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SEMI-ANNUAL REPORT FOR THE UNCONVENTIONAL
GAS RECOVERY PROGRAM

Period ending March 31, 1980

R. D. Manilla, Editor

June 1980

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

TECHNICAL INFORMATION CENTER
UNITED STATES DEPARTMENT OF ENERGY

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ACKNOWLEDGMENTS

This document is the fourth 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 October 1, 1979 through March 31, 1980.

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1. SUMMARY

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1.1 METHANE RECOVERY FROM COALBEDS

The following is a summary of significant accomplishments of the Methane Recovery from Coalbeds Project (MRCP) during the period October 1, 1979 through March 31, 1980. More detailed discussions in Section 2 of this document report progress made on methane recovery projects in prior reporting periods.

1.1.1 RESOURCE ENGINEERING

Resource Engineering activities continued in two areas: 1) The analysis and test program to verify the feasibility of producing methane from coalbeds and 2) conduct of well site investigations in accordance with the current Resource Delineation Plan.

ANALYSIS AND TEST PROGRAM

Progress continued on seven analysis and test projects designed and originated in previous reporting periods, to determine the feasibility of producing methane from coalbeds, principally from unmined beds or seams.

- TRW Contract DE-AC21-78MC08089--"Methane from Coalbeds Resource Delineation":
 - Basin reports for the Illinois, Powder River, San Juan, and Greater Green River Basins were completed and are in publication.
 - Estimates of cubic feet of gas in place were updated and are summarized below:

<u>Basin</u>	<u>Minimum</u>	<u>Maximum</u>
Illinois	5.21×10^{12}	20.0×10^{12}
Powder River	5.91×10^{12}	65.0×10^{12}
San Juan	1.79×10^{12}	25.09×10^{12}
Green River	0.15×10^{12}	30.0×10^{12}
Arkoma	1.5×10^{12}	3.55×10^{12}
Western Washington	0.4×10^{12}	24.0×10^{12}

- Intercomp Contract DE-AC21-79MC10641--"Evaluation of Data from Unmined Coal Seams":
 - Production potential studies were completed for the Arkoma Basin and for the U.S. Steel Corporation's Cumberland Mine in Greene County, Pennsylvania. A study of the U.S. Steel Oak Grove project is in progress.
- Colorado Geological Survey Contract DE-AC21-79MC10643--"Evaluation of Colorado Coalbed Methane Potential":
 - In addition to ongoing desorption tests and development of the Colorado data base, resource estimates were completed for the Raton and Piceance Basins and the Fruitland Formation in the San Juan region.
- Colorado School of Mines Contract DE-FG21-80MC14256--"Effect of Predrainage Stimulation Techniques on Coal Recovery":
 - Research on the theory of hydraulic fracture continued, and construction of an in-mine test facility is underway.
- Utah Geologic and Mineral Survey Contract DE-FG21-79MC11729--"Evaluation of Utah Coalbed Methane Potential":
 - Fifteen core samples were obtained and are being desorbed. Desorption data from 101 samples were compiled.
- Virginia Polytechnic Institute and State University Contract DE-AC21-78MC08089--"Evaluation of Southern Coalfields":
 - Field mapping of the Richmond Basin was completed, and a detailed geologic assessment was received from the Virginia Division of Mineral Resources and is being incorporated into the Richmond Basin report.
- Pennsylvania State University Contract DE-AC21-78MC08089--"Reservoir Fracturing and Mining Through Fractured Areas":
 - Progress continued on assembly of data, in-mine observations of effects of fracturing and relevant analysis.

WELL SITE INVESTIGATIONS

Of the 23 investigations initiated in previous reporting periods, desorption tests were completed and well test data packages compiled for 15 wells. These well test packages are maintained on open file at METC. During this reporting period, the following new test agreements were implemented.

- Three in the Illinois Basin, two in cooperation with the Indiana Geological Survey, and one with R. W. Beeson.
- One in the Green River Basin in cooperation with Belco Petroleum Corporation.
- One in the San Juan Basin with Fuelco.

Discussions were also held with the following potential cooperating drillers in preparation for the 1980 season:

Belco Petroleum	- Green River
Chandler & Associates	- Wyoming and Utah
Coastal States Gas	- Williston and Uinta
Davis Oil	- Powder River
Adolph Coors Co.	- Piceance
Teton Energy Co.	- San Juan and Piceance
Fuelco	- San Juan
USGS	- San Juan, Powder River, and Green River

Results of desorption testing completed at this time are summarized in Table 1-1.

1 . 1 . 2 R E S E A R C H A N D D E V E L O P M E N T

The MRCP R&D effort is directed at development of methods for extraction and utilization of coalbed methane. Progress continued on five ongoing projects.

- Maurer Engineering Contracts DE-AC21-78MC08089 and DE-AC21-79MC11251--"Turbodrill":
 - Phase II testing began in December. Bearing failures were encountered and formal testing was terminated. Reliable bearing packages are a major problem in downhole motors.
- Physics International Contract DE-AC21-79MC10642--"Coalfrac":
 - It was again demonstrated that the detonations reduce permeability in the Pittsburgh bituminous coal.
- Sandia Labs Contract MR-11098--"Water Jet Drilling":
 - A 1/4-scale model of the drill string was constructed and testing was initiated on it and a full-scale prototype. The coupling between the jet and the rotating head currently

Table 1-1. Summary of Desorption Tests Through March 1980

<u>Site</u>	<u>Aggregate Feet of Coal</u>	<u>Gas Content</u>		<u>Comments</u>
		<u>cc/gm</u>	<u>cf/ton</u>	
Arkoma				
Site EAA	12	2.3 to 6.6	73 to 210	Well was abandoned after one foot of coal core was obtained. No coal samples were obtained.
Site EAB	-	7.6	243	
Site EAC	-	-	-	
Site EAD	2.9	9.4	301	
Green River				
Site GAA	16.2	0.6 to 11.8	18 to 376	
Site GAB	5.6	1.0 to 16.8	33 to 539	
Illinois				
Site DAA	8	0.3 to 1.5	10 to 48	Samples are being desorbed. Test being negotiated.
Site DAB	12.8	0.7 to 1.1	22 to 35	
Site DAC	19.4	-	-	
Site DAD				
Site DAE	10.7	1.4 to 1.5	45 to 48	
Northern Appalachian				
Site AAA	60.0	1.0 to 13.3	33 to 426	
Site AAB	29.6	2.2 to 6.1	70 to 195	

Table 1-1. Summary of Desorption Tests Through March 1980 (Continued)

Piceance				
Site FAA	5	0.6 to 2.5	19.2 to 80.9	Objectives not accomplished because of structural complexities. No gas show at this site.
Site FAB				
Site FAC	3.8	3.5 to 8.9	111 to 286	
Site FAD	11.5	1.5 to 1.9	48 to 61	
Site FAE	30	1.1 to 2.3	35 to 74	
Site FAF	11	0.01 to 0.2	1.3 to 5	
Site FAG	11.9	0.03 to 1.0	1.0 to 29	
Site FAH	22	0.5 to 0.8	16 to 26	
Powder River				
Site IAA	54.5	0.03 to 0.08	0.9 to 2.6	
Site IAB	11	0.04 to 0.13	0.9 to 4.2	
Site IAC	23.4	0.02 to 0.41	0.6 to 13.1	
San Juan				
Site HAA	1.2	0.5 to 2.3	16 to 73	
Site to be designated	-	-	-	This test is in planning stage
Southern Appalachian				
Site CAA	9	0.5 to 3.2	16 to 102	
Western Washington				
Site LAA	5.4	0.6 to 2.3	20 to 75	

survives only a few hours of testing. Design corrections are being explored.

- Design of the 300-foot borehole test platform was initiated.
- West Virginia University Contract DE-AT21-79MC11284--"Fracture Mechanics":
 - Tests were conducted on coal to measure fracture toughness and direction of natural weakness. Test equipment for conduct of more complex tests is being designed and fabricated.
 - Development of the elastic moduli model and related analysis also continued.
- University of Pittsburgh Contract DE-FG21-79MC10831--"Carbon Dioxide for Methane Production Enhancement":
 - Higher pressure test vessels have been fabricated to allow conduct of CO₂ enhanced methane extraction experiments in an environment more nearly simulating in situ conditions.

1.1.3 TECHNOLOGY SYSTEMS TESTS

Progress continued on nine of the 10 previously approved tests designed to demonstrate methods of producing and utilizing coalbed methane. The anthracite drainage project, although also previously approved, was deferred due to budgetary limitations.

- Westinghouse Electric Corporation Contract DE-AC21-77MC08098--"On-Site Power Generation Test Project":
 - Agreement was reached to move the generator from the original site in Cambria County, Pennsylvania, to the Marianna mines in Washington County, Pennsylvania, where a more reliable and adequate gas supply is available. Additional horizontal boreholes have been drilled at the Marianna mine.
- Westinghouse Electric Corporation Contract DE-AC21-78MC08332--"Space Heating/Fuel Cell Test Project":
 - One well (#4) continued to provide about one-half the requirements for this process heat application. This well currently produces approximately 27 thousand cubic feet per day (Mcf/d) from coal seams with an aggregate thickness of 26.5 feet and with a methane concentration of only 37 cf/ton.
- Mountain Fuels Company Contract DE-AC21-78MC10734--"Book Cliffs Coal Field Production Test Project":

- Whitmore Park Wells #1 and #2 were completed before the site became inaccessible, during winter. Planning for the third (and final) well was completed.
- Analysis of gas samples indicates methane quantities of 95 to 98 percent. Gas concentration measured by the Utah Geological and mineral Survey ranges from 58 to 215 cf/ton while those measured by Mountain Fuels and IGT range from 221 to 395 cf/ton. The reasons for this difference are being investigated.
- Intercomp Contract DE-AC21-78MC08384--"Piceance Basin Production Test Project":
 - One well on which a small stimulation had been attempted, but with no benefit, averaged 9.2 Mcfd of gas and 8.6 barrels per day of water. Work will resume in the 1980 drilling season if and when a permit for the second well is granted.
- Occidental Research Corporation Contract DE-AC21-78MC08089--"Long Horizontal Holes, Active Mine Test Project, Buchanan County, Virginia":
 - Two drilled slant holes from the mined (#3) seam upward into the #4 seam were completed successfully demonstrating this technique as a means to predrain the area above the roof.
 - To date, more than 6,400 feet of borehole have been completed and 175 MMcf of methane drained from this mine.
 - Drilling of the #9 hole, with a target depth of 2,000 feet, began in March.
- Waynesburg College Contract DE-AC21-78MC08089--"Multiple Completion Development Test Project, Greene County, Pennsylvania":
 - Coring was completed in December. Preliminary desorption testing indicated this well will be productive.
 - Drilling and completion of the production well was accomplished in January.
 - Fracturing of three target zones was performed in February and, following some swabbing, a water pump installed. During fracturing, an undocumented abandoned well 300 feet from the wellhead was ruptured.
- Pennsylvania Energy Resources, Inc. Contract DE-AC21-78MC08089--"Anthracite Coal Drainage Test Project, Luzerne County, Pennsylvania":

- A draft of the Environmental Impact Assessment for this project was completed. Budgetary constraints have precluded implementation of this project.
- United States Steel Corporation Contract ET-75C-01-9027--"Multiple Vertical Borehole Degasification Test Project, Jefferson County, Alabama":
 - Stabilized gas and water flows were achieved from 17 wells in spite of unexpected influx of proppant into the wellbore. Techniques to reduce these sand-related problems are being explored.
 - Daily production from the 17 operating boreholes averaged approximately 1.1 MMcfd during this reporting period. A total of 562 MMcf of gas has been produced from this grid, a quantity over 26% of the gas originally estimated to be present within the 5-foot thick seam.
 - Sites for seven additional boreholes have been prepared for drilling operations scheduled for June 1980.
 - A proposal is under consideration to gather the methane from this site into a nearby pipeline.
- Harold F. Scott Contract ET-77-C-01-8891--"Directional Drilling for Degasification of the Pittsburgh Coalbed":
 - At the beginning of this reporting period a total of 10,882 feet of horizontal drilling had been completed at the Emerald mine and the system was being prepared for production.
- Clinchfield Coal Co. Contract ET-77-C-01-9151--"Vertical Drilling to Degasify the Jawbone Coalbed":
 - The last two of the five boreholes in this project were completed, and the wells in the four-spot pattern have been foam stimulated and are being equipped for water removal.
 - Mining has progressed to within approximately 300 feet of the first well, and gas flow from it is declining.

1.1.4 PROJECT INTEGRATION

Project integration activities continued in the areas of project support and analysis, reporting, and technology transfer.

- Technology Transfer

- Representatives of the MRCP presented papers at The Energy Sources Technology Conference and Exhibition in New Orleans and at a meeting of the South-Central Section of the Geological Society of America in Wichita Kansas.

- General

- A recent ruling in Greene County, Pennsylvania, has clarified ownership of coalbed methane in Pennsylvania. The decision in this case is that landowners or their gas rights lessees, not the coal owners, own the methane.

1.2 EASTERN GAS SHALES

The following is a summary of significant EGSP accomplishments from October 1, 1979 through March 31, 1980.

RESOURCE CHARACTERIZATION AND INVENTORY

Twelve Devonian Shale wells were cored and logged during this reporting period, including completion of coring on three wells commenced during the last period. Details of these wells are given in Table 1-1. Figure 1-1 shows the location of all EGSP core wells to date.

Table 1-1 Summary of Coring & Logging Activities During First Half of FY80

DATE	CONTRACTOR	EGSP WELL NO.	COUNTY STATE	TARGET FORMATION	DATA COLLECTED	SHALE CORE LENGTH (ft.)
9/79	Columbia Gas Corp.	OH #7	Trumbull, OH	Devonian Shale	Core/Log	1187*
9/79	Gruy Federal	IL #5	Wayne, IL	Devonian Shale	Core/Log	275*
9/79	Mound	PA #3	Erie, PA	Devonian Shale	Core/Log	430*
10/79	Mitchell Energy	OH #6-2	Gallia, OH	Devonian Shale	Core/Log	180
10/79	Mitchell Energy	OH #6-3	Gallia, OH	Devonian Shale	Log	Abandoned Lost Circulation
11/79	Mitchell Energy	OH #6-4	Gallia, OH	Devonian Shale	Core/Log	900
11/79	Gruy Federal	PA #4	Indiana, PA	Devonian Shale	Core/Log	900
12/79	Mitchell Energy	OH #6-5	Gallia, OH	Devonian Shale	Core/Log	180
12/79	Gruy Federal	PA #5	Lawrence, PA	Devonian Shale	Core/Log	600
1/80	Gruy Federal	MI #1	Otsego, MI	Devonian Shale	Core/Log	100
1/80	Gruy Federal	TN #9	Grainger, TN	Devonian Shale	Core/Log	240
3/80	Donohue, Anstey, Morrill	OH #8	Noble, OH	Devonian Shale	Core/Log	1403
						6395 TOTAL

*Completion of coring, includes footage reported last period.

Analyses of a pressurized core from Ashtabula County, Ohio show that the controlled off-gassing method gives only 53 percent of the in-place gas, and the conventional method less than 17 percent, as compared to the pressure core barrel taken as 100 percent.

Regional stratigraphic cross-sections for New York and Ohio were completed. The second phase of mapping in Pennsylvania was also completed, providing detailed maps of the best potential gas producing units within the Devonian Shale.

Figure 1-1 EGSP Core Wells

An analysis of the depositional history of the Appalachian Basin, including studies of paleocurrent systems, paleogeography, and tectonic setting was completed. The abundance, thickness, and cementation of siltstone laminae within a shale, as well as its fine-scale interlamination with organic matter, were found to be most significant for gas potential from a depositional viewpoint.

Extensive study of the Eastern Kentucky Gas Field has revealed that it represents a highly complex structural-stratigraphic gas trap. Fracture facies which formed as a result of gravity tectonics and décollement features may be enhanced by the occurrence of complex intertonguing of organic black shale with silty gray shale in the center of the area of high gas production. Inorganic elemental geochemistry shows promise as an exploration tool.

EXTRACTION TECHNOLOGY R&D

Five tailored-pulse-loading (TPL) concepts have been tested at the Nevada mineback test site (NTS). Laboratory determinations of the material properties and inherent flaw characteristics of the NTS tuff, required for the numerical modeling of the experiments, have been completed. Laboratory studies of the effects on fractures of the gases resulting from the explosion are in progress. These effects will be incorporated into the theoretical stimulation models.

A finite element model for vertical hydraulic fracturing of Devonian Shales is being developed, and laboratory experiments to provide data required for validation of the model are in progress. High speed movies have been taken of the experiments to provide quantitative data about proppant transport and fluid penetration into the fracture. Additionally, studies of fracturing fluid and shale interaction on five cores are in progress.

Three separate methods of determining in situ stress are being investigated. The first is based on the observation of fracture patterns in extracted cores, and the use of Mohr-Coulomb shear failure theory. Based on trial and error procedures, a range of in situ stresses were obtained, which compared well with some of the existing information. The second method is based on an ultrasonic technique. The feasibility of this method under uniaxial compression has been demonstrated, and the feasibility under biaxial compression is underway. The third method is aimed at developing a wireline straddle packer tool for in situ stress measurements. A conceptual design for one tool from a set of four alternatives has been selected.

The first three phases of a program to test dual completion have been completed, leading to the identification of four major trends that have a high potential for Devonian Shale gas production. These trends are: East-Central Ohio; Lake Erie shoreline; Western New York; and an eastern area of the Appalachian Basin.

The technical feasibility of a mineback experiment in the Devonian Shale in Ohio is being studied. Preliminary bulkhead design and abandonment procedures have been completed, and the detailed mine design and experimental plan are in progress.

A Technical Implementation Plan was prepared for an Offset Well Test Program. Site selection is in progress, based mainly on reservoir simulation studies.

TECHNOLOGY TESTING AND VERIFICATION

Three field tests of exploration rationales are in progress. Five wells have been drilled in Gallia County, Ohio to test a rationale based on structure at the time of deposition. Only small gas shows were present in the wells. Two of the wells were stimulated, and were still cleaning up with gas shows (too small to measure) at the end of the reporting period.

Sites have been selected for tests of a seismic velocity-based rationale in Noble County, Ohio, and one well was being drilled at the end of the reporting period. Possible sites have also been identified in Southern New York to test the production potential of the Rhinestreet/Marcellus facies.

Four stimulation treatments were performed during this period. A foam fracture of the Marcellus Shale in a temporarily abandoned Clinton sandstone well in Carroll County, Ohio produced gas flow rates too small to measure. A highly instrumented nitrogen frac in Knox County, Ohio produced low flow rates. Three other wells in this area are planned to be stimulated using foam.

Eleven other wells under two contracts have been drilled, and will be stimulated during FY80. Locations of field test projects are shown in Figure 1-2.

Figure 1-2 EGSP Field Projects

1 . 3 W E S T E R N G A S S A N D S

The following is a brief summary of significant WGSP accomplishments during the period October 1, 1979 through March 31, 1980.

1 . 3 . 1 R E S O U R C E A S S E S S M E N T

U. S. GEOLOGICAL SURVEY

During the reporting period 10 reports were published and 5 drafted. Eight maps were completed.

USGS activities in the areas of interest are as follows:

- Greater Green River Basin

Stratigraphic analysis of the Greater Green River Basin continued. Cross sections were completed. Cores from the Washakie Basin were sampled and described. Geochemical analyses were made on samples from the Tierney No. 1 and Koch Adobe Town wells, Washakie Basin.

- Northern Great Plains Province

Petrographic analyses of the Milk River (southeast Alberta) and the Eagle - Telegraph Creek cores (Alberta, Montana and North Dakota) continued. Various reports on mineralogic and diagenetic studies, physical characteristics and reservoir properties of low permeability sands were published.

- Uinta - Piceance Basins

Neslen, Farrer and Tusher cores were sampled and described from the Tavaputs Plateau, Uinta Basin. Analyses of petrographic data were derived from SEM, X-ray, and sedimentation studies of cores from the Rio Blanco MHF-3 well, Piceance Basin. A stratigraphic section which relates rock types, producing intervals, and formation and engineering data for Upper Cretaceous and Lower Tertiary rocks extending from the Price River Canyon to the eastern Uinta Basin was prepared.

CORE PROGRAM

In the Piceance Basin, coring operations were completed at the Pacific Transmission Supply Company No. 22-12 Federal well, Sec. 12, T1N, R99W, Rio Blanco County, Colorado. Core recovery from the Mancos B totaled 118.3 ft from a 120-ft cut (depth 11,669 ft to 11,789 ft).

The total amount of core cut in the Mapco RBU No. 11-17F well, Sec. 17, T10S, R20E, Uintah County, Utah, was 141.6 ft with 98.2 ft recovered (70 percent). Two cores were cut in the basal unit of the Wasatch, locally named the Uteland Buttes unit by Mapco, but recovery was poor. The remaining cores were cut in the upper portion of the Mesaverde.

In the Greater Green River Basin, the Pacific Transmission Supply Company No. 3-10A Federal well, Sec. 10, T22N, R94W, Sweetwater County, Wyoming was cored. About 165 ft of continuous 4-in. core from the Almond Formation was recovered from depths of 11,436 ft to 11,623 ft.

The Rainbow Resources, Inc. No. 1-3 Federal well, Sec. 3, T26N, R103W, Sweetwater County, Wyoming was cored through the Ericson Formation with full recovery. Coring resumed in the Rock Springs Formation (12,630 ft to 12,777.5 ft) with 85 percent recovery, and again in the Rock Springs Formation at 13,410 ft to 13,503 ft with 92 percent recovery.

LOGGING PROGRAM

The Pacific Transmission Supply Company No. 22-12 "Barcus Creek" Federal well, Sec. 12, T1N, R99W, Rio Blanco County, Colorado was logged as follows:

- Dual Induction Log - Laterolog 8/SP/GR;
- Formation Density Log/Compensated Neutron/Caliper/GR;
- Dual Laterolog/SFL/Caliper/SP, BHC Sonic/GR/Caliper; and
- Variable Density Log - Sonic Amplitude.

The Natural Gamma Spectroscopy Tool was not available for this well.

Schlumberger ran its Natural Gamma Spectroscopy Log through casing on the PTS No. 24-19 "Beamers Bluff" Federal well, Sublette County, Wyoming. The logging interval was 5,531 to 4,400 ft in the Mesaverde horizon.

The PTS No. 3-10A Federal well, Sec. 10, T22N, R94W, Sweetwater County, Wyoming was logged as follows:

- Dual Induction Log-SFL-SP-GR;
- Simultaneous BHC Sonic-Caliper;

- Variable Density Log-Full Wave Train Log-Amplitude Log;
- Formation Density-Caliper;
- Simultaneous Compensated Neutron Gamma Ray;
- Dual Laterolog and Simultaneous Micro-SFL-Caliper-Gamma Ray; and
- Logged with pad closed from 11,955 to 11,514 ft, Mud Log (R_{xo} closed from 10,937 to 11,960 ft).

The Mapco RBU No. 11-17F well, Sec. 17, T10S, R20E, Uintah County, Utah was logged as follows:

- Dual Laterolog-Gamma Ray, Microlaterolog-Caliper (failed);
- Compensated Densilog-Caliper-Simultaneous Compensated Neutron Log-Gamma Ray; and
- BHC Acoustilog Caliper-Gamma Ray.

The Rainbow Resources Inc. No. 1-3 Federal well, Sweetwater County, Wyoming was logged as follows:

- Dual Laterolog/Simultaneous Micro-SFL/Caliper/Gamma Ray, pad closed logged 13,756 ft, Mud Log 12,400 to 12,170 ft;
- Dual Induction Log - SFL/SP/GR, Simultaneous BHC Sonic - Caliper, Variable Density Log;
- Dipmeter;
- Formation Density - Caliper/Simultaneous Compensated Neutron/Gamma Ray; and
- Natural Gamma Spectroscopy.

SURVEY OF BASIN ACTIVITIES

Production figures from horizons of interest, and the number of newly staked and completed wells are listed in Table 4-3.

MULTI-WELL EXPERIMENT

The Northwest Exploration Company site (Sec. 20, T6S, R94W, Garfield County, Colorado) was picked for the experiment as the most suitable site from both a geologic standpoint and from a year-round operational basis. It is believed that field activities can commence in late summer.

1 . 3 . 2 R E S E A R C H A N D D E V E L O P M E N T B Y
 E N E R G Y T E C H N O L O G Y C E N T E R S
 A N D N A T I O N A L L A B O R A T O R I E S

B A R T L E S V I L L E E N E R G Y T E C H N O L O G Y
C E N T E R

The low-invasion fluid used in the core fluid tests has been useful in obtaining better pressure cores.

The new Sandia designed core bit bodies are scheduled for completion in May. Plans to diffusion bond polycrystalline diamond cutters to the pilot bit bodies are being formulated. Rework of the first polycrystalline diamond core bit has been completed with the reworked bit scheduled for field testing in May. One advantage of the improved PDC pressure coring system is that excellent cores can now be obtained from lightly consolidated formations where core recovery was very poor in the past.

Experiments in logging studies to determine the effect of overburden pressures on the electrical conductivity of saturated cores continued. Initial results indicate relatively large increases in observed core resistance as a function of increasing confining pressure.

In water resistivity studies of Western gas sands, salinity analyses of 136 waters from flow streams of producing gas wells in the Uinta Basin showed good correlation with those from DST waters. In particular, six DST analyses correlated with analyses of water typifying the formations tested. The large amount of bicarbonate in the Green River and Farrer Formation samples may explain some of the confusion in relating the well potential to R_w .

The relative gas permeabilities of core Nos. 5172, 5205, and 5220 from the Pacific Transmission Supply Company well No. 24-19, were measured for in situ permeability studies. The calculated relative permeability curves show trends similar to those from the Mobil PCU F31-13G and Canyon Largo No. 256 wells.

Experiments were also conducted to establish the combined effect of high net confining pressure and partial water saturation on the gas slippage effects. Core No. 4172 from the PTS 24-19 Federal well was desaturated to 43.2 percent water saturation, and effective gas permeability was measured as a function of mean pore pressure and net confining pressure.

Qualitatively, the gas slippage effect (as measured by the slope of the Klinkenberg plot) is reduced at high net confining pressure for both

dry and partially saturated cores. In addition, it appears that at a given net confining pressure, the presence of water in a part of the pore space has a similar effect on gas slippage.

GAS RESEARCH INSTITUTE

The Gas Research Institute has initiated a project for field evaluations of reservoir fracturing to increase the producibility of tight gas reservoirs by providing essential field data.

Preparation of a proposal for a tight gas sands data base continued during the reporting period. This proposal will be to:

- develop a geologic and engineering data base for the tight sands basins,
- conduct geologic studies of the secondary basins, and
- provide access to a convenient data retrieval system by all segments of industry.

LAWRENCE LIVERMORE LABORATORY

Lawrence Livermore Laboratory is conducting a theoretical program in which calculations are being used to analyze some aspects of hydraulic fracture penetration through a frictional interface. Comparison of these results with laboratory experiments will determine how the critical frictional levels result in stress concentrations that allow fracture penetration of the interface.

Two-dimensional models are being developed to analyze the effect of overpressure in the productive formation on hydraulic fracturing.

Pressure-volume measurements continued on samples of Mesaverde sandstone from Rio Blanco County, Colorado and are 80 percent complete. Testing began on the high pressure system for simultaneous ultrasonic velocity measurements in multiple directions under confining pressure.

LOS ALAMOS SCIENTIFIC LABORATORY

The NMR transmitter and receiver electronics were modified to eliminate intermittent operation, several internal arcs, "jitter" in the pulse length, and receiver noise. This new system has been used to observe spin-echo NMR signals from the homogeneous field region surrounding the simulated wellbore position.

SANDIA LABORATORIES

A borehole seismic experiment was performed on Amoco's Burnett Brothers No. 12 gas well near Carthage, Texas for the hydraulic fracture characterization study. It was determined that the seismic unit was located with the axis of one of the horizontal geophones at an azimuth of 301°, 298°, 303° and 297° for the seismic shots. With a spread of only six degrees from the four shots, it was felt that this is a very usable technique for determining orientation.

An experimental program has been developed to study the dielectric properties of rock samples as a function of frequency. Initially, the region of experimental interest will be in the approximate range of 0.1-100 MHz, which is the region of maximum dispersion of the real and imaginary parts of the dielectric constant. In this regime, two distinct experimental techniques can be used which will indicate the accuracy of the experimental results. The first method is a standard bridge technique; the real and imaginary parts of the dielectric constant of the rock sample are found by using a variable resistor and capacitor to balance the bridge. The second method determines the dielectric properties of the rock sample by measuring the attenuation and phase shift of an applied sinusoidal signal of a given frequency through the rock.

1 . 3 . 3 F I E L D T E S T S A N D D E M O N S T R A T I O N S

C E R C O R P O R A T I O N

Field activities on the RB-MHF 3 well have been suspended. CER has transferred the well to an operator who will attempt to complete the well, commingle the fractured zones, test the well and provide data to industrial participants and DOE.

COLORADO INTERSTATE GAS COMPANY

Cyclic injection of dehydrated gas and production from the Miller No. 1 and Sprague No. 1 wells continued during the reporting period.

The DOE test trailer arrived on location at the Miller No. 1 well on January 10. Both the Miller No. 1 and Sprague No. 1 wells were shut in and all cycling operations were halted on January 12. Both wells began drawdown in preparation for measurement of BHP.

For comparison, the Miller No. 1 well was drawn down twice for BHP buildup measurements. The buildup curves were similar.

No BHP data was available from the Sprague No. 1 well due to problems encountered after shut-in.

DOE WELL TEST FACILITY

The Facility remained at the Rio Blanco Natural Gas Company No. 397-19-1 Government well site until mid October to obtain reservoir data.

In January, the facility was transported to CIG's Miller No. 1 well to acquire BHP and flow rate data.

SANDIA LABORATORIES - MINEBACK

Hydraulic fracture containment experiments have been conducted to investigate the parameters that influence and control containment of hydraulic fracture. A hydraulic fracture with colored grout was initiated in a low modulus ashfall tuff formation which was overlaid by a welded tuff formation of a higher order of magnitude modulus. An extensive coring effort has been completed to determine the extent and shape of this fracture. Twenty-nine coreholes have been completed.

The interface test series experiments show that in situ stress is the dominant mechanism controlling hydraulic fracture propagation.

1 . 3 . 4 P R O J E C T M A N A G E M E N T

During the reporting period, the Western Gas Sands Project Quarterly Basin Activities Report, July 1 - September 30, 1979 and the Western Gas Sands Project Quarterly Basin Activities Report, October 1 - December 31, 1979, were released. Project status reports for the months of August, September, October, November and December 1979 and January 1980 were released. The WGSP financial supplements for the months of September, October, November, December 1979 and January and February 1980 were released to a limited distribution. In addition, the Project Plan Document for FY 1980 was released. The WGSP Coring Report and WGSP Logging Report were finalized and the DOE Well Test Facility Manual was updated as equipment was added or modified.

1.4 METHANE RECOVERY FROM GEOPRESSURED AQUIFERS

The following is a summary of significant activities in this program through March 31, 1980.

RESOURCE ASSESSMENT

Current resource assessment activity is focused on the onshore portion of the Texas-Louisiana Gulf Coast. In Texas, 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 are in the process of being defined.

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 have been completed, and final reports are in preparation. The assembly of high-temperature, high-pressure viscometer at the Institute of Gas Technology has been terminated due to insurmountable technical difficulties.

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 designed well 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 both wells, and the data have been published.

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. Meetings have been held with excellent response from various industry participants.

A geopressured geothermal symposium was held in October 1979, and others are planned for FY 1980.

2. METHANE RECOVERY FROM COALBEDS

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2 . 1 I N T R O D U C T I O N

2 . 1 . 1 B A C K G R O U N D

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 (Tcf). 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 (Scf) per day. The expansion of coal mining over the next 10 years, together with extensive adoption of predraining and gob mining draining techniques, will increase this rate considerably. At present, little 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; onsite

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 M E T H A N E R E C O V E R Y F R O M C O A L B E D S P R O J E C T

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 project 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 otherwise often 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 Pittsburgh 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.

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

Figure 2-1. Methane Recovery from Coalbeds Project Interrelationships

- 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 10 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 March, 1980 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.

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

Table 2-1. Technology Test Projects

TECHNOLOGY TESTS	EXTRACTION TECHNIQUE									UTILIZATION			
	PREDRAINAGE	GOB GAS	SINGLE WELL	MULTIPLE WELL	DIRECTIONAL BOREHOLE	HORIZONTAL BOREHOLE	HYDRAULIC FRACTURING	FOAM FRACTURING	GAS FRACTURING	PIPELINE INJECTION	POWER GENERATION	HEATING APPLICATION	LNG CONVERSION
MINABLE COALBEDS Westinghouse U.S. Steel Occidental Westinghouse Clinchfield J & L	• • • • • •	•	•	• • •	•	•	•	•		• • • •	•	•	•
UNMINED COALBEDS Mountain Fuel Intercomp/Cosaka PERI Waynesburg			• •	• •			• • •	• •		• • • •			

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 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 G E N E R A L

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

- Implementation of the MRCP Resource Delineation Plan to increase the amount of available site-specific data.
- Continuation of an analysis and test program to determine the feasibility of producing methane from coalbeds.

Sections 2.2.2 through 2.2.8 review the efforts of the several organizations directly participating in analysis and test program activities.

Sections 2.2.9 through 2.2.17 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 for each field activity are tabulated in Table 2-2.

Table 2-2. MRCP Well Site Designations

<u>Basin</u>	<u>Well Site Designation</u>	<u>Cooperating Company/Agency and Well Identification</u>
Arkoma	EAA	Arkla Exploration; Brown 1-2
	EAB	Mustang Production; Barringer 1-11
	EAC	Mustang Production; Day 1-14
	EAD	U.S. Burec; DH-A17
Green River	GAA (Type I)	Energy Reserves Group
	GAA (Type III)	Energy Reserves Group
	GAB*	Belco Petroleum Corporation Sublette County, Wyoming
Illinois	DAA	Hagen Oil Company; Henderson #2
	DAB	GeoWest Inc.; Confidential Well
	DAC*	Indiana Geological Survey; Posey County, Illinois Sec. 33, T6S, R13W
	DAD*	Indiana Geological Survey; Posey County, Illinois Sec. 26, T4S, R13W
	DAE*	R. W. Beeson Oil Producer; Seebree County, Kentucky
Northern Appalachian	AAA	Kinloch Development; Murdoch #1
	AAB	Waynesburg College
Piceance	FAA	Fuelco; Cathedral 0-28-3-101-S
	FAB	Twin Arrow; C&K Well #1-13
	FAC	Twin Arrow; C&K Well #4-14
	FAD	Confidential Well No. 2
	FAE	Confidential Well No. 3
	FAF	Confidential Well No. 4
	FAG	Confidential Well No. 5
	FAH	Fuelco; D-26-3-101-S
Powder River	IAA	USGS; Powder River County, Montana. Sec. 22, T8S, R47E
	IAB	Montana BMG; No. U.S.-7735
	IAC	Montana BMG; No. U.S.-7746
San Juan	HAA	Western Coal Company;
Southern Appalachian/Warrior	CAA	Grace Petroleum Corporation; No. 1, Grimsely 35-15
Western Washington	LAA	DOE; Thurston County, Washington

*Implementation of these tests began in this reporting period.

2 . 2 . 2 M E T H A N E F R O M C O A L B E D S R E S O U R C E D E L I N E A T I O N

TRW Energy Systems
McLean, Virginia

Status:
Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AC21-78MC08089
December 12, 1977
February 12, 1981

Principal Investigator:
DOE Technical Project Officer:

C. T. Rightmire (TRW)
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-AC21-78MC08089, 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 IN PRIOR REPORTING PERIODS

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 distribution, quality, and production characteristics of methane 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.

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

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 for each basin were begun. The objectives of these 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.

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

REGION	TOTAL AREA, (Sq. miles)	TARGET AREA, (Sq. miles)	
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	3,000*	(Arkoma Basin)
San Juan	19,000	1,325*	
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	5,000*	
Wind River	3,800	3,800	
Powder River	22,700	6,750*	
Washington	2,500	1,800*	

*Area redefined in this 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

Basin reports for the Illinois Basin, Powder River Basin, San Juan Basin, and the Greater Green River Basin have been reviewed and are in publication. The reports for the Arkoma Basin and Western Washington are being reviewed.

Target areas have been redefined for those basins for which an evaluation has been conducted. 1980 drilling and testing operations will be focused in those redefined targets. This target redefinition has decreased the target size in the six basins studied by about 50 percent. Gas-in-place estimates for the six basins evaluated are shown in Table 2-4.

Table 2-4. Estimated In-Place Coalbed Methane Resource
(Cubic Feet)

	<u>Minimum</u>	<u>Maximum</u>
Illinois Basin	5.21×10^{12}	20.0×10^{12}
Powder River Basin	5.91×10^{12}	65.0×10^{12}
San Juan Basin	1.79×10^{12}	25.09×10^{12}
Green River Basin	0.15×10^{12}	30.0×10^{12}
Arkoma Basin	1.5×10^{12}	3.55×10^{12}
Western Washington	0.4×10^{12}	24.0×10^{12}

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, 1981

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 crosscut 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 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 onsite 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 IN PRIOR REPORTING PERIODS

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, ϕ . The definition of ϕ is the cumulative discounted gas production deliverability for 10 years at a discount rate of 15% per year (referenced in this report as "gas deliverability", ϕ). The assumptions used in this model are:

- 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 unproved 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 ϕ 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, ϕ . The module which included determination of all the independent variables was the best predictor of ϕ . By calculating the standard deviation of the distribution of ϕ 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, ϕ .

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 consideration as to location of those 60 modules.

The data resulting from the Kinloch Development Company #1 Murdock well in Greene County, Pennsylvania, were standardized for use as a test site and an analysis was performed by the Pennsylvania State University.

PROGRESS THIS REPORTING PERIOD

Due to low gas concentrations indicated in recently received data, the resource assessment study has been temporarily suspended until more complete data are available and the resources of this contract are applied to site-specific analyses. The results of these analyses are summarized below.

Arkoma Basin Sensitivity Study

This study was performed to assist in the design of a test sequence in the Arkoma Basin.

Simulations were made using estimated values for four percent porosity and an initial pressure of 2000 psia. Each run was extended through a one-year period. Three different values for the gas content (186, 500, and 700 cubic feet/ton) were assumed, and each value of gas content was coupled with a specific permeability. A value of 2 md was used with the content of 186 cubic feet/ton, 5 md with 500 cubic feet/ton, and 20 md with 700 cubic feet/ton. Evaluations were made using three fracture lengths. Figure 2-3 shows a comparison for a well with no fracture. Figure 2-4 compares the 186 and 500 cubic feet/ton cases for a fracture length of 200 feet. Figure 2-5 is the 700 cubic feet/ton example with a 500 feet fracture.

Pennsylvania State University (PSU) Degasification Project

This study evaluated the historical production performance of three wells producing from the Pittsburgh coal seam at the U.S. Steel Corporation's Cumberland Mine in Greene County, Pennsylvania.

Figures 2-6, 2-7, and 2-8 show the actual and simulated gas and water production. The values of the modeled parameters appear to be consistent across the area. The most noticeable difference is that porosity at well CNG 1034 is higher than at the other two wells. This higher porosity results in the higher water production and lower gas production.

Oak Grove Degasification Project Modeling

Planning of this study began in November 1979, and a 20x23 grid block two-dimensional areal model of the well pattern was set up in January and February. The model is satisfactorily matching all but a few wells.

Changes in the permeability, relative permeability, porosity, diffusivity, well index, and bottom hole pressure have been required. Difficulty was incurred in the beginning because of the length of time it took to make one complete model run. The model run time was reduced considerably by altering the time at which wells were turned on or off by a few days so that less time steps were required. Also, some of the input rates were averaged over longer periods to save time steps.

One of the major changes that have been necessary so far is to insert a simulated fault to the west of the pattern and to increase the permeability in this area. Another problem has been the low gas rates which appear in the eastern part of the pattern. Fault zones may be causing this problem also.

Figure 2-3. Estimated Production from Hartshorne Seam

Figure 2-4. Estimated Production from Hartshorne Seam - 200 Foot Fracture

Figure 2-5. Estimated Production from Hartshorne Seam - 500 Foot Fracture

Figure 2-6. Actual and Simulated Flow from Well CNG 1035

Figure 2-7. Actual and Simulated Flow from Well CNG 1034

Figure 2-8. Actual and Simulated Flow from Well CNG 1036

2.2.4 EVALUATION OF COLORADO COALBED METHANE POTENTIAL

Colorado Geological Survey
Denver, Colorado

Status:
Active

Contract:

DE-FG21-80MC14256

Contract Date:

April 1, 1978

Anticipated Completion Date:

March 31, 1981

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-218377 and DE-FG21-80MC14256 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
- Performance of methane desorption measurements.

PROGRESS IN PRIOR REPORTING PERIODS

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 of samples from the Piceance Basin and the Douglas Creek area of the Uinta region was initiated. Proximate and ultimate analyses were received for samples and reported in the respective well test summaries.

PROGRESS THIS REPORTING PERIOD

As of the end of this reporting period, 169 coal samples have been desorbed or are in desorption.

Resource estimates were calculated for the Piceance Basin and the Fruitland Formation in the San Juan region. Methane resources of 31 trillion cubic feet are estimated for the Piceance Basin and 7 trillion cubic feet for the Fruitland Formation. Estimates of coalbed methane in the Raton Basin are being computed.

2.2.5 EFFECT OF PREDRAINAGE STIMULATION TECHNIQUES ON COAL RECOVERY

Colorado School of Mines
Golden, Colorado

Status:
Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AC21-78MC08089
November 28, 1978
December 31, 1980

Principal Investigator:
DOE Technical Project Officer:

C. T. Rightmire
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 long-wall) 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 preexisting 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 IN PRIOR REPORTING PERIODS

The activities described above were initiated. Review of previously-reported theoretical studies, results of laboratory experiments, and limited field studies on hydraulic fracturing of coal seams were completed.

PROGRESS THIS REPORTING PERIOD

The activities described above were continued. Construction of the in-mine test facility to determine fracture patterns and study the propagation of hydraulically-induced fractures in mine workings is underway.

Work has continued on understanding the theory of hydraulic fracture propagation. The data base in this area is being assembled. Emphasis of work is on understanding fracture propagation across interfaces under load conditions. Determination of the effects of rock properties is part of this effort.

2.2.6 EVALUATION OF UTAH COALBED METHANE POTENTIAL

Utah Geological and Mineral Survey
Salt Lake City, Utah

Status:
Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-FG-21-79MC11729
June 1, 1979
May 31, 1981

Principal Investigator:
DOE Technical Project Officer:

A. D. Smith
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 OCTOBER 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):

<u>Coalfield</u>	<u>Sample Distribution</u>
Alton	3
Book Cliffs	98
Emery	8
Henry Mountains	1
Kaiparowitz 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 were 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.

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.

PROGRESS THIS REPORTING PERIOD*

During the period September through November 1979, 15 core samples were obtained from the following sources:

- Ten from Coastal States Energy
- One from UGMS
- Four from Mountain Fuels Supply Company

These coal samples are being desorbed or have been desorbed.

*The Utah Geologic and Mineral Survey reports on the schedule of June through September. Reporting in this section is based on its reporting schedule.

2.2.7 EVALUATION OF SOUTHERN COALFIELDS

Virginia Polytechnic Institute
& State University
Blacksburg, Virginia

Status:
Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AC21-78MC08089
June 1, 1979
December 31, 1980

Principal Investigator:
DOE Technical Project Officer:

C.T. Rightmire (TRW)
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 unminable 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 selected 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 IN PRIOR REPORTING PERIODS

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.

PROGRESS THIS REPORTING PERIOD

Field mapping of the Richmond Basin was completed. A detailed geologic assessment by the Virginia Division of Mineral Resources was delivered to VPI and is being included in the Richmond Basin report.

2.2.8 RESERVOIR FRACTURING AND MINING THROUGH FRACTURED AREAS

Pennsylvania State University
State College, Pennsylvania

Status:
Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AC21-78MC08089
June 1, 1979
May 13, 1980

Principal Investigator:
DOE Technical Project Officer:

A. A. Lee (TRW)
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 onsite 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 IN PRIOR REPORTING PERIODS

Reported progress was in data base information collection on methane recovery parameters, development of a simulation model for coal seam methane reservoir prediction, and procurement of equipment for evaluation of coal seam degasification impact on mine ventilation operating costs.

PROGRESS THIS REPORTING PERIOD

The following activities are in progress:

- Assembly of a data base providing pertinent methane recovery parameters.
- In-mine observations of the effects of hydraulically fracturing coalbeds.
- Determination of finite-difference approximations to the system equations describing coalbed methane gas production.
- Assembly of apparatus and 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 2-9). 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 240 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 c/f/ton in the Brown Estate No. 1-2 well. The Lower Hartshorne coal from the Bureau of Reclamation well DH-A17 contains 300 cf/ton.

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 2-9.

Figure 2-9. Arkoma Basin Target Area

At the end of this reporting period, the status of well tests in the Arkoma Basin was as follows:

<u>Test Well</u>	<u>Status</u>
Site EAA Arkla Exploration Co.	Well test data package is complete
Site EAB Mustang Production Co.	Desorption completed.
Site EAC Mustang Production Co.	Desorption completed.
Site EAD U. S. Bureau of Reclamation	Desorption completed.

These tests are described in detail in the following sections.

ARKOMA BASIN, SITE EAA (BROWN WELL #1-2)
PITTSBURG COUNTY, OKLAHOMA

Cooperating Company:
Arkla Exploration Company
Shreveport, Louisiana

Status:
Well test data package
is complete.

Field Work Performance Period:
Principal Investigator:
DOE Technical Project Officer

October 1978
C. T. Rightmire (TRW)
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.

SCOPE OF WORK

This cooperative agreement calls for the drilling, logging, sidewall coring and drill stem testing of the Lower Hartshorne coalbeds in the Arkoma Basin. This well (Brown Well #1-2) is in Pittsburg County, Oklahoma, Section 2, Township 6N, Range 13E.

PROGRESS IN PRIOR REPORTING PERIODS

Geophysical well logs were obtained on October 8, 1978. Thirty-six sidewall cores were obtained from 48 shots during testing on October 9, 1978. Drill stem tests were conducted from October 10-13, 1978. Desorption from the sidewall cores was performed in the prior reporting period.

The following data were prepared during the previous reporting periods:

Logging

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

Sidewall Coring

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

<u>Interval (ft)</u>	<u>Shots</u>	<u>Cores Recovered</u>
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 2,700 to 2,740 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 (a) a gas-in-place estimate of 1.4 Bcf per square mile (640-acre section) and (2) a cumulative discounted 10-year gas deliverability 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, ϕ .

Gas Desorption

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

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

PROGRESS THIS REPORTING PERIOD

The well test data package has been compiled and is maintained on open file at the Morgantown Energy Technology Center.

ARKOMA BASIN, SITE EAB (BARRINGER #1-11)
PITTSBURG COUNTY, OKLAHOMA

Cooperating Company:
Mustang Production Company
Oklahoma City, Oklahoma

Status:
Desorption is completed.

Field Work Performance Period:
Principal Investigator:
DOE Technical Project Officer:

July 1979
C. T. Rightmire (TRW)
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.

SCOPE OF WORK

This cooperative agreement calls for the coring and logging of the Middle Booch Seam and Upper and Lower Hartshorne Seams in the Arkoma Basin. This well (Barringer # 1-11) is located in Pittsburg County, Oklahoma, Section 11, Township 4N, Range 15E.

PROGRESS IN PRIOR REPORTING PERIODS

Sixteen feet of core were recovered from conventional coring operations in mid-July 1979. Geophysical logging was conducted prior to coring (electric, gamma ray, spectrolog, compensated density, and caliper). Gas desorption, computer analysis (relative rank, thickness, moisture, mineral content, ash content) and laboratory analysis were performed on the coal sample recovered.

PROGRESS THIS REPORTING PERIOD

A Type III well testing program was prepared by TRW, Dowell, Mustang Production Co. and DOE/METC personnel during several coordination meetings from October 1979 through January 1980. A pre-frac and post-frac testing program was prepared for operation.

Field operations were begun on February 11, 1980 and were terminated on February 13, 1980. Several attempts were made to swage out the collapsed casing at 1,710 feet and 1,744 feet downhole. The casing could not be repaired to accept the required packer unit for subsequent well-completion operations. As a result, the Barringer well was abandoned as a viable prospect for Type III testing.

In summary, one coal seam with a thickness of one foot was sampled for desorption. The total gas content for the sample is given below:

<u>Lithology</u>	<u>Sample Depth</u>	<u>Sample Weight (gm)</u>	<u>Desorped Gas (cc/gm)</u>	<u>Residual Gas (cc/gm)</u>	<u>Total Gas (cc/gm)</u>	<u>Per Unit cf/ton</u>
Coal	3650-3651	1257	6.48	1.2	7.6	243.2

The well test data package is currently being compiled and will be maintained on open file at the Morgantown Energy Technology Center.

ARKOMA BASIN, SITE EAC (DAY WELL #1-14)
HASKELL COUNTY, OKLAHOMA

Cooperating Company:
Mustang Production Company
Oklahoma City, Oklahoma

Status:
Desorption is completed.

Field Work Performance Period:
Principal Investigator:
DOE Technical Project Officer:

July 1979
C. T. Rightmire (TRW)
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.

SCOPE OF WORK

The cooperative agreement calls for the coring and logging of the Upper Booch and Hartshorne Undivided coal horizons in the Arkoma Basin. This well (Day Well # 1-14) is located in Haskell County, Oklahoma, Section 14, Township 7N, Range 20E.

