic constant. A crack, initiated at the midpoint between the interfaces formed by the two materials, propagated bilaterally to the interfaces.

The motion of a point near one interface was followed as the crack propagated to the interfaces and stopped. Calculations continued until the reflected elastic waves from the opposite interface arrived. Even when the crack speed was half the dilational wave speed, these reflected waves arrived shortly after the crack stopped so that particle motion near the crack tip could not be followed for a sufficient time to determine the material rebound characteristics. Reflected waves were not allowed to affect the particle motion because this geometry represented the fracture processes in the earth. The crack could approach one interface unaffected by the presence of another symmetrically located interface. In order to solve this geometry, the model was enlarged so that analysis can be performed using half-plane symmetry.

A time dependent finite element model has been developed, modified and used to determine the material overshoot characteristics from a crack which initiates, propagates bilaterally at half the dilatational wave speed, and stops when one tip reaches an interface. The problem geometry is shown in Figure 4-22. The final half crack length and the time interval from crack starting to stopping is denoted as c and t_d, respectively. The problem is solved in plane strain and the coordinate system is referenced to the center of the crack. The densities of the two materials are set equal (2.7 gm/cm^3), and the Lamé constants for each material are also equal so that Poisson's ratio is 0.25 for both materials.

Calculation results are shown in Figure 4-23. Nondimensional vertical displacement, v/c, is plotted versus nondimensional time, t/t_d, for the point x = 0.8 c, y = 0.1 c. Three calculations were made, corresponding to three sets of values for the Lamé constants as shown in Figure 4-23. The constants μ_1 and λ_1 were kept at 30 GPa for all three calculations so that the center curve corresponded to the homogeneous case. Points of maximum displacement are related to the maximum likelihood of crack reinitiation. Interface penetration becomes less likely and peak displacement occurs earlier as the second material becomes stiffer.

The equilibrium model was applied to analyze some of the effects of frictional interfaces on a pressurized fracture as the crack propagated toward the interface. Three calculations were performed with these different frictional stresses applied along the interface. The geometry of the fracture and the interface used in the calculations are shown on Figure 4-24. The pressure in the crack was constant, and the material

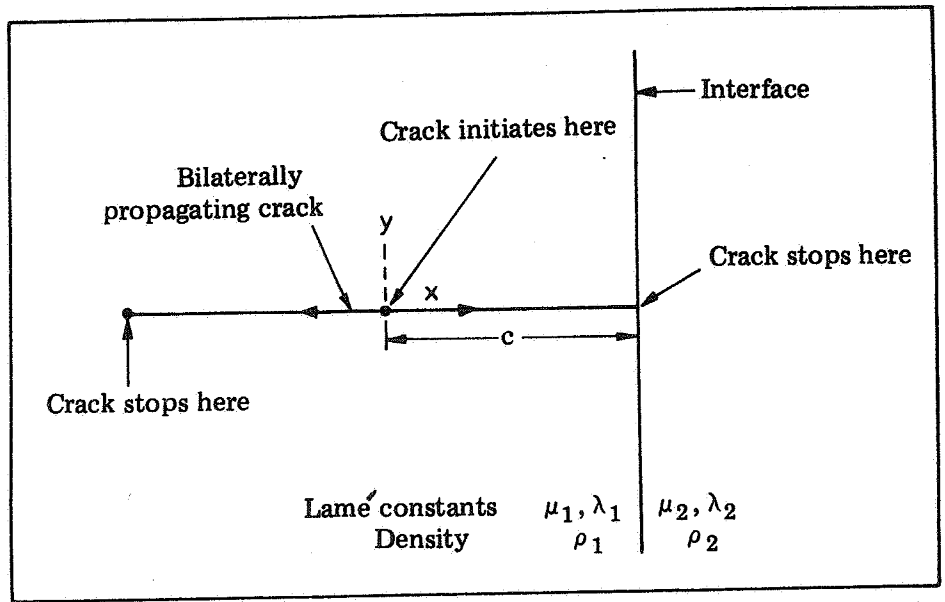


Figure 4-22. Geometry of time dependent crack problem

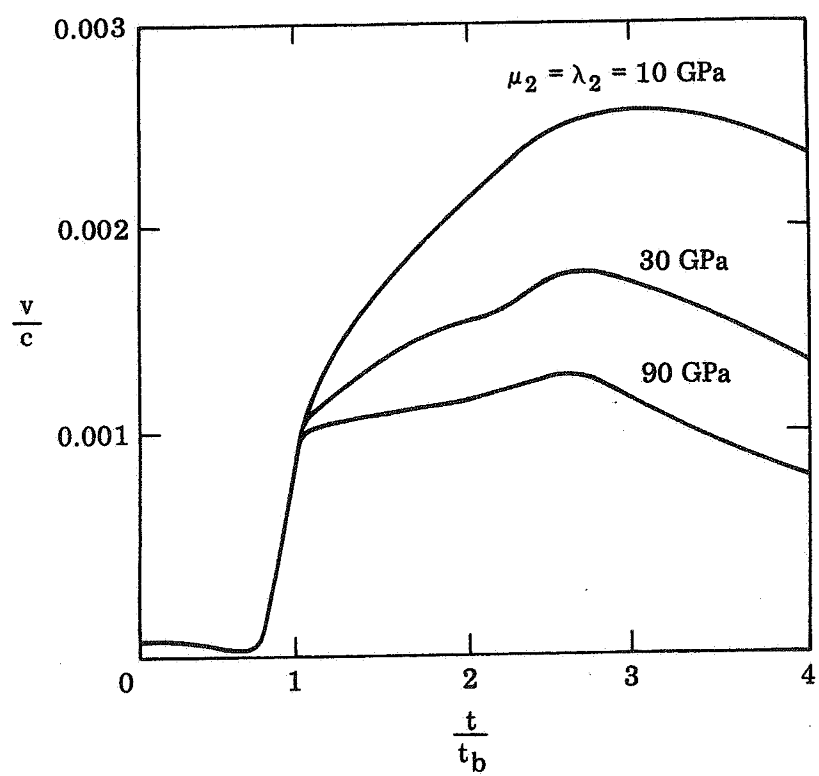


Figure 4-23. Displacement in y direction of point $x=.08c$, $y=.01c$. The elastic constant for material 1 is 30 GPa

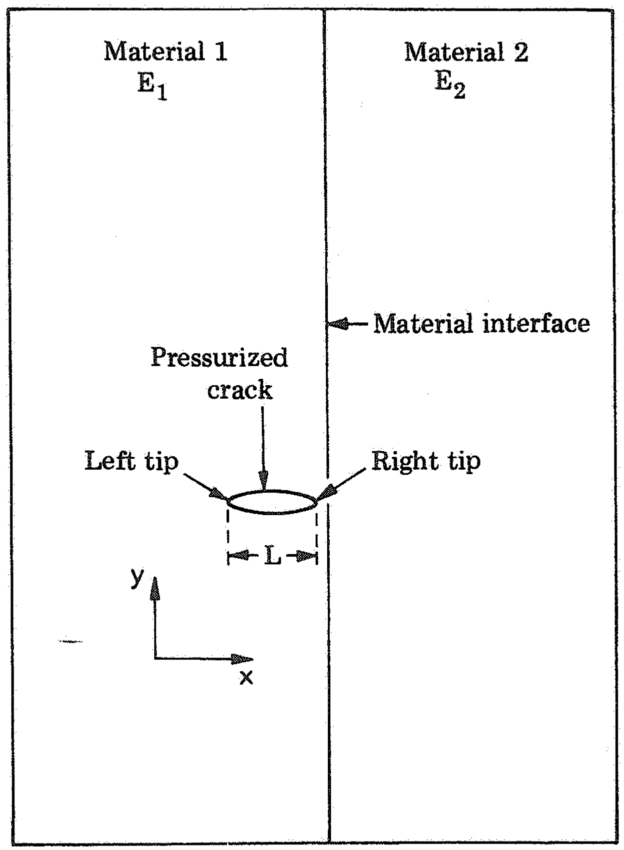


Figure 4-24. Geometry of a fracture near a frictional interface

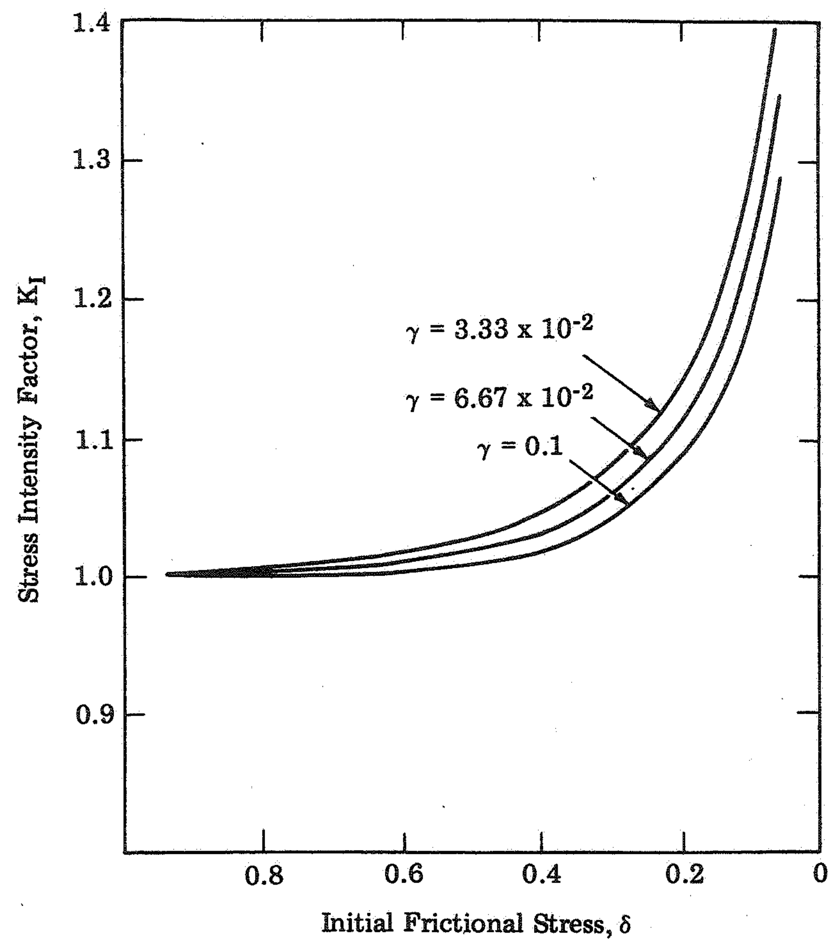


Figure 4-25. Variation in Mode I stress intensity factor as crack approaches a frictional interface for variations in frictional stress along the interface

on both sides of the interface was identical with a Poisson's ratio equal to 0.25. The ratio of the pressure in the crack to Young's modulus for the material (P_c/E) was 1.5×10^{-3}. In these calculations, the effects of changes in pore pressure due to leakage of fluid from the crack into the surrounding material was ignored.

The results of the calculations are shown on Figure 4-25 with the distance of the crack from the interface scaled with the crack length. The ratio of the initial frictional stress to the pressure in the crack $\lambda = \tau_f/P_c$, for these three sets of calculations was 0.033, 0.067 and 0.1. In these calculations, the crack did not penetrate the interface; therefore the frictional conditions for penetration of the interface have not been evaluated. However, experimental data which can provide correlation for these analyses are being developed. The results presented show how changes in the interfacial frictional stress tends to enhance or impede fracture propagation toward the interface.

EXPERIMENTAL PROGRAM

Frictional experiments on dry Indiana limestone have yielded static coefficients of friction of $\mu = 0.61$ and 0.51 for rough and smooth interfaces, respectively. Similar experiments on dry Nugget sandstone have yielded static coefficients of friction of $\mu = 0.59$ and 0.54 for rough and smooth interfaces, respectively. These preliminary values are subject to further analysis and interpretation. Roughening the sliding surfaces by sandblasting increased the coefficient of friction approximately 11 percent for sandstone and 18 percent for limestone above the values of smooth surfaces. Results of the friction experiments are summarized in Figure 4-26. It was also found that with Inidiana limestone, water saturation decreased the tensile strength. The decrease in tensile strength and the increase in the coefficient of friction with water saturation is consistent with the earlier observed decrease in threshold normal stress required for a crack to cross an unbonded interface in saturated limestone from the threshold value for dry limestone. Also, the decrease in the coefficient of friction between smooth surfaces of Nugget sandstone is consistent with the earlier observed increase in threshold stress for cracks to cross an interface made up of these surfaces.

These results indicate that the presence of water has different effects on crack growth across interfaces of different rock types. Water weakens the rock fabric in limestone and enhances comminution of the sliding surfaces. The presence of water in sandstone appears to lubricate the surfaces.

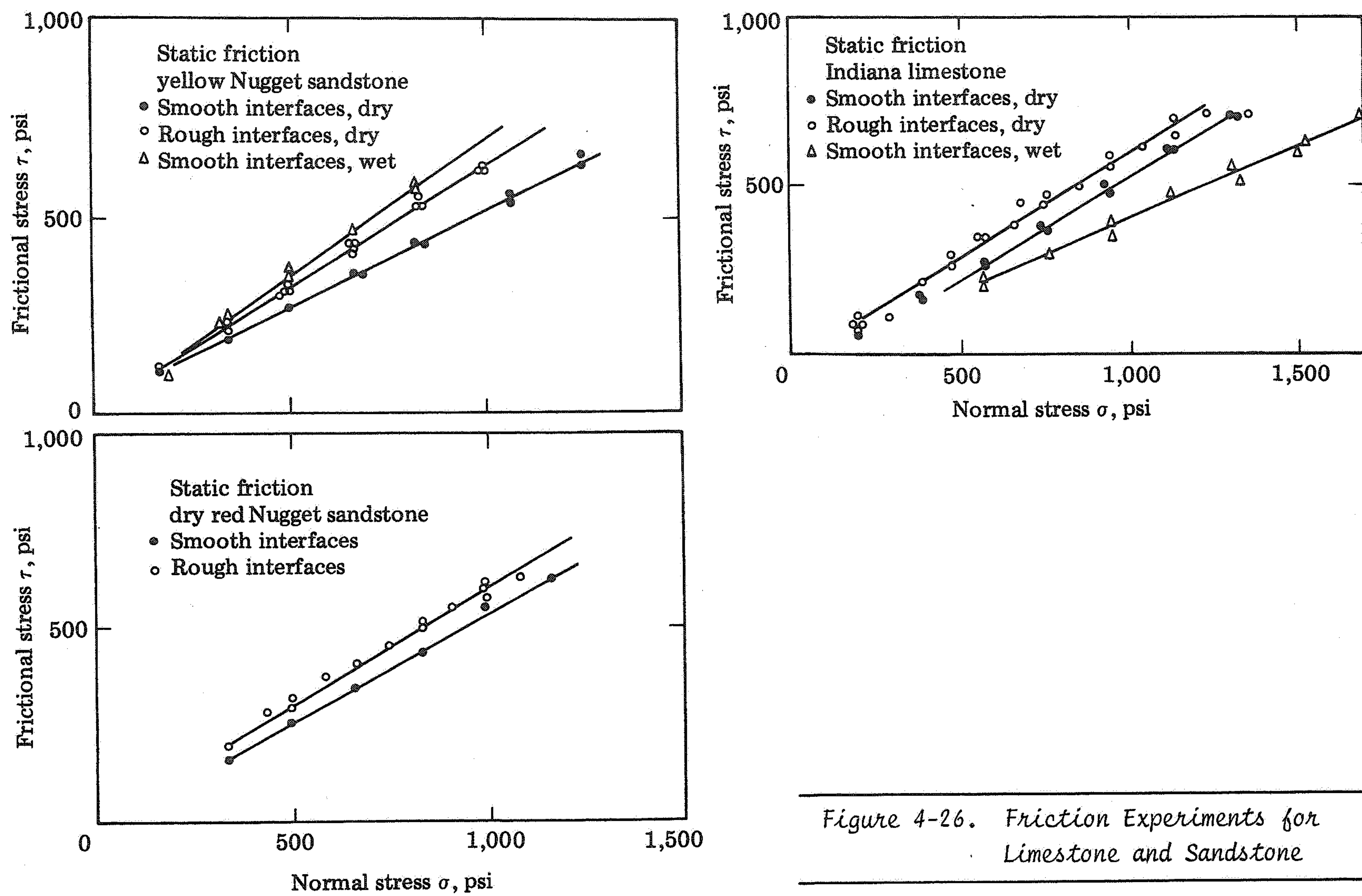


Figure 4-26. Friction Experiments for Limestone and Sandstone

Hydraulic fracture experiments showed a different normal stress threshold for crack growth across rough and smooth interfaces in the sandstone while no difference in stress threshold was observed in experiments on limestone. Frictional characteristics of rough and smooth surfaces of Nugget sandstone at present appear more similar than those in the limestone.