PROGRESS IN PRIOR REPORTING PERIODS

Forty-three feet of core were obtained during operations in July 1979. The core was sampled from the Upper Booch coal horizon and the Hartshorne Undivided coal horizon. No coal was obtained from coring operations due to core lifter failure and air jetting. Computer analyses (relative rank, thickness, moisture, mineral content, gas content and ash content) of the well log data were performed for the coal horizons encountered.

PROGRESS THIS REPORTING PERIOD

The well test data package is being compiled and will be maintained on open file at the Morgantown Energy Technology Center.

ARKOMA BASIN, SITE EAD (U.S. BU REC # DH-A17)
LEFLORE COUNTY, OKLAHOMA

Cooperating Organization
U. S. Bureau of Reclamation
Amarillo, Texas
Field Work Performance Period:

Status:
Desorption completed.

September 1979

Principal Investigator:
DOE Technical Project Officer:

C. T. Rightmire (TRW)
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.

SCOPE OF WORK

This cooperative agreement calls for the coring and logging of the Lower Hartshorne Seam in the Arkoma Basin. Laboratory analysis will be performed on the coal samples (proximate analysis, ultimate analysis, heating value and equilibrium moisture). This well (U.S. Bu. Rec. Well #DH-A17) is located in LeFlore County, Oklahoma, Section 14, Township 8N, Range 16E, SW 1/4 of NW 1/4).

PROGRESS IN PRIOR REPORTING PERIODS

Coring operations continued from surface to T.D. during mid-September with 10 feet of core described in detail above and below the coal seam sampled. Borehole geophysical logs were run on September 13, 1979 (gamma ray, electric and caliper).

PROGRESS THIS REPORTING PERIOD

In addition to desorption of coal samples, laboratory analysis of coal samples was initiated (proximate analysis, ultimate analysis, heating value and equilibrium moisture).

In summary, one coal seam with a thickness of 2.9 feet was cored and sampled for desorption. The total gas content for the sample is given below:

<u>Lithology</u>	<u>Sample Depth (ft)</u>	<u>Total Gas (cc)</u>	<u>Sample Wt (gm)</u>	<u>Total Gas Per Unit (cc/gm)</u>	<u>cf/ton</u>
Coal	191.6-192.6	12,739*	1363	9.4	300.8

*Includes lost and residual gas

The well test data package is being compiled and will be maintained on open file at the Morgantown Energy Technology Center.

2.2.10 GREEN RIVER BASIN (WYOMING AND COLORADO)

The Greater Green River Coal Region, Figure 2-10, occupies approximately 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 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 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 small-scale 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 are approximately 1.6 billion short tons of subbituminous coal within 3,000 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 approximately 3000 square miles in south central Wyoming and northwestern Colorado. In the primary Washakie Basin the major coalbearing 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 119 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 approximately 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 2-10.

At the end of this reporting period the status of well tests was as follows:

<u>Test Well</u>	<u>Status</u>
Site GAA (Type I Test) Cooperating Company Confidential	Well test data package is complete.
Site GAA (new test series) Cooperating Company Confidential	Type III Pre-frac testing complete.
Site GAB Belco Petroleum Company	Well test data package is complete.

These tests are described in detail in the following section.

GREATER GREEN RIVER BASIN, SITE GAA
SPECIFIC PROJECT LOCATION CONFIDENTIAL

Cooperating Company:
Energy Reserves Group, Inc.
Casper, Wyoming

Status:
Well test data package is
complete.

Field Work Performance Period:
Principal Investigator:
DOE Technical Project Officer:

November 1978
C. T. Rightmire (TRW)
H. D. Shoemaker

OBJECTIVE

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

SCOPE OF WORK

This cooperative agreement calls for the conventional coring, logging, drill stem testing and sidewall coring of several coal seams of the Mesaverde Formation in the Greater Green River Basin. In addition to the preceding tests, laboratory analysis will be conducted for the coal samples. The specific location of this well is confidential.

PROGRESS IN PRIOR REPORTING PERIODS

Data were obtained from 139 feet of conventional core obtained during drilling in November 1978. Other tests included logging (compensated neutron, caliper, natural gamma, borehole compensated sonic, dual induction), sidewall coring and drill stem testing. Desorption from conventional coring also was conducted during the prior reporting period. The desorption data from sidewall coring are tabulated below.

Two drill stem tests were performed during the well testing in November, 1978: the first after 30 feet of conventional coring, the second after all conventional coring was completed. Results from the drill stem test are shown below.

TEST #1 - November 19 and 20, 1978

Interval tested: 3700 - 3800 feet

<u>Description</u>	<u>Pressure (psi)</u>	<u>Period (min)</u>
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		

TEST #2 - November 29, 1978

Interval tested: 4,634 - 4,714 feet

<u>Description</u>	<u>Pressure (psi)</u>	<u>Period (min)</u>
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 test #2 there was a slight show of gas to the surface at the end of the final flow period (at 58 minutes).

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 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.

PROGRESS THIS REPORTING PERIOD

In addition to final desorption of coal samples from conventional core, laboratory analysis of the samples was completed (proximate analysis, ultimate analysis, heating value, equilibrium moisture).

In summary, eight coal seams with a total thickness of 16.2 feet were cored and gas concentrations of 18 to 376 cubic feet per ton were measured. Desorption data from conventional core are listed on Table 2-5.

The well test data package has been compiled and is maintained on open file at the Morgantown Energy Technology Center.

Table 2-5. Final Data from Conventional Core Desorption of
Samples from Green River Basin Site GAA

<u>Sample Depth</u> (ft)	<u>Lithology</u>	<u>Approximate Gas-in-Place</u>	
		(cc/gm)	(cf/ton)
3644	Shale	0.58	18.4
3652	Coal	7.84	250.8
3675	Coal	7.99	255.8
3922	Coal	3.77	120.5
3930	Shale	3.86	123.6
3948	Coal	2.72	86.9
4654	Coal	9.01	288.4
4655	Coal	8.43	269.8
4656	Coal	9.26	296.4
4657	Coal	9.40	300.8
4658	Coal	8.56	274.1
4659	Coal	10.08	322.5
4798	Coal	11.76	376.4

GREATER GREEN RIVER BASIN, SITE GAA
MOFFAT COUNTY, COLORADO (NEW SERIES TEST)

Cooperating Company:
Energy Reserves Group, Inc.
Wichita, Kansas

Status:
Complete

Field Work Performance Period:
Principal Investigator:
DOE Technical Project Officer:

June - December 1979
C.T. Rightmire
H.D. Shoemaker

OBJECTIVE

Complete well in one coal interval, frac and conduct long-term production testing to determine the methane content and reservoir properties of several coal seams within the Mesaverde Formation in the Greater Green River Basin as part of an effort to delineate the potential for production from this resource area.

SCOPE OF WORK

This cooperative agreement calls for the Type III pre-frac testing and post-frac testing of several coal seams within the Mesaverde Formation in the Greater Green River Basin. Also includes coal structural/strength testing at Colorado School of Mines. The specific location of this well is confidential.

PROGRESS IN PRIOR REPORTING PERIODS

The Type III testing of the Robert A. Van Dorn Well #1 produced the following results:

June 22, 1979	- Well completion began
June 27	- Injectivity-pressure fall-off testing
July 5	- Halliburton frac (guar gel hydraulic with nitrogen assist)
July 27	- Post-frac clean-up underway
September 9	- Water production -- 6.5 bbl/day
October 24	- Production rates (2-3 bbl/day water, 6 Mcf/day gas)
November 17	- Producing 5 bbl water/day, less than 0.5 Mcf/day gas

PROGRESS THIS REPORTING PERIOD

Due to the low production rate, testing was terminated on January 1, 1980. No further testing is planned.

A test report summarizing the results of the Type III test and coal structural/strength testing is being prepared.

GREATER GREEN RIVER BASIN, SITE GAB
SUBLETTE COUNTY, WYOMING

Cooperating Company:
Belco Petroleum Company
Lakewood, Colorado

Status:
Complete

Field Work Performance Period:
Principal Investigator:
DOE Technical Project Officer:

January 1979
C.T. Rightmire (TRW)
H.D. Shoemaker

OBJECTIVE

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

SCOPE OF WORK

This cooperative agreement calls for the conventional coring, logging, sidewall coring and drill stem testing of several coal horizons within the Mesaverde Formation in the Greater Green River Basin. Laboratory analysis of the coal samples will also be conducted. This well is located in Sublette County, Wyoming, Section 28, Township 30N, Range 113W.

PROGRESS IN PRIOR REPORTING PERIODS

Conventional coring operations recovered 90 feet of core in mid-January. Eighteen sidewall cores were obtained after completion of the conventional coring operation. Borehole geophysical logs were run on January 13, 1979 (Borehole Compensated Sonic Log, Dual Induction-SFL, Compensated Neutron-Formation Density and Computer Processed Log). Desorption of sidewall cores was completed in the prior reporting period. Drill stem testing was canceled at the request of Belco due to inclement weather and potential hole problems. Analysis by gas chromatograph was completed.

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

<u>Sample Depth Range (ft)</u>	<u>Lithology</u>	<u>Gas Content (cf/ton)</u>
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 estimate for an isolated well of between 25,000 and 90,000 Mcf. See Section 2.2.3 for a discussion of gas deliverability.

PROGRESS THIS REPORTING PERIOD

In addition to completion of the conventional core desorption, laboratory analysis of the coal samples was completed (proximate analysis, ultimate analysis, equilibrium moisture).

In summary, three coal seams with a total thickness of 5.6 feet were cored, and gas concentrations of 33 to 539 cubic feet per ton were measured. Final desorption data from the conventional coring are listed below:

<u>Approximate Depth (ft)</u>	<u>Sample Wt (gm)</u>	<u>Total Gas (cc)</u>	<u>Gas Content</u>	
			<u>cc/gm</u>	<u>(cu ft/ton)</u>
3479	856	12,963	15.14	484.6
3480	1269	19,239	15.16	485.1
3481	1312	17,819	13.58	434.6
3495	1321	22,230	16.83	538.5
3496	1057	17,800	16.84	538.9
3507	1864	12,218	6.55	209.7
3520	2065	2,115	1.04	33.4
3527	1342	19,540	14.56	465.9
3528	1167	18,721	16.04	513.3

Evaluation of the coal samples by proximate/ultimate analysis is complete and listed below:

<u>Sample Interval (ft)1</u>	<u>Moisture % (AR)1</u>	<u>Fixed Carbon % (AR)1</u>	<u>Ash % (AR)1</u>	<u>Sulfur % (AR)1</u>	<u>Heating Value Btu/lb (AR)1</u>	<u>Apparent Rank</u>
3479.1-3479.6	3.3	48.1	2.8	1.5	13,671	HvAb2
3479.6-3480.6	3.4	48.2	5.9	1.1	13,348	HvAb
3480.6-3481.6	3.1	42.4	17.4	1.6	11,487	HvAb
3494.8-3495.8	3.5	50.0	3.1	.7	13,477	HvBb3
3495.8-3496.5	3.6	51.4	2.7	.8	13,809	HvAb
3506.6-3507.4	2.7	33.3	33.5	3.6	9,114	Carb. Shale
3519.7-3520.3	2.8	.4	85.1	.8	624	Shale
3526.6-3527.5	3.4	45.8	12.7	.8	12,229	HvAb
3527.5-3528.5	3.6	51.0	2.9	.9	13,564	HvAb

The well test data package has been compiled and is maintained on open file at the Morgantown Energy Technology Center.

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

The Illinois Basin encompasses 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. 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 thicknesses 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.

The recent investigation of gas desorption data indicates that the gas content of 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 from 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 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 2-11. The initial MRCP target area in the Illinois Basin was approximately 9,111 square miles. 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.

At the end of this reporting period the status of well tests was as follows:

<u>Test Well</u>	<u>Status</u>
Site DAA Hagen Oil Company	Well test data package is complete.
Site DAB Geowest, Inc.	Well test data package is complete.
Site DAC Indiana Geological Survey	Field activities complete; analysis in progress.
Site DAD Indiana Geological Survey	Field operations in progress.
Site DAE R. W. Beeson Oil Producer	Field activities complete; analysis in progress.

Figure 2-11. Redefined Illinois Basin Coalbed Methane Target Areas

ILLINOIS BASIN, SITE DAA (HENDERSON #2 WELL)
CLAY COUNTY, ILLINOIS

Cooperating Company:
Hagen Oil Company
Clay City, Illinois

Status:
Well test data package
is complete

Field Work Performance Period:
Principal Investigator:
DOE Technical Project Officer:

October 1978
C. T. Rightmire (TRW)
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.

SCOPE OF WORK

This cooperative agreement calls for the conventional coring, logging, sidewall coring and drill-stem testing and laboratory analysis of several coal seams lying between depths of 975 and 1,525 feet in the Illinois Basin. This well (Henderson #2) is located in Clay County, Illinois, Section 19, Township 3N, Range 8E.

PROGRESS IN PRIOR REPORTING PERIODS

During the drilling activities in late October 1978, 194 feet of conventional core were obtained. Drill stem testing, logging and sidewall coring also was conducted. The well logging was performed by Schlumberger on October 28 (induction-laterlog, porosity, density, sonic and fractive identification). Sidewall coring indicated a gas content of 27.7 cf/ton in the Danville No. 7 seam.

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 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.

Drill stem testing was conducted on October 27 and 28 by Lynes, with the following results:

<u>Date</u>	<u>Coal Seam</u>	<u>Interval Tested(ft)</u>	<u>Shut-In Pressure (psig)</u>
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.

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

In addition to desorption of coal samples, laboratory analysis of the coal was completed (proximate analysis, ultimate analysis, heating value, permeability and porosity). Porosity is estimated to be between 3 and 7 percent; permeability is less than 0.1 md.

In summary, five coal seams with a total thickness of 8 feet were cored and gas concentrations of 10 to 48 cubic feet per ton were measured. Final desorption data are as follows:

<u>Depth of Sample</u>	<u>Lithology</u>	<u>Gas Content (cf/ton)</u>
994	Coal	42
995	Coal Danville (No. 7)	38
1035	Coal	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

The well test data package has been compiled and is maintained on open file at the Morgantown Energy Technology Center.

ILLINOIS BASIN, SITE DAB
MARION COUNTY, ILLINOIS

Cooperating Company:
GeoWest, Inc.
Billings, Montana

Status:
Well test data package
is complete.

Field Work Performance Period:
Principal Investigator:
DOE Technical Project Officer:

May 1979
C. T. Rightmire (TRW)
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.

SCOPE OF WORK

This cooperative agreement calls for the coring, logging, and drill stem testing of multiple coal seams in the Illinois Basin. Laboratory analysis also will be performed on the coal samples. The location of this well is confidential.

PROGRESS IN PRIOR REPORTING PERIODS

During coring operations from May 14-16, 1979, 28.5 feet of core were recovered with six samples taken for desorption. Geophysical borehole logs were run (electric, gamma-ray, gamma-gamma density, and caliper) and a drill stem test was aborted due to hole sloughing.

PROGRESS THIS REPORTING PERIOD

In addition to completion of desorption of the coal samples, laboratory analysis was also completed (porosity/permeability and bulk density determination of roof and floor rock samples and proximate/ultimate analysis).

In summary, four coal seams with a total thickness of 12.8 feet were cored and gas concentrations of 23 to 29 cubic feet per ton were measured. Final desorption data are as follows:

<u>Depth of Sample</u>	<u>Unit</u>	<u>Gas Content (cf/ton)</u>
664.8	Danville No. 7 coal	25.2
698.0	Herrin No. 6 coal	35.4
727.0	Briar Hill No. 5A coal	22.6
735.7	Harrisburg No. 5 coal	29.0
733.4	Harrisburg No. 5 coal	29.0
732.4	Harrisburg No. 5 coal	25.6

ILLINOIS BASIN, SITE DAC
POSEY COUNTY, INDIANA

Cooperating Company:
Indiana Geological Survey
Bloomington, Indiana

Status: Field activities
complete; analyses in
progress.

Field Work Performance Period:
Principal Investigator:
DOE Technical Project Officer:

October 16-November 15, 1979
C. T. Rightmire (TRW)
H. D. Shoemaker

OBJECTIVE

To provide gas content and desorption data from coals in the southeastern part of the Illinois Basin in areas previously untested by MRCP.

SCOPE OF WORK

This cooperative agreement calls for the coring, logging and laboratory analysis of several coal seams in the southeastern part of the Illinois Basin. The well is located in Posey County, Indiana, Section 33, Township T6S, Range 13W.

PROGRESS IN PRIOR REPORTING PERIODS

The cooperative agreement with the Indiana Geological Survey was prepared.

PROGRESS THIS REPORTING PERIOD

Coring operations began on October 16 and continued until November 14, 1979. Seven coal seams were sampled for desorption. Borehole geophysical logs were run on November 14 using gamma ray, SP and resistivity.

Desorption is in progress for the coal samples taken. The Herrin coal seam has produced 26 cubic feet per ton as of March 10, 1980.

Following completion of the desorption, the coal samples will be sent to a laboratory for residual gas determination and proximate/ultimate analyses.

ILLINOIS BASIN, SITE DAD
POSEY COUNTY, INDIANA

Cooperating Company:
Indiana Geological Survey
Bloomington, Indiana

Status: Field operations in
progress.

Field Work Performance Period:
Principal Investigator:
DOE Technical Project Officer:

November 1979-May 1980
C. T. Rightmire (TRW)
H. D. Shoemaker

OBJECTIVE

To provide gas content and desorption data from coals in the southeastern part of the Illinois Basin in areas previously untested by MRCP.

SCOPE OF WORK

This cooperative agreement calls for the coring, logging and laboratory analysis of several coal seams in the southeastern part of the Illinois Basin. This well is located in Posey County, Indiana.

PROGRESS PRIOR REPORTING PERIOD

The cooperative agreement with the Indiana Geological Survey was prepared.

PROGRESS THIS REPORTING PERIOD

Drilling, coring and logging operations were initiated.

ILLINOIS BASIN, SITE DAE
WEBSTER COUNTY, KENTUCKY

Cooperating Company:
R. W. Beeson Oil Producer
Evansville, Indiana

Status: Field operations
complete; analyses in progress.

Field Work Performance Period:
Principal Investigator:
DOE Technical Project Officer:

January 18-22, 1980
C. T. Rightmire (TRW)
H. D. Shoemaker

OBJECTIVE

To test the methane content of coals in this attractive, deep part of the Illinois Basin from which no specific gas content data are available.

SCOPE OF STUDY

This cooperative agreement calls for coring, logging and drill-stem testing of several coal seams in the southern part of the Illinois Basin. Laboratory analyses also will be conducted for the coal, roof rock and floor rock.

PROGRESS IN PRIOR REPORTING PERIOD

The cooperative agreement with Beeson Oil was initiated and finalized.

PROGRESS THIS REPORTING PERIOD

Coring operations from January 19-21, 1980 recovered 64.4 feet of core with 10.7 feet of coal recovered. Borehole geophysical logs were run on January 21 (induction electric log, density, borehole compensated, neutron, borehole compensated and 3-D velocity). A computer analysis will produce a coal quality log.

Drill stem testing for coal seams #9 and #13 was conducted on January 21 and 22. Each coal horizon was tested independently; initial flow was for 60 minutes; initial shut-in was 120 minutes; final flow was 60 minutes; and final shut-in was 240 minutes.

Tests indicated that both coals were very tight (low permeability); fluid return was only a few feet of drilling mud; a small amount of formation pressure does exist.

Laboratory analyses being performed include: desorption testing, roof and floor rock mechanical property analyses, proximate/ultimate analyses and gas quality determination.

In summary, two coal seams with a total thickness of 10.7 feet were cored and gas concentrations of 45 to 48 cubic feet per ton were measured. Desorption data are as follows:

Coal Seam	Depth (ft)	Lost Gas (cc/gm)	Desorbed Gas (cc/gm)	Remaining Gas (cc/gm)	Total Gas Per Unit (cc/gm) cu ft/ton
#13	1200.0	0.03	0.50	0.8	1.4 45
#13	1203.7	0.02	0.75	0.6	1.4 45
# 9	1305.2	0.04	0.61	0.8	1.5 48
# 9	1308.3	0.03	0.54	0.9	1.5 48

The well test data package is being compiled and will be maintained on open file at the Morgantown Energy Technology Center.

2 . 2 . 1 2 N O R T H E R N A P P A L A C H I A N S
 (P E N N S Y L V A N I A , O H I O ,
 W E S T V I R G I N I A)

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 exist 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 MRCP testing program has provided methane data at two sites in the Northern Appalachians. The gas concentrations from sidewall coring of the #1 Murdoch Well provide a range of 33 to 426 cubic feet per ton with the higher values representing samples of the lower perforated coals. At the Waynesburg well, the methane content ranges from 70 to 195 cubic feet per ton.

The current target area of interest within the Northern Appalachian Basin is shown in Figure 2-12. At the end of this reporting period, the status of well tests was as follows:

<u>Test Well</u>	<u>Status</u>
Site AAA Kinloch Development Company	Well test data package complete
Site AAB Waynesburg College	Field activities complete

Figure 2-12. Northern Appalachian Basin Target Area

NORTHERN APPALACHIAN BASIN, SITE AAA (#1 Murdoch Well)
GREENE COUNTY, PENNSYLVANIA

Cooperating Company:
Kinloch Development Company
Langley Park, Maryland

Status: Will test data package
complete

Field Work Performance Period:
Principal Investigator:
DOE Technical Project Officer:

April-June 1978
C. T. Rightmire (TRW)
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.

SCOPE OF WORK

This cooperative agreement calls for the coring, logging and frac tests of several coal seams in extreme southwestern Pennsylvania. Laboratory analysis will be completed on the core samples. This well is located in Greene County, Pennsylvania, Whiteley Township, north of Fordyce.

PROGRESS IN PRIOR REPORTING PERIODS

This well was drilled in early April 1978 and field activities continued through June 1978. Geophysical well logs (neutron, compensated density, and induction) were completed. Desorption plus all testing and analysis of tests were completed.

PROGRESS THIS REPORTING PERIOD

Well test package was compiled.

In summary, desorption of sidewall core samples shows that gas in content of coal seams ranges from 33.3 to 425.6 cu ft/ton with the higher values from samples of the lower perforated coals.

Pre-frac water injection test through acidized perfs indicated permeabilities of 0.5 to 1.0 md depending on tested zone.

The well data test package has been compiled and is maintained on open file at the Morgantown Energy Technology Center.

NORTHERN APPALACHIAN BASIN, SITE AAB
GREENE COUNTY, PENNSYLVANIA

Cooperating Company:
Waynesburg College
Waynesburg, Pennsylvania

Status:
Active field activities
Complete

Field Work Performance Period:
Principal Investigator:
DOE Technical Project Officer:

See Section 2.4.7
N.F. McGinnis (TRW)
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.

SCOPE OF WORK

The cooperative agreement calls for coring and logging of the Waynesburg, Sewickley, Pittsburgh, Bakerstown, Upper Freeport, Upper, Middle, and Lower Kittanning, Clarion-Brookville coals. The purpose is to develop and demonstrate a multiple completion technique system considering a variable need for dewatering each zone and utilizing the recovered methane in a local distribution pipeline. Laboratory analysis of the coal samples will be completed.

PROGRESS IN PRIOR REPORTING PERIODS

Resource delineation planning was initiated in conjunction with a Technology Test project planned at this site.

PROGRESS THIS REPORTING PERIOD

Drilling and testing of the well took place on October 23 to December 19, 1979. Geophysical well logs were run on January 30, 1980 (SFL, Compensated Neutron-Density, and Borehole Compensated Sonic Log). Desorption was initiated and completed during this period.

In summary, eight coal seams were cored and gas concentrations of 70 to 195 cubic feet per ton were measured. Desorption data is as follows:

Sample No.	Coal	Depth (ft)	Lost Gas (cc/gm)	Desorbed Gas (cc/gm)	Residual (cc/gm)	Total Gas (cc/gm)	(cf/ton)
41	Waynesburg	149	0.06	1.58	1.15	2.8	90
42	Waynesburg	153	0.02	1.07	1.06	2.2	70
43	Sewickley	371	0.07	2.66	2.01	4.7	150
44	Sewickley	486	0.05	1.88	2.63	4.6	147
45	Pittsburgh	489	0.08	2.15	1.89	4.1	131
46	Pittsburgh	491	0.15	2.82	2.60	5.6	180
J-L-1	(Rider)	483	0.10	2.75	1.33	4.2	134
155	Bakerstown	888	0.04	2.53	1.78	4.4	141
J-L-2	Upper	1085	?	1.48	2.12	3.6	115
	Freeport						
47	Upper	1187	0.12	3.07	1.64	4.8	154
	Kittanning						
156	(Predom. Shale)	1188	0.35	3.75	2.00	6.1	195
48	Middle	1238	?	2.41	0.67	3.1	99
142	Clarion	1292	0.10	2.93	1.39	4.4	141

The well test data package is in the process of being compiled, and when completed it will be maintained on open file at the Morgantown Energy Technology Center.

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.

Recent MRCP Type I field tests have provided additional desorption data for some of the coals in the Piceance Basin. Preliminary test results provide a range of gas content varying from a low of 1 to 339 cubic feet per ton.

The current MRCP target area of interest within the Piceance Basin is shown in Figure 2-13.

At the end of this reporting period the status of well tests was as follows:

<u>Test Well</u>	<u>Status</u>
Site FAA Fuel Resources Development Co.	Well test data package is complete.
Site FAB Twin Arrow Drilling Co.	Well test data package is complete.
Site FAC Twin Arrow Drilling Co.	Well test data package is complete.
Site FAD Cooperating Company Confidential	Well test data package is complete.
Site FAE Cooperating Company Confidential	Well test data package is complete.
Site FAF Cooperating Company Confidential	Well test data package is complete.

Site FAG
Cooperating Company Confidential

Well test data package is complete.

Site FAH
Fuel Resources Development Co.

Well test data package is complete.

These tests are described in detail in the following sections.

Figure 2-13. Piceance Basin Target Area

PICEANCE BASIN, SITE FAA
RIO BLANCO COUNTY, COLORADO

Cooperating Company:
Fuel Resources Development Company,
Denver, Colorado

Status: Complete
(Well Test Package
Compiled)

Field Work Performance Period:
Principal Investigator:
DOE Technical Project Officer:

September 9-10, 1978
C.T. Rightmire (TRW)
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.

SCOPE OF WORK

This contract provides for coring of approximately 120 feet of coal-bearing Lower Mesaverde Group sediments in the Douglas Creek Arch area of the Piceance Basin. Gas content is to be estimated via desorption studies performed subsequent to sampling. This well is located in Rio Blanco County, Colorado, Section 28, Township 3S, Range 101 W.

PROGRESS IN PRIOR REPORTING PERIODS

- The Fuelco well, 0-28-3-101-A, Section 28, T3S, R101W, Rio Blanco County, Colorado, was cored on September 9 and 10, 1978. Because of unexpected structural complexities, the primary objective coals were not encountered in coring. Less than five feet of coal were cored between 1,582 and 1,623 feet. Two coal samples were collected for desorption studies. The two samples came from depths of 1,584 to 1,586 feet and 1,603 to 1,604 feet.
- Geophysical logging was performed on September 11 and 12 (compensated neutron-formation density, dual induction-laterlog).
- Laboratory analysis was completed for coal samples obtained during coring (proximate/ultimate, heating value, sulfur forms).
- Desorption data from conventional cores are as follows:

<u>Sample Depth</u> <u>(ft)</u>	<u>Total Gas</u> <u>(cc)</u>	<u>Sample</u> <u>Wt (gm)</u>	<u>Total Gas Per Unit</u> <u>(cc/gm) (cu ft/ton)</u>	
1585	898	1584	0.6	19.2
1603	364	144	2.5	80.9

PROGRESS THIS REPORTING PERIOD

All activities for this well are complete. The well test data package for this test is complete, and this is the final report for this well test.

PICEANCE BASIN, SITE FAB
RIO BLANCO COUNTY, COLORADO

Cooperating Company:
Twin Arrow Drilling Company
Rangely, Colorado

Status: Complete
(Well Test Package
Compiled)

Field Work Performance Period:
Principal Investigator:
DOE Technical Project Officer:

October 3-7, 1978
C.T. Rightmire (TRW)
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.

SCOPE OF WORK

This work consists of a well test in Rio Blanco County, Colorado, to be accomplished in four phases. Phase I consists of placing a plug at 1,050 feet in the well (below the present horizon of interest), swabbing out the well, and installing an orifice flow meter on the surface to measure any flow from casing perforations near the coal-bearing zones. Phase II consists of cementing behind the casing from the present top of cement to meet federal lease requirements in the event one or more of the coal seams is fraced. Phase III consists of perforating and flow testing the sections shown as coal on Twin Arrow logs. Phase IV consists of fracturing and flow testing appropriate intervals. This well is located in Rio Blanco County, Colorado, Section 13, Township 3S, Range 101W.

PROGRESS IN PRIOR REPORTING PERIODS

- Twin Arrow well C&K #1-13, was pressure and flow tested, cemented, perforated, acid treated and again flow tested.
 - The following intervals were tested:
 - 573-581 ft.
 - 627-633 ft.
 - 661-665 ft.
 - 726-736 ft.
 - 801-810 ft.
 - Initial pressure and flow testing indicated zero pressure and zero flow.
 - After cementing, the target intervals were jet perforated (1 shot/ft). They were then individually acid treated (7.5% HF), swabbed, and pressure and flow tested. A zero psi shut-in reading was obtained for all five zones, and no flow could be observed or felt through a 1/8 inch orifice.

PROGRESS THIS REPORTING PERIOD

The well test data package for this test has been compiled and is maintained on open file at the Morgantown Energy Technology Center. This is the final report on this test in the semi-annual report.

PICEANCE BASIN, SITE FAC
RIO BLANCO COUNTY, COLORADO

Cooperating Company:
Twin Arrow Drilling Company
Rangley, Colorado

Status: Well test data package
complete.

Field Work Performance Period:
Principal Investigator:
DOE Technical Project Officer:

November-December 1978
C. T. Rightmire
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.

SCOPE OF WORK

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

PROGRESS IN PRIOR REPORTING PERIODS

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

<u>Depth of Sample (ft)</u>	<u>Lithology</u>	<u>Sample Weight</u>	<u>Gas Content (cc/gm)</u>	<u>cf/ton</u>
685.2-685.6	Coal	355	4.73	151
698.1-698.45	Carb. shale/coal	353	8.93	286
772.3-772.6 773.3-773.6	Carb. siltstone	393	3.94	126
770.9-771.6	Carb. shale w/coal	593	2.06	66
759.2-760.0	Coal	397	4.88	156
809.3-809.7	Coal	119	10.6	339
801.9-802.6	Coal	306	4.07	130
804.5-805.0	Carb. shale	643	4.3	138
986.5-987.3	Coal	653	3.47	111

- No well testing was performed because the hole was lost.
- Reservoir simulation was performed resulting in a gas-in-place estimate of 157 MMcf per 640-acre section and a deliverability estimate of zero because of lack of flow in the Twin Arrow #1 Test. See Section 2.2.3 for a discussion of gas deliverability.

PROGRESS THIS REPORTING PERIOD

The well test data package has been compiled and is maintained on open file at the Morgantown Energy Technology Center.

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

Cooperating Company:
Confidential

Status: Well test data package
is complete

Field Work Performance Period:
Principal Investigator:
DOE Technical Project Officer:

June 11-20, 1979
C. T. Rightmire (TRW)
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.

SCOPE OF WORK

This cooperative agreement calls for the coring and logging of several coalbeds of the Mesaverde Formation in the Piceance Basin and laboratory analysis of the coal samples. The specific location of this well is confidential.

PROGRESS IN PRIOR REPORTING PERIODS

Forty-three feet of core were obtained during drilling in mid-June and geophysical well logs (electric, gamma ray, gamma-gamma density and caliper) were obtained on June 16, 1979. Desorption also was conducted in the prior reporting period.

PROGRESS THIS REPORTING PERIOD

In addition to continued desorption of coal samples, laboratory analysis of coal samples will be completed (proximate/ultimate, heating value, equilibrium moisture).

In summary, five coal seams with a total thickness of 11.5 feet were cored and gas concentration of 48 to 61 cubic feet per ton were measured. Desorption data are as follows:

<u>Lithology</u>	<u>Sample Depth (ft)</u>	<u>Total Gas (cc)</u>	<u>Sample Wt (gm)</u>	<u>Total Gas Per Unit (cc/gm) (cf/ton)</u>	
Coal	1324.68-1325.85	2530	1558	1.9	60.8
Coal	1330.65-1331.65	2923	1599	1.9	60.8
Coal	1333.3-1334.3	2675	1614	1.7	54.4
Coal	1335.8-1336.8	2310	1651	1.5	48.0
Coal	1351.1-1352.1	2148	1453	1.5	48.0

The well test data package has been compiled and is maintained on open file at the Morgantown Energy Technology Center.

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

Cooperating Company:
Confidential

Status: Complete
(Well Test Package
Compiled)

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.

SCOPE OF WORK

This cooperative agreement calls for the coring and logging of several coal seams of the Mesaverde Formation in the Piceance Basin and laboratory analysis of the coal samples. The specific location of this well is confidential.

PROGRESS IN PRIOR REPORTING PERIODS

Seventy-nine feet of core were obtained during drilling in late June and early July, 1979 and geophysical well logs (electric, gamma ray, gamma-gamma density and caliper) were obtained on July 2, 1979. Desorption was also conducted in the prior reporting period.

PROGRESS THIS REPORTING PERIOD

In addition to continued desorption of coal samples, laboratory analysis of coal samples will be completed (proximate/ultimate, heating value, equilibrium moisture).

In summary, eight coal seams with a total thickness of 30 feet were cored and gas concentrations of 35 to 74 cubic feet per ton were measured. Desorption data are as follows:

<u>Lithology</u>	<u>Sample Depth (ft)</u>	<u>Total Gas (cc)</u>	<u>Sample Wt (gm)</u>	<u>Total Gas Per Unit (cc/gm) (cf/ton)</u>	
Coal	741.25-742.25	318	1678	0.2	6.4*
Coal	744.25-745.25	3610	1820	2.0	64.0
Coal	758.72-759.72	2838	1596	1.9	60.8
Coal	764.87-765.87	3810	1731	2.2	70.4
Coal	771.50--72.50	3705	1622	2.3	73.6
Coal	795.40-796.40	3168	1646	2.0	64.0
Coal	797.45-798.45	2910	1620	1.8	57.6
Coal	808.60-809.30	1850	1665	1.1	35.2

*Possible canister leak

The well test data package has been compiled and is maintained on open file at the Morgantown Energy Technology Center.

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

Cooperating Company:
Confidential

Status: Complete
(Well Test Package
Compiled)

Field Work Performance Period:
Principal Investigator:
DOE Technical Project Officer

August 23-31, 1979
C. T. Rightmire (TRW)
H. D. Shoemaker

OBJECTIVE

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

SCOPE OF WORK

This cooperative agreement calls for the coring and logging of several coal seams of the Mesaverde Formation in the Piceance Basin and laboratory analysis of the coal samples. The specific location of this well is confidential.

PROGRESS IN PRIOR REPORTING PERIODS

Forty-five feet of core were obtained during drilling late August, 1979 and geophysical well logs (electric, gamma ray, gamma-gamma density and caliper) were obtained on August 26, 1979. Desorption was also conducted in the prior reporting period.

PROGRESS THIS REPORTING PERIOD

In addition to continued desorption of coal samples, laboratory analysis of coal samples will be completed (proximate/ultimate, heating value and equilibrium moisture).

In summary, two coal seams with a total thickness of 11 feet were cored and gas concentrations of 1.3 to 5 cubic feet per ton were measured. Samples of overburden and interburden were also taken for desorption. Desorption data are as follows:

<u>Lithology</u>	<u>Sample Depth (ft)</u>	<u>Total Gas (cc)</u>	<u>Sample Wt (gm)</u>	<u>Total Gas Per Unit*</u> <u>(cc/gm) (cf/ton)</u>	
Coal	911.0-911.8	27	1527	0.01	0.3
Interburden Siltstone	904.3-905.3	105	1756	0.06	1.9
Coal	879.15-880.15	248	1483	0.17	5.4

*Does not include lost gas

The well test data package has been compiled and is maintained on open file at the Morgantown Energy Technology Center.

PICEANCE BASIN, SITE FAG

SPECIFIC SITE LOCATION CONFIDENTIAL (CONFIDENTIAL WELL #5)

Cooperating Company:
Confidential

Status: Complete
(Well Test Package Compiled)

Field Work Performance Period:
Principal Investigator:
DOE Technical Project Officer:

August 23-31, 1979
C. T. Rightmire (TRW)
H. D. Shoemaker

OBJECTIVE

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

SCOPE OF WORK

This cooperative agreement calls for the coring and logging of several coal seams of the Mesaverde Formation in the Piceance Basin and laboratory analysis of the coal samples. The specific location of this well is confidential.

PROGRESS IN PRIOR REPORTING PERIODS

Twenty-nine feet of core were obtained during drilling in late August, 1979 and geophysical well logs (electric, gamma ray, gamma-gamma density and caliper) were obtained on August 25, 1979. Desorption was also conducted in the prior reporting period.

PROGRESS THIS REPORTING PERIOD

In addition to continued desorption of coal samples, laboratory analysis of coal samples will be completed (proximate/ ultimate, heating value, and equilibrium moisture).

In summary, two coal seams with a total thickness of 11.9 feet were cored and gas concentrations of 1 to 29 cubic feet per ton were measured.

Samples of overburden and interburden were also taken for desorption. Desorption data are as follows:

<u>Lithology</u>	<u>Sample Depth (ft)</u>	<u>Total Gas (cc)</u>	<u>Sample Wt (gm)</u>	<u>Total Gas Per Unit*</u> <u>(cc/gm) (cf/ton)</u>	
S1 Floor Rock	1190.96-1191.82	75	2783	0.03	1.0
Coal	1205.05-1206.05	1812	2018	0.9	28.8

*Does not include lost gas

The well test data package has been compiled and is maintained on open file at the Morgantown Energy Technology Center.

PICEANCE BASIN, SITE FAH
RIO BLANCO COUNTY, COLORADO

Cooperating Company:
Fuel Resources Development
Denver, Colorado

Status: Complete
(Well Test Package
Compiled)

Field Work Performance Period:
Principal Investigator:
DOE Technical Project Officer:

August 12-17, 1979
C. T. Rightmire
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.

SCOPE OF WORK

This cooperative agreement calls for the coring and logging of several coal seams of the Mesaverde Formation in the Piceance Basin and laboratory analysis of the coal samples.

PROGRESS IN PRIOR REPORTING PERIODS

Ninety-six feet of core were obtained during drilling in mid-August, 1979 and geophysical well logs (electric, gamma ray, compensated density and caliper) were obtained on August 18, 1979. Desorption was also conducted in the prior reporting period.

PROGRESS THIS REPORTING PERIOD

In addition to continued desorption of coal samples, laboratory analysis of coal samples was completed: proximate/ultimate, heating value and equilibrium moisture for coal samples and rock mechanics tests for interburden and overburden.

In summary, three coal seams with a total thickness of 22 feet were cored and gas concentrations of 19 to 26 cubic feet per ton were measured. Desorption data are as follows:

<u>Lithology</u>	<u>Sample Depth (ft)</u>	<u>Total Gas (cc)</u>	<u>Sample Wt (gm)</u>	<u>Total Gas (cc/gm)</u>	<u>Per Unit (cf/ton)</u>
Coal	1211.6-1212.4	1039	1312	0.8	25.6
Coal	1209.5-1210.5	712	1498	0.5	16.0
Coal	1223.0-1224.0	655	1249	0.6	19.2

The well test data package has been compiled and is maintained on open file at the Morgantown Energy Technology Center.

2 . 2 . 1 4 P O W D E R R I V E R B A S I N (W Y O M I N G A N D M O N T A N A)

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 generally they are 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 2,500 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 3,970 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 2,000 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.

The area considered as the prime methane exploration target within the Powder River Basin is illustrated in Figure 2-14. 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.

At the end of this reporting period, the status of well tests was as follows:

<u>Test Well</u>	<u>Status</u>
Site IAA USGS	Field operations are complete.
Site IAB Montana Bureau of Mines and Geology	Desorption is in progress.
Site IAC Montana Bureau of Mines and Geology	Desorption is in progress.

These tests are described in detail in the following sections.

Figure 2-14. Powder River Basin Target Area

POWDER RIVER BASIN, SITE IAA
POWDER RIVER COUNTY, MONTANA

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

Status: Field Operation
Complete

Field Work Performance Period:
Principal Investigator:
DOE Technical Project Officer:

August 1979
C. T. Rightmire (TRW)
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.

SCOPE OF WORK

The cooperative agreement calls for the coring and logging of the Anderson and Canyon A & B (Dietz) coalbeds in the Fort Union Formation of the Powder River Basin. Laboratory analysis of the coal samples will be completed.

PROGRESS IN PRIOR REPORTING PERIODS

Field activities were performed in late August 1979 during the original drilling of the well with a total of 94.7 feet of strata cored. Borehole geophysical logs (gamma ray, density, SP, and resistivity) were obtained on August 31, 1979. Desorption was also completed in the prior reporting period.

PROGRESS THIS REPORTING PERIOD

Laboratory analysis of the coal samples (proximate/ultimate, equilibrium, moisture) will be completed.

In summary, six coal seams with a total thickness of 54.5 feet were cored and gas concentrations of 0.9 to 2.6 cubic feet per ton were measured.

Coal desorption results as of October 23 from conventional cores:

<u>Lithology</u>	<u>Sample Depth (ft)</u>	<u>Total Gas (cc)</u>	<u>Sample Wt (gm)</u>	<u>Total Gas Per Unit (cc/gm) (cf/ton)</u>	
Coal	247.5	74	1600	0.04	1.3
Coal	266.0	63	1652	0.04	1.3
Coal	291.0	54	1710	0.03	0.9
Coal	377.6	140	1603	0.08	2.6
Coal	385.0	72	2710	0.04	1.3
Coal	400.5	141	1637	0.08	2.6

The well test data package is in the process of being compiled and when completed will be maintained on open file at the Morgantown Energy Technology Center.

POWDER RIVER BASIN, SITE IAB
BIG HORN COUNTY, MONTANA

Cooperating Organization:
Montana Bureau of Mines
and Geology

Status: Desorption in Progress

Field Work Performance Period:
Principal Investigator:
DOE Technical Project Officer

September 1979
C. T. Rightmire (TRW)
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.

SCOPE OF WORK

The cooperative agreement calls for the coring and logging of several coal seams in the Powder River Basin. Laboratory analysis of the coal samples will be completed.

PROGRESS IN PRIOR REPORTING PERIODS

Field activities were performed in mid-September 1979 during the original drilling of the well. A total of 145.4 feet of conventional coring was performed. Borehole geophysical logs (gamma-gamma, density, SP, resistivity, gamma ray and caliper well logs) were obtained on September 6-8, 1979.

PROGRESS THIS REPORTING PERIOD

Desorption was completed and laboratory analyses of coal, overburden, interburden and underburden will be completed.

In summary, 10 coal seams were cored and gas concentrations of 0.9 to 4.2 cubic feet per ton were measured.

Coal desorption results as of November 2 from conventional cores:

<u>Lithology</u>	<u>Sample Depth (ft)</u>	<u>Total Gas (cc)</u>	<u>Sample Wt (gm)</u>	<u>Total Gas Per Unit (cc/gm)</u>	<u>(cf/ton)</u>
Coal	121.0-122.0	107	1310	0.08	2.6
Coal	134.0-135.0	89	1349	0.07	2.2
Coal	144.0-145.0	96	857	0.11	3.5
Coal	348.2-349.2	41	913	0.04	1.3
Coal	390.3-391.3	28	886	0.03	0.9
Coal	400.5-401.7	30	1091	0.03	1.0
Coal	620.5-622.5	48	1208	0.04	1.3
Coal	630.8-631.9	114	852	0.13	4.2
Coal	656.3-657.6	68	963	0.07	2.2
Coal	672.1-673.5	123	1004	0.12	3.8

The well test data package is in the process of being compiled and when completed will be maintained on open file at the Morgantown Energy Technology Center.

POWDER RIVER BASIN, SITE IAC
BIG HORN COUNTY, MONTANA

Cooperating Organization:
Montana Bureau of Mines and Geology

Status: Desorption is in progress.

Field Work Performance Period:
Principal Investigator:
DOE Technical Project Officer

September 1979
C.T. Rightmire (TRW)
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.

SCOPE OF WORK

The cooperative agreement calls for the coring and logging of several coal seams in the Powder River Basin. Laboratory analysis of the coal samples will be completed.

PROGRESSION PRIOR REPORTING PERIODS

Field activities were performed in mid-September 1979 during the original drilling of the well. A total of 157 feet of conventional coring was performed. Borehole geophysical log (gamma-gamma, density, SP, resistivity, and gamma-ray) were obtained on September 10-12, 1979.

PROGRESS THIS REPORTING PERIOD

Desorption was completed, and laboratory analysis of coal, overburden, interburden, and underburden will be completed.

In summary, 9 coal seams were cored, and 1 coal/shale seam was cored, and gas concentrations of 0.6 to 13.1 cubic feet per ton were measured.

Coal desorption results as of November 2 from conventional cores:

<u>Lithology</u>	<u>Sample Depth (ft)</u>	<u>Total Gas (cc)</u>	<u>Sample Wt (gm)</u>	<u>Total Gas Per Unit (cc/gm) (cf/ton)</u>	
Coal	168.0-169.4	39	1016	0.04	1.3
Shale + Coal	172.0-174.0	44	877	0.05	1.6
Coal	448.6-449.7	83	861	0.10	3.2
Coal	455.9-457.2	75	1032	0.07	2.2
Coal	478.8-480.0	59	872	0.07	2.2
Coal	491.2-492.4	35	943	0.04	1.3
Coal	501.4-503.4	30	1234	0.02	0.6
Coal	601.5-603.0	206	1051	0.20	6.4
Coal	754.8-756.3	272	1094	0.25	8.0
Coal	768.2-769.7	473	1159	0.41	13.1

*Does not include lost gas

The well test data package is in the process of being compiled and when completed will be maintained on open file at the Morgantown Energy Technology Center.

2 . 2 . 1 5 S A N J U A N B A S I N (C O L O R A D O A N D N E W M E X I C O)

The San Juan Basin, Figure 2-15, 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 4,000 feet in the northeastern 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 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 2,000 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 estimates 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 2-15. The figure shows three areas totalling about 4,900 square miles, encompassing coals with the highest potential for early commercial gas production.

Figure 2-15. San Juan Basin Target Area

The status of test wells in this basin during this reporting period is as follows:

Test Well

Status

Site HAA
Western Coal Co.

Well test data package is complete.

Site to be designated In firm planning.

These tests are described in detail in the following sections.

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

Cooperating Company:
Western Coal Company
Albuquerque, New Mexico

Status:
Well test data package
is complete.

Field Work Performance Period:
Principal Investigator:
DOE Technical Project Officer:

June 1978
C. T. Rightmire (TRW)
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.

SCOPE OF WORK

This cooperative agreement calls for the coring of coal samples in the outcrop area of the Upper Fruitland Formation or Lower Kirtland Shale, on the western flank of the San Juan Basin. Laboratory analysis of the coal samples will be completed.

PROGRESS IN PRIOR REPORTING PERIODS

Field work was performed during June 16-17, 1978. Two coal samples were taken for desorption and desorbed through August 1978. The coal samples underwent residual gas determination and proximate/ultimate analyses were completed.

PROGRESS THIS REPORTING PERIOD

Well test package was completed.

In summary, two coal samples with a total thickness of 1.2 feet were cored and gas concentrations of 16 and 73 cubic feet per ton were measured. Desorption data are as follows:

<u>Depth</u> <u>(ft)</u>	<u>Gas</u> <u>(cc/gm)</u>	<u>Content</u> <u>(cf/ton)</u>	<u>Coal</u> <u>Rank</u>	<u>Heating</u> <u>Value</u> <u>(Btu/lb)</u>	<u>Moisture</u> <u>Content</u> <u>(%)</u>	<u>Volatile</u> <u>Matter</u> <u>(%)</u>	<u>Fixed</u> <u>C (%)</u>	<u>Ash</u> <u>(%)</u>
398.2- 398.8	2.3	73.0	Hvaa	12293	4.7	38.2	49.3	7.7
398.8- 399.4	.5	16.0	Hvab	12543	4.2	37.1	52.6	6.1

The well test data package has been compiled and is maintained on open file at the Morgantown Energy Technology Center.

SAN JUAN BASIN (SITE: TO BE DESIGNATED)
LA PLATA COUNTY, COLORADO

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

Status: In Planning

Field Work Performance Period:
Principal Investigator:
DOE Technical Project Officer:

Summer 1980
C. T. Rightmire (TRW)
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 Ignacio Field Fruitland--Pictured Cliffs Formations, in the San Juan Basin. This effort will help determine the potential producibility of coalbed methane from this resource area.

SCOPE OF WORK

The cooperative agreement will call for the coring and logging of coal seams in the Ignacio Field Fruitland--Pictured Cliffs Formations in the San Juan Basin. Laboratory analysis of the coal samples will be completed.

PROGRESS THIS REPORTING PERIOD

Firm planning has taken place with tests being agreed upon. Conventional coring, drill stem testing, sidewall coring, geophysical logging, desorption and laboratory analysis of the coal samples are the planned activities.

2 . 2 . 1 6 S O U T H E R N A P P A L A C H I A N / W A R R I O R
B A S I N (A L A B A M A A N D M I S S I S S I P P I)

Coal resources in the southern Appalachians, Figure 2-16, 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 four 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 MRCP testing in the Warrior Basin has evaluated the methane content of four coal seams from the No. 1 Grimsley 35-15 well. The methane content is low with values ranging from 16 to 102 cubic feet per ton.

Figure 2-16. Southern Appalachia/Warrior Basin Target Area

WARRIOR BASIN, SITE CAA
FAYETTE COUNTY, ALABAMA

Cooperating Company:
Grace Petroleum Corporation
Denver, Colorado

Status:
Well test data package
is complete.

Field Work Performance Period:
Principal Investigator:
DOE Technical Project Officer:

July 1979
C. T. Rightmire (TRW)
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.

SCOPE OF WORK

This cooperative agreement called for the coring, logging, and desorption of several coal seams in the Pottsville Formation in the Warrior Basin. Laboratory analysis of the coal samples also will be performed.

PROGRESS IN PRIOR REPORTING PERIODS

Eighty feet of core were obtained during operations conducted from July 6-23, 1979. Samples of four coal seams were taken for desorption and laboratory analysis. Geophysical logging was conducted on July 23, 1979 (Dual Induction (DISF), Formation Density, Compensated Neutron, Microlog and Borehole Compensated Sonic Log).

PROGRESS THIS REPORTING PERIOD

In addition to desorption of coal samples, laboratory analysis was performed (proximate analysis, ultimate analysis, equilibrium moisture and heating value).

In summary, four coal seams with a total thickness of 9 feet were cored and gas concentrations of 16 to 102 cubic feet per ton were measured. Desorption data are as follows:

<u>Lithology</u>	<u>Sample Depth (ft)</u>	<u>Total Gas (cc)</u>	<u>Sample Wt (gm)</u>	<u>Total Gas Per Unit (cc/gm) (cf/ton)</u>	
Coal	593	4950	1789	2.8	89.6
Coal	1102	2131	657	3.2	102.4
Coal	1675	650	1198	0.5	16.0
Coal	1880	2445	1113	2.2	70.4

The well test data package is being compiled and will be maintained on open file at the Morgantown Energy Technology Center.

2 . 2 . 1 7 W E S T E R N W A S H I N G T O N B A S I N

The Western Washington Basin, shown in Figure 2-17, encompasses three regions with an area of approximately 7,500 square miles. Though principally Eocene in age, coal deposits in this basin range from Paleocene to early Oligocene. The deposits formed on a broad low-lying coastal plain in a tropical forest and swamp environment that existed along the eastern shoreline of a north-trending, paleo-sedimentary basin. They also inter-finger with and grade into, marine, coal-bearing rocks to the west. All coal-bearing areas have been structurally deformed since their formation by folding and faulting, and deformation in many of the areas has been intense. Overlying the coal-bearing rocks in most areas of western Washington is a thick mantle of glacial deposits of Pleistocene age. Deposits from at least four separate glacial advances are over 3,000 feet thick in parts of the Puget Lowlands.

Knowledge of coal geology in the basin has been gained almost entirely from mining operations in the Bellingham, Green River, Wilkeson-Carbonado, Centralia-Chehalis and Roslyn fields. In the Bellingham field coal occurs in over 10 beds that range in thickness from a few inches to 15 feet. Coal in the Green River district ranges in thickness from 3 to 40 feet in intensely faulted and deformed beds. The Wilkeson-Carbonado field is a source of coking coal and contains from 15 to 20 beds with a thickness of 2 to 8 feet. The Centralia-Chehalis is the largest field containing at least 12 beds averaging in thickness from 6 to 8 feet with individual beds up to 40 feet thick with partings. The Roslyn field contains at least 8 beds with thickness ranging from 2 to 21 feet. The total coal resource in the basin is estimated to be 60 billion tons, principally high to medium volatile bituminous.

Knowledge regarding methane concentration in this basin is limited and based on methane related mining accidents, water wells producing methane, oil and gas exploration, and coal core desorption from the Centralia-Chehalis district (four cores). The average value desorbed from these cores is 65 cubic feet per ton.

Since these four cores were from coal at the low end of the subbituminous C rank, a value of 65 cubic feet per ton is thought to be a reasonable minimum value for in-place methane resource. It is assumed that the higher-rank bituminous coals would have greater methane content, and also that prime target areas would have even higher concentrations of methane. Therefore, it is thought that 400 cubic feet of methane per ton of coal is a reasonable estimate for the maximum in-place methane resource. Using these figures, coalbed methane resource contained in western Washington is estimated here for the known coal reserves to range from 0.4 to 3.6 trillion cubic feet, and for the total potential coal resource to range from 2.6 to 24 trillion cubic feet.

The currently defined methane recovery target areas in this basin are shown in Figure 2-18.

Figure 2-17. Western Washington Basin

Figure 2-18. Western Washington Methane Recovery Target Areas

WESTERN WASHINGTON, SITE LAA
THURSTON COUNTY, WASHINGTON

Cooperating Company: DOE

Status: Field Activities
Complete

Field Work Performance Period:
Principal Investigator:
DOE Technical Project Officer:

October-November 1979
C. T. Rightmire (TRW)
H. D. Shoemaker

OBJECTIVE

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

SCOPE OF WORK

The cooperative agreement calls for coring and logging of the Big Dirty Coalbed, Skookumchuck Formation in the Tono Basin. Laboratory analysis of the coal samples will be completed.

PROGRESS IN PRIOR REPORTING PERIODS

Planning was initiated.

PROGRESS THIS REPORTING PERIOD

From October 29 to November 6, 1979, 230 feet of strata were conventionally cored. Geophysical logs were obtained and desorption of coal samples was initiated. Laboratory analysis of the samples will be initiated upon the desorption completion.

In summary, 4 coal seams with a total thickness of 5.4 feet were cored and gas concentrations of 20 to 75 cubic feet per ton were measured. Desorption data are as follows:

<u>Lithology</u>	<u>Sample No.</u>	<u>Sample Depth (ft)</u>	<u>Total Gas (cc)</u>	<u>Total Gas Per Unit* (cc/gm)</u>	<u>(cf/ton)</u>
Coal	1	602.8-603.8	1469	2.3	74.7
Coal	2	610.0-611.0	1674	2.3	72.3
Coal	3	617.9-618.9	293	0.7	22.5
Coal	4	623.2-623.9	241	0.6	19.8

*Does not include lost gas.

The well test data package is being compiled and upon completion will be maintained on open file at the Morgantown Energy Technology Center.

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.

The following R&D projects were underway at the end of this reporting period:

- Turbodrill - Maurer Engineering Inc.
- Coalfrac - Physics International Company
- Water Jet Drilling - Sandia Laboratories
- Fracture Mechanics - West Virginia University
- Carbon Dioxide for Methane Production

Information pertaining to these projects is discussed in Sections 2.3.2 through 2.3.8.

2 . 3 . 2 T U R B O D R I L L

Maurer Engineering, Inc.
Houston, Texas

Status: Active

Contracts:

DE-AC21-78MC08380 and
DE-AC21-79MC11251

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 turbodrill downhole motor for use in directional drilling applications in the extraction of methane from coal seams and a tachometer that can be used to monitor turbodrill speeds.

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 and a first generation tachometer. 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 2-19. 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 2-19, for use in drilling with mud through abrasive formations, and (2) the flow-through package shown in Figure 2-20, for 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

Figure 2-19. Turbodrill Schematic - Sealed Bearing Pack

Figure 2-20. Turbodrill Schematic - Flow-Through Bearing Pack

piston assembly in the sealed-bearing pressurizes the oil reservoir (containing a synthetic-bearing lubricant) and prevents the intrusion of drilling mud into the roller bearings (Figure 2-19). 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 IN PRIOR REPORTING PERIODS

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 Figures 2-21 and 2-22). However, pressure drops between various portions of the turbine appeared to be considerably higher than design values.

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 2-23.

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 also was tested in the larger drill motor.

Figure 2-21. Turbodrill Phase I Test, 300 gpm Performance

Figure 2-22. Turbodrill Phase I Test, 300 gpm Performance (Continued)

Figure 2-23. Drilling Performance of METC Turbodrill at TerraTek

PROGRESS THIS REPORTING PERIOD

Phase II turbodrill testing began December 3 at Gearhart-Owen Industries in Fort Worth, Texas. In that test, 23 feet of hole were drilled before the turbodrill locked up. Upon disassembly and examination of the turbodrill, sand and mud were found along with damage to the lower thrust bearing.

Phase II testing resumed the week of 21-25 January 1980. Bearing failures resulted in both turbodrills locking up. The tachometer did not produce discernible signals to indicate downhole rotary speed in the first test but indicated rotary speeds of 2,400 to 2,600 rpm in the second.

Results of turbodrill teardown following resumed Phase II testing indicate that the lowest and uppermost radial roller bearings failed in the first motor with the outer races cracked in both cases. The roller cage in the lowest radial bearing was bent and extruded in part between two rollers. Two rollers in that bearing were broken. Other parts of the uppermost radial bearing were intact. In the second motor, the lower thrust bearing failed because of excessive loading due to hydraulic downthrust of the turbine.

Formal Phase II testing of the METC 5-3/8 inch turbodrills at Gearhart-Owen has been terminated due to continued failures of the bearing package (reliable bearing packages are the major problem in downhole motors).

Performance of the turbodrill to date does not warrant expending any additional Government effort on active field testing until a viable bearing package has been developed and demonstrated.

The Drilling Technology Division of Sandia National Laboratories manages the Geothermal Drilling and Completion Technology Development Program for DOE and as a result has several contracts with various research laboratories having expertise in bearing and seal design and development. Therefore, DOE/METC is providing the two 5-3/8 inch turbodrills to Sandia for additional development and testing in their drilling technology development program. In exchange for the drills, METC will receive turbodrill performance data from the laboratory and field testing conducted by Sandia.

2 . 3 . 3 C O A L F R A C

Physics International Company
San Leandro, California

Status: Active

Contract:

DE-AC21-79MC10642

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 ignition of an explosive gas mixture 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 igniting an explosive gas mixture which has been injected into a fracture system of the coal. 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 gases over a range of pressure, and
 - (3) Determining the permeability of the coal after the gases have 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 detonations.

PROGRESS IN PRIOR REPORTING PERIODS

Contracted work was initiated in April 1979. Major technical activities

involved (1) fabrication, modification and installation of coal test systems, (2) fabrication and preparation of coal samples, (3) performance of experiments, and (4) analyses and reporting.

Two test systems were 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 system 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 1979 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 was advanced at the time.
- The apparent gaseous permeabilities typically follow a linearly decreasing relationship with decreasing reciprocal mean pressure, as expected.
- The "fluid state" permeabilities as measured by gas flow were typical of reported values for Pittsburgh seam coal; i.e., 10 md.
- Two samples were cored from a single block and two samples from another block. These pairs were cored in the same direction from their original blocks. The permeability results revealed no commonality in the pairs.
- The "wet sample" permeability with nitrogen was typically less than or equal to the water permeability.
- A tendency toward reduction in coal permeability values with subsequent flow testing correlated with data obtained in 1976-1977.

During preliminary detonation experiment activities to evaluate the system and instrumentation, a need was identified to equalize the pressures in the

two test chambers to preclude or minimize the flow of hot detonation products through the coal. 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 were nearly identical to those obtained on wet samples, and
- A prior experiment utilized methane and this was the first time the sample had been exposed to methane following its removal from the mine.

PROGRESS THIS REPORTING PERIOD

Two scenarios were identified in which the apparatus and testing sequence could influence the post-detonation permeability results, namely:

- The flow of hot combustion or detonation products through the coal cleats from either the upstream or downstream detonation chamber into the other chamber as a result of a pressure gradient across the coal sample, and
- The extended exposure to hot combustion or detonation gases on the coal sample surfaces.

Both of these scenarios are atypical of the environment to be expected in a production application. Also, the possibility of destroying a sample by displacing it from its sample holder increases when a large pressure differential (i.e., detonation in only one chamber) is permitted to equilibrate through the coal sample. The test equipment was modified to negate these influences.

During November 1979 the permeability to N_2 gas was measured on one coal sample (No. 4, face cleat, Pittsburgh seam² coal); the permeability was shown to increase linearly with increasing inverse mean pressure across the sample, as expected. Extrapolated to zero inverse mean pressure, the results are consistent with the N_2 permeability values observed in July 1979. The measured permeability increased with flow time, suggesting that the sample is dried by the flow of N_2 gas.

Permeability experiments were performed on additional coal samples to evaluate the influence of various parametric changes. The most significant parameter influencing the measured permeability appears to be related to sample moisture content as deduced by the change in permeability with the time dry gas is permitted to flow. Three coal samples were measured for permeability before and after detonation. All of the face cleat samples tested to date indicate a reduction in permeability. Results of these tests are tabulated in Table 2-6.

Additional studies during this reporting period have demonstrated that sample/holder temperature influences the permeability significantly. This is attributed to differences in the thermal coefficient of expansions of a steel containment sleeve and the coal + epoxy. The environmental temperatures ranged from 40-100° F; decreased temperatures result in increased permeability.

A preliminary microscopic examination of coal from the source block and its post detonated sample (experiment CF2-5, coal sample 2) revealed the characteristic structure of coked (pyrolyzed) coal on the surface and within the coal sample cleats after the detonation event. Microstructure changes occurred, possibly resulting from the detonation shock (pressure) wave.

Three detonation experiments were performed during December 1979. The last two samples from the first lot of coal (one a butt cleat) again demonstrated a reduction in permeability as a result of the detonation. A shock experiment performed on a face cleat sample from the second lot also has resulted in comparably reduced permeability.

Permeabilities measured on sample 2 just prior to its detonation experiment were unusually large relative to previous measurements on that sample. This difference was greater than differences measured on other samples. The history of the permeability measurements for sample 2 were reviewed; data correlations suggested that the sample temperature had a strong influence on permeability even though the parameters included in the basic permeability equations were temperature corrected for the viscosity of the gas flowing through the coal. The necessary flow meter corrections were made. Experiments performed to verify this helped to explain some of the "scatter" in permeability results, but do not provide an explanation for the reduction in permeability following a detonation event.

Detonation Experiments

The last two samples from the first coal lot, one a butt cleat orientation, were tested during December. A reduction in post-detonation permeability was measured.

A face cleat sample from the second lot of coal was subjected to the typical detonation pressure and thermal energy at its upstream face. This was achieved by applying a 1/4-inch epoxy cap over that face and filling the downstream chamber, and therefore the coal, to 200 psig N₂. The cap successfully prevented venting of hot combusted gases through the coal but allowed the detonation shock wave to pass. The back surface of the coal spalled in a typical manner. Some coking at the epoxy/coal interface was noted, but it was considerably less than that observed in the "standard" experiments. This is believed to have resulted from the transfer of thermal energy to the epoxy cap. The post-detonation permeability was reduced in a ratio typical of other conventional experiments. Thus, it is concluded that the post-detonation reduction in permeability is a consequence of the shock wave pressure transmitted into the coal.

The post-detonation permeabilities at any test pressure are less than the pre-detonation permeabilities. The pre-detonation permeabilities typically decrease with increasing mean pressure whereas the post-detonation results show an increase or near constant permeability with mean pressure.

In February 1980 an experiment was performed in which a lower order reaction in the upstream chamber was achieved in an effort to minimize the shock wave intensity at the coal, and therefore reduce the effects that the shock wave has on coal permeability. The reduction in permeability measured on a single sample was comparable to previous experiments. However, further low order experiments are required to determine conclusively what effects a combustible gas reaction within a coal cleat has on permeability.

No further experiments are planned for performance in this effort, and experimental data and final reporting will be described in subsequent reports.

Table 2-6. Pittsburgh Seam Coal Permeability
Pre- and Post-Detonation

<u>Sample</u>	<u>Experiment Designation</u>	<u>Date</u>	<u>Permeability¹ (md)</u>		<u>Comments</u>
			<u>Pre</u>	<u>Post</u>	
1	CF2-1 ²	9/26	12	6-2.5	Detonation 1st chamber only ³
1	CF2-2	9/27			Sample destroyed
4	CF2-3	11/17	12.5	2	All chambers vented
8	CF2-4	11/26	13.5	2.2	First chamber vented through coal
2	CF2-5	11/27	20	1.7	Second chamber detonated ³ after venting
3	CF2-6	12/03	9	4	
6 ⁴	CF2-7	12/19	15-20	6-12	
8A	CF2-8	12/22	20-24	6-12	Shock wave experiment ³ . Second chamber fill with 200 psig N ₂ ; epoxy cap over coal facing first chamber. Deto- nation products did not pass through coal.

-
1. Nitrogen permeability from data extrapolated to infinite mean pressure
 2. 200 psig CH₄ + CO₂; all other experiments at 200 psig
 3. A detonation occurred in the second chamber as a result of a detonation or deflagration through the coal cleats in all other experiments.
 4. Butt cleat--all other samples were face cleat.

2 . 3 . 4 W A T E R J E T D R I L L I N G

Sandia Laboratories
Albuquerque, New Mexico

Status:
Active

Contract:
Contract Date:
Anticipated Completion Date:

MR-11098
April 9, 1979
December 31, 1981

Principal Investigator:
DOE Technical Project Officer:

K. M. Timmerman
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 IN PRIOR REPORTING PERIODS

Work began on this project in April 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
- Need for coal seam sensor development, to provide reliable means to keep the drill within the seam.

System hardware design and 1/4-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.

PROGRESS THIS REPORTING PERIOD

Significant progress during the semi-annual period is as follows:

- Assembly of the 1/4-scale model of the drill string and the rotation and advance system have been completed. Structural and kinematic testing of the model are continuing to demonstrate that the rotation and advance system provides a workable method whereby the flexible drill string passes from vertical to horizontal at a uniform rate, by utilizing a guide cam.
- Static testing of the five full-scale drill string sections has been completed. The sections are tubular members (3 x 5 inches) 17 inches long with hinges at the corners on the 3-inch wide portion of the tubular shell. (The tubular construction is used as the protective conveyance for the hydraulic/water pressure hoses, umbilical cord to the water jet drill head.) The hinges at the corners provide the flexibility to the drill string for passing around the corner from vertical to horizontal. The hinge portions of the sections are most critical since they assist in carrying the weight of the drill head and also provide drill string rigidity. In the static testing of the hinge portion of the drill string, the spring pin in the hinge connection was designed to shear at twice the expected design load. In all of the tests the spring pin sheared rather than the hinge separating from the tubular member.
- Design of the long borehole (300 ft) test platform has been initiated. This platform will be utilized in placing a long horizontal borehole into a coal seam highwall with the water jet drill test during the last quarter of FY 80. The platform will utilize the rotation and advance system to advance the water jet drilling head and drill string into the coal seam.

The most critical part of the design of the water jet drill is the high-pressure water swivel coupling in the drill head where the high-pressure water jet stream is delivered from the rotating head. This coupling currently survives only a few hours of testing. Possible means of correcting this problem are being explored.

2 . 3 . 5 F R A C T U R E M E C H A N I C S

West Virginia University
Morgantown, West Virginia

Status: Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AT21-79MC11284
June 1, 1979
November 30, 1980

Principal Investigator:
DOE Technical Project Officer:

W. R. Powell
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 provide for the acquisition of more fundamental knowledge of the mechanisms that control fracture initiation and growth in coal. This knowledge will lead to improved predictions, and possible control, of the fracture patterns and an understanding of when fractures 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 IN PRIOR REPORTING PERIODS

A contract was negotiated with West Virginia University in June 1979. Activities during the initial four months included design and fabrication of required experiment apparatus and preliminary tests of coal specimens (10 fracture toughness tests and approximately 15 tension tests).

Three-point bending tests of Pittsburgh coal seam specimens conducted in September 1979, resulting in the data tabulated in Table 2-7.

PROGRESS THIS REPORTING PERIOD

Accomplishments during this reporting period are described below according to the individual tasks identified in the Scope of Work.

Task 1 - Fracture Toughness

Additional fracture toughness tests were successfully completed in December 1979 at a notch (crack) opening rate approximately 10 times that normally used (0.28 mm/minute vs. 0.03 mm/minute). Review of the earlier tests showed that an intermediate rate (0.05 mm/minute) was used. Statistical analyses of six successful slow tests, seven intermediate rate tests, and three fast rate tests indicate no rate dependence for fracture toughness over the range of notch opening rates used.

Task 2 - Direction of Natural Weakness; Relative Strengths

Five successful tests were performed in November and December 1979 with the notch (crack) oriented 45° relative to the bedding plane (Table 2-7). Two of the resulting fractures crossed the bedding plane and three of the fractures ran along the bedding plane. Additional data are needed before meaningful conclusions can be presented for these tests. Tests performed with the notch oriented at 30° and 60° relative to the bedding plane are planned upon resolution of instrumentation problems and completion of operator training.

Table 2-7. Fracture Toughness Test Results for Pittsburgh Coal Specimens Loaded in Controlled Crack Opening, Three-Point Bending; Load Line on Butt Cleat and Parallel to Bedding Plane

Specimen Reference Number	Nominal Length S(in)	Crack Extension P_Q (lbf)	Ultimate Load P_{max} (lbf)	Fracture Toughness K_{IC} (psi-in)
790704-03	6	2.35	6.10	28.71
790717-02	6	5.05	7.60	55.23
790717-03	6	4.80	5.20	43.20
790717-04	6	5.05	5.80	54.84
790719-05	6	3.45	4.15	39.21
790719-07	6	3.50	4.30	37.22

Mean Value of K_{IC} = 43.07 ± 10.41 psi - in

For Comparison: K_{IC} = 142.30 ± 51.20 psi-in for Waynesburg Coal (1)
 = 31.60 ± 19.00 for Redstone Coal (1)
 = 900 for Indiana Limestone (2)
 = 45,000 for 1340 Hardened Steel (3)
 = 71,000 for 6061-T6 Aluminum (3)

Task 3 - Interaction of Stresses, Weakness, Direction, and Fracture Orientation

Design and fabrication of a hydraulic triaxial fracture load chamber and other experimental equipment were completed in December 1979. However, testing of coal specimens has been held up by a number of problems involving sample preparation, final test equipment component acquisition and assembly, oil leaks through natural cracks in the coal specimens, and fracture of specimens during application of tectonic stresses.

Task 4 - Influence of Liquid Flow Rate, Viscosity, and Tectonic Stress

Performance of this task requires the use of a three-dimensional load chamber (Task 3) which was not available during this reporting period.

Task 5 - Model Development

Fracture toughness analysis of coal as an anisotropic material was performed using compressive stiffness data from literature. This was done to determine if variations in stiffness account for the variations in the fracture stress intensity factors measured in Task 1.

The analysis indicates that the maximum variation in fracture toughness should vary 8-1/2 percent from one direction to another. However, the Task 1 experiment results show a variation of 75 percent. This suggests that either the compressive stiffness moduli are questionable for the tension stress fields around crack tips or that the material is not homogeneous. Tension tests will be conducted when the Task 3 load chamber is available. In preparation for these tests, strain gage bonding to coal specimens was attempted and found to be satisfactory. Large size gages (1 inch) were selected in order to yield strain values that average over a length that is long compared to the natural planes.

Four coal specimens were successfully tested in tension using strain gage techniques. The measured elastic moduli are tabulated below:

<u>Specimen</u>	<u>Modulus (x 10⁶ psi)</u>
T - 16 - 1-1	0.21
T - 15 - 1-1	0.49
T - 15 - 1-2	0.31
T - 14 - 1-1	0.35
Average	0.34 $\pm$ 0.12

Review of theoretical fracture toughness indicates that the modulus perpendicular to the bedding plane must be approximately twice as large as that parallel to the bedding plane in order to produce the experimentally observed variation in fracture toughness. This is a much larger variation than that found in published literature for compressive moduli.

Task 6 - Crack Propagation

Preliminary design calculations were preformed to aid in the selection of materials suitable for bonding to coal and, thereby, provide test specimens simulating a coal overburden interface. After visiting three coal mines in January 1979 without success in locating natural specimens containing both coal and overburden, layered specimens were fabricated and tested. Accurate results have not been obtained to date because of instrument difficulties encountered in Task 1.

Task 7 - Comparison of Coal, Limestone, and Berea Sandstone Fracture Properties

Fracture toughness tests on sandstone have been delayed by problems in notching the specimens. Sawing results in a rectangular tipped notch which needs to be sharpened. The beveled band-saw blade used on the coal specimens does not cut the harder sandstone. Other cutting techniques are being reviewed.

Task 7 was conducted on a low priority basis as time permitted during this reporting period; however, one Berea Sandstone specimen was fractured. Fracture occurred at 900 psi. The fracture size at the point when the crack reached the edge of the specimen is indicated by fluid stains. This is shown graphically in Figure 2-24.

Figure 2-24. Fracture Pattern in 5" Cubic Specimen of Berea Sandstone

2 . 3 . 6 C A R B O N D I O X I D E F O R M E T H A N E P R O D U C T I O N E N H A N C E M E N T

University of Pittsburgh
Pittsburgh, Pennsylvania

Status:
Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-FG21-79MC10831
January 13, 1978
December 31, 1979

Principal Investigator:
DOE Technical Project Officer:

P. F. Fulton
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 (CO₂) to enhance production of methane from coals. An earlier contract (EW-78-X-21-0813) initiated this study in early 1978. Natural and prepared coal specimens will be subjected to a series of experiments designed to determine the extent that CO₂ may be used to increase the amount of methane that can be extracted from various coal types.

PROGRESS IN PRIOR REPORTING PERIODS

This project was initiated in the spring of 1979. Redesign and calibration of required experiment equipment was completed before a period of inactivity during the summer. Preliminary information is described below for two experiment tests completed upon resumption of project activity in September.

A clean, dry coal sample was evacuated and pressurized in steps until 3,500 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 1,008 cc (25 cf/ton) of methane (about 29% of the original gas) during the next nine days. No gas was produced during the following two days. Two cycles of CO₂ injection and methane-CO₂ production were then performed, and an additional 53 percent of the original gas was produced. However, CO₂ 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. CO₂ was injected and after five days of production a total of 565 cc (8.2 cf/ton) of methane and 7,930 cc (110 cf/ton) of CO₂ was collected. After 15 days of production, the composition of the produced gas changed to 62% methane and 26% CO₂. The rest of the produced gas was nitrogen.

PROGRESS THIS REPORTING PERIOD

High pressure vessels have been fabricated to accommodate additional methane production enhancement experiments using CO₂ at a maximum test equipment/component pressure of 1,200 psi. It is planned to conduct tests at operating pressures of approximately 1,000 psi which should simulate more closely actual in situ conditions than in previously performed tests at lower pressures. Also, coal samples having a greater moisture content than that in the prior experiments will be selected for testing.

Following a period of relative inactivity during this reporting period, limited desorption testing should be in process by early July 1980. The results of tests at higher pressure and other project activities will be described in subsequent semi-annual reports.

2 . 4 TECHNOLOGY SYSTEMS TESTS

2 . 4 . 1 GENERAL

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

- Onsite Power Generation Test Project (Washington County, Pennsylvania) -- Westinghouse Electric Corporation
- Space Heating/Fuel Cell Test Project (Westmoreland County, Pennsylvania) -- Westinghouse Electric Corporation
- Book Cliffs Coal Field Production Test Project (Carbon County, Utah) -- Mountain Fuel Supply Company
- Piceance Basin Production Test Project (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 Development 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 for Degasification of The Pittsburgh Coalbed Test Project (Greene County, Pennsylvania) -- Harold F. Scott
- Vertical Drilling to Degasify the Jawbone Coalbed 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 ONSITE POWER GENERATION TEST PROJECT

Westinghouse Electric Corporation
Pittsburgh, Pennsylvania

Status:
Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AC21-77MC08098
September 1, 1977
February 1, 1981

Principal Investigator:
DOE Technical Project Officer:

C.L. Sturgill (Westinghouse)
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, is being conducted in cooperation with the Bethlehem Mines Corporation.

A specific objective of the project is to demonstrate the operation of a gas turbine using coalbed methane as the fuel source.

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 estimated. The turbine is owned by the U.S. Army.

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 IN PRIOR REPORTING PERIODS

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 Kittanning, 2 feet; unknown seam, 3 feet; Middle Kittanning, 4 feet; and Lower Kittanning, 6 feet. Initial testing of this well, located in Cambria County, Pennsylvania, was completed in July 1979 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 and 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.

Planning was initiated to move the project location 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.

Final inspection and shop acceptance testing of the palletized gas compressor assembly were successfully completed in August 1979. The test involved functional operation of control and shutdown devices to the extent possible without actual operation of the 150 HP electrical motor/compressor unit. The present design of the palletized gas compressor was established for operation with "gob" gas inlet conditions and flow of 720 Mcfd (60% CH₄). A cost quotation has been received for modifications to the gas compressor assembly for Marianna No. 58 Mine application.

Implementation of these changes and revised shipping destination will be held in abeyance until planning for the second alternate site is complete and approved by the DOE.

PROGRESS THIS REPORTING PERIOD

Agreement was reached which should enable the project to be continued at the Bethlehem Marianna No. 58 Mine location. (Final negotiations are still in progress.) In preparation for the move, the No. 1 horizontal borehole was lengthened from 1,070 feet to 1,370 feet and this increased production to 340 Mcfd (from 157 Mcfd).

In late March 1979 the total production from the four horizontal holes available to fuel the turbine-generator was 423 Mcfd. Components needed to connect the turbine output power to the Bethlehem mine power grid are available.

Planning for Phase III (turbine operations) continues, and further results of this project will be described in subsequent semi-annual reports.

2.4.3 SPACE HEATING / FUEL CELL TEST PROJECT

Westinghouse Electric Corporation
Pittsburgh, Pennsylvania

Status:
Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AC21-78MC08332
May 12, 1978
July 12, 1981

Principal Investigator:
DOE Technical Project Officer:

C.L. Sturgill (Westinghouse)
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 with an aggregate thickness of 26.5 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 IN PRIOR REPORTING PERIODS

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 because of salt concentration it is hauled away for disposal. The water is suspected to be groundwater and not from the coal seams, indicating some interconnection between aquifers.

Free gas flow over four or five days was 32 to 33 Mcfd initially and 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 nine 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 seven years.

Three wells (#6, 7 and 8), an addition to Phase II, were drilled and cored to determine the methane content of the coal. Drill stem tests were performed on Wells 7 and 8 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 appeared to be two or three times that of Well #4.

The pump in the production well was replaced several times in mid-1979 because of an apparent buildup of chlorides at the inlet and throughout the pump. This was the first time since production from the well began that the pump had not run continuously. Early in September the average daily water production was 8.5 gpm, or approximately 300 bpd. The methane production delivered to the adjacent Westinghouse plant was 30 to 40 Mcfd.

PROGRESS THIS REPORTING PERIOD

As of the end of November 1979, Well #4 continued to supply about half of the facility gas needs, averaging 40 to 44 Mcfd. Water production was about 170 bbl/day. In January 1980 Well #4 delivered 856 Mcf (an average of 27.6 Mcfd). In February similar production continued, although the gas flow meter failed and only 66 Mcf was actually measured. Conversion equipment performance has been satisfactory using commingled methane and natural gas as a fuel.

A permit was issued by the Pennsylvania Department of Environmental Resources (DER) for surface discharge of the pumped water. The permit requires monthly sampling, analysis, and reporting of results to the DER.

Project Phases I and II are essentially complete, and planning and a formal proposal for Phase III have been received for review. Additional Phase I and II information and results of Phase III activities (if implemented) will be described 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:
Contract Date:
Completion Date:

DE-AC21-78MC10734
January 11, 1979
April 11, 1982

Principal Investigator:
DOE Technical Investigator:

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

PROGRESS IN PRIOR REPORTING PERIODS

Results of activities prior to early 1979 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. All the sites are 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 Mathis Canyon 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.

Phases I and II were completed and Phase III was initiated in September 1979. Well site plans for all three wells were prepared, and USGS and State of Utah approvals to drill were received for the Whitmore Park Wells No. 1 and No. 2. USGS denied the drilling permit application for the Mathis Canyon Well No. 3 because of questions concerning gas ownership and "minability" of the coal. Concern was expressed about potential damage to the coal/overburden rock by fracture treatment that might adversely affect subsequent mining operations. The application was resubmitted in September without hydraulic stimulation, and an appeal of the original application, including hydraulic stimulation, was made soon thereafter.

Drill sites and access roads for the Whitmore Park Wells Nos. 1 and 2 were completed and drill site preparation for the Mathis Canyon Well No. 3 was initiated.

A detailed environmental analysis was completed for each site, and surface and subsurface protection plans were filed with the USGS.

PROGRESS THIS REPORTING PERIOD

The Whitmore Park Well No. 1 was drilled and cored in October 1979. Excessive water from an artesian aquifer, encountered at a depth of 760 feet (about 2,100 feet above the first coal seam), slowed progress; however, well testing and completion were accomplished by the end of the month. The coal seam depths and thicknesses are:

<u>Coal Seam</u>	<u>Projected Depth</u>	<u>Actual Depth</u>	<u>Actual Thickness</u>
Sunnyside	2666	2881	12
Rock Canyon	2836	3033	5
Fish Creek	2856	3055	4
Gilson	2874	3097	14
Kenilworth	2937	3160	2

The Gilson coal at this location was found to be high bituminous A coal (ASTM ranking procedure) with a gross calorific value of 14,270 Btu/lb and a helium density of 1.34 gm/cc.

Permeability to water was calculated for the Gilson coal using injection test data. It was determined that the permeability increases with increased injection rates and pressure, rising from 20 millidarcies (md) at an injection rate of 0.47 BPM, to 200 md at a rate of 1.5 BPM. These permeabilities are substantially higher than the 2 to 3 md permeabilities calculated from swab test data. In January one of the coal samples from

Well No. 1 was still desorbing after more than three months and had produced a gas content of 393 cf per ton of coal. Analyses of gas samples indicate that the methane content ranges from approximately 97 to 98.5 percent.

The Whitmore Park Well No. 2 was drilled and cored in November 1979. Initial drilling was slow because of extremely hard rock; however, the artesian aquifer encountered when drilling Well No. 1 did not show although the two wells are only 1,800 feet apart. Problems were also experienced with coring because of "tight" spots and continual sloughing of the well wall.

As of the end of February, gas continued to desorb, although slowly, from most of the coal samples with gas concentrations as follows:

<u>Sample No.</u>	<u>Coal Seam</u>	<u>Gas Desorbed (cf/ton)</u>
10	Lower Sunnyside	222
11	Sunnyside Stringer	397
16	Gilson (Upper Zone)	279
17	Gilson (Lower Zone)	283

Analyses of gas samples indicate that the methane percentage ranges from 95 to 98 percent. This percentage increases during the desorption period, and the percentage of carbon dioxide decreased. Heavier hydrocarbons do not appear to be present in significant concentrations.

As the end of this reporting period approached, the desorption data from the Whitmore Park well coal samples indicate maximum gas content of 395 cf/per ton of coal, excluding residual gas. After each sample has completely desorbed, it will be crushed and the residual gas content will be measured. The desorption samples taken by the UGMS measured less gas desorbed than the Mountain Fuel Supply and IGT samples. Gas content from the UGMS samples ranges from 58 cf/ton to 215 cf/ton, while the Mountain Fuel and IGT sample measurements range from 221 cf/ton to 395 cf/ton. The reason for the apparent difference is unknown, but several possibilities are being investigated.

Well No. 1 is scheduled for completion early in April 1980 when snow conditions permit access to the well site. Acquisition of dewatering equipment for this well experienced long-term procurement delays. A pneumatically operated pump was selected as an alternate for the originally planned pump jack when a two-year delivery was quoted in January. Preparations were made for Well No. 2 gas production operations. A pump jack and other gas production equipment will be installed as soon as well site conditions permit. Dewatering is scheduled to be in operation in April.

Required approvals to drill and fractured the Mathis Canyon Well No. 3 have not been granted.

Final results of the coal sample gas desorption procedures, analyses of the coals, and wheel production information will be described in subsequent semi-annual reports.

2.4.5 PICEANCE BASIN PRODUCTION TEST PROJECT

Intercomp, Inc.
Houston, Texas

Status:
Active

Contract:
Contract Date:
Completion Date:

DE-AC21-78MC08384
September 29, 1978
December 31, 1980

Principal Investigator:
DOE Technical Project Officer

K. L. Ancell (Intercomp)
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 Resources, consists of a project at a Coseka-leased 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 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 Analyses (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 the pilot-scale methane production system including wells, gas-gathering systems, compressor station, etc. Arrangements will be made for prerelease and sales agreements prior to introduction of the gas into the pipeline system.

PROGRESS IN PRIOR REPORTING PERIODS

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

The Coseka Federal well 1-16 remained shut-in all winter and well site activity was not resumed until April 1979. The static bottom hole pressure was determined using a bottom hole pressure bomb. Results were reported as

490 psi at 1,479 feet, 2 psi surface pressure, and fluid level at 200 feet, indicating fresh water in the hole and adequate pressure to produce gas after the fluid level was lowered. 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.

A pumping jack was installed and a 75-day gas production test was started on June 8, 1979. 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 9.5 Mcfd of gas and 9 to 25 bpd of water.

Well 1-16 was shut down in August. 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, approval was not granted by the USGS and DOI to drill and fracture this well as planned. Questions were raised concerning gas ownership and "whether or not the oil and gas lessee has the right to recover gas associated with coal deposits".* This could preclude fracture treatment, which is probably required to provide acceptable gas production. Fracture treatment planning continued pending resolution of this "potential resource conflict".*

PROGRESS THIS REPORTING PERIOD

Intercomp simulated the gas-production rate of the Coseka Federal Well 1-16 in order to characterize the coal seam and to ascertain the effect of a larger fracture. This was done in part because no cores were obtained from Well 1-16. The simulated production rate is compared with the production test measured rate in Figure 2-25.

Intercomp used its Implicit Gas-Water Model with adsorbed gas option, specification designed to handle the diffusion of gas from host rocks such as coal. Because of the shut-down period between swabbing and production, it was decided to match just the production period. The lower rates from about 70 to 90 days occurred because of problems with the water pumping unit. In obtaining this match, two important parameters had to be assumed which seriously affect the ability of this coal seam to produce. One was the gas content of the coalbed and the other was the effectiveness of the

*Quotation is from well permit denial.

Figure 2-25. Test Data and Model Simulation Comparison,
Coseka Federal Well 1-16

fracture treatment. Other reservoir parameters used in the simulation are values that would be considered normal for a coal seam.

From analysis of the fracture treatment performed on Federal 1-16, it is suspected that the coal did not fracture. The low injection rate of 4 bpm and the relatively high pressures needed to inject the foam-sand mixture indicate poor performance of the fracture process. Although a 150-foot fracture length was assumed to begin the matching process, it was necessary to assume no fracture in order to obtain a match of the gas production rate.

However, using the same coal seam parameters obtained in the match of Federal 1-16, Intercomp determined what the production rate would be if the seam was successfully fractured. Assuming an 800-foot length vertical fracture on each side of the well, the gas rate would be increased better than threefold.

Onsite work at Federal Well 12-15 was discontinued in the fall of 1979, as expected, when the well location became inaccessible by heavy equipment because of snow cover. For this and other considerations, the contract period has been extended to December 31, 1980.

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

Occidental Research Corp.
Irvine, California

Status:
Active

Contract:
Contract Date:
Completion Date:

DE-AC21-78MC08089
April 1, 1979
July 1, 1981

Principal Investigator:
DOE Technical Project Officer:

A. Gillies (TRW)
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.

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 horizontal 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 IN PRIOR REPORTING PERIODS

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 was 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 were 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.

Two long holes (#5 and 6) were completed by July 1979 with the modified Acker drill. The first hole was drilled in the face cleat direction to a distance of 1,550 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 easily kept within the seam by varying the drill/collar-stabilizer configuration, the drill speed, and the load on the bit. Drilling of this

developmental hole was stopped at 1,550 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 was drilled to 1,730 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 wellbore survey showed that the hole deviated approximately 30 degrees in azimuth from the intended direction. General dip of the coalbed in the same direction is also a possible cause of the deviation.

The concept of drilling holes from the #3 seam through approximately 50 feet of shale into the overlying #4 seam was explored, and work on it was initiated.

PROGRESS THIS REPORTING PERIOD

The project status was reviewed in detail on November 1, 1979. The project had moved through the design and validation phase ahead of schedule in all major areas, and below estimated costs. Go-ahead for the implementation phase was subsequently given. As indicated below, encouraging technical progress continued.

In October 1979 the slant hole portion of hole #7 into the #4 seam was completed, demonstrating that gas can be drained from adjacent seams. In this test the angle of the drill hole had to be steep enough to minimize the time required to penetrate the rock formations and yet shallow enough to turn the bit within the #4 coal seam once it was encountered. When the #4 seam was entered, gas pressure of 250 psig was measured. The actual pressure probably exceeded this value as only 20 feet of standpipe was grouted into place, and it extended only 3 feet into the roof. Thus hairline fractures, which are normally observed in stable roof, may have allowed gas to escape tending to limit pressure buildup to less than actual reservoir pressure.

Using techniques similar to those used in hole #7, a second slant hole (#8) from the mining level #3 seam to the #4 seam was begun in November and completed in December 1979. This hole was drilled to a total depth of 660 feet, at which point the #4 seam pinched out. Most of the gas flowing from this hole and #7 appears to be from the coal and little from the adjacent shale. Results of mathematical analyses show that 875 cfd are liberated from each foot of hole in coal and only 24 cfd are liberated from a foot of hole in shale.

Preliminary data indicate that the reservoir characteristics of the Pocahontas #4 coalbed are similar to those of the Pocahontas #3 coalbed, but very little is known about the shale unit overlying the Pocahontas #4 seam. It is possible that the gas contained in the shale originates from the Pocahontas #4 coalbed and the gas migrates through both seams.

Experience gained from drilling these holes indicates that bit angle can be controlled in various rock types and across their interfaces. Techniques for increasing bit angle are very effective while techniques for decreasing bit angle are less effective. Research will be conducted to improve control of the bit in the decreasing direction.

In evaluation of methane utilization at the mine, one option considered the use of the gas drained to fuel the onsite coal dryer. However, since the dryer operates only 8 to 10 hours a day, this option requires either storage or intermittent production of gas. To test the feasibility of intermittent production, surge tests were conducted on hole #5. Tests show that these coalbeds can be drained in this manner with no significant sloughing of coal into the borehole and that the coalbeds can effectively function as storage tanks during 14-16-hour gas impoundment periods.

Drilling of the #9 hole into the No. 3 Pocahontas seam began in March with a target depth of 2,000 feet.

As of the end of February a total of 174 MMcf of gas had been drained since March 1978. Figure 2-26 shows flow by month from all holes. A summary of well data as of the end of December 1979 is shown in Table 2-8.

Figure 2-26. Volume of Gas Drained by Month

Table 2-8. Summary of Horizontal Drill Well Data for Methane Drainage in Advance of Mining--December 1979

WELL	DEPTH (FEET)	TOTAL GAS PRODUCED (MMcf)	UNIT PRODUCTION RANGE (CF/FT/DAY)*	LATEST UNIT PRODUCTION RATE (CF/FT/DAY)*	MAXIMUM PRESSURE RECORDED	LIFE OF HOLE (NO. OF DAYS) (FLOWING)	AVERAGE PRODUCTION RATE (CF/FT/DAY)*	AVERAGE DAILY PRODUCTION (CF/DAY)	LENGTH OF STANDPIPE (FEET)
OXY #1	500	7.40	386 - 11	11	60	418	35	17,701	20
OXY #2	502	7.37	429 - 11	27	52	310	47	23,767	20
OXY #3	503	14.89	442 - 29	55	50	323	92	46,112	20
OXY #4	505 (275 Ft. in Coal)	6.11	114 - 72	84	50	121	183	50,471	60
OXY #5	1,550	31.93	323 - 50	143	50	145	142	220,184	50
OXY #6	1,720	61.17	585 - 159	237	80	155	229	394,683	40
OXY #7	385 (35 Ft. in Coal) (and Shale)	0.15	-	343	250	14	300	10,503	15
OXY #8	660 (115 Ft. in Coal) (and Shale)	0.50	-	333	-	20	218	25,135	15
TOTAL	6,323	129.52					15		

*Cubic feet of gas per foot of borehole per day

2 . 4 . 7 M U L T I P L E C O M P L E T I O N D E V E L O P M E N T
T E S T P R O J E C T G R E E N E C O U N T Y ,
P E N N S Y L V A N I A

Waynesburg College
Waynesburg, Pennsylvania

Status:
Active

Contract:
Contract Date:
Completion Date:

DE-AC21-78MC08089
July 1979
September 30, 1980

Principal Investigator:
DOE Technical Project Officer:

N. F. McGinnis (TRW)
H. D. Shoemaker

OBJECTIVE

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

SCOPE OF WORK

The development of multiple methane production zones in a single well is the objective of this planned project. The coal is not being mined since it underlies extensively developed surface areas. The site selected for this project is on land owned by Waynesburg College, the Purman Run tract on the college campus 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 completion in a single well considering the requirements to isolate the production zones and dewater 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 produced in methane drainage.

PROGRESS IN PRIOR REPORTING PERIODS

The following activities were conducted:

- 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.

PROGRESS THIS REPORTING PERIOD

Considerable progress was made during this period beginning with the revision of the Environmental Assessment and initiation of drilling activity. Using a wireline core barrel, 1-7/8" cores were retrieved with the coal cores subjected to desorption tests. Figure 2-27 displays the various coal horizons penetrated.

Coring was completed on December 16. After cementing back to 200 feet, the upper uncemented portion of the well was completed as a groundwater observation well for the U.S. Geological Survey. Following the completion of core drilling an evaluation of the preliminary core desorption data indicated that the coal seams would be productive. Drilling of the production well was begun on January 22 with a TD of 1,450 feet occurring on January 29. Suites of logs were run, including dual induction laterlog/sonic (formation resistivity and hydrocarbon content), formation density (porosity), compensated neutron (precise lithology, depth, bed thickness) and a caliper log (well bore configuration log). Computer log analysis provided additional information on material strength of the rock strata, carbon, ash, and sulfur content of the coal seams. These data confirmed information produced from the core analyses and greatly assisted the determination of which coal seams should be completed.

The well was cased with 5-1/2 inch J-55 API casing and coal seam targets perforated producing three distinctive zones (see Figure 2-27). On February 26, a nitrogen foam stimulation of the well was initiated. Each zone was isolated by placement of a retrievable bridge plug followed by formation breakdown, frac pad placement and the frac itself. Table 2-7 displays the essential data of this hydraulic foam fracturing stimulation. While production testing of the well has not begun during this period, apparently as flow-back from the upper zone was occurring, it was observed that an unknown and improperly abandoned well had blown out during this treatment. This well was observed some 315 feet away on the college practice football field. Prior to full well production, this well will have to be replugged according to state requirements.

After completion of the stimulation treatment, the well was swabbed and bailed, a positive displacement downhole pump installed and the production tubing placed within the 5-1/2" casing. Following this activity a Jensen Jack with an electric motor prime mover was installed and dewatering operations were begun.

Final desorption data, core analyses were completed during the latter portion of this period indicating the following information:

Sample No.	Coal	Depth (ft)	Lost Gas cc/gm	Desorbed Gas cc/gm	Residual Gas cc/gm	Total Gas cc/gm cf/ton	
41	Waynesburg	149	0.06	1.58	1.15	2.8	90
42	Waynesburg	153	0.02	1.07	1.06	2.2	70
43	Sewickley	371	0.07	2.66	2.01	4.7	150
44	Sewickley	486	0.05	1.88	2.63	4.6	147
45	Pittsburgh	489	0.08	2.15	1.89	4.1	131
46	Pittsburgh	491	0.15	2.82	2.60	5.6	180
J-L-1	(Rider)	483	0.10	2.75	1.33	4.2	134
155	Bakerstown	888	0.04	2.53	1.78	4.4	141
J-L-2	Upper Freeport	1085	?	1.48	2.12	3.6	115
47	Upper Kittanning	1187	0.12	3.07	1.64	4.8	154
156	(Predom. Shale)	1188	0.35	3.75	2.00	6.1	195
48	Middle Kittanning	1238	?	2.41	0.67	3.1	99
142	Clarion	1292	0.10	2.93	1.39	4.4	141

During the next reporting period, it is anticipated that the previously abandoned well will be replugged, the methane well dewatered, the surface equipment installed (wellhead separator, dessicator) and hookup to the commercial gas line completed.

Figure 2-27. Coal Horizons

Table 2-9. Fracturing Data

	COMPLETION ZONE	1		2			3		
	COAL SEAM	PITTSBURGH RIDER SEAM	PITTSBURGH MAIN SEAM	BAKERSTOWN	UPPER KITTANNING	MIDDLE KITTANNING	CLARION	MERCER SEAM 1	SEAM 2
	Number of Perforations	2	8	4	2	2	4	2	2
BREAKDOWN INPUT	Volume of Water [M ³]	1.70		3.75			4.73		
	Casing Pressure [mPa]	12.41		13.27			17.75		
	Water Pumping Rate [M ³ /sec]	0.03		0.03			0.01		
PAD INPUT	Percent Nitrogen	45 to 50		75			75		
	Casing Pressure [mPa]	11.72		17.92			26.47		
	Water Pumping Rate [M ³ /sec]	0.01		0.01			0.01		
	Total Volume of Nitrogen and Water [M ³]	37.85		18.93			16.65		
FRAC INPUT	Percent Nitrogen	45 to 50		75			75		
	Casing Pressure [mPa]	8.96		16.20			26.71 Increasing to 27.5		
	Proppant Sand 20/40 [kg]	15,875		10,200			1,050		
	Water Pumping Rate [M ³ /sec]	0.01		0.01			0.01		
	Total Volume of Nitrogen, Water and Sand [M ³]	151.40		94.62			17.87		

REMARKS:

Zone 1 — Frac screened out because of high bottom hole pressure and casing limitation of 27.58 mPa.