Blocks were fabricated out of limestone and used in experiments to study the behavior of a hydraulic fracture in the vicinity of the line where two perpendicular unbonded interfaces, one of which supports a normal load, intersect. The purpose of these experiments was to simulate the case in which the hydraulic fracture approached an interface near the region in which the interface is intersected by a pre-existing crack. This case has been modeled theoretically and the results of the calculations suggest that the presence of pre-existing cracks alters the effective moduli of the material.

Experiments were made to study hydraulic crack growth in limestone near interfaces which were intersected by cracks. The test setup, shown in Figure 4-27, consisted of a sandwich of three 4 in. x 4 in. x 2 in. limestone blocks and the fluid pressurized crack initiated and driven in the center block. A load was applied so that a normal stress was set up across interfaces I_1 and I_2. In these experiments, however, the upper block consisted of three blocks which were precisely machined and aligned adjacent to one another to give the effect of pre-existing cracks, C_1 and C_2, which intersected the interface I_1 at right angles. In an initial experiment in which the applied load, W, exceeded the threshold stress for crack growth across unbonded interfaces in limestone ($\sim$ 650 psi), the pressurized crack crossed the interface I_2 from the central block in which it was initiated into the lower single block. It failed to cross the interface I_1 which was intersected by cracks C_1 and C_2. This result is consistent with the predictions of the mathematical model if the mode I stress intensity factor is used as a criterion for predicting crack growth. However, this result must now be considered preliminary and subject to further modification as it is based on one observation.

4.3.4 LOS ALAMOS SCIENTIFIC LABORATORY

A study of the microstructure and dynamic behavior of various Western gas sands core samples has been initiated. By elucidating the physical structure of these particular reservoir rocks, as well as their response to varying conditions of temperature and pressure, the macro scale behavior of fluids present in these formations can be more completely understood and predicted. The principal analytical methods employed in this effort included scanning electron and optical microscopy.

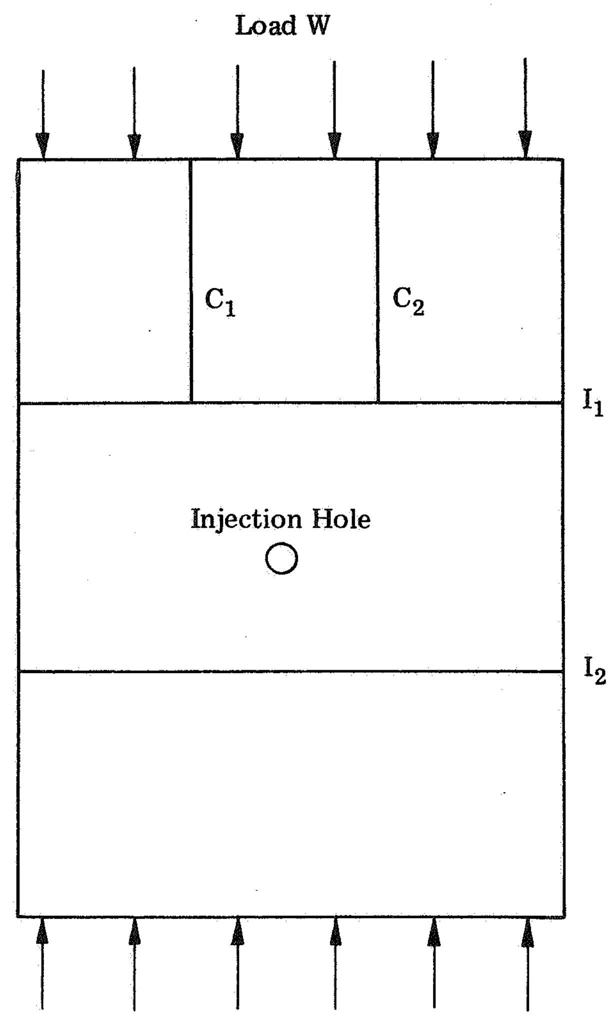


Figure 4-27. Experimental Setup for Fracture Growth (C_1, C_2) near Interfaces I_1 and I_2

The relationship between microstructure and the bulk permeability and porosity of a given formation is believed to be a key element in the production of a tight reservoir. An experimental program has been designed to clarify this relationship, and includes:

- microstructure analysis,
- compression/extension dynamics and
- thermal behavior.

Core samples from the Twin Arrow well C&K No. 4-14 (Piceance Basin) were crushed, pulverized, and analyzed for nitrogen, carbon, hydrogen, and total ash content after combustion on the CHN analyzer. Three of the pulverized samples were dried at 100°C for 20 hrs and compared with samples which were analyzed directly after pulverization. The CHN results showed no statistical differences due to drying.

Each sample was analyzed at least three times. The reported values in Table 4-17 represent the averages of all the runs plus the standard deviation.

Table 4-17. CHN Analysis of Core Samples from Well C&K 4-14

Depth (ft)	% N	% C	% H	% Ash
1,009.45 - 1,009.65	0.155 ± 0.013	3.29 ± 0.16	0.625 ± 0.053	88.9 ± 0.5
1,010.35 - 1,010.50	0.169 ± 0.023	3.81 ± 0.40	0.651 ± 0.081	89.0 ± 0.3
1,012.35 - 1,012.60	0.226 ± 0.044	1.95 ± 0.27	0.362 ± 0.034	91.0 ± 0.1
1,013.75 - 1,013.95	0.155 ± 0.017	1.03 ± 0.06	0.349 ± 0.031	94.4 ± 0.1
1,015.60 - 1,015.80	0.061 ± 0.094	1.73 ± 0.13	0.532 ± 0.023	85.5 ± 3.4
1,016.90 - 1,017.10	0.054 ± 0.020	1.58 ± 0.15	0.517 ± 0.058	91.4 ± 1.0

In order to establish the scientific feasibility of Nuclear Magnetic Resonance (NMR) logging using the remotely-produced region of homogeneous field, experiments were initiated to measure the sensitivity of NMR detection to samples outside a radio frequency coil.

This was first tested at 20 MHz in a 9-in. electromagnet using a 1 cm diameter sample coil. A 1 cm hole was bored in a neoprene stopper. A plug was inserted in the coil and used to obtain a reference signal. The remaining annular part of the stopper was placed around the coil. A signal from the exterior annulus was obtained when the radio frequency pulse length was increased from that used to obtain the interior signal. This was necessary due to the reduced strength of the radio frequency field outside the coil.

A larger coil (approximately 1.5 cm x 4 cm) was wound to resonate at the logging density frequency of approximately 0.5 MHz. Since the lower frequency limit of the NMR preamp and receiver used for the 20 MHz was 2 MHz, it was necessary to design and build a suitable system capable of operating at 0.5 MHz. A new coil and radio frequency system were used successfully to detect signals from the sample exterior to the coil at 0.5 MHz in the laboratory electromagnet.

To remove the influence of the large iron pole, pieces of the electromagnet and a pair of 10-in. diameter coils were wound and arranged to form a Helmholtz pair. This provided a uniform field so that annular samples of one to two inches in diameter could be studied. A 1-in. diameter radio frequency coil was wound, and a set of concentric pyrex cups was made. This allowed the 1-in. diameter coil to be centered in annuli of various diameters and thicknesses.

An extensive set of measurements (using glycerol as the sample material) was made on the signal size of various annular samples relative to a standard sample internal to the coil.

4.3.5 SANDIA LABORATORIES

HYDRAULIC FRACTURE CHARACTERIZATION

Seismic evaluation tests of the borehole seismic unit at the Nevada Test Site have been completed. The borehole seismic unit was clamped in a 20-ft hole in the floor of the Madison drift in the G-Tunnel. A triaxial geophone unit (identical to the clamped unit) was grouted in a 20-ft hole 1.5 ft from the borehole seismic unit. Five other 20-ft holes were drilled to be used as locations for induced seismic activity from a spark plug, pellet gun and a solenoid. Various locations on the floor of the tunnel were used to induce signals from hammer blows. In addition to induced seismic signals, the borehole seismic unit was vibrated at numerous frequencies by use of the attached geophones to determine resonant frequencies.

Signals arriving at an angle greater than approximately 55^{o} from the horizontal may produce large errors due to the low amplitude of the P-wave signal. This was found to be true for the system grouted in the tuff. The S-wave onset is also detectable and apparently responsible for inducing the resonant ringing in the borehole seismic unit.

Further examination of the data is necessary to determine the accuracy of measuring the vertical angle to the seismic source and accuracy of predicting distance to the source.

BOREHOLE HYDROPHONE SYSTEM

The complete hydrophone system underwent electrical and high pressure testing in the Sandia borehole and at the Sandia base. A source of noise was found in the system. Corrections were made and the output signal-to-noise ratio of the system was improved.

The hydrophone system was field tested in the Sandia borehole. The bottom of the 6-in. diameter hole was determined to be at 243 ft. The bottom of the 6-in. diameter casing was 200 ft. The water level was detected at a depth of 142 ft. Two types of tests were made on the system. One consisted of a series of hammer blows on the surface at various distances from the hole. The second included a small vibrator placed approximately 40 ft from the hole, which was driven at cw frequencies from 30 to 500 Hz. A driving frequency of 100 Hz was chosen in recording the hydrophone output signals. In addition to recording the output on a paper recorder, the differences in phase between all hydrophones were measured on an oscilloscope. These measurements were made with the top of the hydrophone tool varying from a depth of 150 to 170 ft in 2-ft increments. Preliminary analysis of the data indicated that multiple reflections from the formation or standing waves in the borehole may have caused the measured formation velocity to be in the range of 1,000 to 2,000 feet-per-second. Since it is believed that the formation velocity should be in the order of 5,000 feet-per-second, another test in the borehole was scheduled in order to determine if the reflection or standing wave interference was causing problems.

In the second series of tests performed on the hydrophone system, the water level in the borehole was increased from 142 ft from the surface to 10 ft. Data from the vibroseis source and hammer blows were recorded. Although thorough analysis of the data has not been made, preliminary investigation indicated the change in the water level did not appreciably influence the data. The signals received from vibroseis locations greater than 50 ft from the borehole were too small to be useful because the power output from the vibroseis was low. A series of tests are being scheduled for the Carlsbad area where deeper boreholes and a more powerful vibroseis are available.

BOREHOLE SEISMIC SYSTEMS

A seismic borehole test was attempted in an Amoco gas well near Marshall, Texas. Signals from the geophones could not be transmitted to the surface due to cable characteristics. It was then discovered that a special high temperature logging cable had been brought in which had not been previously tested. The losses were much greater with the high temperature logging cable than the standard logging cable. The borehole seismic system has since been modified to provide greater driver capabilities and amplifiers have been added to the surface instrumentation. Cable characteristics are also being obtained from the manufactures. Later, two cables were located in the Marshall area that were suitable.

Tests are rescheduled to be fielded in the Shell Oil Company well No. 343 near the Texas-Oklahoma border. The exact date has not been set at this time. A second borehole seismic system will be placed in an adjacent well (No. 309) about 600 ft from the well to be completed (No. 343); this well will be in line with faults in this area. Seismic activity will be monitored in both wells during the breakdown phase. During the main fracture treatment, the seismic unit that was used in well No. 343 will be moved to well No. 333, which is also about 600 ft away but to the north rather than to the east. Surface explosive charges will be used in order to determine package orientation. Successful detection package orientation could eliminate the requirement of the cumbersom and reliable gyro system now being used. The seismic signals from this test will be digitized and stored in a PDP-11 using threshold detectors, thus storing larger seismic signals in near real time. The signal obtained can then be plotted and fracture orientation can be determined even before the fracture is complete if the explosive charges produce the desired results in fixing the seismic system position.

Data analysis from the borehole seismic system evaluation test at the NTS has been completed. Even though the system has resonances, the p-wave and s-wave arrivals can be determined as accurately as with a grouted system, and vertical angles of up to 70 degrees present no serious problems provided the signal is relatively large.

NUCLEAR MAGNETISM LOGGING

Core analyses of eleven samples from CIGE NBU No. 21 are in progress at Petroleum Testing Service, Santa Fe Springs, California. NMR analysis of these same samples will follow the initial tests and will be performed at Chevron Oil Field Research Company laboratories. Sandia will participate in the NMR experiments.

ADVANCED ELECTROMAGNETIC LOGGING TECHNIQUES

Experiments in electromagnetic logging techniques performed at Sandia Laboratories yield information concerning the resistivity, dielectric constant and magnetic permeability of formation materials. A major part of the Sandia logging effort is to relate these electrical parameters to reservoir parameters such as porosity, gas to water ratios, and fluid flow permeabilities. In regard to this goal, recent efforts by BETC have been directed toward relating the dielectric and resistive properties of sandstones saturated with saline water to pore volumes and shapes.

Data have been published on the electrical impedance of saturated sandstones in the 1.5 kHz to 1.8 kHz range. Success has been achieved in fitting these data with a model based on a Maxwell-Wagner-Sillars dispersive dielectric coupled with a nondispersive resistivity given by Archie's law. While the present model qualitatively represents available data, a quantitative model will require a distribution function describing pore shapes. With such a function, the rock matrix will be better described than if only the porosity is known. For example, a continuum of pore-volume and pore-surface areas may be modeled thereby paving the way for fluid permeability determinations through the use of a generalized Kozeny equation. Furthermore, extensions of the model to a three-component system could yield hydrocarbon-water ratios for pore fluids.

The INDINV computer code is being developed to model the response of an induction tool in a borehole with variable conditions of horizontal layering and depths of filtrate invasion. A subroutine was added to the code which automatically reduced the spatial mesh spacing when finer resolution was required for the rapidly varying electromagnetic fields near the source.

The boundary value problems for induction logging tools have been directed toward mathematical transformations between cylindrical and spherical Hankel functions, resulting in improved analytical understandings of tool limitations without numerical integrations. Literature published by U.S. and Soviet investigators stated that asymptotic expansions have established the criteria for neglecting borehole effects without numerical results. The remaining problems concerning invasion-zone effects are more difficult and cannot be treated without numerical integrations.