— 7 M of sand flowed back into the sump.

Zone 2 — First breakdown attempt failed because of faulty perforation run. Rerun with different shaped charges and perforated Bakerstown only.

2.4.8 ANTHRACITE COAL DRAINAGE TEST
PROJECT, LUZERNE COUNTY,
PENNSYLVANIA

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

Status:
Deferred

Contract:
Contract Date:
Completion Date:

DE-AC21-78MC08089
To be determined
To be determined

Principal Investigator:
DOE Technical Project Officer:

H. R. Takamatsu
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 extracting and using 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 (2,000 feet). The contract 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 by the Pennsylvania Gas and Water Company, a company associated with PERI.

PROGRESS IN PRIOR REPORTING PERIODS

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 THIS REPORTING PERIOD

A first draft of the Environmental Assessment for this project was completed and review comments are being incorporated by PERI.

At this time budgetary constraints preclude implementation of this project.

2 . 4 . 9 M U L T I P L E V E R T I C A L B O R E H O L E
 D E G A S I F I C A T I O N T E S T P R O J E C T
 J E F F E R S O N C O U N T Y , A L A B A M A

United States Steel Corporation

Status:
Active

Contract:

ET-75-C-01-9027

Contract Date:

June 1975

Completion Date:

August 1980

Principal Investigator:

J.S. Wallace (U.S. Steel)

DOE Technical Project Officer:

S.W. Lambert (CMTC)

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 28 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 1,000 feet from the underground mine operations. All 28 boreholes will be completed into the Mary Lee coalbed, stimulated, produced, and mined through. The goal of this project is to provide increased coal output, and decreased mine ventilation costs using large-scale application of vertical borehole methane drainage techniques designed to be minimally disruptive to the coal mining process.

PROGRESS IN PRIOR REPORTING PERIODS

A total of 21 boreholes had been completed at Oak Grove before April 1979. 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 12 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 16 boreholes were put into production. On March 15 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 high 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.

In May 1979, 13 of the 17 boreholes produced gas 28 or more days, and 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 preceding months (3,200 gallons/day in June 1978 to 1,100 gallons/day in

May, 1979 indicating the water head on the coal seam was being reduced. Accordingly, the pumps were lowered in several boreholes.

In June 1979, 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 1979, 12 boreholes produced gas every day, two produced at least half 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 1979, 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.

PROGRESS THIS REPORTING PERIOD

Although stabilized gas and water flows have been achieved at the 17-borehole pattern test site, operational difficulties related to the influx of stimulation treatment propping material continue. As the boreholes are pumped, sand that had been used as a proppant during the hydraulic stimulation treatments is routinely observed in the water effluent. At first this sand does not disrupt the water flow; however, as the water levels in the boreholes are lowered, sufficient quantities of sand accumulate in the downhole pumping mechanism to greatly reduce pumping efficiency. As a result, it has been continually necessary to remove, repair and replace the pumps. Because of this problem the scope of research work at Oak Grove has been expanded to include several additional stimulation experiments which, if successful, would reduce or eliminate sand-related problems and thereby substantially reduce the cost of operating future coalbed gas wells.

Seven additional boreholes are to be completed under this latest modification. Six of the boreholes are being added to the 17-hole pattern

while the one remaining borehole already has been completed near the mine. Current stimulation designs for the six new pattern boreholes include:

1. One no-proppant, 50,000-gallon foam treatment using a sequential injection rate profile that initiates at 2 barrels per minute and terminates at 6 barrels per minute.
2. One 50,000-gallon foam treatment using 20/40 mesh sand as a proppant and a constant injection rate of approximately 10 barrels per minute.
3. One no-proppant, 50,000-gallon foam treatment using a sequential injection rate profile that initiates at 2 barrels per minute and terminates at 8 barrels per minute.
4. One 50,000-gallon foam treatment using an injection rate of either 5 or 6 barrels per minute with the sand size (probably 20/40 mesh) and concentration to be adjusted as required.
5. One 50,000-gallon foam treatment using sand proppant larger than 20/40 mesh sand and a constant injection rate of approximately 10 barrels per minute.
6. One 50,000-gallon foam treatment using a sequential injection rate profile that initiates at 2 barrels per minute and terminates at 7 barrels per minute with the sand size and concentration to be adjusted as required.

Sites for these new boreholes have been surveyed and prepared for drilling operations. The holes are scheduled to be stimulated in June 1980.

The remaining borehole test provided under the expanded work program at Oak Grove was completed approximately 1,600 feet ahead of a projected six-entry mining section. The coalbed was treated with 53,000 gallons of 75% quality foam at an average injection rate of 4.7 barrels per minute, using no proppant. The well, referred to as TW5, was allowed to produce 147 days before underground interception.

Stabilized daily water flow from TW5 started at 7 bpd and ended at 4 bpd. Past experience at Oak Grove indicates that initially low rates and the gradual decrease in flow overtime are typical water production characteristics for boreholes placed close to mining.

The total amount of gas produced from TW5 was 9,000,000 cubic feet for an average daily rate of just over 61,000 cubic feet. It is very important to note, however, that gas flow rates measured at TW5 declined sharply over the 147-day production period. Unfortunately the physical location of this stimulation test prevents any definite conclusion regarding the potential of future no-proppant stimulation because the gas flow decline at TW5 could have been due either to gradual closing of induced fractures or to the mine's advance to the test hole. The results gathered underground after

borehole mine-through indicate, however, that the stimulation of TW5 caused no significant fracturing of mine roof or floor, and the use of very low injection rates may be beneficial to keeping induced fractures "in zone". A detailed DOE report of the TW5 experiment entitled, "The Feasibility Of No-Proppant Stimulation To Enhance Removal Of Methane From The Mary Lee Coalbed" will be available in May of this year.

Daily gas production from the 17 operating boreholes at the Oak Grove pattern site averaged approximately 1.1 million cubic feet during the last six months. The total amount of gas produced from the borehole grid area is 562 million cubic feet, which is over 26% of the gas originally estimated present within the 5-foot thick coalbed. After 8,335 well operating days logged, the per well average gas flow is 86,225 scfd. Average monthly gas flow rate from the pattern since January 1978 is shown on Figure 2-28. Large increases in gas production occurring in late 1978 and early 1979 were due to the increasing number of wells first put into operation during that time period. Smaller fluctuations in gas production reflect the number and condition of wells actually operating during any given month. There is still no evidence which suggests individual or overall decline in gas production. On the other hand, total pattern water flow has decreased steadily during this reporting period from 290 bpd in October to 238 barrels per day in March 1980.

In February, United States Steel Corporation formally proposed a 50/50 cost-shared effort designed to commercially pipeline the gas being produced as a result of this prototype borehole degasification program. This utilization plan incorporates a small-diameter pipeline system locally interconnecting the pattern boreholes; a manifold arrangement to gather the gas from multiple holes and direct it to a single point; a main compression station to boost the gas in the low-pressure manifold to the required transport pressure; and a trunk line connecting to an existing commercial pipeline system. Total cost for the proposed gathering and transport system is approximately \$1.2 million. The most conservative economic estimates suggest that the proposed system will pay for itself within two years.

Figure 2-28. Total Gas Production from 17 Producing Wells

2.4.10 DIRECTIONAL DRILLING FOR
DEGASIFICATION OF THE
PITTSBURGH COALBED,
GREENE CO. PENNSYLVANIA

Harold F. Scott, Contractor
Bridgeville, Pennsylvania

Status:
Active

Contract:
Contract Date:
Anticipated Completion Date:

ET-77-C-01-8891
September 27, 1977
May 26, 1983

DOE Technical Project Officer:

W.P. Diamond (USBM)

OBJECTIVE

To demonstrate the capability of using directional drilling techniques to drill long, horizontal methane drainage holes in coalbeds to reduce the explosion hazard of methane/air mixtures and utilize the recovered methane.

SCOPE OF WORK

This contract is a continuation of research initiated by the U.S. Bureau of Mines to determine the adaptability of directional drilling for draining methane from coalbeds in advance of mining. A specific objective of this research is to improve the drilling technology pioneered on previous projects of this type. Improvements in the drilling techniques are expected to increase the effective area of methane drainage and reduce the cost of the system. The use of directionally drilled boreholes is designed to combine the high methane drainage rates of horizontal holes drilled into coalbeds from underground workings with the capability of drilling from the surface. A directional borehole is first drilled to intercept the Pittsburgh coalbed horizontally at a depth of 1,000 feet below the surface. Multiple long horizontal methane drainage holes are then drilled into the coalbed in a "birdfoot" pattern originating at the bottom of the directional borehole. A vertical borehole located near the initial coalbed intercept is designed to remove water from the coal to facilitate methane drainage. Seven vertical monitoring boreholes are located within the project area to continually monitor the progress and extent of methane drainage.

PROGRESS IN PRIOR REPORTING PERIODS

A corehole near the anticipated interrupt of the Pittsburgh coalbed by the directional drill path was completed. Coal cores were obtained to determine the gas content of the Pittsburgh coal by the Bureau of Mines Direct Method test. The depth of the target coalbed was also determined for calculation of angle build requirements for the directional drill path to the coalbed. A vertical dewatering borehole was also drilled near the anticipated coalbed interrupt to remove water from the area. The dewatering borehole was foam stimulated to increase permeability to water and gas flow in the coalbed. The borehole was initially equiped with water level monitoring devices so that the coalbed reservoir pressure could be determined.

Seven vertical monitoring boreholes were drilled within the anticipated horizontal borehole drilling pattern. These boreholes were designed to continually monitor the progress and extent of degasification with time. The seven boreholes were also designed to have the capability of being used as auxiliary dewatering sites if necessary.

A 3-inch diameter directional pilot hole was successfully drilled to intercept the Pittsburgh coalbed at a vertical depth of 1,000 feet. The drill path distance of the directional borehole to the coalbed was 1,600 feet. The 3-inch diameter pilot hole was reamed to 8 3/4 inches and 5 1/2-inch diameter production casing was installed to a drilled depth of 1,595 feet. The reaming operations were accomplished by overreaming a string of BQ rod as a "guide string" and by using a "stinger" assembly

attached directly to the bit and run in the open hole. The "stinger" assembly was determined to be the preferred technique for reaming.

PROGRESS THIS REPORTING PERIOD

Horizontal drilling of methane drainage boreholes into the Pittsburgh Coalbed from the bottom of the directional borehole was completed. The boreholes were drilled using a Dyna-Drill down-hole motor and are 3 inches in diameter. A summary of the drilling results of the horizontal holes is presented in the accompanying table:

Hole #	Total Length (ft)	Length in coal (%)
H1	1,767	62
H2	3,207	84
H3	2,993	92
H4	870	62
H5	707	85

The major difficulty encountered during the initial horizontal drilling phase of the project was keeping the drill path in the coalbed. Due to the undulating nature of the coalbed, the drill path frequently deviated from the coalbed. When this occurred, a determination was made as to whether the drill path deviated into the roof or floor rock, and then the drill path was gradually controlled back into the coalbed using the downhole motor. This technique was not satisfactory because long portions of the horizontal hole was drilled outside the coalbed, which resulted in slower drilling, tool wear and an expected lower gas production. In addition, the shale above the coalbed tended to cave-in when exposed to the drilling fluids, blocking the hole.

At the start of the second horizontal hole, sufficient skill had been developed in directional control to perform sidetracks, within the coalbed whenever the drill path entered roof or floor rock. This technique was very successful in increasing the drilling rate and the amount of hole in coal. Initial horizontal drilling rates were 80 feet/day. Horizontal hole H_4 and H_5 were auxiliary experimental holes generally along the drill path of hole H_1 .

Upon completion of the horizontal drilling, the vertical dewatering hole was equipped for production and monitoring of water and gas. Dewatering of the coalbed was begun. However, the dewatering borehole has not produced at a sufficiently high rate to initiate large gas flows. Gas flows averaged 15,000 Cfd from the directional borehole. A downhole electric pump has been obtained for installation in the directional borehole for additional dewatering.

2.4.11 VERTICAL DRILLING TO DEGASIFY
THE JAWBONE COALBED,
DICKENSON CO., VIRGINIA

CLINCHFIELD COAL COMPANY
MCCLURE, VIRGINIA

Status: Active

Contract:
Contract Date:
Anticipated Completion Date:

ET-77-C-01-9151
September 28, 1977
September 28, 1982

Principal Investigator:
DOE Technical Project Officer:

T. Wallace (Clinchfield Coal Co.)
M. A. Trevits (USBM)

OBJECTIVE

To determine the feasibility of using vertical boreholes to drain methane gas from the Jawbone coalbed and to evaluate the relationship of borehole spacing on gas drainage rates.

SCOPE OF WORK

This is a cost-sharing agreement between the DOE and Clinchfield Coal Co. to test a minimum of five vertical boreholes near Clinchfield's McClure No. 1 mine. Work is to be conducted in two phases. The first phase consists of the drilling and completion of five boreholes into the Jawbone coalbed at appropriate spacings. Borehole DG-1A has been located close to mining operations while the remaining boreholes, DG-2C, 3B, 4 and 5D, have been positioned in a four-spot pattern located two years ahead of active mining. When the first phase of this project has been completed, an evaluation of the results will be made.

The second phase will commence upon mutual agreement that a merchantable volume of pipeline quality coalbed gas can be produced. The second phase will consist of 20 boreholes completed as in the first phase. Gas produced from these test boreholes will be transported through a pipeline and delivered to a point of utilization or to a commercial gas transmission line for sale.

PROGRESS IN PRIOR REPORTING PERIODS

Drilling operations for the first Jawbone coalbed degasification borehole, designated DG-1A, began on May 30, 1978. Direct Method desorption tests performed on two cores recovered from this borehole indicated an in-place gas content of approximately 280 cubic feet per ton of coal. The borehole was subsequently stimulated on June 6, 1978 using 30,000 gallons of nitrogen generated foam and 27,000 pounds of 20- to 40-mesh sand proppant. A number of dewatering pump problems prevented steady gas production. The average production rate for 20 days ending October 20, 1978 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 34.3 bpd of water and the lowest, in July 1979 was 73 Mcfd. By the end of September 1979 gas production had increased to 26 Mcfd. Mining operations had progressed to within 550 feet of the borehole, further lowering coalbed reservoir pressure, decreasing water saturation and thereby allowing an increased amount of gas to desorb from the coalbed.

Drilling operations at the four-spot pattern began in July 1979. Foam stimulation treatments were performed at borehole Nos. 4D and 5D upon completion of drilling operations. Average treatment utilized 30,000 gallons of nitrogen generated foam and 15,700 pounds of 20- to 40-mesh sand proppant.

PROGRESS THIS REPORTING PERIOD

To date, approximately 11.6 MMcf of methane have been produced from borehole DG-IA. Mining operations have progressed to within 300 feet of this borehole and gas production has declined to within 16 Mcfd.

The last two of the five boreholes to be tested under Phase I of this project were drilled and completed by December 1979. Borehole DG-5D was stimulated with 24,400 gallons of nitrogen generated foam and 14,200 pounds of 20- to 40-mesh sand proppant. Borehole Dg-2C was stimulated with 26,200 gallons of nitrogen generated foam and no proppant. The no proppant stimulation treatment was designed to determine the production characteristics of a no proppant stimulation treatment.

All boreholes in the four-spot pattern are currently being outfitted for coalbed water removal. Methane-fueled engines are being utilized to operate the surface pumping facilities because of the high cost of equipping the pattern with electric power. Pattern boreholes DG-2C, 3B and 4 have been produced only intermittently and resulting gas production was 8 Mcfd, 21 Mcfd, and 10 Mcfd respectively.

2.5 PROJECT INTEGRATION

The objectives of the project integration element of the MRCP are to:

- Provide project support and analysis.
- Provide project report development.
- Develop plans and implement systems for project information management and technology transfer.

This integration plays an important part in the implementation and management of this project. Besides normal project planning and coordinating functions, a large amount of informational exchange, or "crossfeeding", necessarily takes place between the several individual R&D and technology system tests and their supporting activities. Also, information resulting from one activity is frequently used as "feedback" input to another. Much of this information is technical and continually pressing the state-of-the-art. The large amount and variation in types of data dictate the use of a systematic information management system to maintain orderly flow, storage, and ready availability.

In the technology test projects integrated planning is required to assure selection of optimum overall systems design and coordination of operational procedures. Tradeoffs involving site locations and design features are also required. Factors in these trades 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. For some test projects, detailed supporting studies and analyses will be required to provide the requisite knowledge for decisionmaking and selection of viable systems and site locations.

New information resulting from activities such as R&D projects and analytical studies will be provided to an appropriate ongoing technology test or support activity for test and proof under field conditions. On the other hand, field operations can be expected to identify problems that may be resolved in a timely manner by immediate assignment to a related ongoing R&D activity.

It is anticipated that as the project progresses, the coordinating effort will continue, but with decreasing government support and increasing industrial participation. To realize this trend, economic and environmental viability of the new technologies must be demonstrated to attract private ventures. Other gas recovery efforts involving methane (not coal-bed associated) are also underway or planned, and MRCP activities will be coordinated with them where mutual support will be beneficial to overall DOE UGR goals.

2 . 5 . 1 P R O G R E S S I N P R I O R R E P O R T I N G P E R I O D S

General

A draft version of the MRCP Project Plan Document (PPD) for FY 1980 was prepared. This document delineated project objectives, roles and responsibilities of project participants, and requirements of information management and project control functions.

The initial version of the Methane Recovery from Coalbeds Resource Delineation Plan was published. This plan encompasses examination of 380,000 square miles of coal-bearing rocks in the conterminous United States, and of the quantity, distribution, and production characteristics of some 789 trillion cubic feet of methane estimated to be contained in those rocks. Early efforts will concentrate on some 20 percent (80,000 square miles) of this area where the probabilities of finding, producing, and utilizing the methane are higher. Attempts will be made within this area of 80,000 square miles to supply one data point every 1,000 square miles. Target areas identified in this plan are modified in accordance with findings of field tests conducted under the Resource Engineering element of the MRCP.

A draft information management plan was developed to identify and structure the activities necessary to provide for efficient, effective, and economic management of information acquired and developed through the MRCP. To provide for rapid dissemination of information the requirements will be reviewed at intervals of three to six months and the information management system will be modified as needed.

2 . 5 . 2 P R O G R E S S T H I S R E P O R T I N G P E R I O D

General

A workshop was held at the Holiday Inn West in Golden, Colorado, on January 30, 1980. Attendees included representatives from METC, DOE Headquarters, USBM, USGS, Colorado Geological Survey, New Mexico Geological Survey, and private contractors and institutions actively involved in coalbed methane recovery, resource engineering, research and development, and technology testing activities. This fostered exchange of activity plans and results among current project participants, and familiarized the other interested parties with project activities.

Participation of the USGS Branch of Coal Resources in the 1980 drilling program was negotiated, and similar negotiations with LASL were initiated.

A recent ruling in the Court of Common Pleas of Greene County, Pennsylvania (United States Steel Corporation, Plaintiff, vs. Mary Jo Hoge, Jessie Lee Cowan, Harvey C. Cowan and Mary L. Cunningham, Defendants - No. 682 in equity) has clarified ownership of coalbed methane in Pennsylvania. The decision in this case is that landowners or their gas rights lessees own the coalbed methane and can remove it by complying with Pennsylvania law. However, coalbeds cannot be fractured without consent of the coal owner. The CONCLUSIONS OF LAW in this case, reported verbatim, are:

1. Coal bed gas is a natural gas by scientific definition and must be considered such by legal definition for these reasons:
 - (a) Coal bed gas was formed over the millions of years in the coalification process as a result of a series of biochemical and geochemical reactions that transformed plant material into hydrocarbon gases, and thereby, with some slightly different technical variations, it was formed in the same way as other natural gases.
 - (b) The component ingredients chemically of coal bed gas and other natural gases is quite similar if not identical, methane being a chief component of each.
 - (c) Existing in its natural state as it was formed and created, it is a gaseous substance, the same as other natural gases and retains its character when initially captured, and continues to do so until and unless changed by some artificial method of transformation or modification.
 - (d) It is adsorbed in the cracks, crevices, fractures, and micropores of the coal seam, but is not absorbed by the coal, and while even the slightest particle of coal emits and diffuses coal bed gas, and it is a part of the important constituent of coal, that of volatile matter, it always retains its separate identity by chemical definition and recognition as a gas.
 - (e) While it is, being a gas, like all gases, of an essentially fugitive nature, and even though it is found mainly and mostly in the close proximity of a coal seam, it is capable of and in some instances does escape its natural habitat to other strata or horizons, by its very nature and without the necessity of any artificial stimuli.
 - (f) Having been long condemned to wasting in the coal industry and having until recent years been thought to have no redemptive qualities nor capability for commercially advantageous recovery, this historic disdain does not in and of itself change its nature, its chemical characteristics,

nor the legal background for the determination of ownership, the same as other natural deposits found beneath the earth's surface, irrespective of its relative worth.

2. Since at the time the coal severance deeds before us were drawn under these as well as under most surface lands of this County, coal bed gas was not generally believed by anyone to have any value, and it cannot be reasonably presumed that the intent of the purchasers of the coal was to include the purchase of coal bed gas, nor that the intent of the landowner was to include it in the sale of coal. If any intent can be reasonably inferred, it was that the landowner intended to sell the coal to one purchaser and the gas and gases to another.
3. The right of the owner of the coal to ventilate the mine, legally is that and nothing more. It gives the coal owner the right to bring fresh air into the mine and to draw stale air, gases and fumes out of the mine, and to waste the coal bed gas or to capture it, at its pleasure, in the course of mining, but this creates no property right by reason thereof in the coal bed gas, except that the coal owner, if he chooses, could capture the gas released in the course of the mining operation and make separate sale of it.
4. The language found to exist in every oil and gas lease in this County that was drawn, almost in standard form, extended to the lessee of the oil and gas all of the oil and gas underlying all that tract of land whether or not the coal had not previously been sold and conveyed. The present leases contained the same language.
5. The coal which was acquired by the grant of it is a separate, solid, carbonaceous substance, formed over millions of years, at the same time as the gas, containing within it the constituents of fixed carbon, volatile matter, moisture and ash, and in addition, by the clear express language found in these and all standard coal deeds there is found the grant of the mining rights attendant thereto, which was a necessary delineation of rights to give value to its ownership, so there unquestionably can be the right to mine and remove it.
6. Equally important, as with the fee ownership of any real property in this Commonwealth, is the inherent right of the owner of the coal not to have its property unnecessarily violated, trespassed upon, or as it concerns the subject matter at hand, it might be better expressed, trespassed into.
7. Thus, the legal conclusion which must be drawn in the carefully reasoned resolve of this issue is that since the coal bed gas was not sold and conveyed with the coal, and it is a separate substance, and is natural gas, the surface owner still retains

control, except for its wasting in the course of mining, and still has the right to lease it to whomever he wants, to capture and produce it from whatever source or strata it is found beneath the surface of the land, except the landowner cannot himself, nor can he extend to the lessee, the right to fracture or artificially stimulate the release of the gas in any manner which violates or diminishes the property value of the coal which was previously sold and severed.

8. As a natural and logical conclusion thereof, when there is a lease of the oil and gas, the lessee of the same, having been expressly granted the right to drill through the coal, has by legal interpretation, the attendant and necessarily included right to drill into the coal seam, and to capture and recover, by normal and standard drilling procedures, the coal bed gas which naturally and freely vents itself from its lodging in and about the coal in the area of the drill hole.
9. Such drilling for coal bed gas, as is now required for drilling for any other natural gas under the provisions of the Gas Operations Well Drilling Petroleum and Coal Mining Act (1955) P.L. 756, Sec. 104, as amended, 1970, 52 P.S. 2101, shall only be done, after a permit is obtained therefor, pursuant to the Act, and after notice is given to the owner of the coal as required thereby, and further, all of the drilling operation must be done in conformity thereto.
10. The right reserved to the landowner to drill into and through the coal as above determined, shall not, without the express consent of the owner of the coal, be construed to include the right reserved to him or by any person acting under him, lessee, driller, etc., to engage in drilling practices which, for purposes of artificially stimulating the release of the coal bed gas, cause or could be reasonably expected to cause abnormal or actual damage to the coal seam, or to the roof, or to the floor of the same.
11. That the coal owner and operator cannot and must not, in the grant or issuance of drilling permits, suffer any deprivation or diminishment, or the unreasonable taking of his coal without just compensation being paid therefore, by the allowance of drilling for coal bed gas in such areas, spaces, or places which interfere with its right to use long-wall production method, or any other operating method, or which unnecessarily requires sizable blocks of coal to be left in place, solely as an accommodation to a well drilled after the date of this decree for the recovery of coal bed gas.

Technology Transfer

Representatives of MRCP presented the following papers during this reporting period:

- D. R. Watkins and H. D. Shoemaker, "Testing for Methane in Coal Seams", presented at the Energy Sources Technology Conference and Exhibition in New Orleans, Louisiana, February 3-7, 1980.
- H. H. Rieke, F. G. Galliers, and S. A. Friedman, "Stratigraphic Relationship of Desmoinesian Coals in the Kiowa Syncline, Pittsburg County, Oklahoma", presented at the South-Central Section Meeting of the Geological Society of America, Wichita, Kansas, March 3-4, 1980.

Representatives of the MRCP also supported the seventh annual Energy Technology Exhibit and Convention in Washington, D.C., March 1980. The display featured methane recovery and utilization concepts and equipment. MRCP personnel staffed the display and answered questions from attendees.

During the reporting period, filming of a movie on unconventional gas recovery was continued. Included in the movie is a segment on the Methane Recovery from Coalbeds Project. A new version of the Technology Transfer Plan is in preparation.

Agreement was reached with SPE to plan, organize and conduct a symposium for coalbed methane and Eastern gas shales topics of interest. The symposium will be held at the Gateway Hilton in Pittsburgh, May 19-20, 1980. Proceedings will be available at the symposium.

3. EASTERN GAS SHALES

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3 . 1 I N T R O D U C T I O N

3 . 1 . 1 B A C K G R O U N D

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.

Attention has recently been focused on the western portion of the Appalachian Basin known as the Appalachian Plateau. Of the approximately 160,000 square miles in 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.

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 E A S T E R N G A S S H A L E S P R O J E C T

The Eastern Gas Shales Project is one of several unconventional gas resource projects currently being funded by the Department of Energy

Figure 3-1 Location of Eastern Gas Shales Geologic Provinces

(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 25,000 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 and is now operational.

The geological evaluation work (including cross sections, isopach, and structure contour maps) 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.

EGSP research has identified the nature of producible gas containment to be the micro- and macro-fractures of the shale formation and also the shale matrix itself. 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. A feasibility study of the use of an inactive mine to directly study the geometry of stimulation treatments, and hence optimize their design, is in progress. Directional deviated well technology is technically feasible, but additional demonstrations are required 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:

- 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 abundant 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 methods of locating 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.

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

Figure 3-2 Eastern Gas Shales Project Description

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:

- Develop a comprehensive understanding of the factors affecting gas production from reservoirs in various geologic regions.
- Develop a forecasting capability by which reservoir response to stimulation will be indicated for various geologic conditions.

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 of specific extraction methods under design conditions.
- An Offset Well Test Program.

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 of this Element 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; and 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 goal of this Element is to provide direction and guidance for meeting project goals and objectives, from an overall systems perspective.

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 C O N T R A C T O R S

The contractors active in the EGSP during this reporting period, are shown in Table 3-1.

3 . 2 R E S O U R C E C H A R A C T E R I Z A T I O N A N D I N V E N T O R Y

3 . 2 . 1 I N T R O D U C T I O N

The goals of this Element are: to estimate the total gas-in-place and the economically recoverable resource; and to develop exploration rationales to locate gas wells.

The development of depositional models for the Devonian Shale is a key activity that integrates the data obtained from geological studies, and provides a framework to develop exploration rationales and to make resource and reserve estimates. Only one depositional study has been completed so far, and some of the main conclusions are given below.

The basin analysis completed during this reporting period indicates that the Appalachian Basin has a systematic arrangement of facies. The progression of non-marine clastics is from east to west through beach, shelf, and slope to the deep basin with prominent clinoform deposition and westward overlap. The depositional strike is possibly near the present western limit; and thus, even thin shale units have much better north-south than east-west lithologic continuity. Black shales are thin and widespread and fan eastward where they pass into greenish-gray shales that form wedge-shaped masses which mostly accumulated on a westward dipping slope or at its base.

Interbedded siltstones and sandstones, and apparently almost all of the shales in the basin were deposited by currents from the east, generally perpendicular to isopach lines. However, black shales, which dominate only in the western part of the basin, imply deposition in a restricted basin.

The source of the organic carbon in the bituminous shales was twofold judging by its isotopic composition--a terrestrial source to the east, and a pelagic source within the basin. As individual black shales are traced westward, the pelagic source becomes predominant. Because marine carbon is better as a source of oil than terrestrial carbon, highest values of oil recovery will occur in those shales with the most

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
Cliffs Minerals, Inc.	X						
Columbia Gas System Service Corp.							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						
Juniata College	X				X		
Lawrence Livermore Laboratory			X				
Mitchell Energy Corporation (2)						X	X
Mound Facility	X						
New York Geological Survey	X						
Ohio Geological Survey	X						
Ohio State University			X				
Pennsylvania Geological Survey	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 Geological Survey		X					
University of Cincinnati	X						
University of Kentucky RF (2)	X						
University of Maryland			X				
J. T. Waggoner							X
Thurlow Weed & Associates							X
West Virginia Geological & Economic Survey	X						
West Virginia University (3)	X		X				

marine carbon along the western outcrop of the basin. Variation of carbon isotopes within the basin dovetails nicely with evidence from paleocurrent mapping, and both indicate an eastern source.

The abundance, thickness, and cementation of siltstone laminae within a shale as well as its fine-scale interlamination with organic matter appear to be most significant for gas potential from a depositional viewpoint.

3 . 2 . 2 A P P A L A C H I A N B A S I N

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 EGSP study area in the Appalachian Basin includes over 90,000 square miles of Devonian Shale formations, or all of the State of West Virginia and portions of New York, Pennsylvania, Ohio, Maryland, Virginia, Kentucky, and Tennessee (see Figure 3-1).

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.

COLLECTION, DESCRIPTION, AND LOGGING OF EGSP DEVONIAN SHALE CORES

Cliffs Minerals, Inc.
Granville, West Virginia

Status: Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AC21-78MC08199
August 16, 1978
May 31, 1982

Principal Investigator:
Technical Project Officer:

J.B. Hollister
C.S. Dean
Morgantown Energy
Technology Center

OBJECTIVE

To collect; describe lithology, fractures, and 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 this 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 13,537 feet of Devonian Shale core from twenty-one 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. These

(Resource Data Acquisition and Analysis)
pressurized cores were the first to be taken in the EGSP. The data from these cores will be used to verify or revise offgassing calculations.

Work continued on sample preparation for point load and directional tensile testing, Phase I and II reports, lithologic logs, fracture logs, photo logs, and correlation charts for previously retrieved cores.

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:
Contract Date:
Anticipated Completion Date:

DE-AC05-77ET12137
August 1, 1979
July 31, 1980

Principal Investigator:
Technical Project Officer:

P.L. Jackson
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 (Contract DE-AC05-77ET1213) 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 remotely sensed lineaments and bring them across the threshold of perception.

Figure 3-3 ERIM Study Area in Western Kentucky

(Resource Data Acquisition and Analysis)

- 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 this reporting period efforts focused towards collection and analysis of geological, geophysical, and remote sensing data for a selected study area in western Kentucky.

Imagery of various types was accumulated and modified to meet the needs of the project. This included Landsat imagery, Skylab photos, and standard NASA air photos. From these imagery prints, maps and overlays of the test site were constructed.

In addition to the imagery, detailed observations were made on geologic features of the site. During December 1979, a meeting was held in order to interpret the data and imagery collected.

Lineament recording and interpretation continues as does preparation to computer enhance the intensive test sites.

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

Gruy Federal, Inc.
Houston, Texas

Status: Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AC05-78MC08382
April 1, 1979
April 1981

Principal Investigator:
Technical Project Officer:

A. Lohse
K-H. Frohne
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 up to 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 for monitoring, collecting, and assimilating all the data generated from the analyses of cores, geophysical logs, well completions, and the well testing of the up to 22 wells.

SUMMARY OF PROGRESS

All activities relating to five shale core wells were completed during the reporting period. These wells are located in Wayne County, Illinois; Indiana County, Pennsylvania; Lawrence County, Pennsylvania; Otsego County, Michigan; and Grainger County, Tennessee (Figure 3-4).

Plans are underway for possible future core and/or stimulation wells in Kentucky, Michigan, New York, Ohio, Pennsylvania, and Tennessee.

Figure 3-4 Wells Cored During First Half FY80 by Gruy Federal, Inc.

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: J.C. Mercer
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

Software development of the high pressure isotherm apparatus was completed. High pressure data on several samples have been run. A decision was made to run low pressure work in conjunction with high pressure work. The low pressure work has been completed on the same samples as the high pressure work, and correlations are proceeding between high and low pressure data.

PHYSICAL AND CHEMICAL CHARACTERIZATION OF DEVONIAN SHALE GAS

Mound Facility
Miamisburg, Ohio

Status: Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AC04-76DP00053
February 15, 1977
September 30, 1980

Principal Investigator:
Technical Project Officer:

R.E. Zielinski
C.S. Dean
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 physicochemical 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:

(Resource Data Acquisition and Analysis)

<u>Location</u>	<u>EGSP Well No.</u>	<u>ft³gas/ft³shale</u>	
Ashtabula County, OH	OH-4	0.41	0.80*
Erie County, PA	PA-3	0.45	
Allegany County, NY	NY-1	0.30	
Allegheny County, PA	PA-2	0.23	
Knox County, OH	OH-3	0.42	
Johnson County, KY	KY-4	0.51	
McKean County, PA	PA-1	0.46	

*Controlled offgassing

Results of these analyses are given below. The first two wells were drilled and stimulated under this contract and are shown in Figure 3-5.

Figure 3-5 Location Map of Mound Facility Pressurized Core Wells

Ashtabula County, Ohio (OH-4)

<u>Analysis</u>	<u>Mean</u>
Total Organic Carbon	2.04%
Bulk Density	2.58 g/cm ³
Vitrinite Reflectance (core samples)	Ro = 0.40
Atomic H/C (Kerogen)	1.34

(Resource Data Acquisition and Analysis)

Sulfur (Whole Rock)	1.99 wt.%
Total H/C (GC-Pyrolysis)	1.15 wt.%
Bitumen	1835 ppm

- Total Organic Carbon - The basal Dunkirk Shale averaged 2.14 percent and the Rhinestreet Shale averaged 1.93 percent.
- Bulk₃ Density (43 samples) - The average₃ density ranged from 2.11 g/cm³ (OH-4-113, 981 feet) to 2.74 g/cm³ (OH-4-128, 1081 feet). The density value for OH-4-113 was confirmed by repeating the density analysis.
- Vitrinite reflectance (41 cores and 18 cuttings samples) - This was compared to sample depth. The comparison indicates a maturation gradient of 0.2 Ro/1000 feet.
- Atomic H/C (28 samples) - This value suggests a significant presence of marine sourced kerogen.
- Sulfur (30 samples) - The range in sulfur content was from 0.1 wt.% (OH-4-124, 1071 feet) to 5.8 wt.% (OH-4-195, 1341 feet).
- Total H/C (43 samples) - The mean volatile hydrocarbon yield and Peak II maximum temperatures were 1560 ppm and 458°C, respectively. The Peak I/Peak II mean value of 0.16 suggests relatively thermally immature organic matter in these shales.
- Bitumen (20 samples) - This bitumen (extractable organic matter) had an average hydrocarbon/nonhydrocarbon ratio (HC/non HC) of 1.93 with paraffin-naphthene/aromatic (PN/AROM) and asphaltene/nitrogen-sulfur-oxygen compounds (ASPH/NSO) values of 0.99 and 1.01, respectively. A more detailed analysis of the saturate hydrocarbons from 18 of these samples indicates that the paraffins are comprised, on the average, of about 25 percent isoprenoids. These samples have average carbon preference index values of 1.18 (CPI_A) and 1.15 (CPI_B).

Lithological descriptions were completed for 146 samples between the 509 to 1381 foot interval of the well. In general, these 100 percent shales were medium gray (N5) to medium dark gray (N4). Occasionally, olive black (5Y2/1) samples and several greenish gray (5GY4/1) samples were identified. The samples were moderately hard tabular and were generally slightly calcareous and anhydritic, becoming more calcareous in some of the deeper mines.

A visual kerogen assessment was completed for 128 samples (509 to 1379 feet). The thermal alteration index (TAI) ranged from 1 to 1+ in the shallowest samples (509 to 579 feet). The TAI increased to 2- at about 860 feet and to 2 for shales below 960 feet. This corresponds to a kerogen coloration change of yellow to yellow-orange to orange-brown with increasing depth. The kerogen was generally in an excellent to

(Resource Data Acquisition and Analysis)

good state of preservation and of a fine to medium grain size. Commonly, the sample kerogen was comprised primarily of herbaceous, secondarily algal-amorphous and lesser amounts of woody-coaly material. In about 15 percent of the cases, the wood-coaly type kerogen was dominant. These wood-coaly shales were located throughout the well interval. The algal-amorphous kerogen principally was made up of amorphous-sapropelic debris. The herbaceous kerogens were comprised primarily of cuticular-membranous and degraded herbaceous material; however, spores and pollen were commonly present in small amounts. The major element of the wood-coaly kerogens was woody debris.

Final results of the gas content analyses show that the controlled offgassing method gives a 53 percent measure of in-place gas content (avg: $0.348 \text{ cm}^3/\text{g}$ or 0.90 SCF/ft^3) and the conventional a <17 percent measure (avg: $<0.114 \text{ cm}^3/\text{g}$ or 0.29 SCF/ft^3) as compared to the pressure core barrel taken as 100 percent (avg: $0.657 \text{ cm}^3/\text{g}$ or 1.70 SCF/ft^3) in the Rhinestreet interval. A well average of $0.310 \text{ cm}^3/\text{g}$ (0.80 SCF/ft^3) was obtained from the controlled offgassing method while the same figure for the conventional method is $0.159 \text{ cm}^3/\text{g}$ or 0.41 SCF/ft^3 (51 percent). Direct sample comparisons for the well show that the conventional methods yields 74 percent of the value obtained by controlled offgassing (avgs: $0.266 \text{ cm}^3/\text{g}$ or 0.69 SCF/ft^3 vs. $0.358 \text{ cm}^3/\text{g}$ or 0.92 SCF/ft^3 , respectively).

The carbon, hydrogen, nitrogen, and ash contents of 56 samples were determined. The minor element (U, Th, V and Ni) analysis was completed for 30 samples. The U and U/Th values were compared to the total organic carbon content of each sample. The correlation coefficients for these comparisons were 0.53 and 0.65, respectively. Dilatometry testing has been completed for samples OH-4-167 and OH-4-109 using H_2O , 2% KCl, H_2CO_3 + 2% KCl, and kerosene at pressures of 14.7, 500, 1000, and 1500 psig. Methane sorption testing has been completed at pressures of 200, 400, 800, and 1200 psig for four samples. Analysis of the experimental data is in progress.

One hundred and eighty-eight samples were tested for total organic carbon from over 877 feet of the Devonian Black Shale stratigraphic interval. One hundred and seventy samples were selected from the core. The remaining samples were periodically obtained from drill cuttings. Core samples were selected from high potential zones (in terms of gas content and organic richness). Thus, the total well average of 2.25 (wt %) TOC is biased high. Chip samples, taken for TOC determination at uniform intervals along the cores, give a more random picture of the TOC distribution and generally average less than the interval and/or well average. Also, the well average is not a weighted average.

Stimulation of OH-4

Mound/DOE participation on this well ended on August 14, 1979 at 1,400 feet, about 25 feet below the base of the Marcellus Black Shale. Bessemer & Lake Erie Railroad Company, a subsidiary of U. S. Steel

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 Corporation and the cooperator on the well, continued drilling to a total depth of 2925 feet, finishing in the Queenston Formation (Ordovician) on September 11, 1979. Production casing was set in the hole and 18 perforations were shot in the lower Clinton and Medina Formations, from about 2600 to 2700 feet. This interval was then hydrofraced with sand proppant on October 25, 1979. Initial open flow from the Clinton and Medina after fracturing was 680 MCFD. Log data indicated that this interval has natural gas reserves of 238 MMCF and 117,000 bbls of oil. These data on the lower producing interval will be used in recommending and designing a dual completion-stimulation program for the Devonian Black Shale interval.

Erie County, Pennsylvania (PA-3)

<u>Analysis</u>	<u>Mean</u>
Organic Carbon	2.00%
Bulk Density	2.61 g/cm ³
Atomic H/C (Kerogen)	1.25

- Organic Carbon - The basal Dunkirk interval averaged 2.17 percent and the Rhinestreet Shale averaged 2.47 percent.
- Bulk Density (39 samples) - A low value of 2.33 g/cm³ for sample PA-3-170 (1238 feet) and a high value of 2.81 g/cm³ for PA-3-21 (407 feet) were observed.
- Atomic H/C (22 samples).

Gross lithological descriptions were completed for 71 samples. These samples were 100 percent shale except in the lowermost samples which were micrites. The sample color was primarily medium to light gray (N4 and N5). One sample interval (PA-3-115, 119, 122, 123, 127, 128 and 132) contained brownish black (5YR2/1) shales. In general, the shales are slightly to non-calcareous, occasionally anhydritic and/or micromicaceous, tabular, and moderately hard.

The visual kerogen analysis of 118 samples was completed (383 to 1272 feet). The TAI increased from 1+ to 2 with depth. This corresponds to a coloration change of yellow to yellow-orange to orange-brown with increasing depth. In general, the kerogen particle size ranged from finely disseminated to medium grained, and was in an excellent to good state of preservation. In general, the sample kerogen was primarily herbaceous, with the secondary kerogen type alternating between woody-coaly and algal-amorphous. Several intervals in the well contain a kerogen type where woody-coaly material is present (e.g., 653 to 751 feet and 1178 to 1218 feet).

Five samples were tested for methane permeability. Values ranged from $>10^{-2}$ darcys to 5.3×10^{-8} darcys. Visual inspection of the samples indicated that only the most impermeable sample is not fractured.

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Intervals of the well were drilled, oriented, cored, and pressure cored, and cuttings were collected from the drilling mud at five foot intervals. These cuttings, as per request, were later turned over to the Pennsylvania State Geological Survey, Oil and Gas Division, in Pittsburgh, Pennsylvania. Approximately 250 grams of oriented core were collected by Mound, at four to five foot spacings, for total organic carbon content analysis. Battelle Columbus Labs and Cliffs Minerals collected approximately 0.25 foot sections of oriented core, at ten foot spacings, for the determination of the gas content by the conventional EGSP method. Mound Facility collected approximately 0.4 foot sections of the oriented core, selected from high potential zones, also for the determination of the gas content, but using the controlled offgassing method.

Testing of PA-3

The well was spudded on September 6, 1979. By September 10, drilling had been completed to 304 feet, and 295 feet of casing had been set and cemented. The cementing shoe was drilled-out on September 13 and drilling continued to the first core point in the Devonian Shale sequence at 375 feet. The subsequent operations involving the oriented coring, pressure coring, and drilling between core points were completed by October 10, 1979.

In the 11 runs that were made with the oriented core barrel, 420 feet of core were cut, generally in 40 foot sections. The measured recovery was 422.40 feet. In general, the recovery of the oriented cores was considered excellent. Numerous natural fractures were observed in most of the oriented cores. Gas was observed bubbling from the oriented cores in several of the intervals.

The pressure core barrel was successful in capturing full formation pressure (167 psi) and in recovering a full ten feet of core. Following the completion of drilling and coring, wet-hole logs were run on October 10 and 11, 1979. The hole was blown dry on October 11 and dry-hole logs were run and completed by October 12, 1979.

Prior to dry-hole logging, the open flow of the well was measured with a pitot tube at 25 MCFD. Dry-hole logging showed that there were at least three zones in the well where significant gas jetting was occurring, indicating open flow production could be greatly enhanced by reaming the hole. All of the indicated gas producing zones were from 375 to 550 feet above the massive basal unit of the Dunkirk black shale. The hole was reamed from 6-1/2 to 7-7/8 inches at 375 to 650 feet (the base of the Dunkirk Formation). Reaming was completed on October 12, 1979, and a second set of dry-hole logs was run following the reaming. Open flow measurement on October 12 was 100 MCFD.

A production head was installed on the well late on October 12 and the well was shut-in. Following a 14 hour shut-in period, pressure in the well had built to 144 psig. The well was then blown-down, and again

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shut-in to allow the determination of a pressure build-up rate. The well was left shut-in from October 13 to November 14, 1979. The pressure reached 100 psig in a little less than one hour and reached 144 psig in slightly less than seven hours. After 12 days of testing, pressure had reached 164 psig. The final well reading, taken after being shut-in for 32 days, was 170 psig. A semi-log plot of the 32 day shut-in period is shown in Figure 3-6.

Following the test, the well was again blown-down, and the subsequent pressure build-up was monitored for two successive days on November 14 and 15, 1979. On both days, the pressure build-up was measured using a pressure transducer, (installed in place of the gauge on the wellhead), and a continuous chart recorder which ran for six hours. The results of these two tests are shown in Figure 3-7.

The initial pressure build-up was more rapid each time. This was probably due to the cleaning of the fractures each time the well was blown-down. In both cases the pressure reached 100 psig in 30 to 40 minutes and the 144 psig mark in less than two hours. It was surprising that the test on November 14 reached a somewhat higher pressure at the end of six hours than that obtained on November 15 (166 psig as compared to 159 psig). This may have been due to leakage which was subsequently noticed on the wellhead near the connection with the pressure transducer.

An open flow production test on November 15, after the six hour build-up, indicated a flow of 165 MCFD as measured with an inclined manometer, further indicating that the reservoir is opening-up each time the well is blown-down.

It is interesting that the pressure build-up after being shut-in for 21 days reached 170 psig. This was exactly the hydrostatic pressure at 375 feet, the top producing zone. This would seem to indicate that all of the producing zones from 375 to 550 feet are interconnected. Before the well is put on production, the open flow and pressure will again be measured.

Allegany County, New York (NY-1)

Biostratigraphic analysis was completed for 161 samples.

The age of samples in this well varies from Frasnian (with possible lower Framennian) at the top of the section to lower Frasnian in the base of the well. In the cored section of the well there are three biofacies. The Tasmanites-rich biofacies is present only in a single sample at the base of this section. The great majority of samples in this well are rich in terrestrial material and were probably deposited in near-shore, intertidal, or even terrestrial environments. Two lenses of a very poorly preserved, inertinite-rich environment may represent deposition in a supra tidal or other oxidizing environment. No normal marine strata are found in these samples.

Figure 3-6 Pressure Build-Up Curve for PA-3 Well from 10/13/79 through 11/14/79

Figure 3-7 Pressure Build-Up Curve for PA-3 Well on 11/14/79 and 11/15/79

Allegheny County, Pennsylvania (PA-2)

Dilatometry tests have been completed for samples from the PA-2 well. The expansions of samples PA-2-12 and PA-2-22 were tested at confining pressures of 14.7, 500, 100, and 1500 psi in contact with four fluids. At each pressure, samples from these cores were tested using H₂O, 2% KCl, kerosene and H₂CO₃ + 2% KCl. Compilation of these test results is in progress. Preliminary analysis indicates reduced sample expansion occurs with increased electrolytic concentrations, increased confining pressures, and decreased organic carbon content. Five samples were analyzed for permeability. Values ranged from $>10^{-2}$ darcys to 88×10^{-5} darcys. All samples were fractured.

Knox County, Ohio (OH-3)

The range of the permeabilities from 19 unfractured, and 24 fractured specimens were studied. Also, comparisons of the sample permeability versus organic carbon content and permeability versus bulk density were made. Unfractured samples ranged from $<10^{-12}$ darcys to 1.4×10^{-3} darcys. Three of the samples had fractures.

Johnson County, Kentucky (KY-4)

The major oxides were determined for 51 samples. Kerogen elemental (C, H, N, O, and ash) analysis was completed for 46 samples. The mean atomic H/C value was 1.10.

McKean County, Pennsylvania (PA-1)

The pyrolysis - GC testing of 35 samples was completed. The average total hydrocarbon yield was 0.22 wt.%; and volatile hydrocarbon yield was 1001 ppm. The average Peak I/Peak II value and maximum Peak II temperature was 0.83 and 463°C, respectively. Six samples were analyzed for permeability. Values ranged from 9.6×10^{-6} darcys to 1.5×10^{-3} darcys.

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:
Contract Date:
Anticipated Completion Date:

DE-AS21-76MC05206
July 1, 1976
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 Shales of New York.

SCOPE OF WORK

This 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 three-dimensional aspect of these shale bodies.

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- To identify and prepare final maps showing the geographic areas most promising for exploitation of the gas resource in these shales.

SUMMARY OF PROGRESS

The resource characterization of the Devonian Shales in central and western New York is nearing completion. Isopach maps of radioactive shale greater than 20 API units above the shale base line for six black shale units and shale greater than 10 API units above the base line in the Middlesex Shale have been completed. The stratigraphic and correlation framework of the shales has been defined with the completion of five interlocking stratigraphic cross sections. In conjunction with the subsurface geologic mapping, a surface lineament map of New York is being compiled.

The data from the geologic and lineament maps are being integrated to develop final prospect maps for Devonian black shale gas exploration in central and western New York.

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

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

Status: Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AS05-76MC05200
April 15, 1977
September 30, 1980

Principal Investigator:
Technical Project Officer:

R.A. Struble
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, cores, and by date.

SUMMARY OF PROGRESS

The set of six interlocking stratigraphic cross sections in Ohio has been completed. Isopach maps of the Cleveland, Chagrin-Huron, Upper Olentangy, and Lower Olentangy shale members have also been completed. A new base map has been prepared for the lithofacies maps of selected Devonian Shale stratigraphic units in Ohio.

Structural mapping continued during the reporting period. The regional structure map on the base of the Rhinestreet Shale Member was revised after new data were posted to the base map. The structure map on the

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top of the "Big Lime" was revised in ten counties and is now complete for 21 counties.

Landsat interpretation at 1:1,000,000 and 1:250,000 scale is complete. Mapping and interpretation of photolinears at a scale of 1:80,000 is complete. Lineaments have been transferred to 1:250,000 scale USGS topographic maps.

Statistical analysis of photolineaments was initiated during the reporting period. The number of linears in a ten thousand meter grid was determined, and work is proceeding to evaluate which polyconical surface and residual map provides the best fit where fracture density excludes the regional area. Experimental physical mapping and computer generated mapping have been completed over a small, orthogonal (8 rows by 6 columns) pilot area. Maps have been generated for the first through fifth order polyconical surfaces and related derivatives. Good correlation was established between second order derivation maps, and these maps correspond to areas of known high fracture density.

All analyses and data compilation for the mineralogy/petrology and geochemical tasks are completed. Interpretation of data and compilation of the final reports have been initiated.

Fifteen wells were monitored for gas shows during the reporting period, bringing the total number of wells to 66. Gas show profiles have been completed for all wells monitored to date.

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: Completed

Contract:
Contract Date:
Anticipated Completion Date:

DE-AS21-76MC05198
July 1, 1976
February 1, 1980

Principal Investigator:
Technical Project Officer:

R.G. Piotrowski
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 units in western and northwestern Pennsylvania.

SCOPE OF WORK

Specific tasks include the following:

- To provide detailed stratigraphic sections of the Perrysburg Formation, 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 Formation, 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 has completed 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

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sections, structure maps, isopach maps, and lithofacies maps. The second phase provides detailed maps and cross sections of the best potential gas producing units within the Devonian Shale: Perrysburg Formation, 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: on the base of the Java Formation, and on the base of the Perrysburg - Huron Formation. One lithofacies map, based on the total Perrysburg - Huron and Java interval, has been completed. A production and show map, showing wells which have had oil and/or gas production, or shows from the Upper Devonian Shales above the base of the Java Formation, has been completed.

With the completion of these two phases, approximately 55 maps and cross sections are available on the regional and detailed stratigraphic and structural framework for use in exploration for Devonian Shale gas in Pennsylvania. In addition, northwestern Pennsylvania has been determined to have the highest potential for shale gas production.

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

Tennessee Department of Conservation
Nashville, Tennessee

Status: Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AC05-76ET12126
July 1, 1976
December 31, 1979

Principal Investigator:
Technical Project Officer:

C. Ferguson
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 Member which contains 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

Wireline coring of eight stratigraphic exploration wells in the Chattanooga Shale has been completed. These data were used to document regional stratigraphy and structure in the Tennessee Valley and Ridge. Additionally, these data were used to locate the Chattanooga Member which contains high hydrocarbon values.

Two cross strike vibroseis seismic surveys have been conducted in order to determine the subsurface extent of the Chattanooga Shale in the study area. The results have been interpreted, and the final report is almost complete.

ENERGY RESOURCES OF THE DEVONIAN SHALE IN THE APPALACHIAN BASIN

University of Cincinnati
Cincinnati, Ohio

Status: Completed

Contract: DE-AC05-76ET12140
Contract Date: July 1, 1976
Anticipated Completion Date: December 31, 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 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 University of Cincinnati has completed all contract work and the final report has been submitted. The final report includes a study of the Pine Mountain Overthrust, Braillier Formation, the Geology of the Ohio Shale along Lake Erie, Basin Analysis, Appalachian Paleocurrents, Texture, Bedding, and Paleontology. This report is summarized below. Figure 3-8 shows some of the stratigraphic cross sections included in the report.

Pine Mountain Overthrust

The overthrust sheet has six subdivisions, and the total volume of the shale is 254 cubic miles. The blowout zone, a zone of structural

Figure 3-8 Changing Perceptions of the Devonian Stratigraphy of the Appalachian Basin

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failure, is located within the Olentangy and Marcellus Shales. Overthrusting was accompanied by rotation. The southwestern part of the sheet advanced about nine miles and the northeastern part only one mile.

Brallier Formation

The Brallier Formation of parts of West Virginia, Maryland, Pennsylvania, and Tennessee is broadly correlative to the Chagrin Shale of parts of western Pennsylvania and Ohio. Both units consist of a wedge of gray and greenish-gray shale, interbedded siltstones, and some sandstones; and represent deposition in a submarine shape by distal turbidites derived from the east. The distal parts of the submarine fans represent the most likely exploration targets.

Geology of the Ohio Shale along Lake Erie

Concentrations of gas shows appear in the Three Lick Bed in the eastern part of the area and in the lower two thirds of the Chagrin Shale. Gas shows appear related to shale types rather than to source rock evaluation, burial depth, and thermal maturity of organic matter. Gas shows are concentrated in units which contain greater than 20 percent mudshale, siltshale, and siltstone. Quartz laminae appear to act as permeable conduits and reservoirs.

Basin Analysis

- Time Span - Fifty million years.
- Geometry and Size - Large incompletely preserved wedge covering about 110,000 square miles (280,000 km²) north of Tennessee with greatest thickness of 12,000 feet (3658 m) along the southeastern side of the Basin in Pennsylvania.
- Lithic Fill - Lithology is varied and includes red pebbly sandstones and red shales; fluvial, deltaic, beach and shelf sandstones, plus slope and basin siltstones mostly of turbidite origin; widespread greenish-gray and black marine shales; and some shallow-water carbonates. Greenish-gray shale is more abundant than black shale and may have a greater gas potential than black shale.

The Basin has a systematic arrangement of facies. The progression of non-marine clastics is from east to west through beach, shelf, and slope to the deep basin with prominent clinoform deposition and westward overlap. The depositional strike is possibly near the present western limit; and thus, even thin shale units have much better north-south than east-west lithologic continuity. Black shales are thin and widespread and fan eastward where they pass into greenish-gray shales that form wedge-shaped masses which mostly accumulated on a westward dipping slope or at its base.

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- Composition - Sublithic to subfeldspathic arenites and wackes plus illitic and chloritic organic-rich shales and greenish-gray mudstones, whose various subtypes have yet to be fully defined and mapped over the entire Basin. Siltstone laminae within both types, as well as possible microfacies, appear to be significant as indicators of gas potential.
- Paleocurrent System - Interbedded siltstones and sandstones, and apparently almost all of the shale in the Basin were deposited by currents from the east, generally perpendicular to isopach lines. However, black shales, which dominate only in the western part of the Basin, imply deposition in a restricted basin.
- Paleogeography and Tectonic Setting - Large, delta complex, now beheaded by continental separation, overlaps craton margin and has a linear, deep marine basin striking north-south. The deepest water may have ranged from 500 to 2500 feet, but was negligible to the east and possibly only several hundred feet to the west. The delta-shelf-slope system prograded westward as a uniform clastic ramp and was supplied by a large river which drained a stable, continental land mass, lacking volcanic rocks.

Appalachian Paleocurrents

The Upper Devonian sediments of the Appalachian Basin have a very uniform paleocurrent system, one that indicates a source to the east. Studies of paleocurrent structures in oriented cores fully corroborate abundant outcrop data: wood fragments are exceptionally good indicators of paleocurrents in cores, are nearly always well oriented and easy to measure, and sole marks on very thin siltstones (millimeters thick) are also commonly present and very well oriented. Such thin siltstone laminae were deposited as far distal turbidites, and could be important as indicators of gas potential.

Chemical Characterization

- The source of the organic carbon in the bituminous shales was twofold judging by its isotopic composition--a terrestrial source to the east, and a pelagic source within the basin. As individual black shales are traced westward, the pelagic source becomes predominant. Because marine carbon is better as a source of oil than terrestrial carbon, highest values of oil recovery will occur in those shales with the most marine carbon along the western outcrop of the Basin. Variation of carbon isotopes within the basin dovetails nicely with evidence from paleocurrent mapping, and both indicate an eastern source.
- Thermal maturity is about the same for every stratigraphic unit in a well, but increases regionally toward the southeast. Illite crystallinity appears to be about the same everywhere across the Basin. The contractor considers this to reflect a

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detrital provenance that was never exceeded by temperatures of later burial.

- Sedimentation rate and oxygen content of bottom water seem to be important controls on the geochemistry of shales, probably because together they determine the amount of organic material. Sulfur isotopes are useful, at least on a relative scale, to estimate the sedimentation rate of ancient shales.

Composition, Fabric, Texture, Bedding, and Paleontology

- Thin section petrology and X-ray radiography appear to be the best for the petrographic study of Devonian Shales--and possibly even for shales in general. The abundance, thickness, and cementation of siltstone laminae within a shale as well as its fine-scale interlamination with organic matter appear to be most significant for gas potential from a depositional viewpoint. Thin section study determines these variables very well, especially when supplemented by radiography which can give a good overview of a large specimen of shale. Radiography is also attractive because it is rapid. The recognition and possible later filling of microfractures developed within the shale and its siltstone laminae deserve equal attention in future petrographic studies.
- Siltstone laminae within the Devonian Shales--their thickness, abundance, and cementation--appear to be a major factor for gas production, insofar as original sedimentation controls it. It is even possible that the abundance of later microfractures within the Devonian Shale may be related to such laminae (i.e., when fracture intensity was low, original lithology may have had a major control on its development).
- Most of the marine shales of the Basin belong to two major types--gray and greenish-gray, and bituminous black shale. The former, however, can be divided into as many as five different petrographic subtypes.
- Burrowed zones, even though they may be very thin (perhaps only a few centimeters), can be very widespread and probably are poor conduits of gas because they lack primary lamination. Burrowed beds develop in oxygenated water, and hence, when regionally mapped and integrated with facies and thickness, may be valuable paleogeographic indicators.
- The Foerstia zone, a zone defined by a fossil algae, appears to be a very useful basinwide time marker, one that is identifiable in both outcrops and cores and possibly even cuttings. This zone extends from Lake Erie, Pennsylvania, and New York on the

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north side of the Basin into Tennessee. Its greater thickness to the east reflects a higher rate of sedimentation, closer to the eastern shelf break of the Basin.

- Trace fossils indicate progressively deeper water in the western part of the Basin and thus imply a classic shelf-to-basin transition as Upper Devonian time progressed. Trace fossils are absent in the black bituminous shales, because water was too anoxic for bottom dwellers.

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: P.Y. Williams
Morgantown Energy
Technology Center

OBJECTIVE

To collect, compile, and analyze all available drillhole 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.

(Resource Data Acquisition and Analysis)

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

SUMMARY OF PROGRESS

Eight structure contour maps on various horizons in the black shale have been completed, and drafting of all isopach maps is almost completed.

A bibliography of black shale paleontology and paleoecology has been completed. Work has started on the report on paleoecological and paleoenvironmental models for black shale deposition in eastern Kentucky.

Geochemical data compilation for eastern Kentucky has been completed, and the final report is being prepared. Significant results from these reports will be summarized in the next Semi-Annual report.

CHARACTERIZATION AND EVALUATION OF THE DEVONIAN SHALES IN WEST VIRGINIA

West Virginia Geological and
Economic Survey
Morgantown, West Virginia

Status: Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AC05-76ET12130
July 1, 1976
July 31, 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

This contract includes the following major tasks:

- To collect, compile, and analyze all available drillhole 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, the work effort was concentrated on the detailed geochemical, petrographic, data analysis, and stratigraphic characterization of the Devonian Shales in outcrops and in the subsurface of West Virginia.

Geochemistry

The geochemical phase of the project officially ended on December 31, 1979. Within this time frame, work was completed on the NE-SW and NW-SE cross sections. These were constructed to determine whether or not any systematic variability can be observed, either stratigraphically or regionally, within the organic components of the shales. A study was completed on sulfide minerals in core samples from Lincoln County and on synthetic sulfides. The analysis of well and outcrop samples was completed. Trend surfaces were calculated and graphed for geochemical data from western and southern West Virginia well cuttings. Statistical, elemental, and x-ray diffraction analyses of well cuttings continue for counties east of the principal study area. The final report of these studies will be completed in June 1980.

Petrology

Thin sections and radiographs were completed and a petrographic study was initiated for the Mason County core. Twelve samples of fractured shale were prepared and sent to Columbia Gas for permeability tests. X-ray and LOI analyses were completed. Elemental analyses, mechanical-log analyses, bulk and matrix density measurements, and porosity determinations were completed. All drafting, PMT's, photographic work, X-ray diffraction analyses, and coding of geochemical data are complete for the Mason County core.

Data Analysis

Coding of stratigraphic data from Braxton, Doddridge, Gilmer, Boone, Cabell, Mason, Mingo, Nicholas, Raleigh, Roane, Tyler, Wetzel, Wirt, Wayne, Jackson, Lewis, Lincoln, Marshall, Pleasants, and Putnam Counties have been completed. This information is being compiled to extend the EGSP data base. Strip logs for physical and geochemical parameters in the Mason County core were initiated and will be completed upon receipt of XRD analyses. Calculations of trend surfaces from data on the thickness and top of the Onondaga limestone, and top of the Oriskany Sandstone in Jackson County were initiated. Stratigraphic data for wells with geochemical data were received; a program is being written to cross-reference and reformat the stratigraphic and well sample data. Processing is underway on data from a restricted portion of the Devonian Shale in the western part of the State in order to define the geographic limits of Marcellus rocks. Compilation of 1979 shale drilling statistics is complete. In general, drilling activity has not been increased from previous years.

Stratigraphy

Statewide cross sections were revised and submitted for drafting. Data compilation has been initiated for the final state-wide stratigraphy report. Work continued on the eastern tight sands that are equivalent to the Huron Shale. Tight sands are the sandstone units between the Berea sandstone and the Onondaga limestone that FERC does not include as a part of the "Devonian Shale". Data were also compiled on the thickness of "hot zones". Data were also compiled on Devonian nomenclature for the COSUNA project. Upon a request by USGS, two new isopach maps were constructed.

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:
Contract Date:
Anticipated Completion Date:

DE-AC21-76MC05194
July 1, 1976
September 30, 1980

Principal Investigator:
Technical Project Officer:

R.C. Shumaker
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 their 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

Structural maps were completed on top of the Berea sandstone and the Onesquethaw group along the east flank of the Warfield anticline. These maps are in the area of the surface joint boundary noted by a previous investigator. The domain boundary area is considered to be a likely region for increased shale gas production in southern West Virginia.

Based on a study of fractures in oriented Devonian Shale cores from the Appalachian Basin, subsurface fractures in the Appalachian Plateau province can be related to Alleghenian deformation, local faulting, and crustal spreading along the Mid-Atlantic Ridge. The stresses generated from spreading along the Mid-Atlantic Ridge have created a regional system of northeast striking natural fractures. Décollement zones in the shales are characterized by intense deformation in the form of numerous natural fractures and slickensides. A porous fracture facies (increased frequency of natural fractures) was found in several shale units. The fracture facies is critical in enhancing gas production from the shales.

The Eastern Kentucky Gas Field, a coalescence of many fields, is concluded to represent a highly complex structural-stratigraphic gas trap. Fracture facies which formed as a result of gravity tectonics and décollement features may be enhanced by the occurrence of complex intertonguing of organic black shale with silty gray shale in the center of the area of high gas production. Inorganic elemental geochemistry shows promise as an exploration tool. The contoured data in the field on the oxides of Si, Al, Mg, K, Fe, Ca; the ratio of Si/Al; and S result in maps which show configurations similar to the density of high gas producing wells.

A set of 15 maps showing the criteria for the selection of test wells to be drilled in the future has been completed. A final map, at a scale of 1:250,000, indicates the priorities of drilling and the justification for these priorities. This analysis represents a major contribution to the Eastern Gas Shale Project as it provides a rationale and strategy for siting future exploratory wells.

Based on a study of the Parsons Lineament in eastern West Virginia, more intensely fractured and thickened organic-rich shales will be found on the northwest limbs of the Plateau folds and particularly within cross-strike structural discontinuities.

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

United States Geological Survey
Reston, Virginia

Status: Active

Contract: DE-AI01-76ET10136
Contract Date: January 1, 1976
Anticipated Completion Date: September 30, 1980

Principal Investigator: W. de Witt, Jr.
Technical Project Officer: C.S. Dean
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 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

Compilation of reviewed radioactive shale zones and structure maps on basal beds of several regionally extensive black shales is continuing. A study of the stratigraphy of the Devonian Chattanooga and Ohio Shales and equivalents in the Appalachian Basin has been completed.

A relationship between Muncell color values and percent organic carbon was found in a study of several hundred pilled samples. The results produced a power curve with a coefficient of determination (r^2) of 0.91.

Analysis of density and gamma-ray logs for extrapolation of organic content of shales across the western part of the Basin has been completed. Results of this study are being used in the Pilot Resource Appraisal.

A trial run of the proposed Basin appraisal formula was made, using the "most probable" data. A value for gas-in-place similar to that of the adjacent Big Sandy area was obtained.

3.2.3 ILLINOIS BASIN

The Illinois Basin encompasses portions of the States of Illinois, Indiana, Kentucky, Wisconsin, Iowa, and Missouri. The EGSP study area in the Illinois Basin includes over 24,000 square miles of Devonian Shale formations in Illinois, Indiana, and Kentucky (see Figure 3-1).

The Devonian Shales outcrop in the northern and eastern portions of the Basin, and reach a thickness of over 450 feet in southeastern Illinois.

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:

June 30, 1980

Principal Investigators:

N. Shimp

R. Bergstrom

Technical Project Officer:

P.Y. Williams

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 the 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.

(Resource Data Acquisition and 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 offgases 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 offgases from approximately ten foot core intervals; 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

GEOLOGIC EVALUATION

All geologic research projects associated with the geologic evaluation of the New Albany Shale Group in Illinois have been completed. A report reviewing the stratigraphy, presenting a new depositional model, and reviewing the major petrographic results of the New Albany is ready for technical editing and drafting. It should be published as an Illinois State Geological Survey (ISGS) Circular in late summer of 1980. All data and reviews of results are expected to be complete by the end of June 1980.

SEM-EDS (scanning electron microscope equipped with an energy dispersive spectrometer) analyses have been completed for the four organic matter concentrates prepared to determine if changes in the forms of organic matter that might be related to chemical changes imposed during maturation could be detected. From limited examinations, it appears that there are some observable differences in the forms of organic matter that may be related to changes imposed during maturation. However, at this point it is difficult to determine how much, if at all, sample preparation affected the observed differences in forms of organic matter. Further work on a similar set of samples is needed to determine to what extent sample preparation affects such observations and to better define the differences observed.

Radiography for the Wayne County, Illinois (12IL, 13IL) cores was completed during the quarter extending from January through March 1980. Analysis of the whole rock and clay mineralogy data for the final report is in progress. Vitrinite reflectance analysis for the Wayne

(Resource Data Acquisition and Analysis)
County, Illinois cores (12IL, 13IL) and 35 deep well samples is completed. Evaluations of vitrinite reflectance, liptinite fluorescence, and organic matter data are being conducted. Testing of the Wayne County core is now almost completed. A log is also being kept of all the samples which have been removed.

ELEMENTAL ANALYSIS

Checking of the analytical results for major, minor, and trace elements and computerization of the final data on the 390 shales samples which will be subjected to statistical analysis are continuing.

The data generated will be used to evaluate: 1) the potential economic importance of trace element concentrations in organic-rich shales, 2) new geochemical exploration techniques for natural gas, 3) trace element enrichment in shale organic matter, 4) the occurrence of heavy metal sulfides in shales, 5) potential catalytic effects of trace elements on shale pyrolysis yields, and 6) potential disposal problems.

Methods of separating organic and inorganic phases of shales that were tested include: float-sink gravity separations, mechanical separations (Humphrey Spiral), acid extractions, and zonal centrifugation.

All kerogens have been isolated by the acid leaching method and submitted for analysis (INAA). Data received are still insufficient to assess correlations of trace element associations with shale organic and inorganic fractions.

The chemical and isotopic fractionation analysis of samples is nearly complete and results are being calculated and tabulated for inclusion in the final report.

ADSORPTION/DESORPTION STUDIES OF GASES THROUGH SHALES

Internal surface area values have been completed for samples in which gas was found. They were from the Wayne County, Illinois core (core 13IL) taken in the deep part of the Illinois Basin. The ISA values showed that the shale is compact with a large proportion of the inherent porosity associated with pores having diameters less than five angstrom units. Thus, the release of contained gas is a slow process.

The highly compact structure, with low porosity, is also reflected in the high pressure methane sorption isotherms. The total methane sorbed at 90 atmospheres is only about 3 cc/g as compared with 4.5 to 5.5 cc/g for the selected samples from the Effingham County, Illinois core (core 02IL), or about 8.5 cc/g for the selected samples from the Tazewell County, Illinois core (core 06IL).

MODE OF OCCURRENCE AND RELATIVE DISTRIBUTION OF HYDROCARBON PHASES IN SHALE

Released Gas Analysis

The analysis of the released gas from all samples for this project has been completed. Final compilation and interpretation of the data obtained are underway.

Low and Medium Volatile Hydrocarbon Analysis Pyrolysis

Eight Devonian Black Shale samples were studied by a Pyrolysis-Gas Chromatography technique. Three of the samples were from the Christian County, Kentucky well; two were from the Tazewell County, Illinois well; and one each from Henderson County, Illinois; Wayne County, Illinois; and the Ohio Standard Devonian Shale sample. The procedure used for pyrolysis was described in the contractor's monthly progress report for January 1980.

Pyrolysis of the shale at lower temperatures (250°C and 350°C) showed that both highly volatile ($<C_8$) and medium volatile (C_9-C_{12}) hydrocarbons were predominant over the less volatile ($>C_{12}$) hydrocarbons. Pyrolysis at the higher (550°C and 750°C) temperatures produced highly volatile hydrocarbons almost exclusively.

The volatility of the hydrocarbons was related to the amount of organic matter in the shale. Of ten shale samples pyrolyzed at 250°C and 350°C; the highly volatile ($<C_8$) fraction was predominant in four shales with a high organic content; the medium volatile (C_9-C_{12}) fraction was predominant in four shales with carbon contents less than 10 percent; and no hydrocarbons were produced in two shales having less than 1 percent organic carbon.

A sample of the residue from the benzene-methanol extraction of shale was pyrolyzed at 250°C. Analysis by GC showed that only residual benzene and methanol were evolved.

These studies indicate that low temperature pyrolysis is useful for fingerprinting the organic matter evolved from organic-rich shales by pyrolysis, and for estimating the organic carbon content of the shale. The origin of this organic matter is believed to arise from weakly bonded molecules and/or molecules easily extracted by solvent.

Solvent Extraction

Selected Devonian Black Shale samples were ground to minus 100 mesh and Soxhlet extracted. The solvent used for extraction was either pure benzene or in some cases a mixture (70:30/V:V) of benzene; methanol. The extraction time was 40 to 48 hours. After extraction the bulk of the solvent was removed by distillation and by use of a rotary evaporator. The final traces of solvent were removed under a stream of nitrogen gas and with gentle heating.

(Resource Data Acquisition and Analysis)

The amount of bitumen extracted was less than 1 percent of the total shale. The bitumen was separated by silica gel and/or alumina column chromatography into three fractions. Two column volumes of each solvent (n-hexane, benzene, and benzene: methanol) were used to elute, respectively, the aliphatic, aromatic, and asphaltene fractions. The benzene: methanol system (extractability ~6%) appears to be more efficient than the benzene-only system (extractability ~4%).

The ratio of the amount of the aliphatic plus aromatic fractions to the amount of the asphaltene fraction in the benzene-only extraction is greater than the like ratio for the fractions in the benzene: methanol extraction. The asphaltene fraction contains nitrogen and sulfur bearing compounds. The polar methanol solvent showed an effect on the N/C and S/C ratio.

Elemental analyses of some Devonian Shale bitumens were carried out. The H/C atom ratio is a good indicator of the extent of saturated carbon and aromatic carbon contents of the given fraction. The average H/C ratio (1.80) for the aliphatic fraction indicates the presence of some unsaturation. The average H/C ratio (1.29) for the aromatic fraction indicates the possibility of aliphatic side-chains. The asphaltene fraction (average H/C ratio: 1.20) is the most aromatic fraction. The latter observation was confirmed by the IR spectrum of the asphaltene fraction.

Infrared spectroscopy aids in evaluating differences in organic composition in terms of functional groups. Spectra taken during and after the application of various analytical procedures were used to ascertain what components in the sample may have been altered by the analytical procedures and to what extent this alteration has taken place.

The aliphatic fraction from the above separations was further separated by molecular sieve into n-paraffins and branched-chain paraffins.

The predominance of molecules containing an odd number of carbon atoms over the molecules containing an even number of carbon atoms may be expressed numerically as the Carbon Preference Index (CPI).

The distribution of n-paraffins is expressed numerically by CPI as described by Bray and Evans. The values for 19 samples from a cluster which has a value very near 1.0 indicates that Devonian-Mississippian shale n-paraffins and crude oil n-paraffins have a nearly equal distribution of molecules containing even and odd numbers of carbon atoms.

Comparative pyrolysis studies were conducted on the asphaltene fractions described above and on kerogen concentrates from shale. The kerogen concentrate is a mineral free organic material separated from the mineral matter of shale by acid leaching.

(Resource Data Acquisition and Analysis)

The average molecular weight of the asphaltene fractions was determined by osmometry. The average molecular weight of the asphaltenes ranged from 400 to 1400.

Approximately one milligram sample of either the asphaltene or the kerogen was used for each analysis. The pyrolysis was carried out as described previously except that each individual sample was pyrolyzed stepwise at 250°, 350°C, 450°C, 550°C, 650°C, and 750°C.

The low temperature steps evolved organic compounds from both the asphaltene and kerogen concentrates that were normally obtained from low temperature pyrolysis of the whole shale. Successively higher temperature steps degraded the large molecular weight, non-volatile organic matter into smaller fragments. Pyrolysis of a kerogen concentrate (from 01KY07C1) and of an asphaltene fraction (from 02IL04C1) show the critical fragmentation temperature to be 550°C or higher.

All data are being sorted and compiled for the final report.

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

Illinois State Geological Survey
Urbana, Illinois

Status: Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AS21-78MC08214
December 1, 1977
June 30, 1980

Principal Investigator:
Technical Project Officer:

J.A. Lineback
P.Y. Williams
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.

(Resource Data Acquisition and Analysis)

- To ensure 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

Work on the following tasks was completed during this reporting period:

Planning

Final plans have been made for the completion of the study of the Devonian Black Shale (New Albany Shale Group) in Illinois by June 30, 1980. Chapters have been outlined and preliminary sections have been written. General conclusions reached in Indiana and Kentucky will be integrated with those from Illinois, resulting in a coordinated basin report covering major results of the study and with particular notice given to possible resource potential.

ILLIMAP Extensions

The extension of the ILLIMAP computer mapping system to the Illinois Basin parts of Indiana has been completed. Digitization of maps necessary to extend the mapping system into Kentucky is well underway. The Carter Coordinate System (a longitude and latitude system) is used for Kentucky due to the absence of a township and range survey grid.

Resource Potential and Publication

A major publication on the stratigraphic and petrographic results of the New Albany study is now being reviewed for Illinois Survey publication.

A contribution has been prepared for the SPE-sponsored Symposium on Unconventional Gas Recovery. This report summarizes the gas release data derived from DOE sponsored coring in Illinois. Offgas studies indicate that a 19 county area in southeastern Illinois is the only area where gas resources are possible in the New Albany Shale. The gas content is highest in black shales within the Grassy Creek Shale, and in the middle black shale unit of the Selmier Shale.

(Resource Data Acquisition and Analysis)

The report emphasizes that drilling and completion techniques commonly used by independent operators that dominate Illinois Basin petroleum activity often result in formation damage that prevents adequate assessment of gas potential in the New Albany Shale.

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

Indiana Geological Survey
Department of Natural Resources
Bloomington, Indiana

Status: Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AC21-76MC05204
September 21, 1976
March 31, 1980

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 drillhole 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

During this reporting period most of the remaining work was completed. However nine maps have not yet been submitted. Seven of the nine are in various stages of final editing and drafting.

The projected date for final report submittal is approximately the end of May 1980. This report will include the following information on the New Albany Shale:

- structure;
- geochemical (and gas) analyses;
- mineralogic and petrographic characteristics; and
- analyses of physical properties.

This information will be summarized in the next Semi-Annual report.

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

University of Kentucky Research
Foundation
Henderson, Kentucky

Status: Completed

Contract:	DE-AS21-78MC08215
Contract Date:	December 1, 1977
Anticipated Completion Date:	November 30, 1979

Principal Investigator:	H.R. Schwalb
Technical Project Officer:	P.Y. Williams
	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.

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

Detailed discussions, cross sections, isopach maps, and conclusions are available in the Final Report which has been submitted. A brief summary of the conclusions follows:

Devonian Black Shale on the western side of the Cincinnati Arch thins from approximately 90 feet in the Bullitt County core to 34 feet in the Russell County core. Underlying units range from the Devonian (Jeffersonville Formation) in the Norm #1 core to Ordovician (Drakes Formation) in the Norm #3 core.

The cores, all of which were cut near partial outcrop sections, display variation in degrees of "black shale." Degrees of black N-1, brownish-black 5YR2/1, grayish-black N-2, and olive-black 5Y2/1 were observed.

Common features of the shale include various forms of pyrite; laminations of siltstone, calcareous siltstone, and fine sandstone; and phosphatic nodules. Outstanding features of the New Albany Black Shale are lamination and beds of lighter shale generally greenish-gray (5YG6/1 to 5G6/1) to light and medium-gray (N-6 to N-7). These zones are thin but remarkably persistent and are known as the Three Lick Bed on the east side of the Cincinnati Arch. This zone was traced for 30 miles.

From a study of oil-well sample sets, it can be said that the shale is very dark at the top, and the center of this shale gets lighter and contains zones of medium-gray to greenish-gray shale (N-5 to N-6 and 5GY6/1 to 5G6/1). The bottom part of the shale becomes very dark again (N-1 to 5YR2/1). It is believed that this method could be used to further study the New Albany Black Shale because of the enormous amount of information available as samples, as well as radioactive logs.

Using the wireline geophysical logging equipment of the Kentucky Geological Survey, experiments were made using various instrumentation. The natural gamma-ray log proved to be very useful for determining the zones of high radioactivity which in turn can be used as a correlation technique.

Profiles developed for the cores using the hand-held scintillometer compare very favorably with the wireline logs. Because the radioactivity profiles generated for natural outcrops near the core locations compare so favorably with the core radioactivity profiles, this instrument can be used as a rapid and effective correlation tool.

Uranium/thorium analyses on the Norm core #1 indicate a range in uranium from 5 to 63 parts per million. In general, these values correlate with the natural gamma-ray wireline and scintillometer profiles.

(Resource Data Acquisition and Analysis)

Although correlation between the Illinois and Appalachian Basins is not feasible with existing data, the organic-rich zones in the upper and lowermost portions of the black shale which contain the highest contents of oil, gas, and uranium can be traced throughout the study area.

3 . 2 . 4 M I C H I G A N B A S I N

The Michigan Basin is a subcircular feature which lies northwest of the Appalachian Basin and north of the Illinois Basin. The Basin encompasses all of the State of Michigan and portions of Indiana, Ohio, Wisconsin, and the Province of Ontario. The EGSP study area in the Michigan Basin includes over 32,000 square miles of Devonian Shale formations in Michigan and Indiana (see Figure 3-1).

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 the development of suitable exploration rationales applicable to the geologic characteristics of the area. An oriented Devonian Shale core was taken from a well in Otsego County, Michigan (north portion of the Basin) during this 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 I N T R O D U C T I O N

The goal of this Element is 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 two main areas of work involve stimulation modeling and reservoir modeling. Models are being developed to predict the effects of both explosive and hydraulic stimulation treatments. These models are being validated with laboratory studies, in situ tests, and mineback experiments. They will then be used to identify new treatments and to optimize existing treatments. Specific theoretical and experimental efforts are being made to study and evaluate the effects of hydraulic fracturing and its mechanics, proppant displacement, and tailored-pulse-loading. Attempts are being made to predict permeabilities for fracture control in explosive stimulation. In addition, instrumentation is being conceptualized in order to develop a tool to increase in situ stresses.

A reservoir model for Devonian Shale gas has been developed, and it is being used in the site selection and test design of an Offset Well Test Program. The development and verification of a two dimensional model will be undertaken during the next reporting period. After being validated, the reservoir model will be combined with stimulation models in order to develop cost-effective recovery methods, and in order to predict the economically recoverable gas.

Other current efforts in this Element are aimed at field testing a new type of explosive, and at investigating the economic attractiveness of dual completion methods.

3 . 3 . 2 F R A C T U R E M E C H A N I C S

Ten contracts, including two national laboratories, are currently active in this Work Package of the EGSP. A summary of these activities is presented in the following pages.

3 . 3 . 3 P R O D U C T I O N E N H A N C E M E N T

The summary of two contracts in this Work Package of the EGSP is presented in the following pages.

3 . 3 . 4 R E S E R V O I R P E R F O R M A N C E

A summary of efforts in this Work Package of the EGSP is presented in the following pages.

3 . 3 . 5 T E C H N I C A L S U P P O R T

There is one technical and management support contractor specifically for the EGSP (Science Applications, Inc.). A summary of this work is presented in the following pages.

GAS STIMULATION PROJECT

Lawrence Livermore Laboratory
Livermore, California

Status: Active

Beginning Date:

February 1, 1976

Anticipated Completion Date:

Ongoing

Principal Investigator:

M.E. Hanson

Technical Project Officer:

C.A. Komar

Morgantown Energy
Technology Center

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 analyses.
- Conventional log evaluation.
- Dry-hole sonic log development and application.
- Environmental reports.

SUMMARY OF PROGRESS

Theoretical Analysis

As reported earlier, numerical models have shown that slippage on an interface will tend to draw the fracture towards but not beyond that

(Fracture Mechanics)
interface. During this period, it was found that increasing frictional stress delays slip until the fracture is closer to the interface. It was also found that the alteration of the components of strain caused by the crack will affect the frictional stress. Material directly ahead of the crack tip is drawn to the tip; hence, as the fracture tip nears the interface it tends to reduce the normal stress across the interface, and thereby decreases the frictional stress.

In the numerical analyses of a crack propagating in the neighborhood of an interface, the dynamic effects resulting from a variation in the crack propagation velocity have been studied. The elastic constants on either side of the interface have been varied to determine interface penetration characteristics. In addition to these analyses, the effects of varying density across the interface will be studied.

During this reporting period, work was begun to formulate the equations needed to describe the interaction between crack growth and the fluid motion inside a hydraulically driven fracture. A numerical technique was developed to solve the equations for the crack shape with an arbitrary pressure distribution in the crack. Crack shapes were generated for three different pressure distributions.

Laboratory Experiments

In the laboratory, hydraulic fracture experiments were performed to study crack growth across unbonded interfaces. Tests have been run on three types of interfaces: dry, lubricated, and lubricated strip on an otherwise dry interface. The results are preliminary at this time and further experiments are needed to quantify the results.

HYDRAULIC FRACTURE AND ASSOCIATED STRESS MODELING FOR THE EGSP

Ohio State University
Columbus, Ohio

Status: Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AC21-79MC10514
January 1, 1979
August 1980

Principal Investigator:
Technical Project Officer:

S. Advani
J.C. Mercer
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

A finite element model for vertical hydraulic fracturing of Devonian Shales is being developed. This model includes the effects of in situ stress and multi-layering. Frac fluid flow and structural responses have been characterized. The model provides a predictive capability for width, height, and length estimates.

A rationale for foam and dendritic fracturing experiments has been developed. Numerical computations for sample cases have been conducted. The effects of crack branching and joint interaction are being studied.

Field data from several hydraulic fracturing experiments are being analyzed. In situ stress and fracture geometry predictions for several experiments have been performed.

IN SITU TESTING OF WELL SHOOTING CONCEPTS

Sandia Laboratories
Albuquerque, New Mexico

Status: Active

Beginning Date: April 1, 1979

Anticipated Completion Date: June 30, 1980

Principal Investigator: R.A. Schmidt
Technical Project Officer: C.A. Komar
Morgantown Energy
Technology Center

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 primarily involves 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.

SUMMARY OF PROGRESS

A series of five full-scale tests was performed in 6 inch by 40 foot long cased boreholes using five different tailored-pulse concepts. The boreholes were horizontal, had 10 or 20 feet of open hole (depending on the specific test), and were drilled in ash-fall tuff from a tunnel under 1400 feet of overburden. This site provides both realistic in situ conditions for the tests and access to the stimulated regions by mineback which permits direct observation of results. The five tailored-pulse concepts tested involve:

- Case A - a decoupled explosive,
- Case B - a decoupled explosive with propellant booster,
- Case C - a small-diameter propellant charge with pressurized water pad,
- Case D - three successive shots of Case C, and
- Case E - a full-diameter charge of a progressively-burning propellant.

While direct observation by mineback is highly beneficial, evaluation and analysis of these test results also depend heavily on other diagnostics. Thirty-six stressmeters and accelerometers were fielded in the surrounding rock to record the dynamic disturbances, and each borehole contained transducers to measure the actual cavity pressures. Pre-test and post-test evaluations include TV log, caliper log, and permeability measurements. Permeability, which evaluates the effectiveness of the created fracture network to transmit fluids, was determined by analysis of constant-pressure, water-injection tests and the subsequent pressure decline after shut-in.

Mineback of these experiments will be completed in April 1980. Results displayed in Table 3-2 show a large increase in formation permeability for Case E, modest increases for Cases B, C, and D, and a decrease for Case A that appears to be due to the formation of a stress cage.

The results of these tests and previous experiments suggest that a multiple fracture criterion based on borehole pressure-loading rate will be less than that which produces tangential compression at the borehole wall. This provides valuable information for site-specific design of tailored-pulse stimulations. Peak pressure conditions may be of little importance if loading rate requirements are adequate.

Table 3-2 Permeability Enhancement with Five Tailored-Pulse Concepts

CASE	TAILORED-PULSE CONCEPT	PRE-TEST PERMEABILITY (md)	POST-TEST PERMEABILITY (md)	FACTOR OF INCREASE	OBSERVATIONS FROM TV LOGS
A	Decoupled explosive with water pad	0.20	0.05	0.25	Enlarged, dis- torted borehole
B	Decoupled explosive* with propellant pusher (water pad)	0.83	5.6	7	No fractures apparent
C	Small diameter propellant with pressurized water pad	0.0015	0.008**	5**	Multiple fractures (very narrow)
D	Three shots of case C with pressurized water pad	0.007	0.034	5	Multiple fractures (narrow)
E	Full bore, progressively- burning propellant with air pad	0.014	25.0	1800	Multiple fractures (wide)
*Explosive did not detonate					
**Some permeability increase may be due to fracture caused by Experiment E					

SMALL SCALE FIELD TEST OF EXPLOSIVE EXPERIMENTS

Stanford Research Institute, 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: J.C. Mercer
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 laboratory measurements to determine the material properties and inherent flaw characteristics required for the calculational simulations of the experiments.
- Conduct laboratory springing experiments to determine: (1) the important phenomenology in explosive/propellant borehole loading of selected geologic materials; and (2) the NAG-FRAG fracture parameters of these materials.
- Conduct a theoretical and calculational effort for the prediction of tensile and shear fracturing and permeability enhancement in the laboratory and field* experiments, including a series of pulse shaping calculations to determine the range in pulse shapes that most enhances permeability for comparison with the field experiments.

*The Small Scale Field Experiments were conducted by Sandia Laboratories at the Nevada Test Site (NTS).

SUMMARY OF PROGRESS

All the laboratory measurements have been completed (with the sole exception of the permeability measurements required in the second year's effort), and the material properties and inherent flaw characteristics of the NTS tuff required for the calculational simulations have been determined.

The laboratory springing experiments in tuff have been completed, and the stress and particle velocity records from the experiments analyzed.

A series of preshot stress and acceleration calculations have been completed to support Sandia's fielding effort at NTS.

A theoretical model for gas penetration effects has been completed and incorporated into NAG-FRAG. A model for shear cracking effects has been incorporated into NAG-FRAG.

A series of preliminary, parameter-sensitivity calculations to guide the laboratory springing experiments has been completed, as has a series of preliminary, calculational simulations of the laboratory springing experiments.

PROPPANT FRACTURE MECHANICS INTERACTION STUDY OF THE FLOW TREATMENT
PROCESS

Stanford Research Institute, International
Menlo Park, California

Status: Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AC21-79MC11597
September 28, 1979
September 1981

Principal Investigator:
Technical Project Officer:

S.L. McHugh
J.C. Mercer
Morgantown Energy
Technology Center

OBJECTIVE

To obtain quantitative experimental data required for the validation of
computational models of wellbore stimulation 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: in which proppant motion is dominated by fluid viscous behavior; and in which proppant transport is dominated by simulated gravitational settling.

SUMMARY OF PROGRESS

Thirteen laboratory experiments have been conducted using blocks of polymethylmethacrylate (PMMA) and pumping dyed water as a hydrofracturing fluid. Vertical fractures were produced and contained in a central layer of bonded sections of PMMA.

Proppants were introduced in some of the experiments. The proppants were observed to settle in the bottom of the vertical fracture.

(Fracture Mechanics)

Borehole pressures and fracture volumes have been measured. High speed movies have been taken to provide quantitative data about proppant transport and fluid penetration into the fracture.

DESIGN OF A WIRELINE TOOL FOR IN SITU STRESS MEASUREMENTS

Terra Tek, Inc.
Salt Lake City, Utah

Status: Active.

Contract:
Contract Date:
Anticipated Completion Date:

DE-AC21-79MC11047
February 15, 1979
August 1980

Principal Investigator:
Technical Project Officer:

A. Jones
J.C. Mercer
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 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.

(Fracture Mechanics)

Only the efforts related to component availability and tool design are funded under the inplace contract.

SUMMARY OF PROGRESS

Progress to date includes the preparation and review, by a panel of independent consultants, of a conceptual design report describing four tool designs capable of determining in situ stresses which operate on a wireline. The conceptual design report also investigates various fracture detection tools that would operate with the stress determination tool. The report has been evaluated, and a single tool design has been selected for more complete investigation and for the generation of design drawings.

FRACTURE MECHANICS TESTS ON SELECTED SHALE CORES

Terra Tek, Inc.
Salt Lake City, Utah

Status: Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AC21-80MC12093
December 1, 1979
February 1981

Principal Investigator:
Technical Project Officer:

A. Jones
J.C. Mercer
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

Under Phase I of this contract, physical properties (porosity, density) and dynamic and static elastic properties will be determined for four zones in the EGSP Well #OH-3. The four zones are: the containment zone above the pay zone, two layers of pay zone (organic rich interval and organic lean interval), and the containment zone below the pay zone. The effect of different fracturing fluids on the matrix permeability and simulated fracture flow capacity of the two pay zones will be evaluated.

Under Phase II, two pay zones (organic rich interval and organic lean interval) will be examined out of each of five wells for a total of thirty zones (two barriers per pay zone). Properties to be measured on all the zones are: physical (density, porosity), fracture toughness, and absolute permeability. The effect of different fracturing fluids on the matrix permeability and simulated fracture flow capacity of the two pay zones will be evaluated.

SUMMARY OF PROGRESS

The physical, dynamic, and static elastic property tests on all the required zones under Phase I have been completed. Initial data evaluation indicates uniform porosity and modulus distribution over the

(Fracture Mechanincs)

entire interval. Fracturing fluid/rock interaction and fracture flow capacity tests are in progress. Phase II will be initiated in June 1980.

The necessary loading frame for performing laboratory tests of hydraulic fracturing through perforated casing is nearly completed. When finished, it will enable the use of cubic samples having dimensions of one meter on a side to be used in a study of size effects and fracture propagation over realistic distances.

FRACTURE CONTROL FOR UTILIZATION IN GAS SHALE STIMULATION

University of Maryland
College Park, Maryland

Status: Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AC21-79MC12010
September 23, 1979
March 1981

Principal Investigator:
Technical Project Officer:

W. Fournery
J.C. Mercer
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

Laboratory tests will be conducted using dynamic photoelasticity, high speed photography, and dynamic holography. Models made of Homalite 100 and plexiglass (birefringent polymers) as well as certain types of rock (limestone and granite) will be used. These tests will be followed by large scale bench- and block-tests in a nearby quarry site to verify results obtained from the laboratory model tests.

The testing is intended to answer the following questions:

- What is the pressure pulse shape for maximum fracture extension?
- How much crack pressurization occurs due to detonation or deflagration of a chemical charge?
- What are the effects of compressibility and density of the medium filling the borehole on crack initiation and propagation?
- What are the effects of in situ stress states on crack propagation direction and distance?
- What is the most desirable number of cracks to initiate and

SUMMARY OF PROGRESS

Many tests were conducted during this reporting period. Models used were either 12 x 6 inches or 12 x 12 inches, and were 4 inches thick. Boreholes were 1/2 inch in diameter, and the charges used ranged from 50 mg of PETN in fluid-filled boreholes to about 1 1/2 grams of propellant in air-filled boreholes. The conclusions reached from the tests can be summarized by the following statements:

- Cracks initiated by explosive detonation in a fluid-filled, notched borehole propagated nearly an order of magnitude further than those initiated under the same conditions in unnotched boreholes.
- A fluid in the borehole tends to spread out the pressure pulse due to explosive detonation, and results in about the same propagation distance for 1/5 the amount of charge as required in an air-filled borehole.
- The use of deflagrating charges in fluid-filled boreholes results in very smooth fracture surfaces. This indicates very little stress wave reflection from nearby free surfaces.
- For the same pressure measured in a fluid-filled borehole, the propagation distance from a deflagration is about twice as far as for a detonation.
- The products from a deflagration in a fluid-filled borehole flow more smoothly into the fracture than from a detonation. The deflagration of the charge was still continuing as the propellant was forced into the opening fractures.
- Numerical and analytical approximations coupled with experimental measurements indicate that a propagating crack is pressurized over about 60 percent of its length.
- The dominant crack growth from highly decoupled explosive charges in air-filled boreholes seems to initiate from the stem area. Pressure recordings indicate an increase in pressure magnitude and pulse duration at this region due to constructive interaction of the shock wave traveling up the borehole with the stem.
- The use of deflagration charges in air-filled boreholes indicates more efficient propagation than for explosive charges.
- The distance a crack can be propagated into an adverse pressure field before turning is a function of the ratio of the borehole pressure to the in situ pressure. At a ratio of 30 to 1, a crack has been observed to propagate 12 borehole radii before turning.

(Fracture Mechanics)

The program will continue over the next 12 months. Preliminary findings certainly indicate that tailored-pulse-loading results in much more efficient propagation than explosive loading.

IN SITU STRESS DETERMINATION BASED ON FRACTURE RESPONSES ASSOCIATED
WITH CORING OPERATIONS

West Virginia University
Morgantown, West Virginia

Status: Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AT21-78MC11284
October 1, 1979
April 1, 1981

Principal Investigator:
Technical Project Officer:

H.V.S. GangaRao
J.C. Mercer
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

The classical theories of elasticity, finite element materials, fracture mechanics concepts such as J-integral formulations, and Mohr-Conlomb failure criteria will be applied to understand the crack formations and propagations in the drilled-out cores; to simulate coring-induced stresses; and to evaluate the magnitude of in situ stresses at great depths. Fracture angles on cores will be measured to find the internal friction angles, which will be used to find in situ stress magnitudes.

Three point bending tests will be conducted on Devonian Shales to find critical Mode I stress intensity factors. These factors are used in mapping the fracture propagation paths developed due to in situ stress relief during coring. The effects of sample size, anisotropy, and notch/crack configurations will be studied. In order to find anisotropic material properties, uniaxial compression tests, split cylinder tests, and simple shear tests will be conducted. All of these units will be incorporated in predictive models to simulate the repetitive fracture patterns observed in Devonian Shales and to establish in situ stress magnitudes.

SUMMARY OF PROGRESS

Preliminary results based on the Mohr-Conlomb shear failure theory showed that failure occurred on the periphery of the core and slightly ahead of the bit load. Based on trial and error procedures, a range of in situ stresses were obtained. The in situ stresses compared well with some of the existing information.

Research work is in progress to evaluate mechanical properties of Devonian Shales. It is of interest to note that several unconventional failure patterns have been observed. These may be helpful in more accurately predicting in situ stresses. Refined failure criteria, two-dimensional nonlinear material properties, and special finite elements with crack tip effects are being employed in order to avoid costly trial and error procedures, and in order to arrive at accurate in situ stress magnitudes directly (i.e., without incurring high computer costs).

DEVELOPMENT OF ULTRASONIC TECHNIQUES FOR MEASURING IN SITU STRESSES

West Virginia University
Morgantown, West Virginia

Status: Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AC21-77MC08087
July 1, 1978
March 31, 1980

Principal Investigator:
Technical Project Officer:

S. Peng
J.C. Mercer
Morgantown Energy
Technology Center

OBJECTIVE

To determine the feasibility of an ultrasonic technique as a method of measuring in situ stress.