In the course of investigation of models for electrical response, the following additional observations have been made.

- Alternate models need to be considered in which the dielectric properties are constant, whereas the conductivity is dispersive (data in the frequency region 1 to 10^6 Hz).

- Data are required to test the proposed relation between the fluid flow permeability and the dispersive dielectric properties of rocks. Likewise, data concerning three-component systems are needed.

- Any logging tool operating under the principles of this paper will be a broad band device. Present logging systems are limited in this capability.

- Sulfides, clays and other matrix materials with complicated electrical properties may negate the assumption of a nondispersive conductivity. This assumption may not be strictly valid for any rock matrix.

- Statistical models of rock grain and pore geometries are compatible with information potentially available from broad band measurements and they need development.

Models used to predict the response of induction logging tools have all assumed a point-source magnetic dipole for the simulation of the transmitting and receiving coils. A higher order series expansion of a single turn coil has been made. The convergence of this series for a coil of finite size has been established and the series has been incorporated into cores required for the evaluation of induction logging techniques in homogeneous media. One significant point of the Sandia solution is that the receiving coils can now be placed as close as one coil diameter to the transmitting coil. Thus, accurate predictions, which were previously unavailable, can now be obtained.

A computer program for analytical calculations for the inductive coupling between single turn coils in a homogeneous medium is now being used. Parametric curves indicate that, under the point-source assumption, an error as large as 25 percent of the correct values can exist for coils whose diameters are less than 0.1 wavelength. When these coils are assumed to be point sources, the induced voltages are always larger than those from solutions, and their errors decrease in proportion to separation distances. For errors to be less than 1 percent of the correct values, the coils need to be separated by a distance of 10 coil-diameters or greater. This separation distance is commonly assumed in the analyses of induction logging devices. When this separation is designed into tools, the probes suffer a loss of sensitivity and may suffer a lack of capability for the determination of the constitutive parameters.

Parametric curves on response sensitivities have been prepared for probe design purposes. After coil diameters are specified and the receiver dynamic ranges are determined, the coil separations can be quickly established according to operating frequencies. For a coil diameter of 2.5 cm, operating frequencies may vary from about 120 kHz to 1.2 GHz in free space. The high frequency limit is reduced in inverse proportion to the refractive index of a medium. Due to the absence of a theory for multi-turn coils, the present results are only applicable to single-turn systems. Multi-turn coils require careful calibrations to assure the accuracy of constitutive parameters in the inversion process.

Receiving-coil responses as functions of constitutive parameters of rocks are being obtained. Inherently low sensitivity is known for low-frequency operations. Better sensitivity can be obtained for frequencies up to 1.2 GHz for small coils. However, gas-oil production parameters will have to have better correlation with constitutive parameters before the most suitable frequencies of operation can be found.

Recently Poley, Nooteboom and deWall published data on the frequency, dependent electrical response of saturated sandstone cores. In their experiments, the measured current was due to conduction and displacement currents. In the model of these experiments, Archie's equation was used to describe the conductivity, whereas a Maxwell, Wagner, Sillars system governed the dielectric response. Some aspects of the Poley, et al data are well represented by such a model. However, a continuum of Maxwell, Wagner, Sillars systems describing a continuum of pore shapes will be required to model all aspects of the data. Dielectric measurements yield information over and above simple porosity determinations, and this information may be relatable to fluid flow permeabilities through the Kozeny equation.

One description of a relaxing dielectric is

$$\varepsilon(\omega) = \varepsilon(\infty) + i\int_0^\infty \frac{A(k)dk}{\omega + i1}$$

where A(k) is the distribution function in frequency space. Several A(k) functions were fit to the real part of $\varepsilon(\omega)$ given by Poley, et al. Although some are complicated, a simple A(k) represented by a histogram,

$$A_1 \ , \ 10^7 < k < 10^8 \text{ Hz},$$
$$A_2 \ , \ 10^5 < k < 10^7 \text{ Hz},$$

etc.

fits the data well. A test of the model ($\varepsilon(\omega)$ agreeing with the data) was successful.

Work is underway to transform this frequency distribution function into distribution functions of preshapes.

4.4 FIELD TESTS AND DEMONSTRATIONS

4.4.1 BACKGROUND

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 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,
- MHF demonstrations in the Piceance Basin, Colorado, by Mobil Research and Development Corporation and Rio Blanco Natural Gas Company, and
- a mineback testing program by Sandia Laboratories.

Table 4-18 summarizes completed and active WGSP MHF treatments. Progress of these projects is presented in the following sections.

Table 4-18. MHF Contract Location and Frac Data

Company Basin & Formation	Location T/R/Sec	Well	Interval Fractured ft	Fracture Date	Fracture Treatment Lb of Sand	Injected Fluid 10^3 Gal	Production Rates MCFD Before	After	Ratio
AUSTRAL Piceance, Mesaverde	7S/94W/Sec 3 Garfield Cty, Colorado	Federal 3-94	6,198-6,333 5,170-5,630	8-13-76 8-25-76	420,000 720,000	226 Gel 316 Gel	35	62	1.8
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 05-02-75 04-04-76 11-03-76	400,000 880,000 815,000 448,000	117 Gel 285 Gel 400 Gel 228 Gel	60 — 42 57	60 40 160 70	— — 3.8 1.2
DALLAS PRODUCTION Fort Worth, Bend Cong.	Ben D. Smith Survey A-779 Wise Cty, Texas	Ferguson A-1	5,957-6,794	09-16-76	506,000	139 Foam 198 Emul	40	15	—
EL PASO NATURAL GAS Northern Green River, Fort Union	30N/108W/Sec 5 Sublette Cty, Wyoming	Pinedale Unit No. 5	10,950-11,180	07-02-75	518,000	183 Emul 8 Gel	150	340	2.3
			10,120-10,790	10-20-75	1,422,000	459 Gel	—	150	—
GAS PRODUCING ENTERPRISES, INC. Uinta, Wasatch and Mesaverde	10S/22E/Sec 10 Uintah Cty, Utah	Natural Buttes No. 18	6,490-8,952	09-22-76	1,480,000	745 Gel	—	1,400	—
	10S/21E/Sec 21 Uintah Cty, Utah	Natural Buttes No. 19	8,909-9,664 7,224-8,676	09-21-76 09-28-76	424,000 784,000	280 Gel 364 Gel	—	166	—
	9S/21E/Sec 22 Uintah Cty, Utah	Natural Buttes No. 14	6,646-8,004	03-15-77	1,093,000	544 Gel	38	800	21.0
	9S/21E/Sec 28 Uintah Cty, Utah	Natural Buttes No. 20	8,498-9,476	06-22-77	826,000	322 Gel	75	1,200	16.0
	10S/22E/Sec 18 Uintah Cty, Utah	Natural Buttes No. 22	6,838-8,550	11-21-77	1,151,000	499 Gel	—	700	—
	9S/22E/Sec 19 Uintah Cty, Utah	Natural Buttes No. 9	5,661-8,934	03-27-78	554,000	349 Gel	140	540	3.9
	10S/21E/Sec 29 Uintah Cty, Utah	CIGE No. 2	9,237-9,653 7,251-8,774	06-22-78 08-08-78	170,500 1,965,000	203 Gel 722 Gel			
	10S/22E/Sec 7 Uintah Cty, Utah	Natural Buttes No. 23	5,080-6,294	10-04-78	470,000	240 Gel	—	800	—
MITCHELL ENERGY Cotton Valley, Limestone Trend	Limestone Cty, Texas	Muse-Duke No. 1	11,235-11,418	11-15-78	2,800,000	891 Gel	2,000	6,600	3.3
MOBIL Piceance, Mesaverde	2S/97W/Sec 13 Rio Blanco Cty, Colorado	F31-13G	10,549-10,680 9,392-9,538 8,765-8,972 8,163-8,650 7,704-7,794 7,324-7,476	06-22-77 08-24-77 05-10-78 07-06-78 09-07-78 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	300 700 479 — — 1,000	800 2,600 430 360 180 2,000	2.7 3.7 — — — 2.0
PACIFIC TRANSMISSION Uinta, Mesaverde	8S/23E/Sec 25 Uintah Cty, Utah	Federal 23-25	NO FRACTURES PERFORMED						
RIO BLANCO NATURAL 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	57 80	130 350	2.3 4.4
WESTCO Uinta, Mesaverde	10S/19E/Sec 34 Uintah Cty, Utah	Home Fed. No. 1	10,014-10,202 7,826-9,437	12-21-76 10-01-76	500,000 600,000	248 Gel 412 Gel	33 40	155 Water	4.7 —

RIO BLANCO MASSIVE HYDRAULIC FRACTURING EXPERIMENT

EY-76-C-08-0623

CER Corporation
Las Vegas, Nevada

Status: Awaiting Advisory Committee Decision

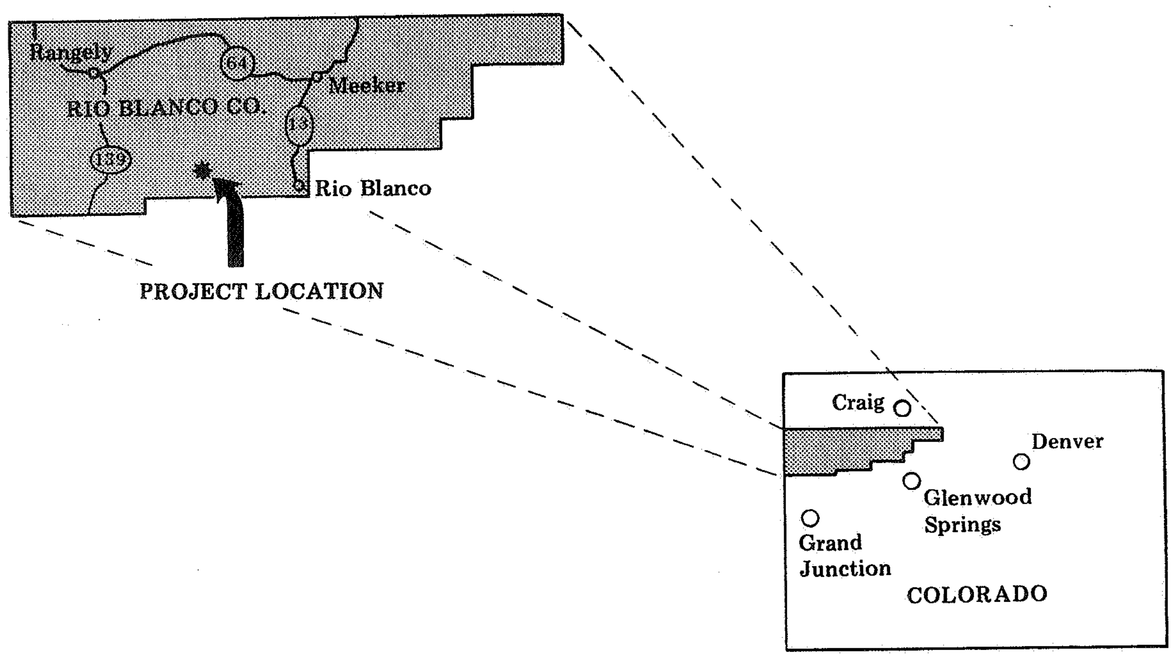
Interagency Agreement Date: June 19, 1974
Anticipated Completion Date: December 31, 1978

Project Cost (estimated):	DOE	$1,975,000
	Industry	1,630,000
	Total	$3,605,000

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.



4.4.2 CER CORPORATION

DOE contract EY-76-C-08-0623 was awarded to CER Corporation in March, 1974 for the drilling of a well and two MHF treatments in Rio Blanco County, Colorado. Contract modifications added two additional MHF treatments.

Three documents developed to close out CER involvement in the MHF experiment were:

- assignment of MHF experiment rights and obligations between CER Corporation and Rio Blanco Natural Gas Company;
- agreement and consent to assignment among the DOE, CER Corporation and Rio Blanco Natural Gas Company,
- agreement and assignment of rights of recoupment among Rio Blanco Natural Gas, Equity and the fifteen industrial participants.

CER Corporation is transferring the MHF well in return for the agreement that an attempt will be made to complete the well, commingle the previously fractured zones, test the well and provide the data to the industrial participants and DOE.

The transfer is still pending. A comprehensive 3 volume final report on the RB MHF-3 well has been released.

WATTENBERG FIELD

EY-77-C-08-1514

Colorado Interstate Gas Company
Colorado Springs, Colorado

Status: Active

Contract Date: September 1, 1977
Anticipated Completion Date: March 1, 1981

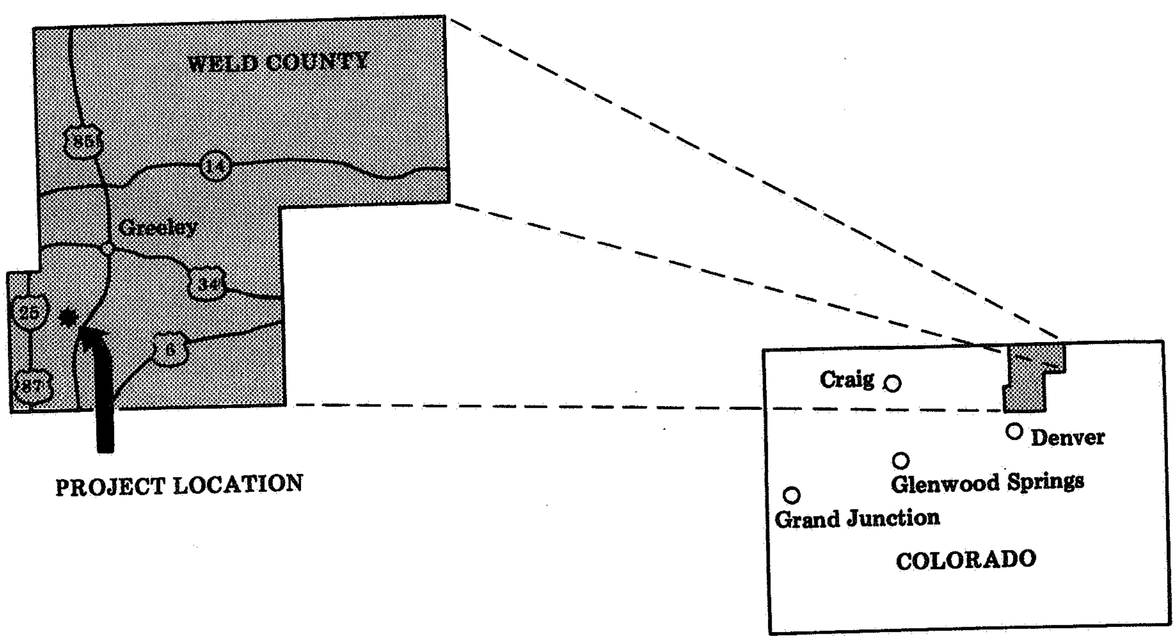
Total Project Cost (estimated):

	DOE	$ 75,000
	CIG	99,000
	Total	$174,000

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.



4.4.3 COLORADO INTERSTATE GAS COMPANY

DOE and Colorado Interstate Gas Company (CIG) entered into contract No. CY-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 removing formation damage adjacent to the surfaces of induced fractures.