SCOPE OF WORK

Under Phase I of this contract, the feasibility of this research will be assessed under both uniaxial and biaxial compression, beginning with the design of a borehole measuring device. The relationships between stress and P-wave velocity for core specimens will be established. Twelve P-wave velocity measurements will be taken around the circumferential directions of the borehole created by the coring process, while the whole block is subjected to different levels of uniaxial compressive stress. The block also will be subjected to several different combinations of stress for biaxial compression testing. Data obtained will be interpreted mathematically and correlated to measurements done on the core specimens in order to predict both the direction and magnitude of the applied stresses. The effect of transverse anisotropic properties will also be studied.

Phase II of this contract will be a field study where field measurements will be made using a special P-wave velocity measuring device. These velocity measurements will be correlated to the calibration results performed on the available core specimens.

SUMMARY OF PROGRESS

The feasibility study under uniaxial compression has been completed. The relationship between stress and P-wave velocity was fitted into a power equation. Sandstone blocks of one cubic foot were tested under

(Fracture Mechanics)

the conditions of both dry and 100 percent saturation. Twelve P-wave velocity measurements were taken around the circumferential direction of the borehole while the block was subjected to pressures of 100 psi, 200 psi, 300 psi, 400 psi, and 500 psi. Data obtained were examined theoretically and were mathematically interpreted. The prediction of the direction and the magnitude of the applied principal stress were quite satisfactory. The feasibility study under biaxial compression is currently underway.

STUDY OF EXPLOSIVE STIMULATION IN DEVONIAN SHALE GAS WELLS

E.I. Dupont DeNemours and Company
Wilmington, Delaware

Status: Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AC21-79MC11843
September 30, 1979
September 1980

Principal Investigator:
Technical Project Officer:

C.E. Coffey
K-H. Frohne
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 E1-836 explosive.

SUMMARY OF PROGRESS

Aerial photographs of the area have been obtained and interpreted, and will be correlated with existing production in order to assess the effectiveness of using photolineaments to locate new wells to be stimulated under this contract.

The program was suspended for several months because of an adverse PUC ruling.

ASSESSMENT OF SHALE PRODUCTION IN DUAL COMPLETED WELLS

Tetra Tech, Inc.
Houston, Texas

Status: Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AC21-78MC10389
February 5, 1979
September 1980

Principal Investigator:
Technical Project Officer:

J.P. Trunz
K-H. Frohne
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 original scope of work has been modified, due to poor results in the initial study area.

The revised contract consists of five phases: Phase I, data acquisition and evaluation; Phase II, map preparation; Phase III, project identification and classification; Phase IV, land acquisition; and Phase V, drilling and testing.

SUMMARY OF PROGRESS

Phase I - Data Acquisition and Evaluation

This phase is 95 percent complete. All acquired data have been analyzed and integrated onto regional base maps. Selected data are being obtained to identify prospects and to target drillsites in the prospective areas identified in Figure 3-9.

Phase II - Map Preparation

All regional base maps previously prepared are being reevaluated, and new stratigraphic and structural data are being integrated with existing data.

Maps that have evolved from the review of the regional mapping system for the project area are:

<u>Maps</u>	<u>Title</u>
1	Producing Fields and Gas Shows in the Devonian Shale
2	Upper Devonian Radioactive Shale Isopach
3	Middle Devonian Radioactive Shale Isopach
4	Base Upper Devonian Dunkirk-Huron Structure
5	Structural Contours on the Top of the Middle Devonian Onondaga Formation
6	Tectonic Framework Appalachian Basin
7	Aeromagnetic Map of Appalachian Basin

Phase III - Prospect Identification and Classification

Four major trends have been defined that have a high potential for gas production from the Devonian Shale. These trends are identified in Figure 3-9.

1. Trend 1 - East-Central Ohio Area: This area is located along the western limit of the Upper Silurian Salina Salt section. Reservoirs are possible in the Upper Devonian Shale sequence because of a décollement in the shale and associated fractures along the Cambridge arch and fault.

Figure 3-9 Principal Tectonic Elements of the Appalachian Basin and Location of Areas Selected for Detailed Study of the Potential for Devonian Shale Gas Production

(Production Enhancement)

2. Trend 2 - Lake Erie Shoreline Area: Fracture reservoirs in the Devonian Shale are possible because of glacial on-loading and off-loading along the Lake Erie shoreline in Ohio, Pennsylvania, and New York. Glacial lake deposits may provide a seal for these shallow gas reservoirs.
3. Trend 3 - Western New York Area: Fracture reservoirs possible in the Devonian Shale are caused by both glacial on-loading and off-loading and the décollement in the Silurian Salina Salt beds.
4. Trend 4 - Eastern Area: This is a deep Middle Devonian Marcellus trend that lies adjacent to the Appalachian Overthrust Belt. Fractured reservoirs in the Devonian Shale have been created by intense folding and faulting. The depth required to penetrate these reservoirs (8,000 to 9,000 feet) is economically prohibitive.

An investigation has determined that the most favorable areas for gas production from the Devonian Shale are located along the western and northern margins of the Appalachian Basin in Ohio, Pennsylvania, and New York. These areas have abundant source beds of black shale accompanied by the necessary stratigraphic-structural conditions for entrapment. Comparing producing fields and gas shows in the Devonian Shale with those areas having the thickest deposits of black shale source-beds, indicates that the gas has migrated upward from these source-beds into the gray shales deposited around the margins of the basin. The most prolific gas production can be expected from the sandier layers of the shales that have been fractured naturally.

During the reporting period, a land survey of the prospective areas was made. The areas surveyed are identified below along with the results of the survey.

- Washington County, Ohio - Washington County is very active with shallow drilling and no appreciable amount of acreage can be leased at present. Most wells are being drilled to test the Gordon Formation. The pipeline gas gathering system in this county is inadequate.
- Columbiana County, Ohio - Some acreage can be obtained in this county from brokers.
- Lawrence and Butler Counties, Pennsylvania - There is little drilling activity in these counties.
- Venango County, Pennsylvania - Drilling rights must be obtained from other producers.

(Production Enhancement)

- Lorain County, Ohio - Columbia Gas Company has leases in almost every township and has done some shale drilling, especially in LaGrange township. Haddad and Brooks, Inc. has also drilled several wells in this county.

GAS WELL TESTING AND ANALYSIS SERVICE IN THE DEVONIAN SHALE

Gruy Federal, Inc.
Houston, Texas

Status: Active

Contract: DE-AC21-78MC08096
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 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 20 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

A schematic of the surface facilities used in the testing procedure developed is shown in Figure 3-10.

During this reporting period, the CE POWER well test results were analyzed.

The Combustion Engineering Power Systems Group Well No. 1 is located near the town of Belle Vernon in Allegheny County, Pennsylvania (see Figure 3-11). It was drilled to a total depth of about 7,500 feet and completed through perforations at 7,020 to 7,080 feet and 7,330 to 7,440 feet in the Burkett and Marcellus shales, respectively. An oriented core was also retrieved, and results of the core analysis are given in Table 3-3 .

Figure 3-10 Schematic of Gruy Federal, Inc., Surface Facilities for Eastern Devonian Shale Gas Testing Program

Table 3-3 Results of Allegheny County (PA-2) Core Analysis

ANALYSIS	MEAN
Gas Volume	0.28 ft ³ gas/ft ³ shale
Organic Carbon	1.74 %
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 %

Figure 3-11 Location Map of C.E. Power Systems Group Well No. 1

(Reservoir Performance)

The Marcellus Zone was stimulated during May 1979 using a 40 pound gel and 20% CO₂. 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 flowback, the well was shut-in pending stimulation of the second zone.

The Burkett Zone was stimulated during August 1979, using Versagel 1400 with 20% CO₂. 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 CO₂. Instantaneous shut-in pressure was 3200 psi. After flowback, the well was shut-in to run pressure buildup and drawdown tests.

Fracture half length was calculated at 299 to 599 feet for the Burkett zone, assuming 10 percent flowback of sand, grain density of 2.66 gm/cc, fracture porosity of 33 percent, fracture width of 0.1 to 0.2 inches, and a fracture height of 60 feet. Similar calculation for the Marcellus Zone gave a fracture half length of 388 to 577 feet.

An extensive log analysis was performed and the following four cases, each based on a different reservoir geometry, were considered for analysis of the test results.

Case I. This is the simplest case and would give the most conservative values for matrix permeability and fracture half lengths. In this case the net productive interval was taken to be 60 feet for the upper zone and 110 feet for the lower zone.

Case II. Log analysis shows that the Burkett is the better gas-producing interval; this was confirmed by information available from the operators. In the opinion of CE, estimated production from the Burkett was 3 to 4 times that from the Marcellus.

The log analysis also shows a water-bearing zone within the lower perforations, which may result in a water column in the wellbore causing a back pressure on the lower zone and thus preventing even minimal gas production from the lower zone. Therefore, in this case the lower zone was ignored and only the net productive interval of 60 feet for the upper zone was taken into account.

Case III. Analysis of the available logs indicates that neither the entire upper zone nor the entire lower zone could be productive of gas. It is hard to quantify the net total intervals productive of gas in

(Reservoir Performance)

these zones. Using an arbitrary resistivity cutoff of 100 ohm-meters, the estimated productive intervals are 20 feet and 10 feet in the upper and lower zones, respectively.

Case IV. Extending the logic of Case II, another reservoir geometry was considered, which ignores the lower zone and considers only 20 feet of the upper zone as productive. It should be noted that this would give the most optimistic results for matrix permeability and fracture half-length.

The matrix permeabilities and fracture half-lengths were estimated using both conventional analysis and a reservoir simulator. The results are shown below.

1. Estimation of Matrix Permeability and Fracture Half-Length from Conventional Analyses

	Permeability, millidarcies			
	<u>Case I</u>	<u>Case II</u>	<u>Case III</u>	<u>Case IV</u>
First drawdown	0.00077	0.00218	0.00437	0.00655
Buildup	0.00082	0.00232	0.00463	0.00695
Second drawdown	0.00166	0.0047	0.0094	0.0141
Arithmetic mean	0.00108	0.00307	0.00613	0.0092

	Fracture Half-Lengths, feet			
	<u>Case I</u>	<u>Case II</u>	<u>Case III</u>	<u>Case IV</u>
First drawdown	23	30	51	56
Buildup	16	24	42	46
Second drawdown	30	46	80	88
Arithmetic mean	23	33	58	63

* Assuming two equal fractures in Cases I and III and using arithmetic mean permeability values for respective cases.

2. History Match Using Reservoir Simulator

RESERVOIR

Effective porosity	0.95%
Effective permeability	0.005 md
Pay thickness (Upper zone)	20 ft.
Pay thickness (Lower zone)	None

FRACTURE

Fracture half-length (upper zone)	62 ft.
Fracture half-length (lower zone)	None
Fracture porosity	33%
Fracture permeability	500,000 md
Fracture height (upper zone)	20 ft.
Fracture height (lower zone)	None
Fracture width	0.1 in.

The actual history match is shown in Figure 3-12 and a deliverability projection is given in Figure 3-13.

The conclusions of the study were:

- Almost all of the gas production can be attributed to the upper zone (Burkett).
- Extensive natural fracture systems exist in both the upper and lower zones. The bulk of the sand, however, appears to have created fractures in nonproductive intervals. Fractures created within the productive intervals lie in the range of 20 to 63 feet.
- Maximum storage was seen during the buildup because of the large pressure drop during the preceding drawdown. Storage was more dominant in the first drawdown.

Figure 3-12 History Match for C.E. Power Systems Group Well No. 1

(Reservoir Performance)

Figure 3-13 Deliverability Projection for C.E. Power Systems Group Well No. 1

(Reservoir Performance)

- On the basis of sensitivity analyses, it is obvious that the reservoir configuration of Case IV is more representative of the actual situation.
- Turbulence effects were negligible.

TECHNICAL AND MANAGEMENT SUPPORT SERVICES

Science Applications, Inc.
Morgantown, West Virginia

Status: Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AT21-78MC08216
August 1, 1978
July 31, 1981

Principal Investigator:
Technical Project Officer:

J. Pasini III
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. Compilation and analysis of geochemical and geological data to rank the resource potential by areas and to determine future exploration targets was commenced during this reporting period.

All available data on outgassing, total carbon, organic carbon, and vitrinite reflectance have been compiled for the Appalachian and Illinois Basins, and were plotted against depth on strip logs.

Fourteen isochemical maps have been completed, and stratigraphic equivalents are currently being plotted throughout the Appalachian Basin to show continuity of chemical variables over the Basin.

This study is due to be completed by the end of 1980.

(Technical Support)

2. Determination of a probabilistic estimate of the economically recoverable resource by extrapolation of existing production data to unexplored areas on the basis of geological similarity is in progress. This study is described more fully under Section 3.5.4 (Economic Evaluation).
3. Laboratory and numerical modeling efforts are being conducted as a part of stimulation technology evaluation development and rationale.

Laboratory efforts on NTS tuff are essentially complete. Dynamic yield data using a modified split-Hopkinson-bar apparatus have been obtained and reduced. Static yield data using uniaxial and triaxial compression tests have also been obtained and reduced. Tensile strength data (indirect Brazilian, direct pull and pinch tests) have been obtained. Three-point bending tests have been completed to obtain the energy of fracture propagation which can be correlated with K_{IC} through the elastic moduli. Tests on the Devonian Shale have been initiated.

Numerical calculations in support of the NTS mineback experiments are continuing. Pre-test results compare well with the observed fracture for the decoupled explosive experiment. Sensitivity analyses to evaluate the influence of material yielding, crack propping, and internal pressurization have suggested their influence on multiple fracture development. This provides valuable information for improvement of tailored-pulse-loading and explosive stimulation treatments. A literature review of the effect of natural fractures on stimulation treatments has been completed. Numerical calculations are being performed to evaluate the effects of natural fractures and in situ stress anisotropy.

A state-of-the-art report has been completed describing the stimulation rationale for shale gas wells. Devonian Shale production characteristics are addressed, and hydraulic stimulation and explosive stimulation treatments are discussed.

4. The preliminary bulkhead design with abandonment procedures for a mineback experiment in an abandoned limestone mine in Ohio has been completed. Work is in progress on the experimental design and detailed mine design.
5. As part of the validation of the previously developed reservoir simulator, production history from a well in Meigs County, Ohio was used to history-match field data. The well was chosen because its production was consistent over a period of 17 years, with little variation in line pressures over the life of the well, and with very few shut-in periods. The well was shot with borehole explosives.

(Technical Support)

Close history matches were obtained for both single-porosity and dual-porosity systems; however, input parameters for each match were significantly different. The parameters listed below were established in each case.

	SINGLE POROSITY (Blanket Sand)	DUAL POROSITY
Well Spacing	160 Acres	40 Acres
Initial Gas In Place	168 MMSCF	173 MMSCF
Fracture Spacing (a)	---	500 cm
Matrix Porosity (ϕ_m)	---	.005
Matrix Permeability (km)	---	0.2×10^{-7} md
Fracture Porosity (ϕ_f)	0.85×10^{-2}	0.2×10^{-3}
Fracture Permeability (k_f)	0.015 md	0.25 md

6. A procedure for screening sites that will be used to identify optimum sites for the Offset Well Test Program has been outlined as follows:
 - Identify key reservoir parameters based on geological, geophysical, and production information.
 - Perform a reservoir simulation study by history matching long-term production data. The wells provided so far have been producing for approximately ten years.
 - Based on matched production history, predict reservoir pressures at different offset distances (100 feet, 200 feet, 300 feet) from the active well.
 - Perform simulated buildup and drawdown responses for sites at the control (active) and offset wells.
 - Perform cost analysis for key sites. Factors that will be considered are:
 - Well depth
 - Location preparation
 - Well test time requirements
 - Other costs associated with site

(Technical Support)

Initial ranking of candidate sites has been completed. The advantages and disadvantages of each site have been listed in tabular form and rankings have been given to various parameters such as: pressure, rates, depletion, and depth. From this initial ranking, the preferred order is as follows: Meigs County, Ohio; Mingo County, West Virginia; and Jackson County, West Virginia (Cottageville periphery). Boone County, West Virginia and the Cottageville Field areas have been eliminated. Reservoir simulation of wells in each area is now being performed, and the prime candidates will then be selected.

The reservoir simulator is also being used to provide a basis for analyzing well test data to be generated by the Offset Well Test Program.

3 . 4 TECHNOLOGY TESTING AND VERIFICATION

3 . 4 . 1 I N T R O D U C T I O N

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 eight contracts in this Element, three are designed primarily to test exploration rationales, and the other six to test stimulation techniques.

Two exploration rationales are currently being tested. The first rationale is based on seismic velocity analysis. Prospects have been developed and fielding has been initiated. The other rationale is based on the theory that the development of natural fracture systems is related to the structure at the time of deposition. Five wells were drilled in Ohio to support the theory of the relationship of hydrocarbon distribution to depositional environment. Evidence collected to date from drilling, coring, sampling, and logging data supports the theory since natural fractures and gas shows were present in all five wells. Stimulation tests, however, have not been completed, and will be continued through the next reporting period.

The stimulation treatments to be tested under the other five contracts are primarily foam, as previous EGSP research has indicated that this is the most promising technique for further development. Results to date are varied with a southern New York test showing significant production. Results of a gas frac, however, have not shown a significant increase in production.

3 . 4 . 2 E X P L O R A T I O N R A T I O N A L E

Three contractors are currently active in this Work Package of the LGSP. A summary of their work appears on the following pages.

3 . 4 . 3 E X P L O I T A T I O N R A T I O N A L E

A summary of the work of the six contractors in this Work Package of the LGSP follows.

NEW EXPLORATION CONCEPT FOR LOCATING FRACTURE ZONES IN THE DEVONIAN SHALE

Donohue, Anstey and Morrill
Boston, Massachusetts

Status: Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AC21-78MC08339
February 23, 1979
October 1980

Principal Investigator:
Technical Project Officer:

D.A. Donohue
K-H. Frohne
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

As reported previously, two drilling prospects were recommended in Noble County, Ohio based on velocity lows. A lease has been acquired for one of these sites, and drilling was in progress at the end of the reporting period.

SHALE TEST WELLS IN SOUTHERN TIER COUNTIES OF NEW YORK

Donohue, Anstey and Morrill
Boston, Massachusetts

Status: Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AC21-79MC12697
September 28, 1979
September 1981

Principal Investigator:
Technical Project Officer:

D.A. Donohue
K-H. Frohne
Morgantown Energy
Technology Center

OBJECTIVE

To locate, drill, and test by stimulation methods the production potential of ten 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 (see Figure 3-14) which will be a candidate area for the drilling, coring, logging, testing, stimulating, and retesting of one to ten 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 ten wells will be based on the results of the stimulation and testing of the initial wells.

SUMMARY OF PROGRESS

All available information on old shale gas fields and recent shale gas shows in the Rhinestreet Formation in the study area has been compiled.

Surface lineaments, subsurface structure, and faulting have been analyzed in three regions: the old Rathbone Field, the old Dansville Field, and the recent gas shows near Corning.

Drilling locations to test modern fracturing techniques in the old fields have been identified. The identification of locations near Corning to test the conduit-bed hypothesis is in progress.

CONTOUR INTERVAL 100'

STUDY AREA

RECENT SIGNIFICANT
SHOWS IN RHINESTREET

ABANDONED SHALE-GAS
FIELDS

IMPORTANT INDUSTRY

SCALE
0 25 MI

Figure 3-14 Southern Tier Counties of New York Showing Radioactive Shale Isopach of West Falls Formation

(Exploration Rationale)

**SUPPORT DEVELOPMENT OF AN UNCONVENTIONAL EXPLORATION TECHNIQUE TO
SELECTIVELY LOCATE NATURAL FRACTURE SYSTEMS IN THE DEVONIAN-OHIO SHALE**

Mitchell Energy Corporation
Houston, Texas

Status: Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AC21-78MC08387
September 1978
March 1981

Principal Investigator:
Technical Project Officer:

W.M. Hennington
K-H. Frohne
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

During the first 11 months of this project, work centered around the planning, exploration, and temporary test line tasks, with a great deal of time and effort spent in obtaining necessary approvals. During this reporting period, the drilling, coring, openhole logging, and casing stages of Phase I were completed. The last three months have been spent obtaining approvals for completion work and initiating these procedures.

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 for the contractor's purposes. Enough data were 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). This study, which was used as a model for the Gallia County, Ohio project study, was presented at the Third Annual Eastern Gas Shales Symposium in Morgantown, West Virginia, October 1-3, 1979.

Only a limited amount of well data was available in the immediate project area, so the exploration technique being investigated in this program utilized the top of the Ohio Big Lime as the critical control surface. This structural surface was used because it was thought to provide the most reliable data available from well records and the spot

(Exploration Rationale)

correlation seismic. As a result, a 65-point spot correlation seismic survey was conducted to detail the structure on top of the Ohio Big Lime.

The relationships found in the model study (Cottageville Field) were projected into the project area, where the approximate depositional structure of the Devonian Shale was reconstructed from the present day structure on top of the Ohio Big Lime (as interpreted from the above seismic data). According to the compaction fracture theory, naturally fractured reservoirs are located on the flanks of the depositional high. In order to test this theory, the five Phase I wells were located to test the various depositional structural positions. The #1-5 Carpenter, #1-8 Straight-Wisemandle Unit, and the #1-9 Carter were proposed to test the flanks of the depositional high (where natural fractures should be encountered); while the #1-7 White-Price-Newberry Unit was proposed to test the depositional low; and the #1-6 McCombs was proposed to test the depositional high (where natural fractures should be minimal). These locations may be reviewed in the "Site Selection Report" submitted to USDOE.

Problems have been found with the seismic interpretation of the present day Ohio Big Lime structure. Logs run on the five Phase I wells have revealed significant discrepancies between the top of the Ohio Big Lime interpreted from the seismic and that actually encountered. These discrepancies are given below:

Well Name	<u>Big Lime Datum</u>		<u>Discrepancy</u>	
	Seismic	Actual	Seismic to Actual	
#1-5 Carpenter	-2030	-2032	2'	High
#1-7 White-Price-Newberry	-2080	-1973	107'	Low
#1-6 McCombs	-1950	-2073	123'	High
#1-8 Straight-Wisemandle	-2100	-2097	3'	Low
#1-9 Carter	-2020	-1999	21'	Low

Since this present-day seismic-based structure on top of the Ohio Big Lime is a key element in the reconstruction process, the depositional structure resulting from the exploration technique was also affected. Correcting the present-day seismic structure (above) resulted in the following revisions to the depositional interpretation:

Well Name	<u>Depositional Datum</u>		<u>Depositional Position</u>	
	Seismic	Actual	Seismic	Actual
#1-5 Carpenter	560	560	Flank	Flank
#1-7 White-Price-Newberry	655	558	Low	Flank
#1-6 McCombs	450	565	High	Flank
#1-8 Straight-Wisemandle	570	565	Flank	Flank
#1-9 Carter	575	565	Flank	Flank

(Exploration Rationale)

Thus, all five Phase I wells were drilled into the flank of a depositional high, where the compaction fracture theory predicts the presence of naturally fractured reservoirs. Evidence collected to date from drilling, coring, sampling, and logging data supports the theory, since natural fractures and gas shows were present in all five wells.

The archaeological approval proved to be very time consuming. Twenty-one locations were submitted in order to obtain approval for five which would test various depositional structural positions. The locations were 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 Carpenter, #1-7 White-Price-Newberry Unit, and #1-9 Carter should have more natural fractures than either the #1-8 Straight-Wisemandle Unit or the #1-6 McCombs. Results may be reviewed in the "Remote Sensing Reports" submitted to USDOE.

All of the well cuttings have been analyzed and plotted, and final logs are being distributed. The core samples are currently being analyzed.

The 4 inch test line and 2 inch well line system have been planned and surveyed. All regulations have been checked. Right-of-way has been obtained along with archaeological approval.

Phase I drilling operations have been completed and completion operations are in progress for the lower zone. Cementing problems, severe enough to warrant squeeze cementing operations, were encountered in the #1-6 McCombs and the #1-8 Straight-Wisemandle. The resulting perforations in the upper zone necessitated revisions to the perforation and stimulation programs proposed for both zones.

The cased-hole prestimulation logging program has been completed in all five wells. The lower zone in each well has been perforated, broken down, balled out, and cleaned up resulting in gas shows (TSTM) in four of the five wells (#1-5, #1-6, #1-7, #1-9).

The lower zones of two wells (#1-5 Carpenter and #1-7 White-Price-Newberry) were foam fraced through 4-1/2 inch casing and are currently cleaning up with gas shows (TSTM).

ASSESSMENT OF THE ECONOMIC POTENTIAL OF DEVONIAN SHALE GAS PRODUCTION

Columbia Gas System Service Corporation
Columbus, Ohio

Status: Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AC21-78MC08385
September 27, 1978
January 1981

Principal Investigator:
Technical Project Officer:

W.F. Morse
A.B. Yost II
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

September 1979 marked the initiation of field work on this program. By the end of November 1979, Columbia had drilled, cored, logged, and cased all ten project wells.

Significant gas shows occurred in wells #20150 and #20152 in Lorain County, and well #20144 in Trumbull County. Table 3-4 lists the important drilling and logging information.

During February, Columbia drilled cement plugs and staging tools in wells #20144 and #20147. Cement bond and perforation logs were run and these wells were acidized and perforated. Field activities were temporarily halted as a result of disagreements with DOE/METC on stimulation programs for the wells.

Table 3-5 presents an outline of progress to February 29, 1980, and illustrates the activities completed since the project began.

Table 3-4 Drilling and Logging Information for Ten Wells Under
Columbia Gas Contract

Well Number	County	Top of Shale	Base of Shale	Feet Cored	Temp./Sibill. Events at:	Gas Show at:	Open Flow
20143	Trumbull	263	2701	1187	--	trip gas 1616 Conn. gas 1792, 1906, 2198, 2256, 2316, 2434, 2552	TSTM*
20144	Trumbull	228	2593	--	614	Bariod 1913-2102 Ø1500 to 2000 units	Estimated at 90-100 MCF
20145	Trumbull	240	2610	--	--	--	TSTM
20146	Trumbull	229	2629	--	--	--	TSTM
20147	Trumbull	226	2593	--	--	--	1 MCF before logging
20148	Lorain	252	1246	--	345-347, 405-428, 514-525, 572-576, 610-624, 650-669, 1239-1286	398, 642, 656, 664, 980	4 MCF
20149	Lorain	293	1273	879	465-475, 538-543, 558-628, 729-732, 756-758, 790-797, 1274-1290, 1302-1308	--	8 MCF
20150	Lorain	230	1253	--	650-745, 1092-1124	603-653	38 MCF
20151	Lorain	247	1292	--	1200, 1270, 1224	--	TSTM
20152	Lorain	296	1277	--	300-400, 476, 648-652	527, 760	35 MCF

*Too Small To Measure

(Exploitation Rationale)

Table 3-5 Columbia Gas 10-Well MHF Program Summary as of 2/29/80

Area	Well No.	Site Selection			Drilling & Coring	Logging	Perf. & Brkdn	Pre-frac Test
		EIA	Archeo Survey	Site Prep				
AREA 1 Trumbull County, Ohio	Well 1 20143	X	X	X	X	X		
	Well 2 20144	X	X	X	X	X	X	X
	Well 3 20145	X	X	X	X	X		
	Well 4 20146	X	X	X	X	X		
	Well 5 20147	X	X	X	X	X	X	X
AREA 2 Lorain County, Ohio	Well 1 20148	X	X	X	X	X		
	Well 2 20149	X	X	X	X	X		
	Well 3 20150	X	X	X	X	X		
	Well 4 20151	X	X	X	X	X		
	Well 5 20152	X	X	X	X	X		

DEVONIAN SHALE TEST WELL/HOUGHTON COLLEGE AREA OF NEW YORK

Houghton College
Houghton, New York

Status: Completed

Contract:
Contract Date:
Anticipated Completion Date:

DE-AC21-79MC10640
February 26, 1979
December 1979

Principal Investigator:
Technical Project Officer:

R.G. Tighe
K-H. Frohne
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 in August 1979. The well was drilled to a total depth of 2332 feet. Cuttings from the well were studied and a description completed.

During September 1980, the well was stimulated using a 50,000-gallon 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 flowback of frac fluids, the well was shut-in in preparation for and drawdown tests to be performed by Gruy Federal, Inc.

Initial buildup tests indicate that the well is highly productive. The well is being extensively tested, and the results will be presented in the next Semi-Annual report.

ASSESSMENT OF DEVONIAN SHALE POTENTIAL IN CARROLL COUNTY, OHIO

Mitchell Energy Corporation
Houston, Texas

Status: Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AC21-78MC12537
September 8, 1979
May 1980

Principal Investigator:
Technical Project Officer:

W.M. Hennington
K-H. Frohne
Morgantown Energy
Technology Center

OBJECTIVE

To assess the production potential of the Devonian Shale in Carroll County, Ohio through recompletion techniques in existing wells.

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

The primary test interval was stimulated with a 50,000 gallon foam frac, displacing 60,000 pounds of sand at a 30 BPM rate into a fracture at a depth interval of 2800 to 3500 feet. Gas flow rates following fracture fluid recovery were too small to measure, indicating the test site is an unfavorable area for development.

ASSESSMENT OF DEVONIAN SHALE POTENTIAL IN PRESTON COUNTY, WEST VIRGINIA

J. T. Waggoner
Silver Spring, Maryland

Status: Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AC21-79MC010515
August 8, 1979
May 1980

Principal Investigator:
Technical Project Officer:

J.T. Waggoner
K-H. Frohne
Morgantown Energy
Technology Center

OBJECTIVE

To assess the production potential of the Devonian Shale in Preston County, West Virginia through recompletion techniques in existing wells.

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/CO₂ treatment.

SUMMARY OF PROGRESS

The well logs have been analyzed and the stimulation procedure designed. Stimulation and well testing will be performed once a rig becomes available.

TESTING PROGRAM FOR SHALE GAS PRODUCTION POTENTIAL

Thurlow Weed and Associates, Inc.
Mount Vernon, Ohio

Status: Active

Contract:
Contract Date:
Anticipated Completion Date:

DE-AC21-78MC08386
September 1978
September 1980

Principal Investigator:
Technical Project Officer:

T. Weed
K-H. Frohne
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

The first of the four planned stimulation treatments to be performed under this contract was carried out on the Everett Black No. 1 well on October 22, 1979.

This fracturing experiment was instrumented using a borehole seismic and surface tiltmeter system to evaluate the induced fracture geometry. The well was plugged back to 1120 feet. After cementing, two extra joints of 4 1/2 inch casing were found to be in place in the hole, and so perforations were made from 1005 to 1025 feet. Thus, the interval of softer gray shale from 1030 to 1041 feet was, perhaps fortuitously, cemented off from exposure as a fracture initiation point.

An acoustic cement bond log was run, but was unusable, due probably to gas bubbles in the hole, especially on the pipe walls. The attempt to secure a good cement bond log was terminated to allow time for the before-frac run of the Deep Venture Diving Service Television equipment which required until 10:00 p.m. of the night before the frac, but was successful in terms of valuable information obtained. The views of outgassing fractures in the open hole section were spectacular and were recorded on tape.

On October 22, 1979, two Halliburton nitrogen trucks began pumping nitrogen into the well. The pressure rose until leveling off at 800 pounds.

When the pressure leveled off, Halliburton began adding pumping equipment until nitrogen was being injected at 90 bpm. This was double the expected rate, due to the lower than expected breakdown and treating pressures.

968,000 SCF of nitrogen were displaced into the well in approximately 27 minutes. Instantaneous shut-in pressure was 1,000 pounds, falling to 900 after the first two minutes before leveling off for approximately 12 minutes, when it began a slow 25 minute decline to 865 pounds. At that point Sandia requested that some gas be allowed to blow back, and an estimated 100 MCF was released over the next six minutes, dropping the pressure to nearly 800 pounds, where an unaccounted for rise of approximately 25 pounds was recorded.

The well was then shut in, and in seven minutes the pressure had built back up to about 850 pounds per square inch. Sandia's downhole instrument was removed, and a gamma radiation detection instrument was run into the hole to trace Birdwell's radioactive beads which had been run in two stages during the frac. This log, taken with 850 pounds in the shut-in well, shows intense radioactivity everywhere in the hole and pipe, as though reading beads smeared everywhere on the walls by the nitrogen moving at such a high injection rate.

The well was shut-in overnight on the hypothesis that elasticity laws predict a longer lasting deformation (of the fractured rock formation) when the deforming force is applied over a longer time.

That same evening, it was noticed that the Wade wells to the east and east-southeast were producing some type of gas through a meter at extraordinary rates and that their flowing pressure had increased by about 5 pounds. No pressure increases were indicated at the Yauger, Peairs, or Beckholt wells.

The Wade wells, which were not included in this project originally, but were monitored for pressure increases as a result of a loan by Columbia Gas of pressure recording equipment, were found to have pipeline manifolding and downhole caving conditions about which not enough was known to determine with certainty which (or if both) wells were making nitrogen. It is known that nitrogen in some quantity was present in the wells. A later sample taken from the northernmost Wade well contained 40 percent nitrogen. This could have been backed through connecting lines into that well from the other Wade well if the nitrogen broke into the southernmost well (first?) with sufficient pressure.

The Black well was blown back and tested for pressures and flow rates at various intervals for two days (and nights) beginning at 7:30 a.m. October 23, 1979 (the morning after the frac).

By October 24, 1979, the well was estimated to be making such a low percentage of nitrogen that it was shut-in to test its top pressure (600 pounds) and to be made ready to sell gas. However, a sample from October 23 proved to be 62 percent nitrogen, so the well was blown several more days before the third sample was taken on October 31, 1980. This proved to contain 52 percent nitrogen, while a sample taken from the Peairs well 1,000 feet to the south contained the normal 6.4 percent nitrogen.

Natural fracture analysis in the boreholes of all four project wells was carried out using the downhole video camera system.

Results of the analysis of the core from one of the wells are given in Table 3-6. This core is presently being investigated further to determine which fracturing fluids are more suitable for the three remaining project wells.

Table 3-6 Results of Knox County (OH-3) Core Analysis

ANALYSIS	MEAN
Gas Volume	0.36 ft ³ gas/ft ³ shale
Organic Carbon	2.23 %
Total Carbon	3.3 %
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)	6.37
O/C (whole rock)	4.30

3 . 5 P R O J E C T I N T E G R A T I O N

3 . 5 . 1 G E N E R A L

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 data base management system, economic analysis, and technology transfer.

3 . 5 . 2 E N V I R O N M E N T A L A C T I V I T I E S

An environmental assessment of the seismic exploration field project in Ohio has been completed, and assessments of the seismic project in New York are in progress. Environmental studies of all other field projects were completed during the previous reporting period.

3 . 5 . 3 P R O J E C T D A T A B A S E M A N A G E M E N T S Y S T E M

The initial loading of data into the EGSP data base has been completed. There are two data bases in the system, one containing information on EGSP core wells, the other with information on non-EGSP wells.

Documentation of the system has been completed, and it is currently undergoing testing, updating, and evaluation.

3 . 5 . 4 E C O N O M I C E V A L U A T I O N

A study to determine the economically recoverable gas from Devonian Shale in the Appalachian Basin was initiated in September 1979 and is expected to be completed by October 1980.

Historical production data have been compiled. The data are mostly confined to proven fields such as the Big Sandy and Cottageville. Quantitative analyses will first be performed on the recoverable resource and associated geological factors of these and other regions where production data are available.

A preliminary analysis of counties with production data shows that the recoverable resource on a well-by-well basis has a statistically skewed distribution which appears to be lognormal. An aggregation of these probabilistic distributions, given suitable well spacings and

success-ratios of wells, will be made in order to obtain interval estimates of the recoverable resource.

Initial cluster analyses have been performed to obtain different clusters or groupings with distinct geological features for the Basin. The clusters are based on geological factors such as radioactive shale thickness, thermal maturity, and stress-ratios.

The results of the cluster analysis will be used in attempts at extrapolation from training to target areas for obtaining statistical distributions of the recoverable resource. This will be followed by an economic analysis so that price-supply curves of the economically recoverable resource can be determined.

3 . 5 . 5 T E C H N O L O G Y T R A N S F E R

An additional six geologic maps were printed during this reporting period, and are available from DOE's Unconventional Gas Recovery (UGR) Information File located at METC. The maps are:

- EGSP Series 13: Black Shale and Sandstone Facies of the Devonian "Catskill" Clastic Wedge in the Subsurface of Western Pennsylvania (39 plates and publication)
- EGSP Series 100: Wells Penetrating Middle and Upper Devonian Black Shales in New York
- EGSP Series 101: Oil and Gas Shows in Devonian Black Shales and Interbedded Units in New York
- EGSP Series 102: Oil and Gas Fields in New York
- EGSP Series 805: Map of Indiana Showing Thickness of New Albany Shale (Devonian and Mississippian) and Equivalent Strata
- EGSP Series 806: Map of Northern Indiana Showing Thickness of the Sunbury, Ellsworth, and Antrim Shales (New Albany Shale Equivalents)

Other information generated from the EGSP can also be obtained from the UGR Information File, and from the National Technical Information Service (NTIS). The UGR File contains approximately 270 publications and 83 maps.

A 20 page brochure on the EGSP was produced and distributed in January 1980. A 27-minute film on the UGR Program, including segments on the EGSP, is being prepared and will be ready for the joint SPE/DOE UGR Conference in May 1980.

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 ft. 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 in 1973, supplemented by the United States Geological Survey 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 also evaluated nine other basins which were estimated to contain an additional 190 trillion cubic feet of gas in low permeability reservoirs.

Figure 4-1 Map of Western United States, Showing Areas of Interest
(Refer to this figure for the location of WGSP Study Areas)

Table 4-1. Principal Study Areas and Resource Base Estimates

AREA	STATE	ESTIMATED RESOURCE (TCF)*	
		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 W E S T E R N G A S S A N D S P R O J E C T

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, and
- 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, and
- 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 4-2 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 needed 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 stimulation and computer use to provide a basis for conducting statistical, parametric and prediction analyses. Test data will be used to validate the models which, in turn, may be used in the interpretation of subsequent test results.

Innovative stimulation technology will be evaluated. Core samples will be analyzed to obtain rock mechanics data and other formation properties needed to improve stimulation technology.

Energy Technology Centers and National Laboratories participating are the Bartlesville Energy Technology Center, Lawrence Livermore Laboratory, Sandia Laboratories, and Los Alamos Scientific Laboratory.

The Bartlesville Energy Technology Center is handling R&D tasks associated with logging research, rock-fluid interactions, instrument development (such as new coring and logging tools) and will provide various other support as the project develops. Lawrence Livermore Laboratory 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 projection 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	<p>Develops and defines division budget requests</p> <p>Formulates policies encompassing project content, goals and objectives</p> <p>Approves project plans</p>
MORGANTOWN ENERGY TECHNOLOGY CENTER	<p>Provides overall guidance for the Unconventional Gas Recovery Program, which includes the WGSP.</p> <p>Monitors project progress, evaluates results, initiates project reviews and modifies project direction as appropriate.</p>
BARTLESVILLE ENERGY TECHNOLOGY CENTER	<p>Provides project manager (resident at NV) to staff project office and supports the project with in-house and contracted R&D</p>
PROJECT OFFICE	<p>Executes technical direction to contractors and agencies participating in the project within the guidance originated by headquarters</p> <p>Participates in the planning, review, evaluation and overall guidance of the project</p> <p>Provides reports of project status and accomplishments</p> <p>Assists in contract work statement preparation, proposal evaluations and technical negotiations</p> <p>Is responsible for contract technical performance</p> <p>Certifies contractor expense vouchers for NV payment</p>
NEVADA OPERATIONS OFFICE (NV)	<p>Prepares and negotiates contracts, performs related contractual administrative activities, and makes necessary payment to contractors</p>
CONTRACTORS AND AGENCIES	<p>Execute contract work</p> <p>Maintain proper interface with project office and its representatives on technical matters</p> <p>Interface with NV on financial, legal and contract administration matters</p>
NATIONAL LABORATORIES	<p>Perform and direct research and development in various areas of expertise</p>

4 . 2 RESOURCE ASSESSMENT

4 . 2 . 1 U . S . G E O L O G I C A L S U R V E Y A C T I V I T I E S

UINTA-PICEANCE BASINS

"Preliminary results of mineralogic and diagenetic studies of low-permeability sandstones of Late Cretaceous age, Piceance Creek Basin, Colorado," was prepared by P. Hansley and R. C. Johnson.

Open file analyses of petrographic data were derived from SEM, x-ray and sedimentation studies of cores from the Rio Blanco MHF-3 well, Piceance Basin.

Tucher and Farrer cores from the Tavaputs Plateau, Uinta Basin were sampled and described.

Mesaverde core from the Exxon Wilkins Ridge Unit No. 1 was sampled and described. This Neslen Formation core is representative of the Neslen in part of the Tavaputs Plateau.

Rocks from the outcrops west of the Green River were described and correlated to Lower Tertiary and Upper Cretaceous gas-bearing reservoir rocks in the Island, Natural Buttes and Peters Point fields in the Uinta Basin.

Structure (top of the Cretaceous) and isopach maps of some Upper Cretaceous rocks in the Piceance Basin were submitted for review prior to publication.

The geologic appropriateness of a proposed DOE multi-well test and core site in the Piceance Basin near the Divide Creek Anticline was reviewed. The analysis indicated that some gas-bearing Upper Cretaceous rocks would be encountered. However, the proposed location is far enough away from subsurface control points to be a wildcat test and near enough to surface exposures of the target rocks to perhaps contain a number of water-bearing reservoirs. The analysis was based on calculation of borehole log properties, analysis of drillstem test results and knowledge of the stratigraphy and depositional character of the Upper Cretaceous rocks in the region.

Manuscripts are being prepared that describe and discuss rocks in the producing intervals at Pariette Bench and Southman Canyon fields in the Uinta Basin.

A stratigraphic section is being prepared that relates rock types, producing intervals, and formations and engineering data for Upper Cretaceous and Lower Tertiary rock extending from Price River Canyon to the eastern Uinta Basin.

GREATER GREEN RIVER BASIN

T. Tyler published a cross section entitled "Preliminary chart showing electric log correlation, section F-F' of some Upper Cretaceous and Tertiary rocks, East Flank Rock Springs Uplift, Wyoming," as USGS Open-File Report 79-1573. He also published "Wildcat well penetration map showing wells drilled into and through potentially gas-bearing, low-permeability Upper Cretaceous and Tertiary reservoirs, Sand Wash Basin, Colorado," as USGS Open-File Report 79-1437.

L.W. Kiteley published a report entitled "Stratigraphic measured sections of the Upper Cretaceous Mancos Shale (upper part) and Mesaverde Group (lower part), Moffat County, Colorado," as USGS Open-File Report 79-1306.

Core samples from the Tierney No. 1 and Koch Adobe Town wells, Washakie Basin, were submitted for geochemical analyses.

The first draft was completed of a paper entitled "Evaluation of organic matter and subsurface temperature and pressure with regard to gas generation in low-permeability Upper Cretaceous and Lower Tertiary sandstones in the Pacific Creek area, Sublette and Sweetwater Counties, Wyoming."

J.C. Webb completed a draft paper entitled "X-ray and quantitative mineralogy of twelve samples from the Upper Cretaceous Mesaverde Group, Washakie Basin, Wyoming."

R.E. Lanham and D.J. Markochick completed a draft paper entitled "Authigenic kaolinite in low-permeability sandstones of the Almond Formation, Washakie Basin, Wyoming."

B.E. Law and D.J. Markochick collected Mesaverde core samples from the Rainbow Resources No. 1-3 Pacific Creek Federal well, Sec. 3, T26N, R103W, Sweetwater County, Wyoming, for gas desorption studies.

Gas desorption was completed of core samples from Rainbow Resources Inc. Pacific Creek Federal Well, Sec. 3, T26N, R103W, Sweetwater County, Wyoming.

Desorbed methane from core samples of the Rainbow Resources Inc. No. 1-3 Pacific Creek Federal well, Sec. 3, T26N, R103W, Sweetwater County, Wyoming were sent to METC for residual gas determination.

H. Bucurel redescribed Mesaverde core samples from the Amoco No. 1 Tierney Unit, Sec. 15, T20N, R94W, Sweetwater County, Wyoming. This well is located on the Wamsutter Arch in the Greater Green River Basin.

Work continued on a stratigraphic analysis of the Greater Green River Basin.

Preparation began of a manuscript by B.E. Law concerning the correlation Upper Cretaceous rocks between the Hoback Basin and Rock Springs Uplift, Wyoming.

An 84-ft core from the Belco No. S-29-27 well, Sec. 28, T30N, R113W, Sublette County, Wyoming was received from TRW.

The USGS Core Lab slabbed core from the PTS Beamers Bluff No. 24-19 well, Sec. 19, T33N, R114W, Sublette County, Wyoming.

NORTHERN GREAT PLAINS PROVINCE

Petrographic analysis of Milk River core from southeastern Alberta continued.

Samples from the Joseph J.C. Paine No. 1-9 Aansen well from the Little Missouri field were sent to Caprock Laboratory and Reinhart Laboratory for analyses.

An open-file report on the distribution of the Niobrara chalk in North Dakota and South Dakota was prepared.

An open-file report on the pinch-out of coastal sandstones in the Eagle sandstone in central Montana was prepared.

Petrographic analysis continued of tight reservoirs in the Eagle-Telegraph Creek interval in Alberta, Montana and North Dakota.

A report entitled "Reservoir geometries in the Shannon Sandstone near the northern Black Hills, Montana and South Dakota," by G.W. Shurr was revised.

D.D. Rice continued work on a regional cross section from southeastern Alberta to north-central Montana.

A report entitled "Generation, Accumulation, and Resource Potential of Biogenic Gas," by D.D. Rice and G.E. Claypool was revised for the AAPG Bulletin.

D.L. Gautier is preparing an open-file report on regional reservoir characteristics of the Eagle Sandstone and equivalent rocks.

A report entitled "Physical characteristics, burial history, and reservoir properties of low-permeability, biogenic methane reservoirs in the northern Great Plains" was prepared.

A report entitled "Revision of Cretaceous nomenclature in Montana and South Dakota" was prepared by D.D. Rice, G.W. Shurr and D.L. Gautier and for the USGS Bulletin.

4 . 2 . 2 C O R E P R O G R A M

In the Piceance Basin, coring operations of the Mancos B at the Pacific Transmission Supply Company No. 22-12 Federal well, Sec. 12, T1N, R99W, Rio Blanco County, Colorado began on October 1 and ended October 3 with 118.3 ft of core recovered from 120 ft cut (depth 11,669 ft to 11,789 ft). The Mancos B is a fairly consistent deltaic sand-shale sequence. Individual sand and shale lenses are closely interspersed and one to two inches thick. The laminar bedding is somewhat contorted and both sands and shales are micaceous and slightly calcareous. The sandstone is generally fine-grained and tight. Background gas recorded by the mud logger during earlier coring operations at the Mesaverde level (6,500 ft) registered two units, yet at the Mancos B level 750 to 1,000 units were recorded.

The Pacific Transmission Supply Company No. 3-10A Federal well, Sec. 10, T22N, R94W, Sweetwater County, Wyoming was cored in the Almond Formation. About 165 ft of continuous 4 in. core was recovered from depths of 11,436 ft to 11,623 ft. The first core included 20 to 25 ft of good reservoir sand, which was whole-core analyzed. Commercial laboratory core analysis is in progress and selected core samples have been shipped to LLL, LASL, Sandia and BETC for special analyses.

Coring commenced December 29 on the Rainbow Resources, Inc. No. 1-3 Federal well, Sec. 3, T26N, R103W, Sweetwater County, Wyoming. Two Mesaverde (Ericson Formation) cores were cut by December 31 with full recovery. Coring resumed January 6 when drilling reached 12,630 ft and continued to 12,777.5 ft with 85 percent recovery from the Rock Springs Formation. When drilling reached 13,410 ft, coring again resumed in the Rock Springs Formation until 13,503 ft, with 92 percent recovery. Coring operations were completed on January 17. Core samples were sent to BETC, LLL and Core Laboratories. Figures 4-4 and 4-5 show some of the activities related to the coring operation.

In the Uinta Basin, coring of the Mapco RBU No. 11-17F well, Sec. 17, T10S, R20E, Uintah County, Utah, occupied most of November. Operations began on November 13 and, due to minor difficulties, continued to November 27. The total amount of core cut was 141.6 ft, with 98.2 ft recovered (70 percent). Two cores were cut in the basal unit of the Wasatch, locally named the Ute land Buttes unit by Mapco, but recovery was poor. The remaining cores were cut in the upper portion of the Mesaverde. The core was comprised mainly of sandstone, siltstone and shale. Samples were taken for BETC and LASL and chips were taken every foot through the sand intervals for Sandia Laboratories.

Figure 4-4 Pulling Inner Core Barrel

Figure 4-5 H. E. Newman, CER Corporation Staff Geologist

4 . 2 . 3 L O G G I N G P R O G R A M

G.C. Kukal (CER Corporation) assisted in logging operations at the Pacific Transmission Supply Company "Barcus Creek" No. 22-12 Federal well, Sec. 12, T1N, R99W, Rio Blanco County, Colorado. Before logging, a circulated mud sample was caught on October 17. The general mud type was low solids non-dispersed. Additives included sodium bichromate and ammonium nitrate. From October 17 to October 19, the well was logged as follows:

- Dual Induction Log - Laterolog 8/SP/GR;
- Formation Density Log/Compensated Neutron/Caliper/GR;
- Dual Laterolog/SFL/Caliper/SP;
- BHC Sonic/GR/Caliper; and
- Variable Density Log - Sonic Amplitude.

The Natural Gamma Spectroscopy Tool was not available for this well.