As of April 19, 1979, BHP of the Miller No. 1 well was 1,033 psi at 248°F and, for the Sprague No. 1 well BHP was 941 psi at 252°F. BHP increased slowly and inconsistently at 4 to 6 psi per day at the Miller well and an average of 3 psi per day at the Sprague well.

The final bottom-hole pressure for the Miller No. 1 well was 1,088 psi and the Sprague No. 1 well was 1,050 psi. The pressure bomb was removed from the Sprague No. 1 well on May 13, 1979.

An attempt was made to begin gas cycling operations on May 16. The Miller No. 1 well was put on production May 17, at which time the compressor shut down. This was due to lack of pressure because the regulator on CIG's line failed to open. Bottom-hole pressure was 406 psi, and the compressor discharge was about 1,300 lb. The dew point of the gas being injected into Sprague No. 1 well was measured at the discharge of the dehydrator at 4.5 lb per million cubic feet. An additional problem was incurred when the producer's separator failed and the system was flooded with liquid hydrocarbons. It was difficult to maintain inlet pressure to the compressor between 80 and 200 lb because of the speed the pressure dropped at the Miller No. 1 well.

Cyclic gas injection resumed on June 7. The Sprague No.1 well produced for approximately 24 hours, at which time the compressor shut down due to lack of pressure. While the Sprague No. 1 well was shut down, the pressure built up enough that it was possible to restart the compressor and run it another day. Initial wellhead pressures were 1,000 lb at the Miller No. 1 well and 850 lb at the Sprague No. 1 well. Wellhead pressures as of June 20, 1979, were 1,375 lb at the Miller No. 1 well and 80 lb at the Sprague No. 1 well.

Cyclic injection of dehydrated gas and production continued throughout July, August and September. By September, however, an increasing number of interruptions and compressor shutdowns plagued the wells. The problems were primarily due to faulty ball valve operation on the inlet side of the compressor. It appears that conventional gas pipeline valves do not provide the level of consistent operation under the varying pressure and volumetric conditions incurred during cyclic operations. It may be necessary to install valves and/or controls of a different design.

Figures 4-28 and 4-29 illustrate the production, injection volumes and associated pressure of these wells since cyclic operations began.

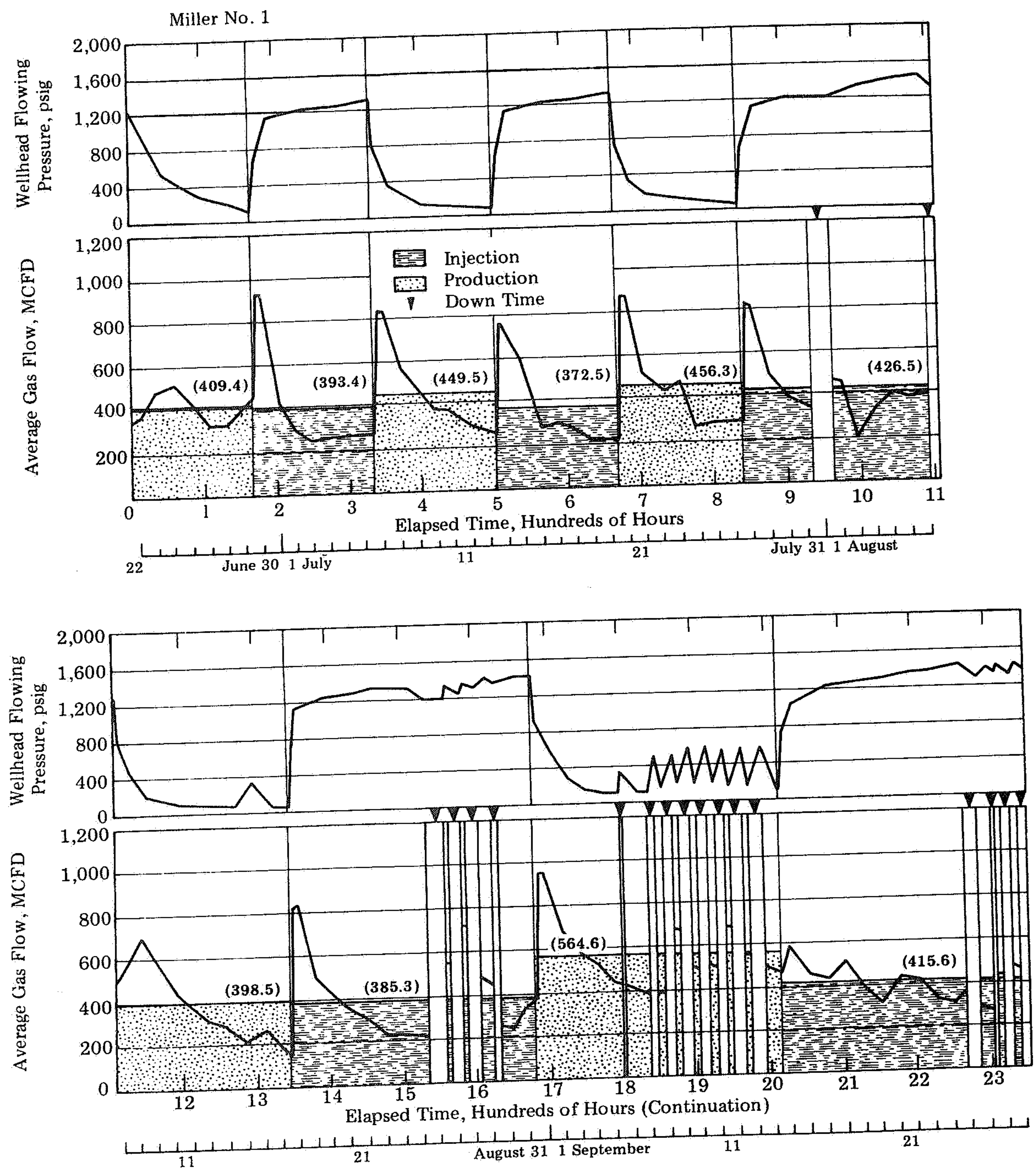


Figure 4-28. Production and Injection Volumes and Associated Pressure of CIG Miller No. 1 Well

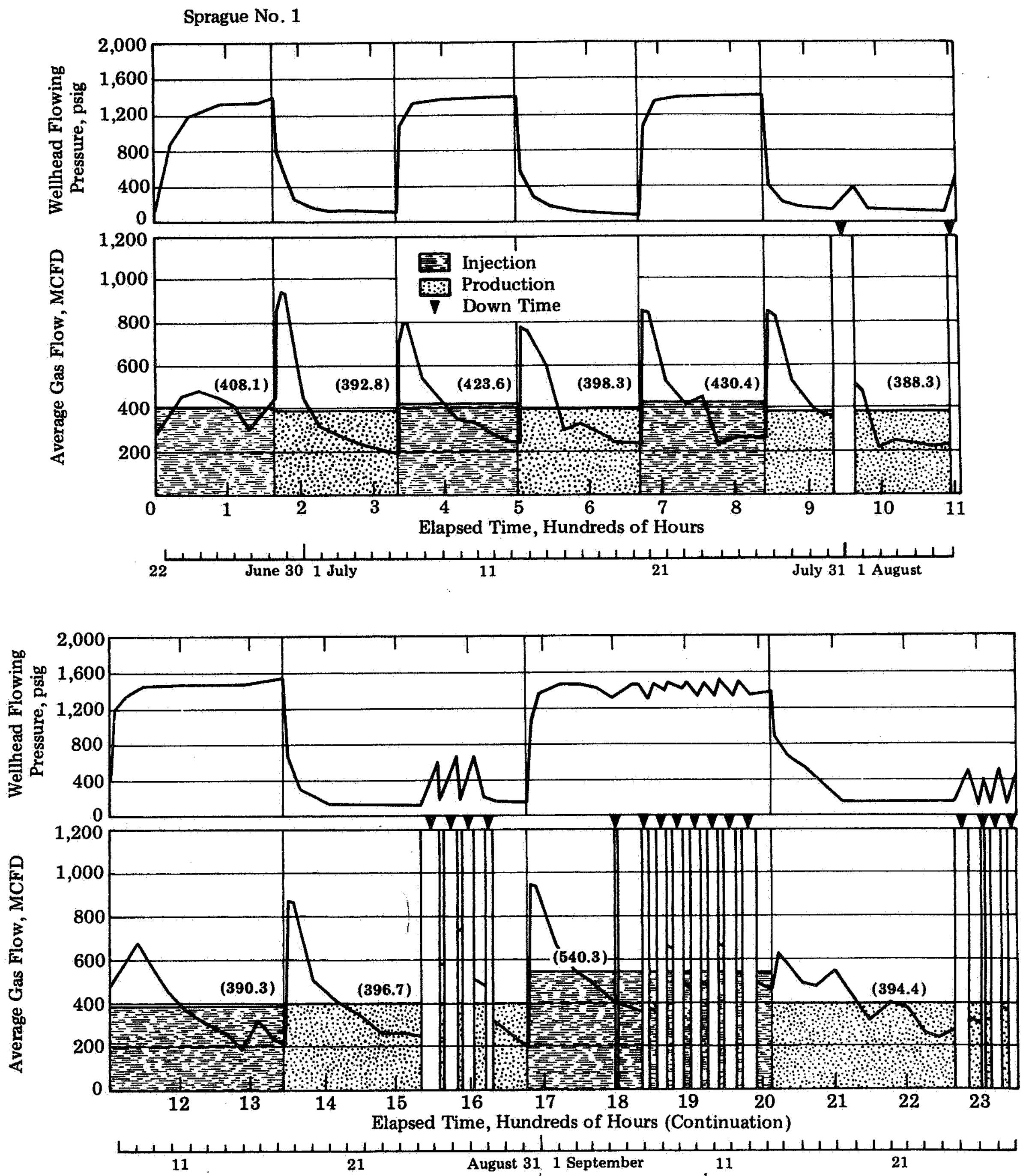


Figure 4-29. Production and Injection Volumes and Associated Pressure of CIG Sprague No. 1 Well

DOE WELL TEST FACILITY

DE-AC08-79-BG01569

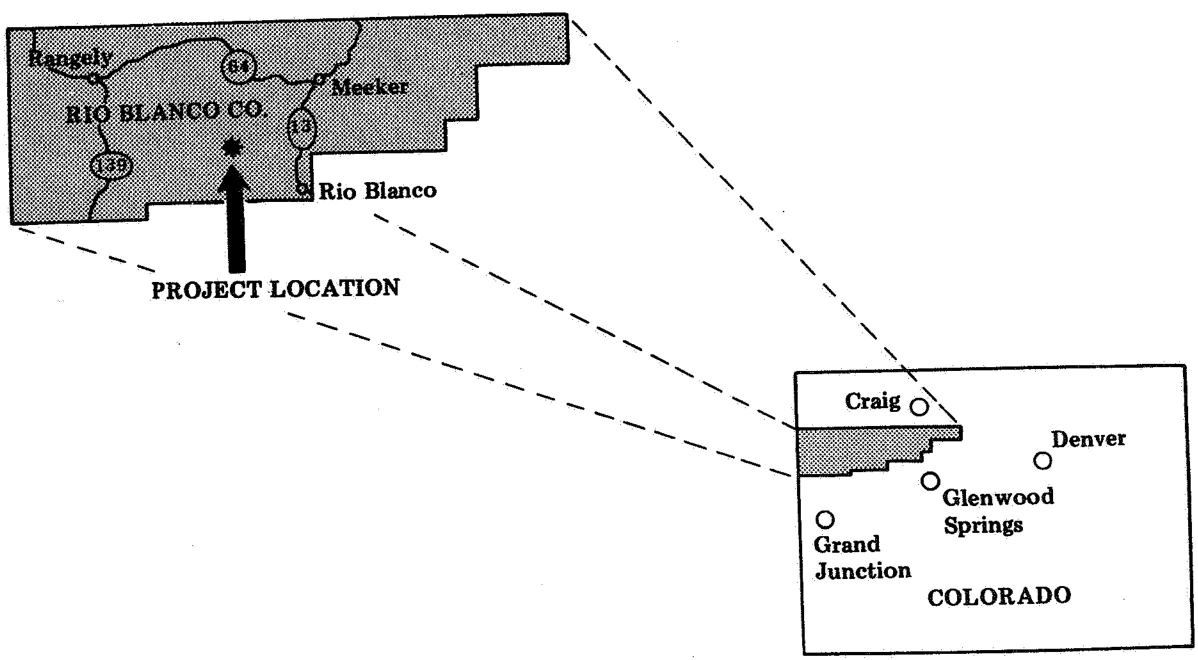
CER Corporation
Las Vegas, Nevada

Status: Operational

Principal Investigator: R. L. Mann
Technical Advisor for DOE: C. H. Atkinson

OBJECTIVE

The DOE Well Test Facility, consisting of two vehicles, provides deep well instrumentation and investigation system to monitor and evaluate the productive potential of all types of wells.



4.4.4 DOE WELL TEST FACILITY

CER Corporation's support contract includes the operation of a well test facility at various locations selected by DOE. A 10 ft x 50 ft instrument and winch trailer, a two-ton truck equipped with a hydraulically controlled telescoping 50-ft mast, and two trailer-mounted 30 kw and 90 kw electric generators comprise the facility.

The facility was transported to Basin Machine in Vernal, Utah for minor repairs and storage in June. Work continued on several computer programs. The "Flow" program used to calculate flow rates through a meter run was modified to increase efficiency and versatility, particularly in view of the large volume of data acquired during drawdown periods. The "Caldat" program was modified to allow more efficient data manipulation and selection.

The G.O. downhole multiplexing temperature tool was tested in a temperature chamber for 2 weeks at temperatures ranging from 210°F to 285°F. The tool appeared to operate successfully but showed severe discoloration and warping of most of the electronic components.

The facility was transferred to the RBNG 397-19-1 Government well in July to acquire reservoir data and provided analytical support for the proposed joint GRI/RBNG fracture experimentation.

NATURAL BUTTES UNIT, UINTAH COUNTY, UTAH MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

EY-76-C-08-0681

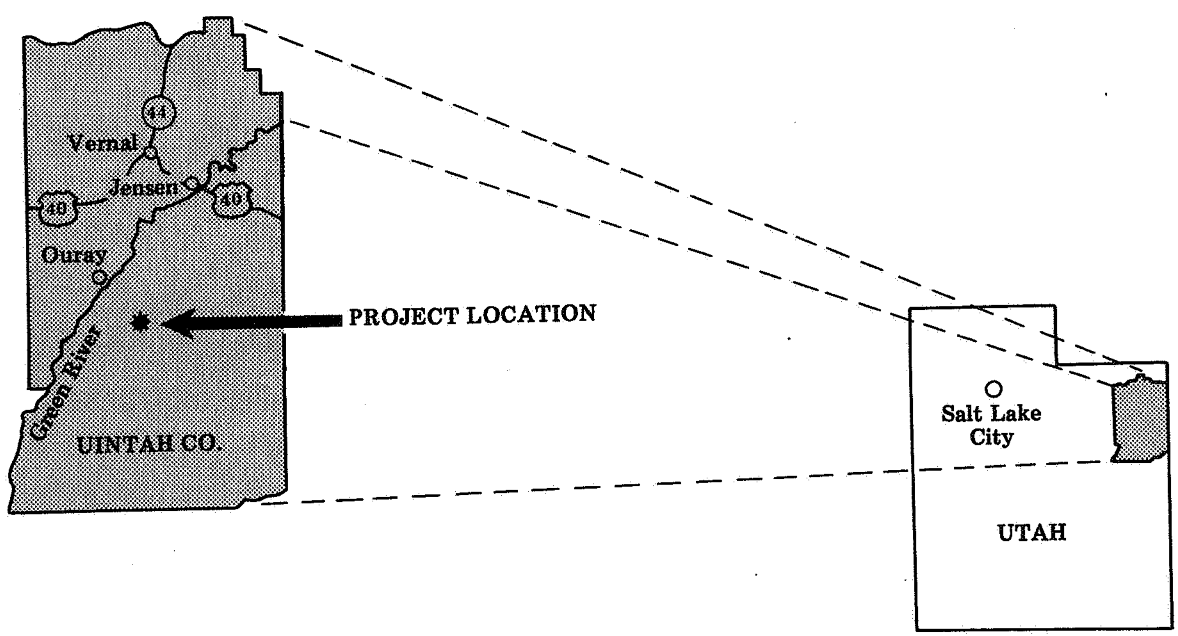
Status: Active

Gas Producing Enterprises, Inc.
Subsidiary of Coastal States Gas Co.
Houston, Texas

Contract Date:	July 1, 1976	
Anticipated Completion:	September 30, 1979	
Total Project Cost (estimated):	DOE	$2,827,000
	Industry (prior costs)	1,881,000
	Industry (new costs)	3,051,000
	Total	$7,759,000
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.