On October 22, 1979, Schlumberger ran its Natural Gamma Spectroscopy Log through casing on the PTS "Beamers Bluff" No. 24-19 Federal well, Sublette County, Wyoming. The log interval was 5,531 to 4,400 ft in the Mesaverde horizon.

G.C. Kukal assisted in logging operations at the PTS No. 3-10A Federal well, Sec. 10, T22N, R94W, Sweetwater County, Wyoming. A circulated mud sample was collected from the flowline. The well was logged beginning November 16 as follows:

- Dual Induction Log-SFL-SP-GR;
- Simultaneous BHC Sonic-Caliper;
- Variable Density Log-Full Wave Train Log-Amplitude Log;
- Formation Density-Caliper;
- Simultaneous Compensated Neutron Gamma Ray;
- Dual Laterolog and Simultaneous Micro-SFL-Caliper-Gamma Ray; and
- Mud Log.

Field prints of the above logs were delivered on location. CYBERLOOK Log was computed over interval 11,950 to 9,900 ft. The Spectral Gamma Log equipment was unavailable for this well.

G.C. Kukal and S.R. Anderson (CER Corporation) assisted in the logging operations of the Mapco RBU No. 11-17F well, Sec. 17, T10S, R20E, Uinta County, Utah. Logging commenced November 28. A circulated mud sample was collected (general mud type was KCl-NaCl brine). The well was logged as follows:

- Dual Laterolog-Gamma Ray;
- Microlaterolog-Caliper (failed);
- Compensated Densilog-Caliper-Simultaneous Compensated Neutron Log-Gamma Ray; and
- BHC Acoustilog Caliper-Gamma Ray.

Field prints of the above logs and computed log (PROLOG) were delivered on location. The Microlaterolog was judged invalid and was going to be run again following the BHC Acoustilog. However, the hole's condition deteriorated to the point that extensive logging was unjustified. When the Spectralog tool would not pass a bridge at 8,100 ft, additional open hole logging (Spectralog, Microlaterolog and Variable Density Log-Signature with SP) was cancelled. The Spectralog and Compensated Neutron or Neutron Lifetime Log will be run in casing prior to performance.

G.C. Kukal and W.J. Brown (CER Corporation) assisted in logging Rainbow Resources No. 1-3 Federal well, Sweetwater County, Wyoming. The well was logged on January 19 as follows:

- Dual Laterolog/Simultaneous Micro-SFL/Caliper/Gamma Ray;
- Dual Induction Log - SFL/SP-GR;
- Simultaneous BHC Sonic - Caliper;
- Variable Density Log;
- Dipmeter;
- Formation Density - Caliper/Simultaneous Compensated Neutron/Gamma Ray; and
- Natural Gamma Spectroscopy.

Field prints were delivered on location. CYBERLOOK Log was computed over the interval 3,650 to 11,420 ft and the CYBERDIP Log was run from 12,850 to 11,850 ft. Logging was completed on January 20.

4.2.4 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 joint 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 in the Introduction, 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.

Table 4-3 is a summary of the drilling activities in the four areas of interest during the reporting period.

Table 4-3. Summary of Drilling Activities from October 1979 through March 1980

	Greater Green River	Northern Great Plains Province	Piceance Basin	Uinta Basin
Development				
Producers	85	112	63	20
D&A	15	34	4	1
Wildcats				
Discoveries	29	14	9	2
D&A	28	36	4	10
New Locations				
Development	119	80	72	31
Wildcat	40	39	16	4
IPF (MCFD)	142,358	61,030	28,629	25,615
Total IPF (MCFD)				257,632

4 . 2 . 5 C K G E O E N E R G Y C O R P O R A T I O N

The final report has been issued for contract No. ET-78-C-08-1601 (Reservoir Characteristics in the Uinta Basin Gas Wells).

Data continued to be processed for the Green River and Wind River Sandstone Geometry Study. Corehole DOE-GC-1 information is being coordinated with Seismic International and Sandia Laboratories' Seismic Program.

This experiment will attempt to show that new high resolution dipmeter logging tools can determine paleocurrent directions from small scale sedimentary structures in lenticular sands. It is known that paleocurrent directions correlate with the long axis of sandstone lenses. Thus, if logging idrection data correlates with the long axis and the hydraulic fracture direction is known, fracture size can be optimized for lenses from tight gas development wells.

The Himes Drilling Company rig was mobilized to the DOE GC-1 corehole. The fill was blown out and coring started at 663 ft. The hole was conventionally cored to about 800 ft, where an attempt was made to commence cutting 200 ft of oriented core.

Several coal beds were cored in the Neslen, with one 10 ft thick bed. No indication of this bed had been previously noted.

Coring was terminated at 1,010 ft; recovery was 98 percent. The hole will be reamed to about 6-1/2 in. diameter, mudded up and logged from TD (1,200 ft) up to 32 ft (bottom of surface pipe).

The core was photographed and described at the site before being shipped to USGS in Denver for slabbing and detailed description. Additional field work to tie in the seismic work should be completed by the end of April.

4 . 2 . 6 M U L T I - W E L L E X P E R I M E N T

This experiment's objectives are to obtain a comprehensive geologic characterization of a lenticular, low permeability reservoir in the western United States and to evaluate state-of-the-art and developing technology for the recovery of gas from tight reservoirs. Activities in this reporting period have focused on experiment planning and site selection and acquisition.

Various planning activities have resulted in a detailed experiment plan. The plan is in a loose-leaf notebook form which can be continually updated as further planning and progress permit. Sandia and CER personnel

have responsibility for different activities which form separate sections of the report. Most effort has occurred in the areas of geology, drilling and coring, core handling and analysis, logging, stress testing, and formation testing. The multi-well experiment Technical Review Panel met on October 31, 1979 and March 25 and 26, 1980 as part of a continued development of these plans.

A major planning meeting was held on January 15-17, 1980 in Albuquerque, New Mexico with thirty-five key people in attendance. The objective was to initiate and develop a network, showing estimated time and responsibility for six areas: site acquisition, drilling, core handling and analysis, logging, well testing, and stress testing.

CER Corporation investigated a number of possible sites in the Southern Piceance Basin area of Colorado and assessed these against a set of criteria developed early in the program. The site selection was eventually narrowed to three locations:

- Exxon Vega Site Sec. 28, T9S, R93W,
Mesa County, Colorado
- Union Oil Company In the Buzzard Creek Unit,
2 miles north of the Exxon
site
- Northwest Exploration Company Sec. 20, T6S, R94W,
Garfield County, Colorado

A final review of the sites was made at the March 25 and 26 meeting in CER Corporation offices. The meeting confirmed the recommendation that the Northwest Exploration Company site is the most suitable from both a geologic standpoint and from a year-round operational basis. CER Corporation is presently meeting with Northwest Exploration and the surface landowner to obtain the necessary legal agreements so that operations can start as soon as possible. It is believed that field activities can commence in late summer.

4 . 3 RESEARCH AND DEVELOPMENT BY ENERGY TECHNOLOGY CENTERS AND NATIONAL LABORATORIES

4 . 3 . 1 BARTLESVILLE ENERGY TECHNOLOGY CENTER

The general objective of the BETC research effort is to determine parameters critical to successful application of stimulation technology for hydrocarbon production from marginal reservoirs. This includes the evaluation of potential productivity of low permeability and low porosity formations by applying new or innovative logging techniques and interpretations. The project will also examine the degree of formation damage due to presence of hydraulic fracture fluids and proppants.

IMPROVED PRESSURE CORING SYSTEM -- SANDIA LABORATORIES, ET AL

Core Retriever Design and Test

During the reporting period, recovery rates for cores under pressure continued to improve. Recovery rates of 90 to 95 percent appears to be probable when all the core barrel modifications are fully implemented.

Data analysis on 120 pressure coring runs indicated that most of the problems resulted from pressure regulator malfunctions. A redesigned regulator section will be field tested.

The ball seal was redesigned to incorporate two O-rings in series to give a statistically better chance of sealing the ball.

Occasionally, the ball valve mechanism has been jammed by the core. When Stratapax® bits are used, the core breaks much closer to the bottom of the hole, resulting in a longer core. To compensate for this, several components of the pressure coring system are being redesigned to permit increased downward travel of the ball valve to eliminate clearance difficulty.

Core Fluid Tests

The low-invasion fluid has been useful in obtaining better pressure cores. Even though it is an added expense, operators are requesting it, and reports from Shell's petrophysicists indicate that it provides additional core handling benefits during core analysis.

Viscosity tests of the low invasion fluid at 350°F indicated that base mud and particulate mud decomposed and had viscosities as low as 10 to 15 cp. However, mud containing an MgO additive had a viscosity of approximately 80 cp and regained significant viscosity upon cooling after the tests, while the other muds did not. These results confirm that the low invasion fluid remains usable at temperatures up to 300°F if the MgO additive is present in small amounts.

Calcium bromide has been evaluated as a replacement for calcium chloride as the freezing point depressant. Laboratory tests showed that the filtration characteristics appear unchanged while the fluid did not freeze at dry ice temperatures. This may further simplify the preparation of cores for analysis.

Bit Design and Fabrication

A one-piece diamond compax core bit was designed based on cutter elements which were diffusion bonded to steel studs. The bit is designed for use with low invasion coring fluid and utilizes a build-in dam to reduce core washing and invasion. A two-piece diamond compax core bit, fully interchangeable with the Sandia one-piece design, was also completed.

More than 120 pressure coring runs have been completed, mostly in the Denver City, Texas area. Industry response to the improved coring capabilities continues to be good and a version of the single piece diamond compax core bit will continue to be offered by DOWDCO as an option for standard coring operations. Since bit and barrel improvements have been made, successful pressure core retrieval has increased from 75 percent in 1978 to the present 90 percent.

Presently, the new Sandia designed core bit bodies are scheduled for completion in May. Plans to diffusion bond polycrystalline diamond cutters to the pilot bit bodies are being formulated with Industrial Materials Corporation and are scheduled as soon as their autoclaves are again operational; rework of the first PDC bit has been completed with the reworked bit scheduled for field testing in May.

Polycrystalline Diamond Core Bit Tests

The single piece bit, tested in the laboratory and twice in the field, was used on two wells to drill 41 cores. Good bit life was demonstrated by these tests. The bit was modified to use only stud mounted cutters in core drilling tests. Penetration rates were reduced, so further modification is planned to regain the lost penetration capability. Gage trimmers were added to the bit body to reduce torquing in the original design to an acceptable level.

One advantage of the improved PDC pressure coring system is that Pressure Coring, Inc. can now obtain excellent cores in lightly consolidated formations where core recovery was very poor in the past.

LOGGING STUDIES

Interface Conductivity Effects on Electric Logging

Experiments are in progress to determine the effect of overburden pressures on the electrical conductivity of saturated cores. Initial results indicate relatively large increases in observed core resistance as a function of increasing confining pressure.

The cation exchange capacity (CEC) has been determined for 33 samples from cores of the J.J.C. Paine, 1-0296 Federal, and Twin Arrow, C&K 4-14X wells. Correlation of these CEC values with gamma ray log, clay analysis, and surface-area data is in progress.

In general, the CECs for samples from the J.J.C. Paine well are high, whereas those from the Twin Arrow well are relatively low. The standard ammonium acetate technique (ph = 7.0) was used for all CEC determinations.

Sixty samples from five other wells within the Western Gas Sands Project area were analyzed for CEC, γ -ray count (potassium-40, uranium and thorium), mineral content and surface area. The initial results are given below.

- CEC versus Surface Area:
The slopes of the CEC versus surface area plots are shown in Table 4-4. If there is to be a strong, predictable correlation between CEC and the surface area of a sample, these slopes should be the same regardless of the clay type. The slope of the data for the Pacific Transmission well is considerably greater than the remainder. These other four wells have a mean slope of 175 ± 28 m/meq, and slope of the Pacific Transmission well is 5.9 standard deviations greater. The correlation coefficient is 0.94. This "anomaly" will be interpreted when the remainder of the data is obtained.
- Measured CEC (ammonium acetate technique versus Calculated CEC (from clay analysis):
Typical values of the CEC/g for various constituent clays were used to calculate the CEC of each sample. As seen in Table 4-5, the ratios of the calculated-to-measured CEC are not similar. The samples from J.J.C. Paine well were high in montmorillonite, much higher than any other well, indicating that the low ratio for this well may be due to an under estimation of the montmorillonite CEC/g value. An over estimation of the CEC/g values for the low-CEC clays could explain the high ratios of the remaining wells. Since the CEC/g values for clay types are actually ranges, the CEC and clay analysis data can be used to calculate the best CEC/g values for the various constituent clays found in this geographic region.

- **CEC Versus the Potassium-40 Natural Gamma Count Rate:**
A summary of the slopes (pico curies/meq) for the five wells is given in Table 4-6. The correlation for the J.J.C. Paine, Pacific Transmission and Twin Arrow data is poor. It is known that the Pacific Transmission and Twin Arrow wells contained KCl water at the time the gamma ray logs were run, indicating that the wells were probably drilled with KCl-based fluid which probably exposed the core material to KCl during the coring process. This would probably cause the potassium-40 count rate to not be indicative of the clays present. The mean slope with 345 ± 163 picocuries/meq) or without (338 ± 20 picuries/meq) the CIGE and J.J.C. Paine data is about the same, although the standard deviations of the two means are very different. The variable potassium content of the clays and other potassium-containing minerals probably make potassium-40 correlations with the CEC qualitative at best.

Table 4-4 Slopes of CEC Versus Surface Area Data For Several Wells Within the WGS Project Area

Well	Slope* m ² /meq	No. of Data
Mobil PCU F31-13G	140	4
Joseph J. C. Paine 1-0296 Federal	174	12
Twin Arrow C&K 4-14X	207	19
Pacific Transmission Supply 24-19 Federal	339	13
CIGE 21-15-10-22	181	5

* Through origin.

Table 4-5 Comparison of Measured and Calculated CEC

Well	Measured CEC * Ave, meq/q	Calculated CEC * Ave, meq/q	No. of Data	Calc. CEC Meas. CEC
Mobil PCU F31-13G	.0266	.0402	4	1.51
J. J. C. Paine 1-0296	.0918	.0773	9	0.84
Twin Arrow C&K 4-14X	.0226	.0325	21	1.44
PTS 24-19 Federal	.0190	.0308	13	1.62
CIGE 21-15-10-22	.0106	.0265	1	2.50

* From ammonium acetate technique, pH 7.0

** Calculated from clay analysis and typical values of CEC/g for various clays (literature values).

Table 4-6 Slopes of the CEC Versus the Potassium-40 Natural Gamma Count Rate

Well	Slope pCuries/meq	No. of samples
Mobil PCU F31-13G	323	3
J. J. C. Paine 1-0296 Federal	127	12
Twin Arrow C&K 4-14X	330*	22
PTS 24-19 Federal	361*	14
CIGE 21-15-10-22	585	4

* Drilled with KCl present.

Additional measurements on shale conductivity were made using potassium brines. Many of the wells now being drilled in the tight Western gas sands are using potassium-based drilling muds to help stabilize the clays being encountered. Consequently, there has been some concern that the potassium and sodium ions may behave differently in electric logging. Models to explain the conductivity of shaly formations^{1 2 3} have been centered on the use of sodium brine.

Mapping and Contouring Water Resistivities in Western Tight Gas Sands

Salinity analyses of 136 waters from flow streams of producing gas wells in the Uinta Basin showed good correlation with those from DST waters. In particular, six DST analyses correlated with analyses of water typifying the formations tested. Three samples were from the Green River Formation, and three were from the Farrer. Both waters contained large amounts of bicarbonate ion.

One sample contained a surprisingly high carbonate ion content. Since large concentrations of bicarbonate and carbonate ions rarely exist in conjunction with each other, it appears likely that this sample was diluted with mud filtrate. Another sample, taken from the flare line, rather than from a drill stem test, had lower concentration of ions than the other two Farrer samples. It is possible this occurred due to vapor water from the reservoir condensing at the choke and moving to the flare.

The large amount of bicarbonate in the Green River and Farrer Formations may explain some of the confusion in relating the well potential to R_w . If the accompanying ion is sodium, the activity of the solution and thus the effect on an SP curve usually is close to that for a NaCl solution having the same sodium ion concentration. However, the resistivities of NaCl and sodium carbonate solutions are different. The R_w of a NaHCO_3 solution is 1.75 times greater than that of a NaCl solution having the same ion concentration.

¹Clavier, C., Coates, G. and J. Dumanoir, "The Theoretical Experimental Bases for the 'Dual Water' Model for the Interpretation of Shaly Sands," presented as paper SPE-6859 at SPE 52nd Annual Fall Conference, Denver, Colorado, October 9-12, 1977.

²Waxman, M.H. and L.J.M. Smits, "Electrical Conductivities in Oil-Bearing Shaly Sands," Society of Petroleum Engineers (June 1978), 107-122.

³Waxman, M.H. and E.C. Thomas, "Electrical Conductivities in Shaly Sands - I. The Relation Between Hydrocarbon Saturation and Resistivity Index; II. The Temperature Coefficient of Electrical Conductivity," Journal of Petroleum Technology (February 1974), 213-225.

Self potential logs in the Uinta Basin are difficult to read because of drift. But this drift can be utilized in differentiating between fluvial and lacustrine sediments. SP curves for fluvial sands are asymmetrical, with sharp gradients below the peak and gradual gradients above.

Lacustrine sands exhibit asymmetrical SP curves with sharp gradients above the peak and gradual gradients below. But variations due to interruption of ideal sedimentary cycles are to be expected.

Determination of R_w from the values of the self potential requires that the in situ temperature be known. In the Uinta Basin, a maximum-reading thermometer is always run with logging tools and the reading is recorded on the log. However, at the time of logging, the bottom hole temperature is always lower than that of the undisturbed formation, the usual discrepancy is 10 to 20°F. So, judicious use of the temperature obtained from logs means the error caused by the temperature dependency would be less than 5 percent.

In Situ Permeability

The relative gas permeabilities of core Nos. 5172, 5205 and 5220 from the Pacific Transmission Supply Company well 24-19, T33N, R114W, Sublette County, Wyoming, were measured and are plotted in Figure 4-6. The relative permeability curves show trends similar to those from the Mobil PCU F31-13G and Canyon Largo No. 256 wells.

To study the effect of partial water saturation on gas-slippage effects, relative gas permeability was measured at different water saturations as a function of mean pore pressure as shown plotted in Figures 4-7 and 4-8. An increase in partial water saturation resulted in reducing slippage effects. The slope of the straight line relating relative gas permeability and reciprocal mean pore pressure decreases as partial water saturation decreases.

The value of b , the constant associated with Klinkenberg's equation which accounts for gas slippage effects, increased with increasing water saturation. This observation, along with the results of experimental measurements of gas permeability at high confining pressure indicated that high water saturations and high confining pressure reduced gas-slippage effects. High confining pressure may close small pores which are mainly responsible for gas-slippage effects.

Measurements have commenced on core from the Mapco RBU 11-17F-S17 well, T10S, R20E, Uinta County, Utah. The results of measurements on core No. 8298.8 are shown in Figure 4-9. Gas permeabilities were measured as a function of pore pressure under different confining pressures.

The effective gas permeability of core No. 5210.3 from the PTS 24-19 Federal, T33N, R114W, Sublette County, Wyoming and core No. 8493 from the Mobil PCU F31-13G well, Rio Blanco County, Colorado was measured as a function of water saturation. The effect of mean pore pressure on effective permeability was simultaneously evaluated. The results are shown in Figures 4-10 and 4-11, respectively.

Well: Pacific Transmission Supply Co. No. 24-19 Federal

Figure 4-6 Effect of Water Saturation on Gas Permeability

Figure 4-7 Effect of Water Saturation and Pore Pressure on Relative Permeability to Gas

Figure 4-8 Effect of Water Saturation and Pore Pressure on Relative Permeability to Gas

Figure 4-9 Effect of Net Confining Pressure on Gas Slippage

Figure 4-10 Effect of Partial Water Saturation on Gas Slippage Effect, Well: PTS 24-19 Federal S19, R114W (Sublette County, Wyoming)

Experiments were conducted to establish the combined effects of high net confining pressure and partial water saturation on the gas slippage effects. Core No. 5172 from the PTS 24-19 Federal well was desaturated

Figure 4-11 Effect of Partial Water Saturation on Gas Slippage Effect, Well: Mobil PCU F31-13G (Rio Blanco County, Colorado)

Figure 4-12 Effect of Net Confining Pressure on the Gas Permeability of a Partially Saturated Core

to 43.2 percent water saturation, and effective gas permeability was measured as a function of mean pore pressure and net confining pressure. The results are shown in Figure 4-12. The slope of the Klinkenberg plot decreased from 0.37 (md)(psi) at 120 psi net confining pressure to 0.17 (md)(psi) at a net confining pressure of 2,600 psi.

It is clear, qualitatively, that the gas slippage effect (as measured by the slope of the Klinkenberg plot) is reduced at high net confining pressure for both dry and partially saturated cores. In addition, it appears that at a given net confining pressure, the presence of water in a part of the pore space has a similar effect on gas slippage.

ADVANCED LOGGING TECHNIQUES AND INTERPRETATION

Instrumentation for Formation Evaluation and Advanced Logging Techniques

A histogram distribution function fits the dielectric data of Poley et al. This function has been transformed into a distribution function of pore shapes using the techniques of Sillars. Work is now underway to evaluate the validity of the assumptions made for the transformation.

Numerical integrations are being performed using a coded two-zone solution that can be, as analytically required, reduced to the homogeneous solution already reported. Because of slow convergence, extensive transformation using analytical continuity is warranted.

Developments and Applications of a Wide-Band Laboratory Dielectric Constant Measurement System - Colorado School of Mines

A simple sample holder has been designed as shown in Figure 4-13 to operate at pressures not greater than 10 psi. The chamber will take a disc-shaped sample of 1.5 in. diameter and 0.5 in. thickness. A saturation fluid reservoir will be used for saturating samples. Fluid inlet and outlet are laterally displaced to insure maximum efficiency in saturation.

A power supply has been designed and built to actuate a mechanical beam exterior access shutter for the laser beam. Laser beam mode has been adjusted to accomplish the most uniform heating energy intensity on sample. An HP pulse generator is being integrated to develop capability of a pulsed laser beam.

Eight sandstone cores have been obtained from the USGS Core Library in Denver. Prepared samples will be washed in distilled water and dried in an oven under 105° C until weight losses are minimized. With these cores, the samples will cover a significant range of porosities and permeabilities.

A GenRad 1606B radio frequency bridge has been obtained for test and calibration measurements in the .5-50 MHz range.

Figure 4-13 Sample Holder - Saturation Chamber

Table 4-7 Sample Data for Matrix Travel-Time Measurements

Sample No.	Depth (ft)	Porosity (percent)	Matrix Density (gm/cc)	Carbonate (percent)
28	7,476.67	3.2	2.772	58
17	6,472.00	8.5	2.645	13
33	7,482.00	6.2	2.698	31

The hardware and software interface between the PDP-11 and the HP 1825 has been developed. This will enable the indexing of data files between the systems and will add capability of plotting data from PDP-11 files.

Study of Sonic, Neutron, and Density Logging of Low Permeability Gas Sands - Texas A&M University

Several preparatory steps were started to evaluate the sonic log. Whole core analyses were performed, and core plugs were obtained for analysis by scanning electron microscopy. Plugs from the Natural Buttes No. 21 well core, Uinta Basin, were used to determine the average porosity of selected intervals. These average porosities were used to correlate core depths with log depths.

To insure that the laboratory properties obtained from the plugs were representative of reservoir properties, whole core analyses began on the NBU No. 21 core. Also, new plugs were taken for examination by scanning electron microscopy.

When evaluating the sonic log, Schlumberger assumed a matrix travel time of 52.6 microseconds per ft. Using laboratory-measured porosities and sonic log travel times in zones of varying shale concentrations, actual matrix travel times were calculated. For selected intervals, these ranged from 53.2 to 69.8 microseconds per ft. Methods are being considered for correlating these travel times in individual zones and throughout the Western sands.

Velocity measurements were taken on three cores of the CIGE 21-15-10-22 Natural Buttes Unit. Physical properties of each sample are listed in Table 4-7.

Sample 28 provided the most useful data. Elastic wave propagation theory indicated that a material 100 percent saturated with an incompressible fluid would maintain a nearly constant matrix travel time over a wide range of pressures. A compressible saturating fluid would allow the porosity to decrease with increasing pressures. Water was the saturating fluid for these three samples. Sample 28 responded as expected to changes in pressure. The other two samples, 17 and 33, showed a large variation in matrix travel times with changes in pressure. Because each sample had to be exposed to air when the transducers were cemented on and when the epoxy coat was applied, it was likely that samples 17 and 33 were not 100 percent saturated with water. These samples are being redone to check this possibility.

Sample 28 also indicated that the presence of the carbonate cement might not effect matrix travel-times as expected. Normally, a carbonate has a matrix travel time of 43 to 47 micro-seconds per foot. Sample 28 had a carbonate content of 58 percent (from petrographic analysis). The matrix travel-time, however, was 63 micro-seconds per foot. Apparently, some other factor, possibly the presence of shales, which cannot be

readily identified, controlled matrix travel-times. Data from the re-saturated samples plus the other unexamined samples should provide the information.

Nuclear Magnetic Resonance Studies

A NMR logging tool under consideration uses a superconducting magnet in a 9 in. borehole. A homogeneous region shaped like a toroid can be produced several inches out into the formation. Computer calculations and actual measurements can be used for correlation purposes.

Preliminary experiments were conducted in the laboratory to evaluate several different ways of detecting uniaxial stress by acoustic velocity measurements.

A pulse generator was used to send a square pulse to a transducer sample-transducer assemblage. The output signal was processed with a spectrum analyzer and displayed with an oscilloscope. The sample was a Nugget sandstone cube, 10 cm thick which has a strong anisotropy in velocities. Shear transducers were used with the polarization direction 45° to the fast velocity direction. Uniaxial stress was added to the sample in the direction normal to the propagation direction. The initial anisotropy of the sample produced a minimum in the frequency domain on the spectrum analyzer due to interference of the two shear waves. When uniaxial stress was added, the frequency minimum was shifted due to the change of the shear velocities.

For a continuous wave method, the frequency synthesizer sent a sine wave to the transducer sample-transducer assemblage. The sample signal and the original signal were simultaneously displayed on the oscilloscope. Initially, the frequency was adjusted so that the two signals were in phase as a reference condition. When the uniaxial stress was added, the sample signal was shifted. The frequency difference to make the two signals in phase again was proportional to the velocity change due to stress.

Analytic studies have been performed which indicate that the phenomenon may be detected on same-face geometries that would be required in a bore-hole measurement. Experiments are being developed to test the same-face geometry relationships.

RESERVOIR SIMULATION STUDIES

Perform Parametric Analysis of MHF Test Data and Engineering Studies of Western Gas Sands -- Intercomp

The purpose of this research is to investigate methods for more efficient gas recovery from low permeability reservoirs. The research will focus upon factors affecting the production performance of wells that have been subjected to massive hydraulic fracture (MHF) treatments.

Intercomp's fractured gas well simulation program has been modified to simulate the behavior of a well having multiple vertical fractures. The program will now simulate the pressure-transient behavior of a well-bore intersecting two fractures of equal length. It assumes the two fractures intersect at an angle of 90° .

Final drafting on a set of short flow time type curves is in progress. The curves are for use in analyzing pressure buildup data from fractured, low permeability gas reservoirs. A computer model of a fractured gas well has been used to develop test problems for use with the type curves. The pressure buildup data from the model appears to match more than one of the type curves in some cases. This results in values for permeability, k , and fracture half-length, X_f , that are not unique. The multiple matches are covered by the similar shapes of the curves.

When the value of k and X_f calculated using the wrong type curves are used in the model, the original buildup curve is not reproduced. The model generates a unique set of data for a given k and X_f . An attempt is being made to find a test for uniqueness to use with the type curves.

The feasibility of conducting lens continuity tests in the Western Gas Sands Project multi-well experiment is being studied. The test will involve two wells. One well will be alternately produced and shut in. This will cause a series of pressure pulses to be sent through the reservoir. The second well will be used as an observation point in the reservoir. Reservoir permeability and porosity compressibility product of the reservoir can be calculated from the arrival times and amplitudes of the pressure pulses.

ROCK-FLUID INTERACTION

Gel Fracture Fluid Characteristics

A significant percentage of the material in a degraded or broken 40 lb (0.48 wt percent) low-residue guar still has a molecular weight of 10^6 or greater. Improved resolution in the 2×10^3 and 2×10^6 molecular weight region indicates that the percentage remaining above a molecular weight of 10^6 may be even greater than previously thought.

Maximum percentage of selected molecular-weight fractions in a 40 lb, low-residue guar degraded with $(\text{NH}_4)_2\text{S}_2\text{O}_8$ are:

Molecular Weight	Maximum Percent
5×10^5	27.0
7×10^4	3.7
4×10^4	2.3
1×10^4	1.8
1×10^3	1.1

The high molecular weight of the fracturing gel remaining after breaking may prove to be one of the reasons for lower-than-expected production rates after stimulation.

Proppant Embedment

Efforts are now underway to examine the embedment of 20-40 and 40-60 mesh sintered bauxite proppant into formations of various hardnesses. This will supplement data previously reported with 12-20 mesh on rock from the Mesaverde Formation.

Determine Feasibility of Fabricating Light-Weight Proppants for Application in Gas Oil Well Stimulation -- Terra Tek

This study is to determine the feasibility of fabricating light weight proppants for application to deep gas and oil well stimulation, and select viable materials and manufacturing techniques.

New specifications have been selected for light-weight proppants:

- density of less than or equal to 2 gm/cm^3 ,
- the ability to withstand pressures up to 20,000 psi at brine temperatures to 400°F , whether it is placed as a partial monolayer or as a multilayer in hard formation,
- chemically inert in brines at 400°F ,
- have an average Krumbein roundness of 0.8 or higher, and
- have a grain-size distribution of the present 20-40 wash sand.

Three proppants have been given consideration: porous ceramic, hollow ceramic, and composite bead, with an inner core of light-weight material and outer layer of ceramic. The main criterion is that the material sustain high loads in corrosive, high-temperature environments.

The basic proppant geometry to be considered is that of an assembly of perfect spheres with a uniform characteristic diameter. While the usual mesh specification will actually give a distribution of diameters, the first consideration will not admit this possibility. The characteristic diameter of the usual 20-40 mesh sieve will be taken as midway between these spacings, thus approximately 0.6 mm. The spheres themselves will be solid, hollow or a two-layered sphere with a light weight core.

Drilling-Mud Particle Size Distribution

The measurement of particle-size distributions was continued for several different concentrations of available drilling muds in 2 percent KCl solutions, including two field samples. During the measurements, an

attempt was made to keep the particle concentrations of these mixtures within a narrow range to insure the most accurate results with the Coulter TA II Particle Counter. However, such extreme dilutions were needed at times to achieve this that the results were more reflective of the 2 percent KCl solution, rather than the suspended mud particles.

A new mud sample (No. 6494) and 2 percent KCl solution were investigated.

Table 4-8 shows the population means and modes of samples of this mud mixture to be generally lower than those of drilling mud No. 6325. However, the volume means, modes, and medians are generally somewhat higher. Reproducibility of the data was generally very good.

Drilling and mud samples from the PTS 3-10 A (Sweetwater County, Wyoming) and PTS 22-12 Federal (Rio Blanco County, Colorado) were analyzed for particle-size distribution. All three of the drilling mud samples were diluted with 2 percent KCl solutions to reduce the total number of particle counts per ml to approximately 100,000. Thus, the resulting statistical parameters could all be compared on the same population basis.

Drilling mud from the PTS 3-10A (11,557 ft) well appeared to have lower values for nearly all of the parameters calculated with a mean diameter of 8.4 microns on a volume basis.

Muds from the PTS 22-12 Federal well averaged 11.0 microns on a volume basis. The biggest differences occurred in the parameters which were calculated on volume basis.

4 . 3 . 2 G A S R E S E A R C H I N S T I T U T E

The Gas Research Institute has initiated a project for field evaluations of reservoir fracturing to increase the producibility of tight gas reservoirs by providing essential field data. GRI will coordinate their proposed work with DOE-funded projects to increase the efficiency, cost-effectiveness and scope of research in critical WGSP-related areas of resource characterization and stimulation technology.

Preparation of a proposal for a tight gas sands data base continued during the reporting period. This proposal will be to:

- develop a geologic and engineering data base for the tight sand basins,
- conduct geologic studies of the secondary basins, and
- provide access to a convenient data retrieval system by all segments of the industry.

Table 4-8 Drilling Mud No. 6494 (In 2% KCl Soln.)

Run No.	Total Particle Counts (Per Ml)	Mean (microns)	Population		S.D. (microns)
			Mode (microns)	Med. (microns)	
1	96,420	2.65	1.41	2.29	1.82
2	90,706	2.84	1.41	2.48	1.87
3	98,376	2.70	1.41	2.34	1.85
4	100,066	2.70	1.41	2.32	1.85
5	99,384	2.69	1.41	2.32	1.84
6	100,440	2.63	1.41	2.28	1.81

Run No.	Total Particle Counts (Per Ml)	Mean (microns)	Volume		S.D. (microns)
			Mode (microns)	Med. (microns)	
1	96,420	11.62	14.63	12.40	1.91
2	90,706	11.51	16.56	12.43	1.82
3	98,376	11.09	16.00	11.98	1.81
4	100,066	11.16	15.28	12.07	1.81
5	99,384	11.20	14.97	12.21	1.80
6	100,440	11.63	16.06	12.34	1.92

EVALUATION OF SEISMIC DATA FOR DETAILED STUDIES OF LENTICULAR SANDS

A project has been funded to perform seismic research using recently developed techniques to determine if the geometry and character of lenticular sands at depth can be determined. Sandia Laboratories has proposed to obtain data in the Uinta Basin that will complement and extend outcrop and core hole studies being made under contract to DOE.

The Bryson Canyon No. 1 site in the Uinta Basin was finalized for the field experiment. Well log data near the site have been obtained and assimilated, approval was obtained from the Bureau of Land Management, and requisite bonds were posted.

A basic geometric model of channel size, primarily height and width as well as frequency in various members of the Mesaverde Group, has been established.

The Seismic Modeling Group spent a week at USGS in Denver working on the seismic computer model, and work was completed on a seismic model study of channel sandstone bodies representative of those at the study site in the Uinta Basin. The model study incorporated various channel sizes, number of channels, and separations between the channels. Results of the study will be used in interpretation of the results of the forthcoming seismic survey.

Field activities at the site were completed by the end of December. Early tests involving shooting primacord on conspicuous sand channel outcrops were also completed. The top of the survey site was recorded to provide information on travel times to the channels plus frequency, velocity, and attenuation characteristics of the section.

CORING AND LOGGING OF PACIFIC TRANSMISSION SUPPLY COMPANY NO. 22-12 FEDERAL WELL

Coring of Mancos B (funded by GRI) commenced October 1, 1979. No problems were encountered and the operation took six days to complete. A total of 120 ft of 4 in. core was cut from 11,669 to 11,789 ft, with recovery totalling 118.3 ft, or 99 percent. Portions of the core were shipped to Lawrence Livermore Laboratory, Los Alamos Scientific Laboratory and Bartlesville Energy Technology Center for analyses, with the bulk being sent to Core Laboratories, Inc. in Casper, Wyoming. Upon completion of conventional analysis by Core Laboratories, the samples will be shipped to the USGS in Denver for geologic and mineralogic analyses and archiving.

Logging operations on the No. 22-12 Federal took place October 17-19, 1979. In addition to the basic suite of logs run by the operator, CER Corporation prescribed two additional geophysical well logs and special data processing.

CORING AND LOGGING OF PACIFIC TRANSMISSION SUPPLY COMPANY NO. 3-10A FEDERAL WELL

DOE-funded coring of 187 ft of the Mesaverde in this Sweetwater County, Wyoming, well was successfully conducted November 9 - 13, with recovery of 166.7 ft (89 percent). Logging operations, funded in part by GRI, were carried out immediately thereafter without problems. Core analysis, as well as log and other data evaluation, is in progress.

CORING AND LOGGING OF RAINBOW RESOURCES, INC. NO. 1-3 FEDERAL WELL

Field work commenced December 29 on this project in Sweetwater County, Wyoming, funded jointly by GRI and the operator. Coring operations concluded January 17, and logging took place January 19-20. A total of 310 ft of Mesaverde core was recovered from the 339 ft cut (91 percent recovery). Core samples were cut intermittently from 12,398 to 13,503 ft.

The bulk of the core recovered was shipped to Core Laboratories, Inc. in Casper, Wyoming, for commercial core analysis. Certain whole core samples were sent to BETC and LLL, and chip samples were shipped to Sandia Laboratories for special analysis and experiments.

4 . 3 . 3 L A W R E N C E L I V E R M O R E L A B O R A T O R Y

LLL is conducting a theoretical-experimental program on the hydraulic fracturing process. A primary objective of the program is to determine those reservoir properties or characteristics which can control the created fracture geometry. Theoretical models have been applied to analyze some aspects of the dynamics of fracturing near material interfaces.

Small scale laboratory experiments are performed to study the effects of frictional characteristics on hydraulic fracture growth across unbonded interfaces in rocks. Various lubricants and mechanical preparation of the interface surfaces are used to vary the coefficients of friction on the interface surfaces. It is found that the frictional shear stress that the interface surface can support determines whether a hydraulically driven crack will cross the interface.

THEORETICAL ANALYSIS

Theoretical calculations are being used to analyze some aspects of hydraulic fracture penetration through a frictional interface. Comparison of these results with laboratory experiments will determine how the critical frictional levels result in stress concentrations that allow fracture penetration of the interface. In previous status reports it was shown that due to frictional slip, the stress intensity factor changed as a pressurized crack approached an interface. These calculations were performed with relatively coarse grids, which did not allow

sufficient detail to evaluate stress concentration effects across the interface. The current calculations use a finer grid.

Two-dimensional models are being developed to analyze the effect on hydraulic fracturing of overpressure in the productive formation. It has been suggested that overpressure can help induce a hydraulically driven fracture to propagate into the surrounding non-productive layers.

Two sets of calculations were made with the time dependent finite element model to quantify the changes in material response due to a variation in density. In the problem geometry of Figure 4-14, a crack initiates at $x = 0, y = 0$, propagates bilaterally at half the dilatational wave speed for a distance "c", and stops. The result is the time history of the y displacement of a point just behind the final position of the right crack tip. In the calculations, the elastic constants did not vary across the interface but in some cases the densities did. The Lamé constants were set at 30 GPa each and the density of material 1 (Figure 4-14) was always 2.7 gm/cm^3 . However, the density of the second material was varied from 0.3 to 24.3 gm/cm^3 . Obviously the largest value of density does not correspond to any known material, but a large variation was made to determine the magnitude of the effect of density variation on material overshoot.

The results are given for two final crack lengths. In Figure 4-15 perpendicular nondimensional displacement is plotted as a function of nondimensional time (crack initiates at $t_d = 0$ and crack stops at $t_d = 1$) when $c/L = 0.6$. Thus the crack stops approximately as scaled in Figure 4-14. The rather large change in density did not affect the material response to a large degree.

A similar plot is shown in Figure 4-16, but here the crack propagates to the interface and stops ($c/L = 1.0$). The variation in material response is larger for this case than for the previous one and the line corresponding to the least dense material crosses the other two lines at later time. There is a change in material response, but even in the last case, this change is not large when viewed as a fraction of the maximum displacement.

FLUID FLOW-CRACK GROWTH INTERACTION

The development of a theoretical model to calculate the flow and pressure distribution in a propagating hydraulic crack continued.

Experiments have been performed to evaluate several lubricants that will reduce the frictional properties of smooth, unbonded interfaces. Of the lubricants tested, the one which most significantly reduced the friction was a compound called "Hi-Temp C-100 Anti-Ball Lubricant." Friction experiments using the three block sandwich apparatus (Figure 4-17), were performed on blocks of Indiana limestone whose smooth interface surfaces had been coated with a thin layer of this lubricant. It was found that the relationship between the frictional and normal stresses across the interface could be represented by:

Figure 4-14 Geometry of Time Dependent Crack Problem

Figure 4-15 Displacement perpendicular to the crack when $c/L = 0.6$ (the crack does not reach the interface).

Figure 4-16 Displacement perpendicular to the crack when $c/L = 1.0$ (the crack stops at the interface).

Figure 4-17 Experimental Setup to Study Crack Growth

$$fr - 30 + .125N$$

Hydraulic fracture experiments were then performed to determine the threshold normal stress across an unbonded interface lubricated with C-100. The threshold stress was found to be near 2,200 psi compared to 650 psi for the dry, unlubricated surface. These experiments on dry and lubricated unbonded interfaces indicate that the interface in limestone must be able to support a shear frictional stress in the range of 300 to 350 psi in order for a hydraulically driven crack to penetrate it.

ROCK MECHANICS MEASUREMENTS

Pressure-volume measurements continued on samples of Mesaverde sandstone from Rio Blanco County, Colorado, and are 80 percent complete. Testing began on the high pressure system for simultaneous ultrasonic velocity measurements in multiple directions under confining pressure. Preparation began on test specimens of Mesaverde shale and sandstone from Colorado and Wyoming for these ultrasonic measurements.

GEOLOGY AND GEOPHYSICS

Work during the reporting period consisted of a review and evaluation of Piceance Basin data on structure, natural fractures, and mini hydraulic fractures used in attempted measurement of in situ stress. This was in Green River Formation with the following preliminary results.

- Minor folds are due to differential vertical movements rather than compression. Minor extensional normal faults are oriented parallel to the fold axis, giving an apparent lesser horizontal stress perpendicular to, and a greater stress parallel to, the fold axis.
- The major sets of natural surface fractures strike parallel to the faults and have a greater horizontal stress. "A review of the mechanics and occurrence of natural fractures in rock as applied to the development of the tight western gas sands," was revised and delivered for processing as an LLL report.

4 . 3 . 4 L O S A L A M O S S C I E N T I F I C
 L A B O R A T O R Y

NUCLEAR MAGNETIC RESONANCE STUDIES

The purpose of the nuclear magnetic resonance studies is to develop methods to define fluid saturation, porosity, and permeability in Western gas sands as a function of in situ stress conditions. The results will then be used to improve the downhole nuclear magnetic resonance tool design.

Figure 4-18 is a cross section of a tool design under consideration, with a plot of the magnetic field strength within the homogeneous "resonance" region and the NMR resonant frequency as a function of radial distance from the borehole centerline and depth into the formation. The solid line shows the result of computer calculations and the dotted line shows measurements on a normal wire mockup of the super-conduction magnets which were scaled to the fields in the super-conducting cases.

The NMR signal-to-noise ratio (S/N) for distances into the formation surrounding the wellbore was estimated by using the 8 in. diameter rf coil experimental data. The experiments, which estimated the S/N from a tool using superconducting magnets, were conducted using a fixed toroid and varying the size of the rf coil.

The MNR transmitter and receiver electronics were modified to eliminate intermittent operation, several internal arcs, "jitter" in the pulse length, and receiver noise. This new system has been used to observe spin-echo NMR signals from the homogeneous field region surrounding the simulated wellbore position. They are considerably easier to observe than the free induction decay signals previously utilized.

Remote NMR signals have been obtained from simulated reservoir rock in a downhole configuration. The reservoir was simulated by surrounding the borehole with glycerol-saturated sea sand. The distribution of sand was approximately:

- 33 percent between 32 and 42 mesh,
- 33 percent between 42 and 60 mesh, and
- 33 percent between 60 and 80 mesh.

Porosity for this distribution of glycerol-saturated sand was measured to be approximately 50 percent. Preliminary data are now being analyzed with further experiments planned.

4 . 3 . 5 S A N D I A L A B O R A T O R I E S

EGR INSTRUMENTATION AND DIAGNOSTIC PROGRAM

Hydraulic Fracture Characterization

In November, a borehole seismic experiment was performed on Amoco's Burnett Brothers No. 12 gas well near Carthage, Texas. Because of high temperatures in the well, a thermistor was used to monitor the temperature inside the borehole seismic unit with the intent of pumping cooling fluid to the unit when destructive temperatures were approached. However, the unit began to fail at about 7,000 ft producing erroneous

Figure 4-18 Cross Section of Design of Improved Downhole Nuclear Magnetic Resonance Tool

temperature readings. The unit failed to respond to the clamping control signals when it reached 9,490 ft, 2 ft above the top of the perforations.

A second seismic unit, which did not have the capability of monitoring temperature, was then used for the experiment. The unit was clamped at about 7,000 ft and cooling water was pumped in. The unit was then clamped at 9,490 ft and a slow pump rate was begun while 4 explosive charges were prepared. These charges produced seismic signals at a known location to determine the unit's orientation. After pumping was stopped for about 10 min, a 5 lb shot was detonated 9,000 ft from the well. The shot was detected but was of fairly low amplitude.

A 15 lb shot was also detonated at this location but produced only a small increase in amplitude. Two more 5 lb shots were detonated in different locations, each at a distance of 9,000 ft from the treatment well. Both produced low amplitude signals.

Using these known locations of the seismic source, it was determined that the seismic unit was located with the axis of one of the horizontal geophones at an azimuth of 301° , 298° , 303° and 297° for the seismic shots. With a spread of only six degrees from the four shots, it was felt that this is a very usable technique for determining orientation.

Between the explosive shots, seismic data were recorded for determining fracture orientation. These signals indicated a fracture plane whose direction was probably between $N 30^{\circ} W$ and $N 70^{\circ} W$.

The borehole seismic unit became stuck while still in the fracture valves, so the well could not be shut in for removal. The wireline attached to the seismic unit broke and the unit fell to the 9,600 ft level. A fishing trip was made and the seismic unit was removed from the well, but was dropped and broken after removal.

Sandia participated in a multifaceted experiment with Shell Oil Company at their Big Mineral Creek field near Sherman, Texas on February 26 and 27. Three wells were involved in this combined seismic and SEPS fracture mapping experiment. The main fracture was produced with 48,000 gal of fluid at 5,800 ft in the "S" sands, with an estimated radius of 360 ft.

The SEPS was fielded at radii of 1,200 and 1,600 ft (48 test probes) around fractured well No. 343. Current was injected into the formation at 5,700 ft. Two current sinks were used: the first, another well located approximately 8,900 ft to the south-southeast and the second sink was that of the fractured well casing. Although both methods produced signals of comparable strength, the fractured well casing produced waveshapes with almost no spectral distortion. The potential measurement boxes (PMB), which monitor the probe potentials, were increased to a gain of 72 db from a previous gain of approximately 42 db. Apparently this was possible because of the increased risetime of the injected current pulse and the use of shielded current wire throughout the PMB portion of the system.

Although good signals were obtained, a fracture length of 360 ft minimized the possibility of seeing this from the surface. However, the success seems to be more from the improvement of the surface current injection system.

On February 26, a breakdown test was performed in Unit No. 343. Borehole seismic units were placed in that well just below the fracture interval and in well No. 309 about 580 ft east at approximately that same depth.

The fracture signals that occurred during the breakdown pumping from well No. 343 have been given a preliminary scan. A large number of seismic signals were recorded and a much closer examination of this data will be necessary to gain an accurate conclusion as to the fracture orientation.

The next mapping test will be a breakdown test on Amoco's Patricia Pope Whaley Gas Unit No. 1 well in the Cotton Valley area near Marshall, Texas and is scheduled to take place on April 19, 1980. Further reduction in this data will resume after this test.

Electromagnetic Logging

Efforts have been directed toward evaluating the overall program feasibility and merit. Seminars concerning the modeling of the dielectric and ohmic constitutive relations were presented at BETC, Amoco, Welx, Chevron and Dresser-Atlas; and a short talk was given at the Institute of Gas Technology. Comments and criticisms concerning the modeling work and the merit of this electromagnetic logging were solicited. In general, interest by industry was universal. However, parallel acoustic programs do exist and since they have the same objective, the electromagnetic and acoustic concepts can be tested against each other.

Most companies are not willing to expend the resources needed to solve the electromagnetic problem. But they are willing to help out in their areas of expertise.

Prototype sondes now exist that provide some of the required electromagnetic data. If instrumentation problems preclude sonde development, the program may yield a valuable laboratory tool.

Borehole Resistivity System

The borehole resistivity system will be capable of ascertaining the resistivity profile surrounding a single wellbore. The formation resistivity is assumed to possess axial symmetry where resistivity is a function of the depth coordinate, Z , and the radial distance from the borehole, r . The determined resistivity profile will be used to:

- ascertain the radial extent of the borehole fluid invasion zone, from which fluid flow permeability can be determined if a mud cake flow model is assumed and if porosity has been determined,

- determine the flushed zone and virgin formation resistivities, from which porosity and water saturation can be determined if borehole fluid resistivity is measured and virgin formation water resistivity is estimated from geologic considerations,
- investigate applications in other fossil fuel programs.

The borehole mechanism will be a long cylinder with cylindrical electrodes placed at regular intervals along the exterior wall. Electric current will be injected at one electrode, with the current return at either the surface of the earth or another electrode. Potential data will be recorded at the remaining electrodes. The entire system will then be raised one electrode spacing and the sequence repeated. A large amount of potential data will be gathered, which will then be used to obtain the resistivity profile. The borehole system is shown in Figure 4-19.

As a preliminary to the full two dimensional solution, the numerical solution to the forward layered one-dimensional borehole resistivity problem was programmed and compared with the continuous one dimensional solution. Figure 4-20 shows a comparison of the continuous solution with three-layered approximations. The apparent resistivity as a function of position along the surface of the probe is given. The two-layer and continuous solutions agree closely but the one- and zero-layer approximations show visually recognizable discrepancies. This comparison gives an indication of the resolution possible in obtaining the location of the invasion front with typical field measurement accuracies.