4.4.5 GAS PRODUCING ENTERPRISES, INC.

Of the GPE wells, only the Natural Buttes Unit No. 18 continued to flow to sales throughout the reporting period. Natural Buttes Unit Nos. 9, 14, 19, 20, 21, and 22 were all shut-in at various times. NBU 21 was temporarily abandoned in the Mesaverde horizon in June, but GPE plans to complete it in the Wasatch. Figures 4-30 through 4-39 show production figures.

A comprehensive final report is in preparation.

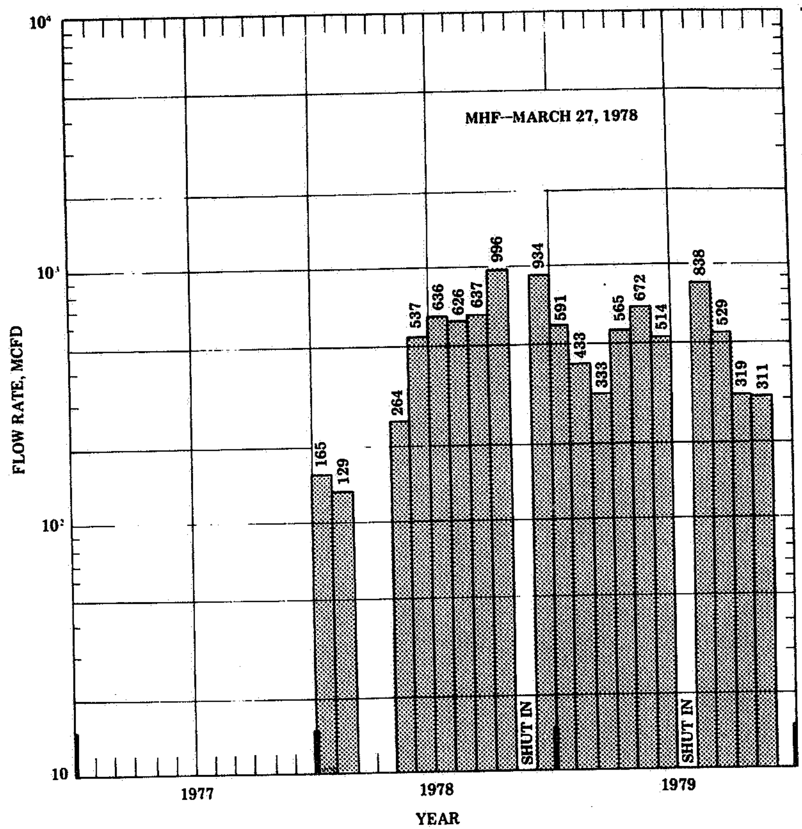


Figure 4-30. Flow Rate Performance of Natural Buttes No. 9 Well

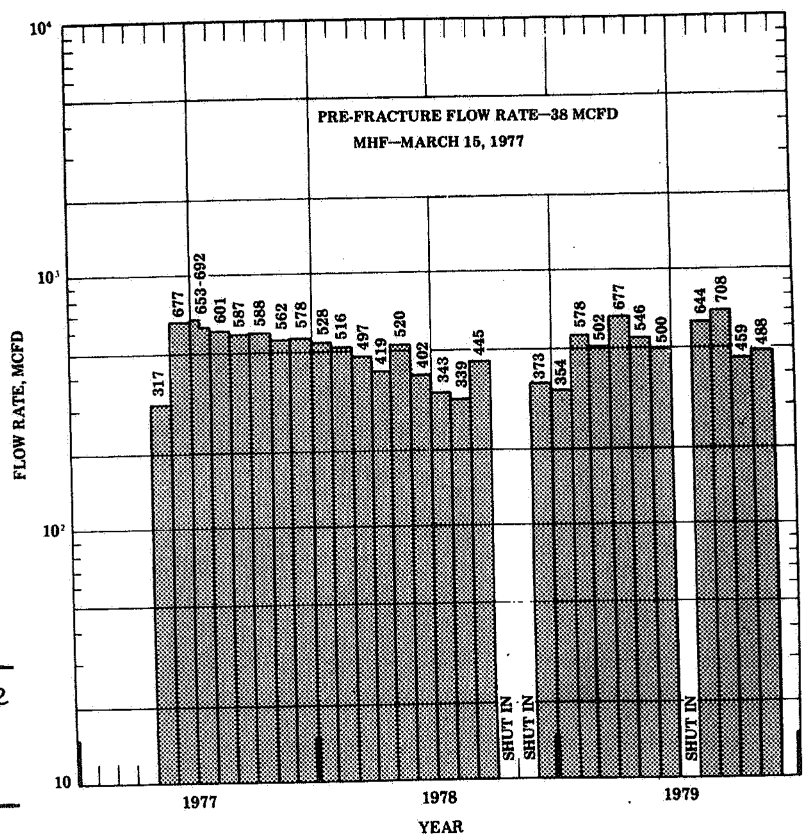


Figure 4-31. Flow Rate Performance of Natural Buttes No. 14 Well

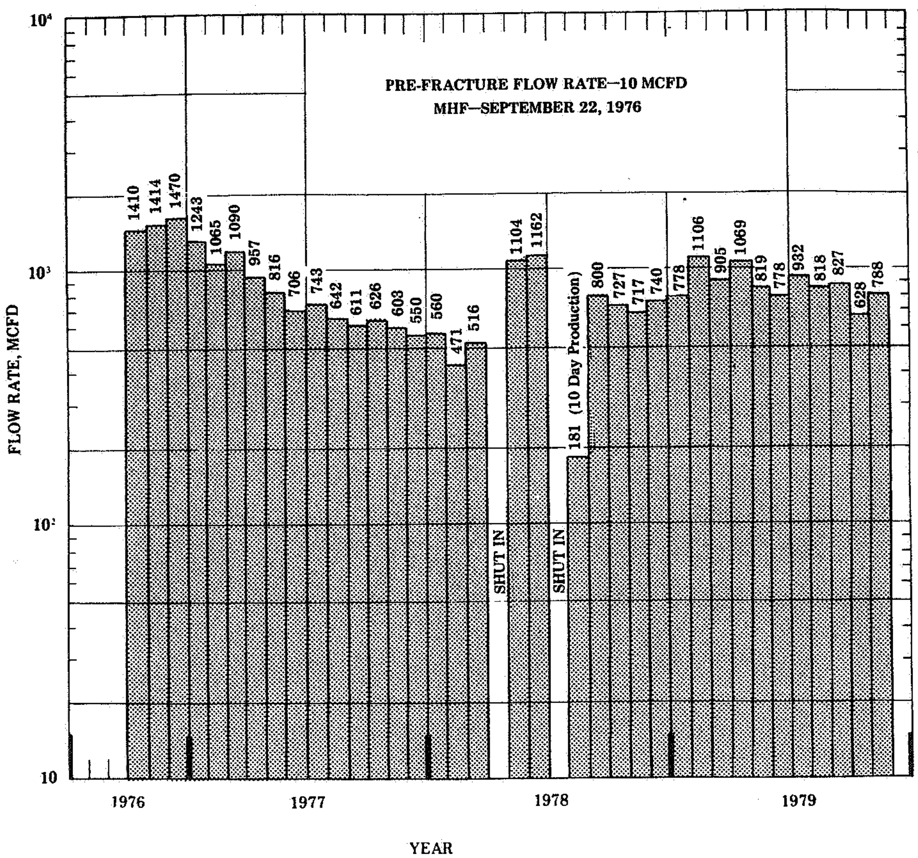


Figure 4-32. Flow Rate Performance of Natural Buttes No. 18 Well

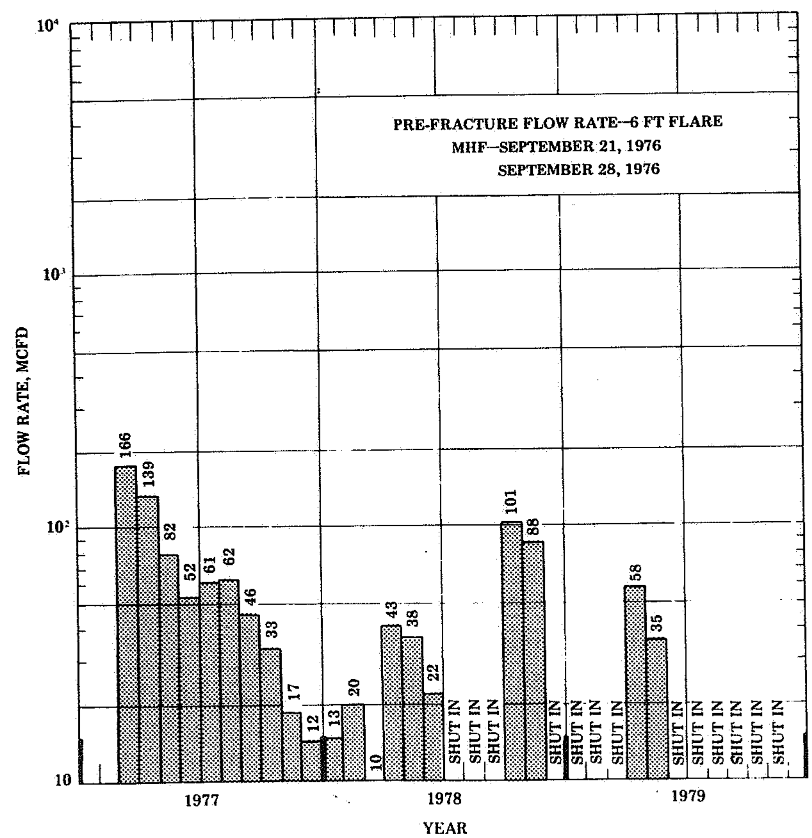


Figure 4-33. Flow Rate Performance of Natural Buttes No. 19 Well

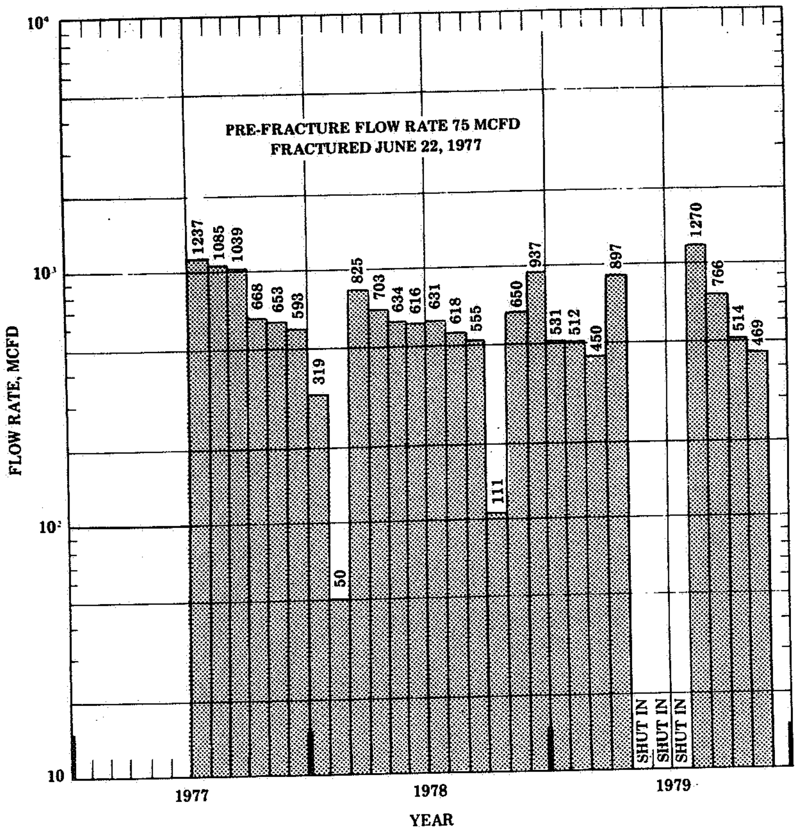


Figure 4-34. Flow Rate Performance of Natural Buttes No. 20 Well

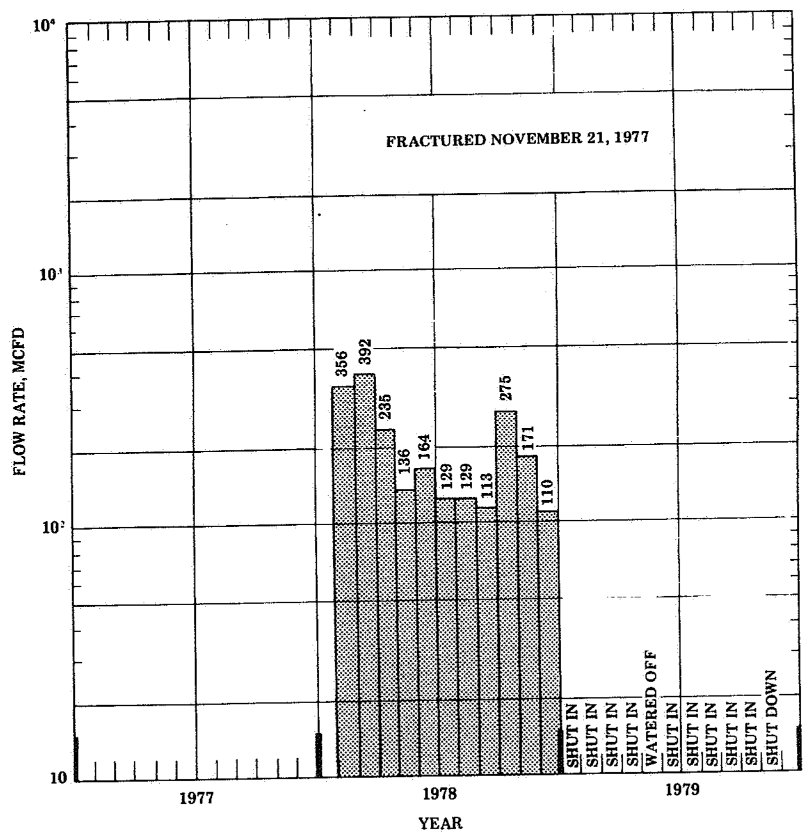


Figure 4-35. Flow Rate Performance of Natural Buttes No. 22 Well

FALLON-NORTH PERSONVILLE FIELD, TEXAS, MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

EF-78-C-08-1547

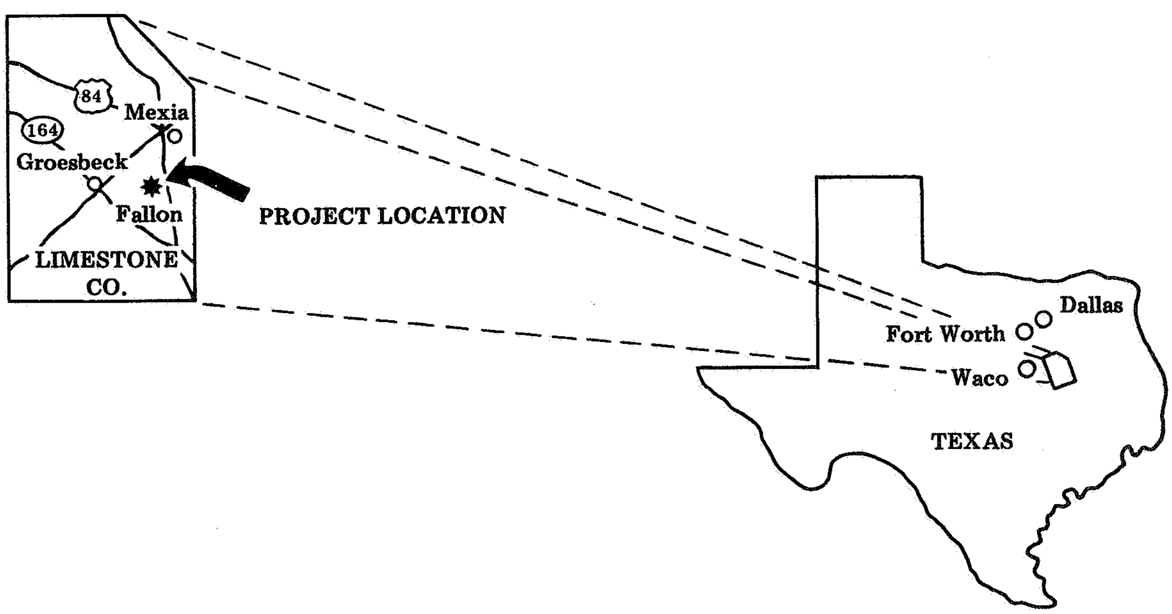
Mitchell Energy Corporation
Houston, Texas

Status: Active

Contract Date:	March 15, 1978
Anticipated Completion:	April 30, 1979
Total Project Cost (estimated):	DOE .... $ 553,771
	Industry 1,074,550
	Total $1,628,321
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.



4.4.6 MITCHELL ENERGY CORPORATION

Before being shut-in for testing August 8, the Muse-Duke No. 1 well was flowing 3,000 MCFD and 18 BBL of water with a flowing tubing pressure of 970 psi. The cumulative production as of July 31, 1979, was just over one billion cubic feet of gas.

The well was reopened on September 5 after a 28-day shut-in period. The maximum wellhead shut in pressure was 2,590 psig. The initial rate was 5,700 MCFD and 18 BWPD with a flowing tubing pressure of 1,500 psig. As of September 30, the flow rate was 5,100 MCFD and 24 BWPD, with a flowing tubing pressure of 1,800 psig. However, during the month, a series of curtailments occurred; therefore, no stabilized rate can be reported.

Final pressure analysis was delayed due to difficulty in gathering all post pressure data, and some work had to be repeated.

PICEANCE CREEK FIELD, COLORADO, MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

EY-76-C-08-0678

Mobil Research and Development Corporation
Dallas, Texas

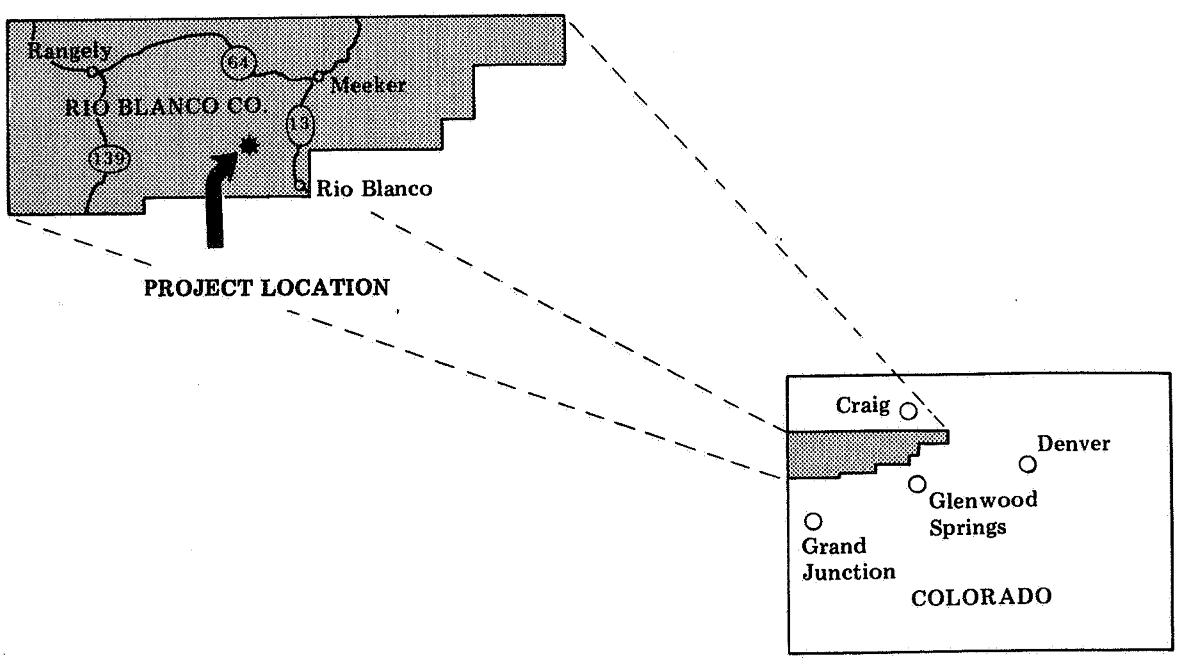
Status: Active

Contract Date:	July 1, 1976	
Anticipated Completion:	December 31, 1978	
Total Project Cost (estimated):	DOE	$2,510,000
	Contractor (prior costs)	2,376,485
	Contractor (new costs)	1,590,515
	Total	$6,477,000

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 extremely low-permeability.



4.4.7 MOBIL RESEARCH AND DEVELOPMENT CORPORATION

A comprehensive final report is in preparation.

RIO BLANCO COUNTY, COLORADO MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

EY-76-C-08-0677

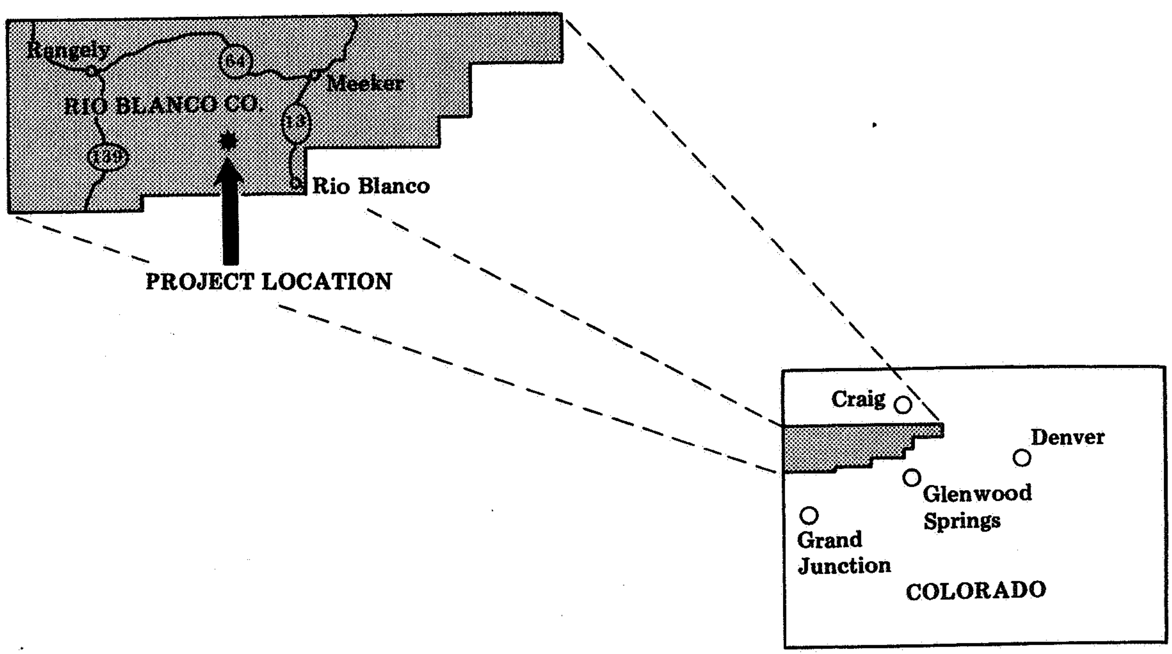
Status: Active

Rio Blanco Natural Gas Company
Denver, Colorado

Contract Date:	August 1, 1976	
Anticipated Completion:	December 15, 1978	
Total Project Cost (estimated):	DOE	$ 410,000
	Contractor	593,000
	Total	$1,003,000
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.



4.4.8 RIO BLANCO NATURAL GAS COMPANY

The final report has been received.

NEVADA TEST SITE
NYE COUNTY, NEVADA
MINEBACK TESTING

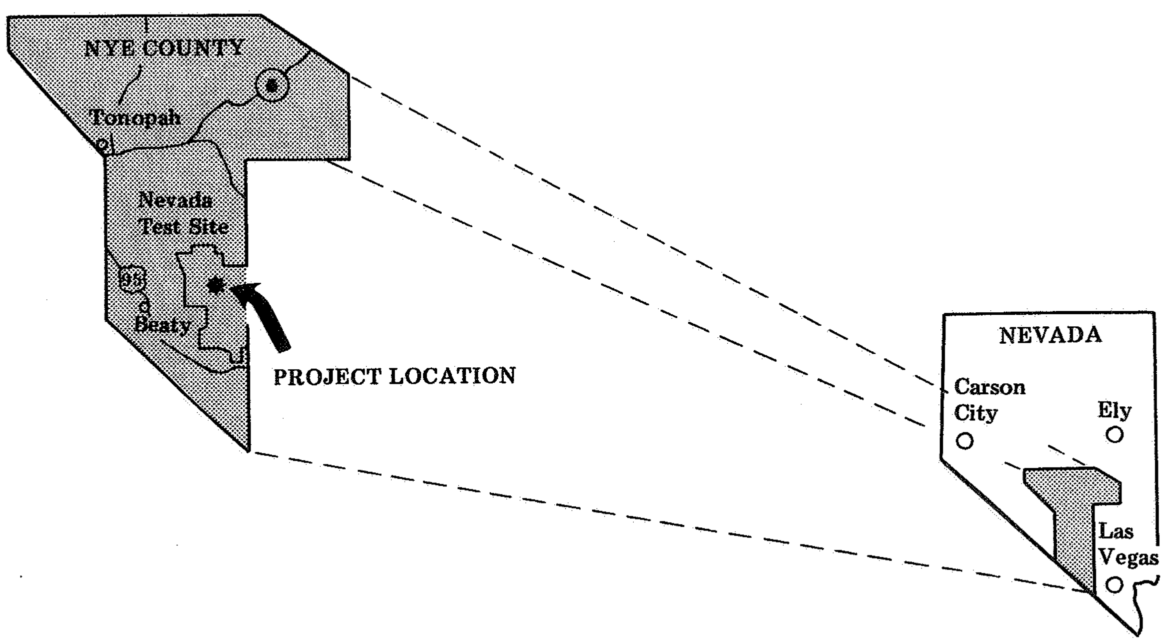
Sandia Laboratories
Albuquerque, New Mexico

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 mine-back for direct observation and evaluation.



4.4.9 SANDIA LABORATORIES – MINEBACK

Research being performed includes in situ testing of hydraulic fracturing theory and technology, modeling of hydraulic fracturing behavior and laboratory testing. In situ testing is being performed at DOE's Nevada Test Site in a tunnel complex through volcanic ashfall tuff under approximately 1,400 ft of overburden. This site provides:

- facilities and equipment for mineback and direct observation of created hydraulic fractures,
- the capability of determining in situ stresses and obtaining rock samples for testing in regions of interest, and
- a direct knowledge of the reservoir parameters and structure (i.e., permeability, porosity, location of faults, fractures, etc.).

Modeling efforts involve many aspects of fracturing, from details of the processes occurring at the fracture tip to numerical codes describing the fluid/rock mechanics of the entire fracture. Laboratory testing includes the determination of rock properties and small scale experiments.

FORMATION INTERFACE FRACTURE EXPERIMENT

The formation interface fracture experiment (Hole No. 6) is an experiment to determine the parameters which control hydraulic fracture containment.

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 a fracture which 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 are in error that predict a bounding higher modulus material will contain a hydraulic fracture. Figure 4-36 shows Hole No. 6.

An exploratory coring program is underway to determine the general shape of the fractures. This shape should reflect the influence of the interface and the in situ stresses on overall fracture propagation and behavior. Twenty-two coreholes have been completed to date. Approximately five more holes will be cored to complete the experiment and a final evaluation will then be performed.

INTERFACE TEST SERIES

The interface test series is a set of small hydraulic fracturing experiments at the Nevada Test Site to examine the factors that affect containment of hydraulic fractures. The effect of variations in material properties and in situ stresses on hydraulic fracture behavior is of particular importance. Small hydraulic fractures (50-150 gal) were created in horizontal boreholes at various distances below a welded tuff/ashfall tuff interface by injecting a dyed-water frac fluid at low flow rates.

In the first two tests of this series (designated CFE-1 and CFE-2), a horizontal borehole was fractured in six zones; a number of different flow rates and volumes of fluid were utilized and each zone was at a different distance from the interface. A map with the locations of these fractures is shown in Figure 4-37. Mineback showed that the fractures crossed the interface and propagated into the higher modulus welded tuff; however, fractures did terminate in regions where a sharp increase in the minimum principal **in situ** stress level was measured. Flow rate apparently has a negligible effect on propagation across the interface.

The mineback of the third test, CFE-3, and the associated in situ stress measurement hole, CFE-4, are near completion.

Thus far, these experiments indicate that the in situ stress is the dominant mechanism controlling hydraulic fracture propagation. The fractures show little or no change as they approach and cross the material property interface, but the unfavorable stress gradients near the peak readily terminate fracture growth.

MULTI-WELL EXPERIMENT

A multi-well experiment has been conceived as part of the Western Gas Sands Project. Its objectives are to obtain a comprehensive geologic characterization of a lenticular, low permeability reservoirs in the western United States, and to apply and evaluate state-of-the-art and developing technology for the recovery of natural gas from these reservoirs. Sandia Laboratories and CER Corporation will technically direct the experiment under the auspices of C. H. Atkinson, Manager for the Western Gas Sands Project. An industry group will aid in the overall technical guidance of the experiment. Six tasks have been formulated: analysis and evaluation, laboratory testing, field drilling program, stimulation program, production testing, and field diagnostics. This is a research-oriented project and it will be conducted to obtain the maximum amount of technical information.