Borehole Hydrophone System

Some analyses have been made of the data from the Sandia borehole test in area Y. The hammer blow series has been digitized and plotted and various ranges of bandpass filtering were included. A sampling period of 1 millisecond was used. Although the Nyquist frequency of this sampling rate was approximately 400 Hz, most of the energy of the signals was in the range of 100 to 200 Hz. The data was taken from hammer blows at 20 ft and 50 ft, then in 50-ft intervals to 300 ft. At 20 ft and 50 ft, the early part of the signals showed frequency content in the range of 600 to 700 Hz. However, because of the sampling rate used, very little above 400 hz was clear. Some of the signals at 100 ft and 150 ft distances were examined in more detail and clearly showed measurable differences in arrival times at the hydrophones. However, higher frequency sampling rates will be required to determine the location of signal sources with any degree of accuracy.

Assembly of the ITC system has started. A flexible cable will replace the 10-ft rigid center section to increase the ease in handling the tool.

Borehole effects, due to changes in borehole size, shape, and fluid, have a large number of combinational possibilities. Systematic studies have started from the worst-case situation where the borehole is assumed

Figure 4-19 Borehole Resistivity System

Figure 4-20 Comparison of Continuous Solution with Three-Layered Approximations

to be flooded by fluid of salinity equal to that of sea water. Data on 10, 40 and 80 MHz operations have indicated a clear trend of larger borehole effects toward higher logging frequencies.

Formation Mapping

A basic geometric model of channel size (primarily height and width), as well as frequency in various members of the Mesaverde Group have been established. This information together with available sonic and density log data from nearby wells, will be used to provide information on channel shape and size effects on the resolution of seismic data. The purpose of modeling is to evaluate seismic field parameters, such as sandstone channel thickness, multi-channel separation and seismic pulse bandwidth and their effects on the resulting seismic record sections.

An example of modeled section is given in Figure 4-21. Figure 4-21 is a display of the depth model: two 50-ft thick sand channels superimposed and separated by 400 ft. Figure 4-22 represents the reflection arrival times from each surface, excluding diffractions from the channel edges. The upper (convex) surfaces cause a spread out (diverging) reflection pattern while the bottom (concave) surfaces are shortened (focused). The focal point of the bottom surface of the lower channel is actually below the ground surface, which results in the complex crossing reflection pattern commonly referred to as a "buried focus." The "velocity pull-up" or upward warping of the flat reflection is caused by the local higher velocity zones represented by the channels. Such a presentation is a simplified means of looking at reflection; the actual recording consists of a convolution of a source wavelet with this figure, including the effects of reflection coefficients at each interface.

Topographic surveying was completed during the reporting period at the Bryson Canyon No. 1 site and shooting commenced. Initial evaluation of the data shows that the maximum useful bandwidth of the seismic data extends up to approximately 100 to 120 Hz. Analysis of shot-generated noise on records shows that ground roll when present, is dominantly 30 to 40 Hz and less. The dominant noise source, however, is the air blast which may eliminate or disrupt recording of reflections from an estimated 1,000 to 3,000 ft depth interval. A preliminary stack record among a single traverse is given in Figure 4-23. This stack has not been corrected and is only a quick look at reflection possibilities. There are several line-ups or events which correlate for some distance. A look at a synthetic seismogram generated from the CK GeoEnergy borehole (Figure 4-24) shows possibilities of several reflections from the sand section and a good reflection from the 8 ft coal seam. Processing of the site No. 1 data is continuing. Plans for laying out survey points at site No. 2 (Horse Point Site) have been developed.

DEPTH MODEL 3
WGSP SEISMIC MODELING PROJECT

Figure 4-21 Depth Model of Two Sandstone Lenses Underlain by a Continuous Sandstone Layer

DEPTH MODEL 3
WGSP SEISMIC MODELING PROJECT

Figure 4-22 Normal Incidence "Spike" Reflection Record Section for a Model of Figure 4-10

Figure 4-23 Brute CDP Stack of Traverse 2
Seismic Data - Bryson Canyon Site

Figure 4-24 Synthetic Seismogram - Bryson
Canyon Site

Dielectric Modeling

Previously a model of the dielectric and conduction currents generated when a saturated rock was subjected to a time-dependent electromagnetic field was developed. Recently, a study of partially saturated rocks was initiated. Partial saturation occurs when gas or oil replaces some of the pore water. The new model uses Archie's Rule of the form:

$$\epsilon_{\text{rock}} = (\phi S_w)^2 \epsilon_{\text{H}_2\text{O}}$$

to describe the conduction current. In this equation N , ϕ and S_w are the conductivity, the porosity and the watersaturation, respectively. The dielectric on displacement currents were again based on Sillars' work, although a decision was required as to where the water is located in the overall pore structure when saturation is incomplete. Previously, the pore structure was modeled as a distribution of spheroids with different aspect ratios. Pores could be long and thin at one extreme, or spherical at the other. If a partially saturated rock is water wet, capillary forces cause the water to seek out the pores that maximize its surface-to-volume ratio. Therefore, starting from dry rock, the long and thin pores would fill first. Using this information in Sillars' model, the dielectric "constant" is strongly frequency-dependent, even for small values of S_w , and this dispersion is in accord with data generated by Soviet investigations.

Laboratory Investigations

An experimental program has been developed to study the dielectric properties of rock samples as a function of frequency. Initially, the region of experimental interest will be in the approximate range of 0.1 to 100 MHz, which is the region of maximum dispersion of the real and imaginary parts of the dielectric constant. In this regime, two distinct experimental techniques can be used which would indicate the accuracy of the experimental results. The first method is a standard bridge technique: the real and imaginary parts of the dielectric constant of the rock sample are found by using a variable resistor and capacitor to balance the bridge. The second method determines the dielectric properties of the rock sample by measuring the attenuation and phase shift of an applied sinusoidal signal of given frequency through the rock.

Equipment, such as bridges, signal generators and other related items, has been carefully examined to begin setting up a laboratory for the dielectric measurements.

Probe Modeling

The evaluation of Hankel functions with complex arguments has been improved to an accuracy of better than the sixth significant digit. After the

accuracy was assured, numerical integrations were improved to perform 40 to 200 times faster. The third major completed task was plotting sub-routines for displaying inversion curves.

Responses of coils in a borehole are generally expressed in terms of the refractive index which quantifies the wave-front propagation velocity and attenuation rate. The refractive index of a formation becomes the square root of the complex dielectric constant when the magnetic permeability of a formation is assumed the same as that of an empty space. A set of universal curves has been completed to evaluate the refractive index of a formation when coil responses are known. For the purpose of interrogating all possible formations, three receiving coils have been selected at 10, 20 and 30 times the coil diameter from the transmitting coil. As soon as the normalized responses of these coils are measured, the formation parameters can be readily evaluated from three refractive-index charts. The utility of these charts is being documented.

Effects of borehole fluids are being evaluated to quantify the extent of perturbation to coil responses. Preliminary results indicate that borehole effects are negligible if operating frequencies are low and formations are not too lossy. In general, borehole effects are quantifiable as long as the parametric variations can be assigned realistically.

4 . 4 F I E L D T E S T S A N D D E M O N S T R A T I O N S

4 . 4 . 1 B A C K G R O U N D

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 4-9 summarizes completed and active WGSP MHF treatments. Progress of these projects is presented in the following sections.

Table 4-9 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		Ratio
							Before	After	
AUSTRAL Piceance, Mesaverde	7S/94W/Sec 3 Garfield Cty, Colorado	Federal 3-94	6,198-6,333	8-13-76	420,000	226 Gel	35	62	1.8
			5,170-5,630	8-25-76	720,000	316 Gel			
CONSORTIUM MANAGED BY CER CORPORATION Piceance, Mesaverde	3S/98W/Sec 11 Rio Blanco Cty, Colorado	RB-MHF-3	8,048-8,078	10-23-74	400,000	117 Gel	60	60	—
			7,760-7,864	05-02-75	880,000	285 Gel	—	40	—
			5,925-6,016	04-04-76	815,000	400 Gel	42	160	3.8
			5,851-5,869	11-03-76	448,000	228 Gel	57	70	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
			10,120-10,780	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	— —	Water Water	— —
	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	06-22-77	580,000	316 Gel	300	800	2.7
			9,392-9,538	08-24-77	600,000	260 Gel	700	2,600	3.7
			8,765-8,972	05-10-78	388,000	150 Gel	479	430	—
			8,163-8,650	07-06-78	660,000	288 Gel	—	360	—
			7,704-7,794	09-07-78	218,000	120 Gel	—	180	—
			7,324-7,476	11-15-78	700,000	365 Gel	1,000	2,000	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 488-4-1	6,150-6,312	10-22-76	766,000	276 Gel	57	130	2.3
			5,376-5,960	11-30-77	243,000+ 22,500 Beads	164 Gel	80	350	4.4
WESTCO Uinta, Mesaverde	10S/19E/Sec 34 Uintah Cty, Utah	Home Fed. No. 1	10,014-10,202	12-21-76	500,000	248 Gel	33	155	4.7
			7,826-9,437	10-01-76	600,000	412 Gel	40	Water	—

RIO BLANCO MASSIVE HYDRAULIC FRACTURING EXPERIMENT

EY-76-C-08-0623

CER Corporation
Las Vegas, Nevada

Status: Awaiting Advisory
Committee Decision

Interagency Agreement Date:
Anticipated Completion Date:

June 19, 1974
December 31, 1978

Project Cost (estimated):

DOE	\$1,975,000
Industry	1,630,000
Total	<u>\$3,605,000</u>

Principal Investigator:
Technical Advisor for DOE:

G. R. Luetkehans
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 C E R C O R P O R A T I O N

DOE Contract No. EY-76-C-08-0623 was awarded to CER Corporation in March, 1974. The original contract provided for the drilling of a new well and two MHF treatments. Contract modifications added two additional MHF treatments and extended the terms of the contract.

Field activities on the RB-MHF 3 well have been suspended. CER Corporation transferred the MHF well to an operator who will attempt to complete the well, commingle the previously fractured zones, test the well and provide the data to the industrial participants and DOE.

WATTENBERG FIELD

DE - AC08 - 77ET12046

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	<u>\$319,754</u>
	Total	\$394,754

Principal Investigator: David Wilson
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 C O L O R A D O I N T E R S T A T E G A S
C O M P A N Y

Cyclic injection of dehydrated gas and production from the Miller No. 1 and Sprague No. 1 wells continued during the reporting period. A diaphragm regulator was installed in December on the suction side of the compressor to eliminate shutdowns due to low pressure.

The DOE test trailer arrived on location at the Miller No. 1 well on January 10. Both the Miller No. 1 and Sprague No. 1 wells were shut in and all cycling operations were halted on January 12. Both wells began drawdown in preparation for measurement of BHP. Initial pressure at the Miller No. 1 was approximately 1,600 psi.

Some wet gas was injected prior to shut in.

BHP measurements began February 1 at the Miller No. 1 well, and on February 19 at the Sprague No. 1 well. On February 22, the BHP at the Miller No. 1 well was 1,260 psi compared to the 1,115 psi achieved during the initial BHP measurement made prior to cyclic injection and withdrawal. Measurements continued to March 7.

No BHP data was available from Sprague No. 1 well.

For comparison, the Miller No. 1 well was drawn down again from March 7 to 15 for a second BHP buildup measurement. The buildup curves were similar.

See Figures 4-25 and 4-26 for graphic display of the production and injection volumes and associated BHP of the Miller No. 1 and Sprague No. 1 wells.

Figure 4-25 Production and Injection Volumes and Associated Pressure of CIG Miller No. 1 and Sprague No. 1 Wells

Figure 4-26 Production and Injection Volumes and Associated Pressure of CIG Miller No. 1 and Sprague No. 1 Wells

DOE WELL TEST FACILITY

DE-AC08-79-BG01569

CER Corporation
Las Vegas, Nevada

Status: Operational

Principal Investigator:
Technical Advisor for DOE:

R. L. Mann
C. H. Atkinson

OBJECTIVE

The DOE Well Test Facility, consisting of two vehicles, will provide a deep well instrumentation and investigation system to monitor and evaluate the productive potential of all types of wells.

4 . 4 . 4 D O E W E L L T E S T F A C I L I T Y

The DOE Well Test Facility remained at Rio Blanco Natural Gas Company No. 397-19-1 Government well site until mid October. The facility and personnel had been on site since early July to acquire reservoir data and to provide analytic support for the joint GRI/RBNG fracture experiment.

The final buildup test commenced on October 5 following a 10,000 gallon, 15 percent MSR breakdown. The data are presented in Table 4-10. Figure 4-27 is a Horner plot of the BHP buildup data. A flow capacity of 5 μ d-ft is indicated by the last few data points.

It has been determined from four BHP buildup tests that the formation flow capacity is between 4 μ d-ft and 20 μ d-ft, and in all probability less than 10 μ d-ft. This indicates a reservoir of insufficient quality to effect a valid and meaningful fracture stimulation experiment. On October 16, after termination of the tests, the Well Test Facility went into temporary storage at the DOE facility in Grand Junction, Colorado.

In January the facility was transported to CIG's Miller No. 1 well, Wattenberg field, Weld County, Colorado. The facility acquired BHP and flow rate data for a drawdown test that commenced January 18. The well flowed for 12 days and was subsequently shut-in on January 30. A total of 5,387 MHF of gas was produced for an average flow rate of 450 MCFD.

The BHP buildup test being performed on Miller No. 1 ended March 8th and included a total buildup time of about 600 hours. A second drawdown of Miller No. 1 commenced in mid March followed by another BHP buildup test. This second test was necessary in order to assure that perturbations that occurred in the initial drawdown would not adversely affect the buildup results, and thus hamper later testing comparisons.

**Table 4-10 BHP Buildup Test Commencing October 5,
RBNG No. 397-19-1 Government Well**

**Net Gas Pay = 1.00 ft
Well Radius = .2100 ft
Gas Specific Gravity = .69000
Carbon Dioxide = 0.0000 mol pct**

**Formation Porosity - 7.5000
Bottom Hole Temp. = 226.0°F
Hydrogen Sulfide = 0.0000 mol pct
Nitrogen = 0.0000 mol pct**

**Buildup Test
Flow Time: 30.00 hrs.
Flow Rate: 15.00 MCFD**

Time (ΔT) (hrs)	Horner Time	Pressure (psi)	Slope (psi/ cycle)	P-Star (psi)	kh (μd-ft)	Skin
26.00	2.15	684.0	131.3	771.8	417.0	.73
48.50	1.62	787.0	1,703.0	1,247.0	317.0	-2.11
50.00	1.60	1,000.0	8,940.0	2,730.0	58.9	-1.59
56.00	1.54	1,044.0	2,557.0	1,521.0	20.5	-1.96
64.00	1.47	1,095.0	2,790.0	1,563.0	18.7	-1.95
72.00	1.42	1,142.0	3,040.0	1,602.0	17.0	-1.94
78.00	1.38	1,173.0	3,111.0	1,613.0	16.6	-1.94
84.00	1.36	1,200.0	3,798.0	1,703.0	13.6	-1.91
88.00	1.34	1,227.0	3,329.0	1,645.0	15.4	-1.93
96.00	1.31	1,250.0	3,000.0	1,608.0	17.1	-1.94
102.00	1.29	1,274.0	3,950.0	1,716.0	12.9	-1.90
108.00	1.28	1,296.0	6,017.0	1,944.0	8.5	-1.81
114.80	1.26	1,341.0	7,560.0	2,101.0	6.7	-1.74
118.80	1.25	1,361.0	6,028.0	1,949.0	8.4	-1.81
124.80	1.24	1,385.0	5,673.0	1,916.0	8.9	-1.82
130.80	1.23	1,407.0	5,641.0	1,913.0	8.9	-1.83
136.80	1.22	1,427.0	6,113.0	1,955.0	8.2	-1.81
142.80	1.21	1,449.0	6,309.0	1,971.0	7.9	-1.80
148.80	1.20	1,467.0	6,115.0	1,955.0	8.2	-1.81
154.80	1.19	1,485.0	6,368.0	1,975.0	7.8	-1.80
158.80	1.19	1,495.0	6,563.0	1,990.0	7.6	-1.79
162.50	1.18	1,507.0	9,363.0	2,199.0	5.3	-1.68
173.50	1.17	1,551.0	9,563.0	2,211.0	5.2	-1.68
185.50	1.16	1,588.0	8,417.0	2,135.0	5.9	-1.72
197.50	1.15	1,617.0	8,439.0	2,137.0	5.9	-1.72
209.50	1.14	1,647.0	9,748.0	2,215.0	5.1	-1.67
221.50	1.14	1,678.0	9,960.0	2,226.0	4.9	-1.67
233.50	1.13	1,703.0	9,960.0	2,226.0	4.9	-1.67

4-70

Figure 4-27 Horner Plot for October 5 BHP Test, RBNG No. 397-19-1 Government Well

NATURAL BUTTES UNIT, UINTAH COUNTY, DE-AC08-76 ET 12060

UTAH MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

Gas Producing Enterprises, Inc.
Subsidiary of Coastal States Gas Co.
Houston, Texas

Status: Active

Contract Date: July 1, 1976
Anticipated Completion: March 31, 1980

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 G A S P R O D U C I N G E N T E R P R I S E S

The GPE wells, Natural Buttes Unit Nos. 9, 14, 18 and 20 flowed to sales and NBU Nos. 19, 21 and 22 were shut in during the reporting period. No. 21 was temporarily abandoned in the Mesaverde horizon and No. 22 was reworked because of excessive water production. Figures 4-28 through 4-33 display the production rates of the wells.

A comprehensive final report is in preparation.

Figure 4-32 Flow Rate Performance of Natural Buttes No. 20 Well

Figure 4-33 Flow Rate Performance of Natural Buttes No. 22 Well

FALLON-NORTH PERSONVILLE FIELD, TEXAS, MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

DE - AC08 - 78ET12150

Mitchell Energy Corporation
Houston, Texas

Status: Active

Contract Date:

March 15, 1978

Anticipated Completion:

April 30, 1979 (Extension being processed)

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 M I T C H E L L E N E R G Y C O R P O R A T I O N

The Muse-Duke No. 1 was shut in on August 7, 1979, for approximately 29 days to conduct a post MHF pressure transient buildup test. A bottom-hole tubing pressure difference plot and Ramey's type-curve matching plot were prepared for a better delineation of the type flows. Linear or fractured flow was dominant for the first 360 hours of shut-in time, and the pseudoradial flow regime was reached throughout the remainder of the buildup test.

It was concluded that the values from Ramey, Horner and bottom-hole tubing pressure difference plots are representative of the Cotton Valley Lime matrix within the radii of pressure investigations. After the well was massively fractured, the linear flow period increased from 12 to 360 hrs and the negative pressure loss increased from 510 to 6,220 psi. This would yield a wellbore improvement of approximately 1,100 percent.

Qualitatively, it is believed that a long fracture having a high flow capacity was obtained by the massive stimulation. This was further substantiated by comparing the pre-MHF and the post-MHF performance data.

The massive hydraulic fracture on the Muse-Duke No. 1 was designed for 210,000 gal of pad and 750,700 gal of gel containing 2,665,000 lb of sand. This would yield calculated created and propped half lengths of 3,504 ft and 2,625 ft, respectively. However, the well sanded up after pumping a pad volume of 235,000 gal, a gel volume of 663,000 gal, and 2,800,000 lb of sand. Thus, on a proportional basis, this size stimulation would have a created length of 3,220 ft, and a propped length of 2,530 ft. Therefore, a half fracture length ranging from 2,500 ft to 3,200 ft would be anticipated if the fracturing performed approximately as designed. To assess the validity of this design, the type-curve method for calculated length and finite capacity was utilized. For the constant rate case, plots of shut-in times versus the differences in the squares of the flowing and static bottom-hole pressures divided by the stabilized gas rate were constructed. These plots were compared with type curves generated by Amoco and S. A. Holditch and Associates, Inc. Although fairly good matches were obtained, the resultant calculations yielded unrealistically short fracture lengths and high capacities. These values were as follows:

Type Curves	Fracture Half Length	Fracture Capacity
Amoco Production	710 ft	13.1 d-ft
S. A. Holditch & Assoc.	775 ft	9.0 d-ft

The Mitchell Energy Corporation Muse-Duke No. 1 flowed 3,400 MCFD and 12 BWPD with a flowing tubing pressure of 1,050 psig through a 25/64 in. choke in November. The well will be produced for a year after it reaches constant line pressure of 650 psi before another check will be made on reservoir performance. All testing was completed in November and work is proceeding on the final report.

PICEANCE CREEK FIELD, COLORADO, MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

DE - AC08 - 76ET12062

Mobil Research and Development Corporation
Dallas, Texas

Status: Active

Contract Date: July 1, 1976
Anticipated Completion: September 30, 1979

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

The final report was issued in December and the contract was closed.

RIO BLANCO COUNTY, COLORADO MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

DE - AC08 - 76ET12148

Rio Blanco Natural Gas Company
Denver, Colorado

Status: Active

Contract Date: August 1, 1976
Anticipated Completion: July 31, 1979

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 R I O B L A N C O N A T U R A L G A S C O M P A N Y

DOE Contract No. DE-AC08-76ET12148 was signed with Rio Blanco Natural Gas Company in June, 1976. The first MHF treatment was performed on November 30, 1977.

The final report was issued in December and the contract was closed.

NEVADA TEST SITE NYE COUNTY, NEVADA MINEBACK TESTING

Sandia Laboratories
Albuquerque, New Mexico

Status: Active

Principal Investigator:

D. A. Northrop

OBJECTIVE

To develop an understanding of the fracturing process for stimulation and thereby improve the production of natural gas from low permeability reservoirs. This will be accomplished by conducting controlled fracture experiments which are accessible by mineback for direct observation and evaluation.

HYDRAULIC FRACTURE CONTAINMENT EXPERIMENTS

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 the DOE Nevada Test Site (NTS) 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.

FORMATION INTERFACE FRACTURE EXPERIMENT

This experiment was conducted to investigate the parameters that influence and control containment of hydraulic fracture. A hydraulic fracture with colored grout was initiated in a low modulus ashfall tuff formation which was overlaid by a welded tuff formation of an order of magnitude higher modulus. Mineback along the interface, shown in Figure 4-34, indicated that the fracture broke upwards into the higher modulus formation. This shows that present rock mechanics models, which predict containment of a fracture by a higher modulus material, are in error.

An extensive coring effort has been completed to determine the extent and shape of this fracture. Twenty-nine coreholes have been completed and the fracture boundary is shown in Figure 4-34. Assuming containment by the interface, the fracture design would have predicted a fracture length and height of 600 ft and 50 ft respectively. Observed length, and height were 150 ft and 200 ft.

Interface Test Series

The effect of material property differences on hydraulic fracture containment were further examined in this series of experiments. Twenty-four small volume (< 150 gal) hydraulic fracture were created at different distances from a formation interface. The results show that fractures will consistently cross an interface from a low modulus material to a high modulus material, but will terminate in layers where there is a sharp increase in the minimum principal stress. Flow rate apparently has no effect on containment other than controlling the fluid pressure, which may induce a fracture to propagate into a higher stressed region. The fracturing data consistently show variations in the minimum in situ stress within the ashfall tuff formation as shown in Figure 4-35.

Figure 4-34 Experimental Coring Program of Hole No. 6 Fractures

Figure 4-35 Schematic of the Effect of In-Situ Stresses on Hydraulic Fractures based on the Interface Test Series Results

4 . 5 P R O J E C T M A N A G E M E N T

4 . 5 . 1 T E C H N I C A L M O N I T O R I N G A N D E V A L U A T I O N

A meeting of the Multi-well Technical Review Committee was held on October 31 in Denver. Participating in the meeting were C. H. Atkinson (DOE/BETC-NV), H. Carroll, D. C. Ward (DOE/BETC), A. Hunt (DOE/METC), R. L. Mann, G. C. Kukal, J. C. Schillo (CER Corporation), D. A. Northrop, C. L. Schuster (Sandia Laboratories), R. J. Saucier (Shell Development Company), J. L. Fitch (Mobil R&D Corporation), and C. E. Cooke (Exxon Production Research Company). The meeting included tentative drilling, coring and logging plans of the multi-well experiment, the tentative schedules for Phase I as well as discussions of Phase II.

C. H. Atkinson and R. L. Mann participated in a BETC Planning Conference, November 26-28, to update the section of the Liquid Fossil Fuel Cycle planning framework which pertains to the WGSP.

C. H. Atkinson attended a meeting of the National Petroleum Council tight gas study group with CK GeoEnergy personnel in Las Vegas, January 8. The discussion concerned modeling lenticular sands for production prediction calculations.

C. H. Atkinson, G. R. Luetkehans (CER Corporation) and R. L. Mann met with Sandia Laboratories and the Institute of Gas Technology personnel in Albuquerque, New Mexico on January 14 to discuss the WGSP multi-well experiment. They were joined on January 15 by additional CER personnel and personnel from Bartlesville Energy Technology Center, Lawrence Livermore Laboratory, Los Alamos Scientific Laboratory, Institute of Gas Technology and DOE/HQ to develop activity planning networks for the multi-well experiment.

C. H. Atkinson met with A. Crawley (BETC) in Las Vegas, February 19 and 20 regarding WGSP plans and budget.

A meeting with the multi-well experiment industry technical review group was held in Las Vegas, Nevada, March 25-26. Representatives from DOE, CER Corporation, BETC, METC, Sandia Laboratories and industry were present. The Northwest Exploration site was reviewed and approved by the group.

These experiments show that in situ stress is the dominant mechanism controlling hydraulic fracture propagation as shown in Figure 4-35. 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.

Work on this activity has been completed.

Proppant Experiments

The two important problems associated with hydraulic fracturing technology are, first, to find the conditions which will make the fracture propagate in the pay zone and second, to provide a conductive flow path in the fracture once it has been created. The latter problem deals with the interaction between the fluid (viscosity, other proppant transport characteristics) and sand (concentration, size, density, staging) as well as the interaction with the rock (embedment, crushing) to obtain a proppant distribution (packed bed, monolayer) with a resultant flow conductivity. Knowledge of the conductivity of a propped hydraulic fracture would be valuable for analysis of post-fracture pressure buildup and flow tests. It would then be possible to deduce the actual fracture length and probably the damage zone near the fracture surface. Several experiments are now being planned to investigate fracture widths and pressure during fracturing and the resultant proppant distribution and fracture conductivity.

A site in a new area of G-tunnel is being prepared for these experiments. An in-tunnel pump system is under construction which will pump high viscosity gels with concentrations of sand up to 3 lbs per gal. These experiments are expected to commence this year.

In Situ Stress Measurement by Hydraulic Fracturing Through Perforations

Mineback experiments have shown that the most important factor governing containment of hydraulic fractures is variations in the minimum principal in situ stress. Material property differences and interface characteristics (friction) appear to be insignificant. In the Multi-Well Experiment, the distribution of the minimum in situ stress will be measured through the Mesaverde Group. A large number of in situ stress measurements will be obtained by conducting minifrac through perforations.

To be certain that performing these tests through perforations will yield accurate data, an experiment will be conducted in G-tunnel to compare fracturing through perforations to those in an open hole. Approximately five zones in a cased, horizontal borehole will be fractured with a small volume (10 gal) of dyed water through perforations oriented at different directions to the in situ stress. Important pressure data will be recorded. Another hole will be drilled 6 to 8 ft from the cased hole and five comparable zones will be fractured open hole. Differences in the instantaneous shut in pressure (if any) will be compared with dissimilarities in fracture behavior observed during mineback. At present, it is

not expected that there will be any significant difference. However, the damaged zone due to perforating may result in anomalous fracture behavior near the wellbore and a higher observed closure stress or shut-in pressure.

Rock Mechanics

The origin of the in situ stress variations observed in the mineback experiments and shown in Figure 5-10, have been investigated in a series of finite element analyses. The effects on the stress distribution due to regional horizontal stress, overburden stress, material property differences, and possible thermoelastic effects have been considered. The calculations have not been able to match the observed stress profile exactly, but significant stress variations can be shown to occur. These analyses are continuing.

In addition, a field and laboratory program was recently initiated to determine the extent of influence of residual stress on hydraulic fracture growth at NTS. Residual strains in a large block of ashfall tuff from G-tunnel, containing a grout-filled fracture, have been measured in the laboratory by a double overcoring technique. Residual stresses calculated from these measurements show that the minimum horizontal principal compressive stress is within 10^0 of being perpendicular to the hydraulic fracture plane. The stress magnitude difference of the principal residual stresses is 0.86 MPa (compressive).

In situ stress measurements by the overcoring technique have been made at the site of the Interface Test Series (5.9.1.2) to determine the influence of in situ and residual stresses on the containment of hydraulic fractures. Nine sites were instrumented with delta strain rosettes (3 sites on 3 separate bedding horizons 0.28 meters apart) on the central portion of a tunnel wall within one meter of an exposed mined-back hydraulic fracture.

All of the sites were in a single bed of ashfall tuff. The lowest bedding horizon which was instrumented corresponded to the horizon in which the hydraulic fracture abruptly terminated. After overcoring, eight of the nine gages were still operational.

Preliminary data analysis indicates significant and consistent increase in the minimum principal strain, ϵ_3 , from 80 $\mu\epsilon$ tension at the upper horizon, to 140 $\mu\epsilon$ compression at the middle horizon, to 980 $\mu\epsilon$ compression at the lower horizon. In all cases, ϵ_3 was essentially normal to plane of the hydraulic fracture. The maximum principal strain showed no significant variation between the three horizons, with an average strain of 2,650 $\mu\epsilon$ compression. Stress calculations from these measured strains will be made once the elastic properties of each core are determined from laboratory compression test. The results suggest a strong correlation between the large compressive increase in ϵ_3 and the termination of the hydraulic fracture. Additional work will involve residual stress measurements on each of the core.

GEOCHEMISTRY AND PETROLOGY

Ten samples of the Mesaverde Group were obtained from the Mobil PCU F31-13G well in the Piceance Basin, Colorado. Thin-section petrographic study of these samples shows the Mesaverde, in the intervals 8,441 ft to 8,493 ft and 9,964 ft to 9,994 ft, consists of silty or shaly sand composed of angular, poorly-sorted quartz grains cemented by variable quantities of silica, calcite, and/or dolomite. In addition, all of the samples contained variable but significant proportions of authigenic clays and detrital grains, primarily feldspar. Preliminary scanning electron microscopy (SEM) has revealed a great deal of variation within individual samples. Silica cementation predominates in the uppermost samples, while carbonate cementation appears to increase with depth. Of the clay minerals, only chlorite shows a systematic decrease with depth.

Samples from the Mapco RBU No. 11-17F well, Uintah County, Utah, were shown to have an abundance of authigenic clay lining and filling the pore spaces. In addition, authigenic quartz is common, and, as with the Mobil PCU No. F31-13G well samples, the abundance of chlorite decreases with the core depth.

The petrographic examination of samples of the Mesaverde sandstone from the Pacific Creek Federal 1-3 well (Sweetwater County, Wyoming) is continuing. The field core descriptions by CER noted that several intervals were visibly outgassing on extrusion from the core barrel, and these intervals have been the primary focus of the current scanning electron microscope study. The results obtained so far indicate that diagenetic effects (specifically, the formation of authigenic clays, feldspar, and quartz) are most evident in the "cleaner," coarser-grained sandstone. Conversely, only rarely were authigenic clays observed in the finer-grained, silty, organic-rich and gassy layers. This observation of mineral authigenesis in organic-free sandstone versus its absence in the organic-rich silty portion of the sand lenses suggest that possibly the stability fields of the commonly-observed authigenic minerals are not within the Eh-pH conditions under which methane forms. Thus, the processes of methane formation and mineral authigenesis appear to be mutually incompatible.

4 . 5 . 2 T E C H N O L O G Y T R A N S F E R D O C U M E N - T A T I O N R E P O R T S

During the reporting period, the Western Gas Sands Project Quarterly Basin Activities Report, July 1 - September 30, 1979 and the Western Gas Sands Project Quarterly Basin Activities Report, October 1 - December 31, 1979, were released. Project status reports for the months of August, September, October, November and December 1979, and January 1980 were released. The WGSP financial supplements for the months of September, October, November, December 1979 and January and February 1980 were released to a limited distribution. In addition, the Project Plan Document for FY 1980 was released and work is proceeding on the Project Plan Document for FY 1981.

The WGSP Coring Report and WGSP Logging Report were finalized and the DOE Well Test Facility Manual was updated as equipment was added or modified.

PROJECT DATA BANK

The following maps have been added to the WGSP project data bank:

"Wildcat well penetration map showing wells drilled into and through potentially gas-bearing, low-permeability Upper Cretaceous and Tertiary Reservoirs, Sand Wash Basin, Colorado," by T. Tyler, USGS, 1979;

"Energy Resources Map of Colorado," by D. A. Myers, J. A. Sharps (USGS), D. K. Murray, D. C. Jones, and R. H. Pearl (Colorado Geological Survey, 1977);

"Energy Resources Map of Utah," USGS, Utah Geological Survey, 1977;

"Oil and Gas Discoveries Map of Rocky Mountain Region," Petroleum Information, March 1976;

"Northeastern Utah, Oil and Gas Well Location Map," Petroleum Information;

"Northwestern Colorado, Oil and Gas Well Location Map," Petroleum Information, 1959;

"Preliminary Chart Showing Electric Log Correlation Section F-F' of Some Upper Cretaceous and Tertiary Rocks, East Flank Rock Springs Uplift, Wyoming," Open File Report, T. Tyler, USGS, 1979;

"Simple Bouguer Gravity Anomaly Map of Utah," by K. L. Cook, J. R. Montgomery, J. T. Smith, and E. F. Gray, Department of Geology and Geophysics, University of Utah, Salt Lake City, Utah, 1975;

"Geologic Map Index of Utah," compiled by L. F. Hintze and L. Boardman, Utah Geological & Mineralogical Survey, 2 sheets, 1964;

"Penetration Chart of Utah Oil and Gas Fields," compiled by J. A. Campbell and R. S. Bacon, Utah Geological and Mineralogical Survey, October 1976;

"Catalog: Sample Library. Consolidated Index to Samples, Cores, Lithologic Logs and Electrical and Other Mechanical Logs on File," compiled by D. C. Mann, Utah Geological and Mineralogical Survey, May 1973;

"Maps Showing Generalized Structure Contours on the Tops of the Wasatch and Green River Formations, Geologic Section, and Contours of Thickness of the Green River Formation, Southeastern Uinta Basin, Utah and Colorado," by W. F. Holmes, USGS;

"Cross Section A-A' of Upper Cretaceous and Lower Tertiary Rocks, Northern Piceance Creek Basin, Colorado," by R. C. Johnson, U.S. Geological Survey MF-1129-A;

"Cross Section A-A' of Upper Cretaceous and Lower Tertiary Rocks, Southern Piceance Creek Basin, Colorado," by R. C. Johnson, M. P. Granica and N. C. Dessenberger, U.S. Geological Survey MF-1130-A;

"Cross Section B-B' of Upper Cretaceous and Lower Tertiary Rocks, Northern Piceance Creek Basin, Colorado," by R. C. Johnson, U.S. Geological Survey MF-1129-B;

"Cross Section B-B' of Upper Cretaceous and Lower Tertiary Rocks, Southern Piceance Creek Basin, Colorado," by R. C. Johnson, M. P. Granica and N. C. Dessenberger, U.S. Geological Survey MF-1130-B;

"Cross Section C-C' of Upper Cretaceous and Lower Tertiary Rocks, Northern Piceance Creek Basin, Colorado," by R. C. Johnson, U.S. Geological Survey MF-1129-C;

"Cross Section C-C' of Upper Cretaceous and Lower Tertiary Rocks, Piceance Creek Basin, Colorado," by R. C. Johnson, M. P. Granica and N. C. Dessenberger, U.S. Geological Survey MF-1130-C;

"Preliminary Chart Showing Distribution of Rock Types, Lithologic Groups and Depositional Environments for Some Early Tertiary and Late Cretaceous Rocks from Outcrops at Willow Creek-Indian Canyon through the Subsurface of Duchesne and Altamont Oil Fields, Southwest to North-Central Parts of the Uinta Basin, Utah, Section A-A'," by T. D. Fouch, 1977; and

"Preliminary Chart Showing Distribution of Rock Types, Lithologic Groups and Depositional Environments for Some Lower Tertiary,

Upper and Lower Cretaceous and Upper and Middle Jurassic Rocks in the Subsurface between Altamont Oil Field and San Arroyo Gas Field, Northcentral to Southeastern Uinta Basin, Utah, Section B'," by T. D. Fouch and W. B. Cashion, 1979.

Articles and publications relating to the WGSP include:

"Mapping Deep Hydraulic Fractures with Surface Tilt Instrumentation," by M. D. Wood and G. R. Holzhausen;

"Pressure Transient Analysis of Tight Western Gas Sands — Pre- and Post-Fracturing," by J. H. Kennedy and J. E. McElhiney, Intercomp;

"Preliminary Results of Organic Maturation, Temperature, and Pressure Studies in the Pacific Creek Area, Sublette County, Wyoming," by B. E. Law, C. W. Spencer, and N. H. Bostick, U.S. Geological Survey;

"Remote Production of a Region of Homogeneous Magnetic Field," by R. K. Cooper and J. A. Jackson, Los Alamos Scientific Laboratory;

"Sensitivity of NMR Detection for External Samples," by L. J. Burnett and J. A. Jackson, Los Alamos Scientific Laboratory;

"Detection of NMR in a Remotely Produced Region of Homogeneous Magnetic Field," by J. A. Jackson, L. J. Burnett and J. F. Harman, Los Alamos Scientific Laboratory;

"Factors Affecting Water Blocking and Gas Flow From Hydraulically Fractured Gas Wells," by S. A. Holditch, Texas A&M University;

"On the Development of a Wireline Tool for In Situ Stress Measurement by Hydraulic Fracturing," by A. H. Jones and A. S. Abou-Sayed, Terra Tek, Inc.;

"Experimental Determination of Particle-Size Distributions from Proppant Interactions with Tight Reservoir Rocks," by B. A. Baker and H. B. Carroll, Jr., BETC;

"Characteristics of Pores in Some Upper Cretaceous Nonmarine Sandstones, Uinta Basin, Utah," by C. W. Keighin, USGS;

"Fourth Fracture Treatment Well No. 498-4-1, Rio Blanco County, Colorado (Final Report)," by A. A. Ashteiwy and R. E. Chancellor, Van Poolen and Associates and Rio Blanco Natural Gas Company;

"Evaluation and Performance Prediction of Low-Permeability Gas Wells Stimulated by Massive Hydraulic Fracturing," by R. G. Agarwal, R. D. Carter, C. B. Pollock, Amoco Production Company; and

"Ball Sealer Diversion of Matrix Rate Treatments of a Well," by S. R. Erbstoesser, T. W. Muecke, and C. E. Cooke, Jr., Exxon Production Research Company.

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.

There are indications that dissolved methane may exist in geopressured aquifers in areas other than the Gulf Coast. A study is currently under way to research available data to identify areas outside the Gulf Coast probable of containing this resource.

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 geopressed-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 geopressed aquifers; and two, the amount of recoverable methane, a key factor in the economics of the utilization of geopressed resources. To this end, the assessment of all known onshore geopressed 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 geopressed 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 geopressed 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 geopressed-specific as well as broadly applicable (e.g., hydrothermal, hot dry rock) elements. The geopressed-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 geopressed-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 G E N E R A L

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 geopressed resources of the Gulf Coast.

5.2.2 T E X A S R E S O U R C E A S S E S S M E N T

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 geopressed 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 geopressed 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 hydro pressured and geopressured formations encountered in test wells. Compressional and shear wave data will be obtained from using Schlumberger long-spaced sonic log and Birdwell clamped geophones. Correlations with lithology and well logs will be made. Data obtained from this project will be used to determine permeability and porosity.

To date, the long-spaced sonic log has been run in the 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.

5.2.4 IDENTIFICATION OF OTHER POTENTIAL AREAS

Science Applications, Inc., has been awarded Contract DE-AC08-80NV10133 for the purpose of researching available information from areas outside the Gulf Coast to identify other potential areas of occurrence of the resource.

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 geopressed 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 geopressed 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 geopressed aquifers.

IDAHO STATE UNIVERSITY (DE-AS08-78ET12145)

One of the most important factors concerning geopressed 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.

Methane solubilities in aqueous NaCl solutions of 5 to 20 percent have been determined for temperatures of 100 to 240°C and pressures of 2,000 to 22,500 psi. This project is approximately 70 percent complete.

UNIVERSITY OF SOUTHERN CALIFORNIA (DE-AS08-78ET11396)

The basic purpose of this laboratory study is to ascertain whether methane can be produced from geopressed 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 geopressedured aquifers have been constructed to represent consolidated (Berea sandstone) and unconsolidated (graded loose sand) reservoirs. In situ conditions have been created by using methane-saturated water and brine under high pressures. These "aquifers" have been 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.

The project has been completed and the final report is in preparation.

INSTITUTE OF GAS TECHNOLOGY (DE-AC08-78ET27086)

This contract was to establish viscometer capability for measuring viscosity of geopressedured fluids at in situ temperature and pressure conditions. It is important to know the geopressedured 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 was thought that it could be upgraded to determine the viscosity of geopressedured fluids up to the limit of 10,000 psi and 340° F. The refurbishing, upgrading, and calibration of this instrument would allow accurate determinations of brine viscosities and would indicate whether the dissolved gas under high temperature and pressure conditions has a significant effect on viscosity.

The viscometer upgrading was not successful, and work on the project was discontinued. A final report is in preparation.

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.

Analysis of data from the Fairfax Foster Sutter No. 2 have been completed. Analysis of data from the Pleasant Bayou wells has been commenced.

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 geopressed aquifer research areas.

Known as the Geopressed Geothermal Information System (GGIS), the various tasks include 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. Work under this contract is complete and the final report is in preparation.

5.3.4 L E G A L, I N S T I T U T I O N A L, A N D O P E R A T I O N S R E S E A R C H

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.

Work on these two contracts has been completed and final reports are in preparation.

In addition to the overall effort as described above, local studies will be carried out in areas recommended for testing. One such project is already under way in connection with the Brazoria County site (see Section 5.4). The Alvin Community College has been funded (DE-AS08-78ET27032) to establish an information network and data base for socioeconomic planning assistance in the county to educate the public, industry, and governmental entities in the geopressured aquifer development program.

LEGAL ISSUES

As already mentioned, 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 geopressed 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 geopressed 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 releveled 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 releveled in east Texas. The first survey was completed in August 1978, and future surveys will be performed as needed.

5.3.6 EXPANSION OF AREA OF STUDY

SCIENCE APPLICATIONS, INC. (Contract No. DE-AC08-80NV10133)

This contract has recently been awarded to SAI for the purpose of investigating areas outside of the Gulf Coast where geopressured aquifers containing methane may occur. A literary search will be conducted to determine occurrence of the resource mentioned in literature. This will be followed by a field study to verify such occurrences and estimate their magnitude.

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 good geopressured aquifers (as indicated by local geology and well logs). Other wells which have depleted their productive oil and gas reservoirs and are to be abandoned are also included in these prospects. Such well(s) are being acquired from the original operator for the express purpose of short-term tests and are being 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, any further attempts to reenter plugged and abandoned wells will be researched to the point where the probability of success is high or funding exposure is strictly limited.

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.

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 General Crude Oil Company's Martin Ranch property.

PROGRAM OBJECTIVES

The objectives of the well drilling and testing program are to determine the following parameters:

- Reservoir permeability, porosity, thickness, rock material properties, depth, temperature, and pressure
- Reservoir fluid content, specific gravity, resistivity, viscosity, and hydrocarbons in solutions
- Reservoir fluid production rates, pressure, temperature, production decline, and pressure decline
- Geopressured well and surface equipment design requirements for high-volume production and possible sand production
- Specific equipment design for surface operations, hydrocarbons distribution, and effluent disposal
- Possibilities of reservoir compaction and/or surface subsidence.

SUMMARY OF PROGRESS

Drilling was started on the GCO-DOE Pleasant Bayou No. 1 in July 1978. By November 1978, the well had reached 15,675 feet. A total of nine cores were taken and full suites of well logs were run. While attempting to take core No. 10, the core barrel stuck at 10,505 feet. All efforts to recover the drill pipe and resume drilling operations failed, and it was decided to plug this well and select a new location 500 feet away. This move was preferred over sidetracking because of the poor condition of 13 3/8-inch protection casing and the possibility

5.4.2 DESIGNED WELLS PROGRAM--TEXAS

Fenix & Scisson, Inc.
Las Vegas, Nevada

Status: Active

Contract:
Contract Date:
Contract Completion Date:

DE-AC08-76ND00038
November 1977
April 1, 1981

Principal Investigator:

Ken Ortego (Fenix & Scisson,
Las Vegas)

DOE Project Manager:
DOE Project Engineer:

J. K. Westhusing (Houston)
R. D. Clarke (Las Vegas)

OBJECTIVE

To drill, complete, and test a well on a site in Brazoria County, Texas.

5.4.2 DESIGNED WELLS PROGRAM

Dow Chemical, U.S.A.
Midland, Michigan

Status: Active

Contract:
Contract Date:
Contract Completion Date:

DE-AC08-79ET27255
September 1979
September 1981

Principal Investigator:
DOE Project Manager:
DOE Project Engineer:

Dr. John Wilson (Dow Chemical)
J. K. Westhusing (Houston)
R. D. Clarke (Houston)

OBJECTIVE

To drill, complete, and production test a geopressured aquifer in the Parcperdue field in Vermilion Parish, Louisiana. Long lead time items have been ordered. Spud date is planned for October 1980.

Magma Gulf/Technadril
Houston, Texas

Status: Active

Contract:
Contract Date:
Contract Completion Date:

DE-AC08-78ET27082
December 1979
November 1981

Principal Investigator:
DOE Project Manager:
DOE Project Engineer:

Dr. Clay Durham (Magma Gulf)
J. K. Westhusing (Houston)
R. D. Clarke (Las Vegas)

OBJECTIVE

To drill, complete, and production test a geopressured aquifer in Cameron Parish, Louisiana. Long lead time items have been ordered. MGT expects to spud in early July 1980.

5.4.2 DESIGNED WELLS PROGRAM--LOUISIANA

5.4.3 WELLS OF OPPORTUNITY PROGRAM

H. J. Gruy & Associates
Houston, Texas

Status: Active

Contract:
Contract Date:
Contract Completion Date:

DE-AC08-77ET28460
September 1977
April 1980

Principal Investigator:
DOE Project Manager:
DOE Project Engineer:

R. J. Dobson (Gruy)
J. K. Westhusing (Houston)
E. X. Zuniga (Las Vegas)

OBJECTIVE

To acquire, complete, and production test geopressed
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"

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°F.

Surface flowing temperature: 264°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 contract was transferred to Fenix & Scisson on January 1, 1980. Surface facilities for a long-term flow test are in the final stages of construction with a completion date of the end of May 1980. F&S has issued an RFP for a testing contractor and expects to award a contract in early June 1980.

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. Of three other attempts, three were made on newly drilled wells. Two of these were successful. 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 uncontrolled. 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 geopressed 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 CO₂ 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 geopressed 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 and completed in December 1979.

The reservoir pressure measured with a Hewlitt-Packard downhole gauge was 13,015 psia at 14,722 feet (midpoint of the perforations). The well flowed at a rate of approximately 8,000 barrels per day during initial cleanup flow. Bottom hole temperature was measured at 266°F prior to starting a test flow. Surface flowing temperature was 220°F. A flow test of approximately 7,000 barrels per day was started but was discontinued when the Hewlitt-Packard gauge was pushed up the tubing by the flowing brine and became lodged in the production string. The well was killed and the tubing pulled to recover the gauge and tangled cable.

A final flow test for 10 days was accomplished with the Hewlitt-Packard gauge out of the hole. The rate of flow was measured starting at 11,200 barrels per day and ending at 10,780 barrels per day. The surface pressures were measured starting at 5,210 psia and ending at 4,658 psia on the casing, and starting at 4,300 psia and ending at 3,221 on the tubing. Flowing temperatures measured at surface ranged from 256°F to 269°F, and gas/water ratios ranged from 21.85 cubic feet per barrel to 22.69 cubic feet per barrel.

The well was shut in for 20 days and the pressure buildup recorded with a Hewlett-Packard gauge at bottom hole and with dead weight gauges at surface. The data obtained is being analyzed and a report will be prepared by the contractor.

TENNECO FEE "N" WELL NO. 1

This well was completed as a dry hole by Tenneco Oil Company in January 1979, and cased to a total depth of 17,276 feet. It was offered for testing of two geopressured sands occurring from 16,906 to 17,005 feet, and from 17,098 to 17,185 feet, respectively. The well was acquired by DOE and completion operations began in January 1980. The well location was at an inland water site and operations had to be conducted from barges. The well was cleaned out to 13,148 feet and a 5-inch tieback casing string was set and cemented from 13,148 to 12,270 feet. A 7-inch casing string was set from the crossover at 12,270 feet to surface. The well was then cleaned out to a total depth of 17,226 feet. A cement bond log was run which indicated questionable cement bonding behind the 4 1/2-inch liner which was in the well from total depth of 17,242 to 13,148 feet. Several unsuccessful attempts were made to effectively recement the 4 1/2-inch liner. Evidence of a hole in the 4 1/2-inch liner was detected and it was concluded that it would be impossible to complete the well in the target sands. The well was plugged and abandoned.

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, numerous 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 fifth symposium is planned after the results from the design wells and some additional wells of opportunity 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.