Site acquisition has been delayed since the primary site is not available. The delay precludes any site activity prior to winter, so drilling of the first well will probably occur in a May-June 1980 time-frame.

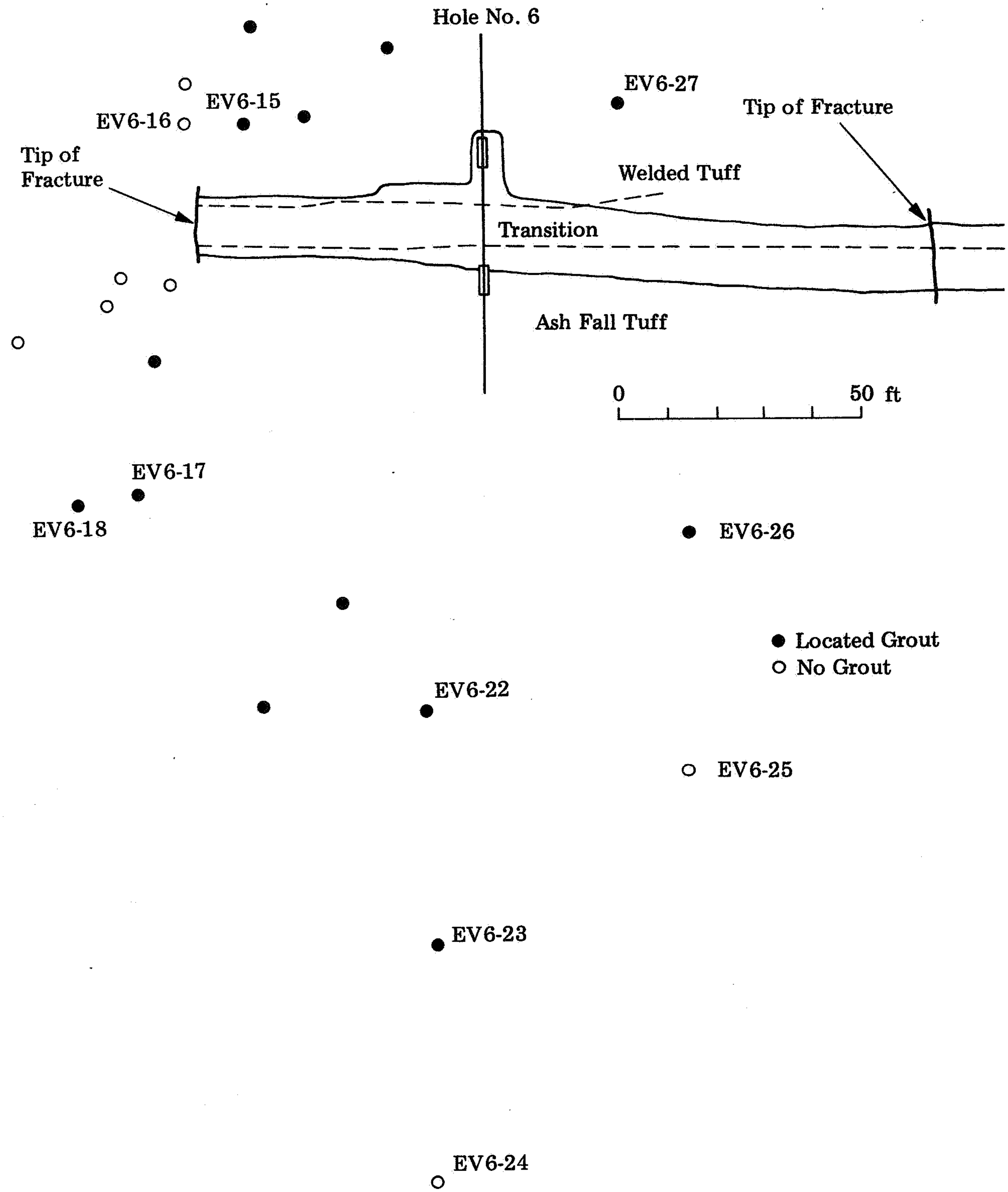


Figure 4-36. Results of Exploratory Coring of Hole No. 6

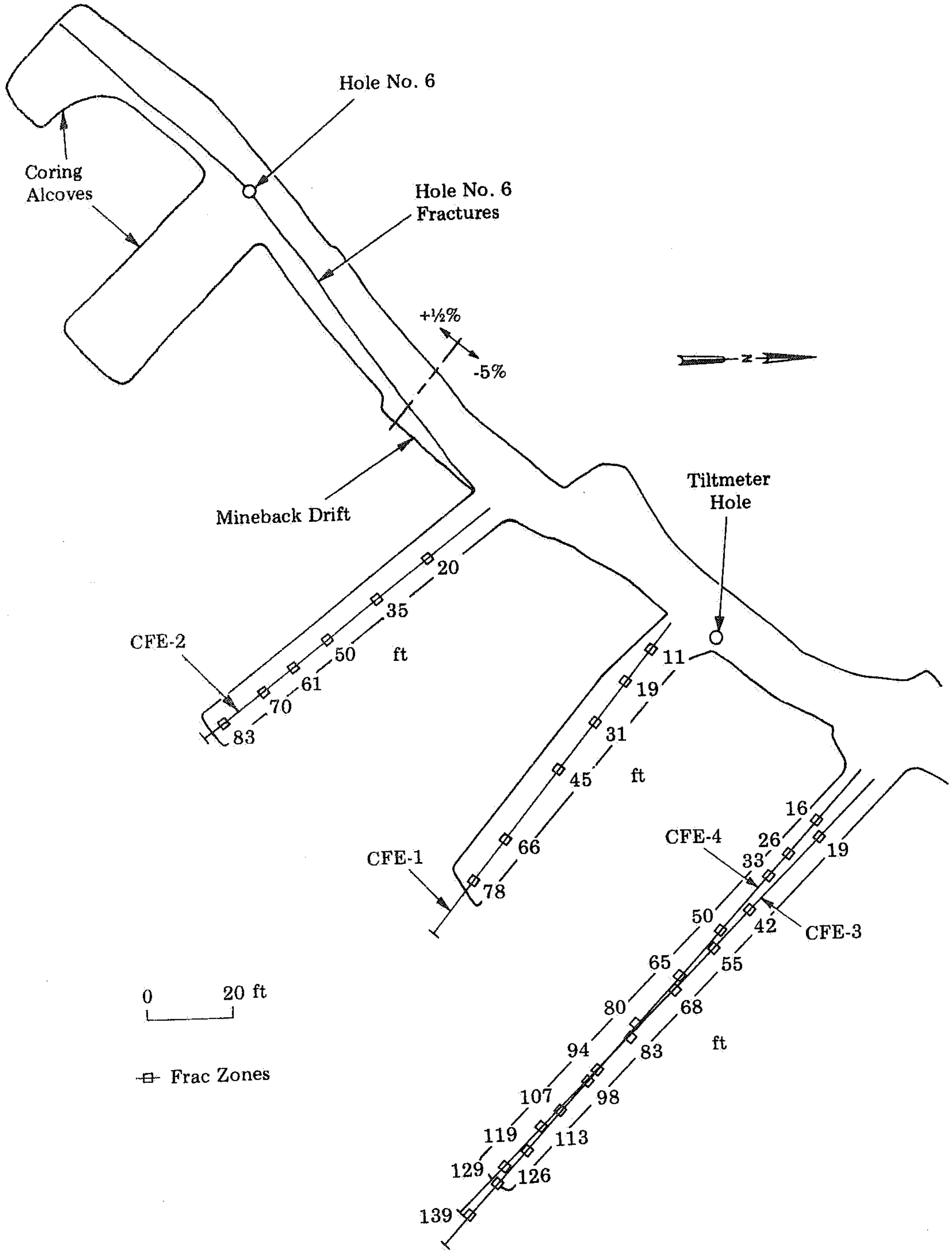


Figure 4-37. Location of CFE Fracture Zones and Mineback

4.5 PROJECT MANAGEMENT

4.5.1 GENERAL

The Western Gas Sands Project Quarterly Basin Activities Report, January 31, 1979, the Western Gas Sands Project Quarterly Basin Activities Report, April 30, 1979, and the Western Gas Sands Project Quarterly Basin Activities Report, August 31, 1979, were released in April, June and September, respectively. Data for July, August and September's basin activities are being compiled.

The WGSP financial supplements for April through September, 1979, were released within the reporting period. A final report on the CER-managed government/industry Rio Blanco Massive Hydraulic Fracture 3 demonstration well was released in April. The WGSP logging program report and the DOE Well Test Facility Manual were revised in July. The Western Gas Sands Project Northern Great Plains Province Review by H. E. Newman III of CER Corporation was released in August.

4.5.2 PROJECT DATA BANK

Work on the Western Gas Sands Project bibliography continued during the reporting period.

The following maps and papers were added to the data bank:

- a stratigraphic section of Cretaceous rocks of the northern Denver Basin, northeastern Colorado and southeast Wyoming;

- a USGS Open File Report entitled "Preliminary chart showing electric log correlation section D-D' of some Upper Cretaceous and Tertiary rocks, east flank Rock Springs Uplift, Wyoming," and Public Information Circular No. 10;

- a cross section entitled "Preliminary Stratigraphic Studies" of the Upper Part of the Mesaverde Group, Wasatch Formation, Lower Part of the Green River Formation, Debeque Area, Colorado, "by Johnson and May;

- a map entitled "Surface and Subsurface Correlations of some Upper Cretaceous and Tertiary Rocks, Green River Basin, Wyoming," USGS Open File Report No. 79-357, section A-A', by B. E. Law, C. W. Spencer and H. W. Roehler;

- the proceedings of the Wyoming Oil and Gas Fields Symposium, "Greater Green River Basin";

- a compilation of abstracts of papers presented at a recent joint meeting of the Survey, Wyoming Geological Association and the University of Wyoming's geology department;

- the 1979 SPE Symposium on Low-Permeability Gas Reservoirs;

- USGS professional paper No. 776: "Stratigraphic and Geologic History of the Montana Group," by Gill; and

- USGS professional paper No. 404: "Stratigraphy and Structure of the Flanks of the Black Hills Uplift, Wyoming, Montana and South Dakota," by Robinson.

4.5.3 TECHNOLOGY TRANSFER

The following papers are relevant to the Western Gas Sands Project and have been put into the project data bank.

"Gas Recovery from Tight Formations: A Function of Technology and Economics," V. A. Kuuskraa, J. P. Brashear, Lewin and Associates, Inc.

"Influence of Diagenetic Reactions on Reservoir Properties of the Neslen, Farrer, and Tuscher Formations, Uinta Basin, Utah," C. W. Keighin, U.S. Geological Survey.

"Experimental Evaluation of Fracturing Fluid Interaction with Tight Reservoir Rocks and Propped Fractures," U. Ahmed, A.S. Abou-Sayed, and A. H. Jones.

"Development of Shallow Gas Reserves in Low-Permeability Reservoirs of Late Cretaceous Age, Bowdoin Dome Area, North-Central Montana," G. L. Nydegger, D. D. Rice, and C. A. Brown.

"A Case History for Massive Hydraulic Fracturing the Cotton Valley Lime Matrix, Fallon and Personville Fields - Limestone County, Texas," H. G. Kozik, B. C. Bailey, and S. A. Holditch.

"Application of a New Method for Determining Flow Characteristics of Fractured Gas Wells in Tight Sands," J. O. Scott, Cities Service.

"Pressure Transient Analysis of Tight Western Gas Sands -- Pre- and Post-Fracturing," J. H. Kennedy and J. E. McElhiney, Intercomp.

"On the Computation of the Three-Dimensional Geometry of Hydraulic Fractures," R. J. Clifton, Brown University, and A. S. Abou-Sayed, Terra Tek Inc.

"Some Results from Continuum Mechanics Analyses of the Hydraulic Fracturing Process," M. E. Hanson and R. J. Shaffer, Lawrence Livermore Laboratory.

"Particle Size Distributions Generated by Crushed Proppants and Their Effects on Fracture Conductivity," H. B. Carroll, Jr., and B. A. Baker, U.S. Department of Energy.

"Prefracturing Pressure Transient Testing: East Texas Cotton Valley Tight Gas Play," J. N. Boxtic and J. A. Graham, Amoco Production Company.

"Development of Techniques for Optimizing Selection and Completion of Western Tight Gas Sands. Phase II report, 1 January 1979 - 28 February 1979," C. F. Knutson and C. R. Boardman, C K GeoEnergy Corporation.

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"Theoretical and Experimental Analyses of Hydraulic Fracturing and Some Reservoir Response to the Stimulation," by M. E. Hanson, G. D. Anderson, R. J. Shaffer, L. D. Thorson and D. N. Montan, Lawrence Livermore Laboratory.

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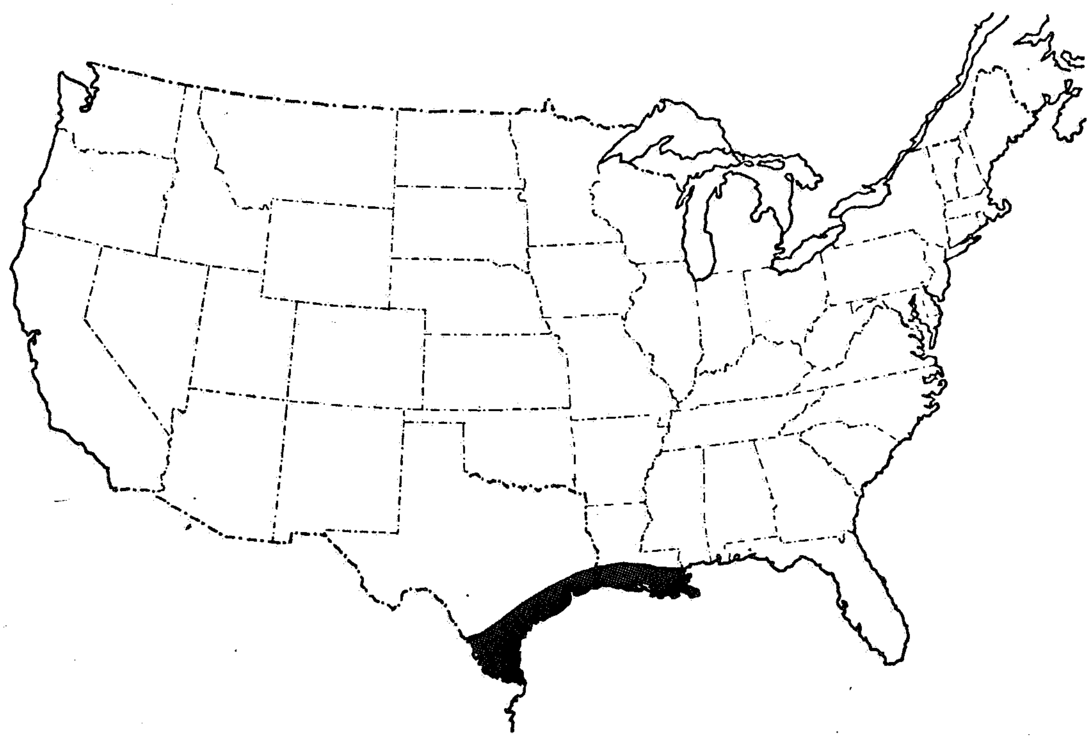
5. METHANE RECOVERY FROM GEOPRESSURED AQUIFERS



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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 and 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 lifetime 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 continuation 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) is being 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 four 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 four 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 barrels 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. Data from the Fairfax Foster Sutter No. 2, Beulah Simon No. 2, and Pleasant Bayou No. 2 indicate gas production of

20 to 25 scf/bbl and recombination sample data indicate the water is saturated with gas at reservoir conditions.

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 organizations associated with 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 Pleasant Bayou No. 1 and No. 2 wells have been tested and data 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 hydropressured 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 Pleasant Bayou test wells and 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 have resulted in a 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 wells 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 under way 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 awaiting delivery of high-pressure pumps for laboratory simulation of geopressured reservoirs.

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 production 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 in progress.

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 buildup, 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 pinpoint 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 socio-economic planning assistance in the county to educate the public, industry, and governmental entities in the geopressured aquifer development program.

LEGAL ISSUES

As already mentioned, 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 I," 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 baseline 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 baseline 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 penetrated a good geopressured aquifer (as indicated by local geology and well logs). 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 expected 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 WELLS PROGRAM--TEXAS

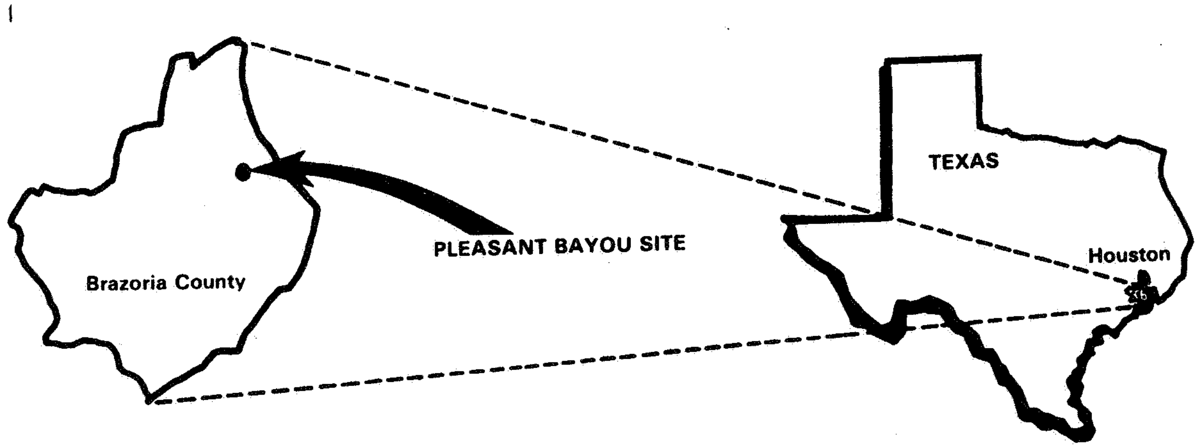
Status: Active

I. P. Farms, Inc.
Houston, Texas

Contract:	DE-AC08-77ET28401
Contract Date:	November 1977
Contract Completion Date:	October 1980
Principal Investigator:	Tom Cotman (I. P. Farms, Inc.)
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 the Chocolate Bayou on I.P. Farm'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, 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
- Possiblities 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 was recompleted as an injection well in November 1979.

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 16,500 feet, at which point the well was completed 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 feet.

7-inch liner set from 13,992 feet to 16,500 feet.

The zones 15,988 feet-16,006 feet, 16,038 feet-16,046 feet, 15,576 feet-15,586 feet, and 15,580 feet-15,590 feet were perforated and drill stem tested. Production from these zones varied from 3 BWPH to 14 BWPH. The zone from 14,644 feet-14,704 feet was perforated to test. The No. 1 well was completed as a disposal well and a 10-day flow test was completed on December 13, 1978. Results of the test are as follows:

Static bottom-hole pressure: 11,275 psi
Static surface pressure: 4,391 psi
Bottom-hole temperature: 301^{o} F.
Surface flowing temperature: 264^{o} F.
Flow rate (approx.): 13,500 BWPD
Flowing BHP after 10 days: 10,436 psi
Flowing surface pressure: 3,733 psi
Gas/water ratio: 20 to 22 cu. ft./BW

The contractor transferred to I.P. Farms in 12/1979. Surface facilities for a long-term flow test are planned to be constructed during January and February 1980.

5.4.2. DESIGNED WELLS PROGRAM--LOUISIANA

Dow Chemical, U.S.A.
Midland, Michigan

Status: Active

Contract:	DE-AC08-79ET27255
Contract Date:	September 1979
Contract Completion Date:	September 1981
Principal Investigator:	Dr. John Wilson (Dow Chemical)
DOE Technical Project Officer:	J. K. Westhusing (Houston)

OBJECTIVE

To drill, complete, and production test a geopressured aquifer in the Parcperdue field in Vermilion Parish, Louisiana.

5.4.2. DESIGNED WELLS PROGRAM--LOUISIANA

Magma Gulf/Technadril
Houston, Texas

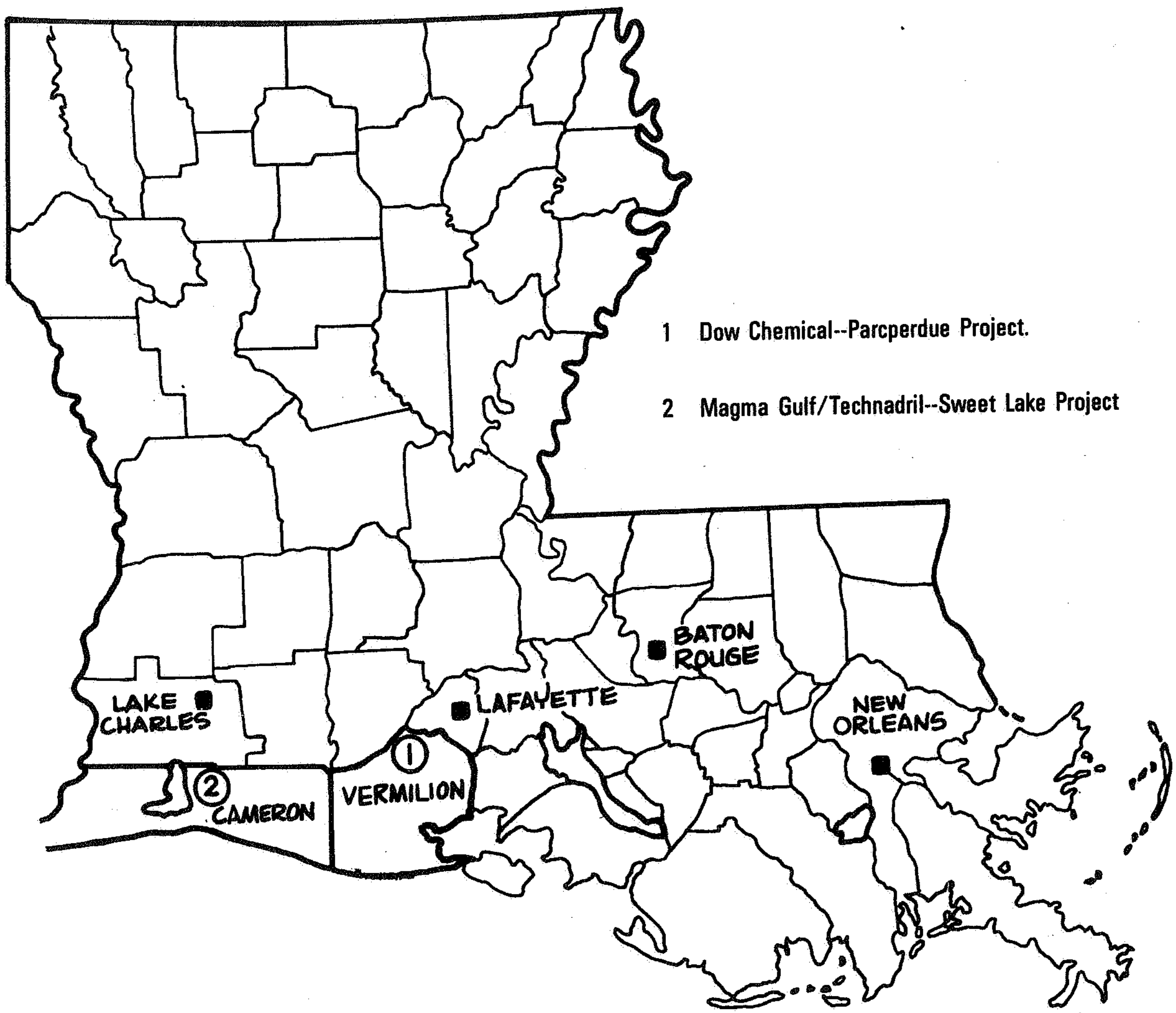
Status: Active

Contract:	DE-AC08-78ET27082
Contract Date:	December 1979
Contract Completion Date:	November 1981
Principal Investigator:	Dr. Clay Durham (Magma Gulf)
DOE Technical Project Officer:	J. K. Westhusing (Houston)

OBJECTIVE

To drill, complete, and production test a geopressured aquifer in Cameron Parish, Louisiana.

5.4.2 DESIGNED WELLS PROGRAM--LOUISIANA



1 Dow Chemical--Parcperdue Project.

2 Magma Gulf/Technadril--Sweet Lake Project

5.4.3 WELLS OF OPPORTUNITY PROGRAM

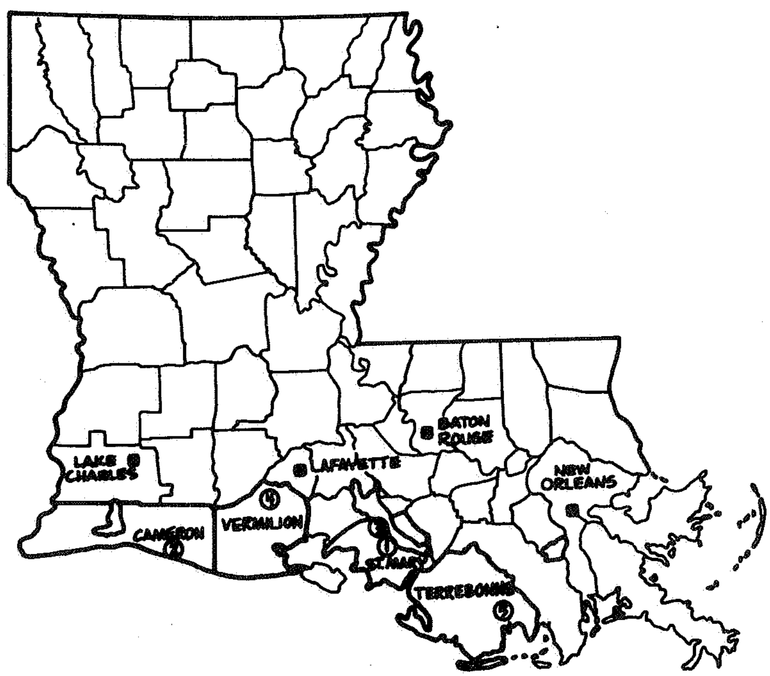
H. J. Gruy & Associates
Houston, Texas

Status: Active

Contract:	DE-AC08-77ET28460
Contract Date:	September 1977
Contract Completion Date:	April 1980
Principal Investigator:	R. J. Dobson (Gruy)
DOE Technical Project Officer:	J. K. Westhusing (Houston)

OBJECTIVE

To acquire, complete, and production test geopressured aquifer wells of opportunity in the U.S. Gulf Coast.



1 Alice C. Plantation

2 Gladys McCall

3 Fairfax Foster Sutter

4 Beulah Simon

5 Tenneco Fee "N"

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 of oil or gas in commercial quantities.

Reentry 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 nonproductive of oil or gas in commercial quantities at the objective completion depth. This well was drilled by Neuhoff Oil and Gas Company to 16,340 feet.

Completion operations began in March 1979. A 5 1/2-inch liner was run from 14,130 feet to the total depth of 16,340 feet. A section of the MA-6 sand of lower Miocene age was perforated from 15,780 feet to 15,930 feet. Production tubing consisting of 3 1/3-inch tubing from surface to 13,947 feet and 2 7/8-inch tubing from 13,947 feet to 15,573 feet was installed. A saltwater disposal well was drilled and cased with 5-inch casing to 3,962 feet, cemented to surface, and perforated from 3,609 feet to 3,669 feet. Production equipment was installed and the well was tested. Both production well and disposal well were returned to Neuhoff on August 20, 1979, after removing the production tubing and plugging the well back to 14,935 feet.

The testing consisted of two flow rates and two pressure buildups. Initial reservoir pressure was observed to be 12,200 psi and the initial reservoir temperature 270° F. The brine contained an average of 190,904 mg/liter of total dissolved solids and the salinity expressed in equivalent NaCl concentration was 160,000 mg/liter. The average dissolved gas content was 22.8 standard cubic feet per stock tank barrel of water. The gas consisted of 89.57 mol percent methane and 7.85 mol percent CO_2 and had a specific gravity of .6447 and a heating value of 948 Btu per cubic foot.

The maximum flow rate measured from the well was approximately 7,747 barrels per day, but this rate could not be sustained due to the low permeability of the reservoir, estimated at 14 md. Analysis of the drawdown and buildup data indicate two reservoir boundaries interpreted as parallel faults approximately 1,800 feet apart, with the well approximately midway between the faults.

BEULAH SIMON WELL NO. 2

This well was drilled by Southport Exploration, Inc., to 15,265 feet, found nonproductive of oil or gas in commercial quantities, and offered for testing of the geopressured sands which had been penetrated. Completion operations commenced in September 1979. A 5 1/2-inch liner was run from 11,556 feet to 15,234 feet and tied back to surface with 7-inch casing. A string of 3 1/2-inch tubing was installed from surface to 14,224 feet and a section of the Lower Camerina sand was perforated from 14,674 feet to 14,770 feet. A saltwater disposal well was drilled and cased with 5 1/2-inch casing to 2,702 feet, cemented to surface, and perforated from 2,464 feet to 2,524 feet. Production equipment was installed and testing operations were commenced in October 1979. Testing is expected to be completed in December 1979.

TENNECO FEE "N" WELL NO. 1

This well was drilled by Tenneco Oil Company and cased to a total depth of 17,276 feet. The well has been offered for testing of the geopressured sands. Well logs indicate seven geopressured geothermal *Textularia warreni* sands of mid-Miocene age between the depths of 13,765 feet and 15,880 feet. Agreements have been approved for the completion and testing of the aquifers and operations are to begin upon obtaining a barge rig for operations since this is an inland water location. A barge rig has been contracted and is scheduled to move onto the location in December 1979. Active participation in this project by Tenneco represents the first major oil company involvement in the resource assessment of geopressured geothermal energy.

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 firsthand basis. Active participation is continually sought from industry, government entities, and the public.

The first meeting was held in September 1977; and to date, 21 such meetings have been held.

5.5.3 GEOPRESSURED-GEOTHERMAL SYMPOSIA

Four symposia have been held, with the last one being in Austin, Texas, in October 1979. 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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