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Western Gas Sands Project Status Report

July 31, 1978

Prepared for
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Bartlesville Energy Technology Center
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Compiled by CER Corporation
Las Vegas, Nevada
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1. SUMMARY

This report summarizes the progress of government sponsored projects undertaken to increase gas production from low-permeability gas sands of the western United States during June, 1978. Background information is given in the September 1977 Status Report, NVO/0655-100.

The U.S. Geological Survey (USGS) is continuing geological and geophysical studies to characterize the resource base in the four primary study areas. Field work is underway at the following locations:

- Western Green River Basin
- Sand Wash Basin
- Central Montana
- Southern Piceance Basin
- Uinta Basin near Price, Utah

The National Laboratories, funded by the Department of Energy (DOE), are continuing their work of research and development. These activities are directed toward the development of mathematical models, new tools and instrumentation systems, data analysis, and rock mechanics.

Active field tests and demonstrations continue in the Piceance and Uinta Basins. CIGE Well No. 2 was fractured on June 22, 1978 with 170,500 lb sand and 203,000 gal of gel.

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2. PROJECT MANAGEMENT

2.1 Technical Monitoring and Evaluation

Two meetings were held during June by the Program Manager, D. Ward of DOE/HQ Washington, D.C. and the WGSP Manager, C.H. Atkinson of DOE/NV.

- June 9, 1978 with Bartlesville Energy Technology Center (BETC) to discuss the WGSP progress and status.
- June 13, 1978 with Mobil Research and Development Corporation at Dallas, Texas to discuss the Piceance Creek Field massive hydraulic fracture (MHF) demonstration. Further discussions reviewed the possibility of additional work in that area by DOE and Mobil as a joint effort.

C.H. Atkinson of DOE and R.L. Mann of CER Corporation met with W.J. Graves and J.A. Cross of Fenix & Scisson, Inc. to draft a joint DOE/Industry core acquisition contract with Joseph J.C. Paine and Associates to obtain core from a well located in Valley County, Montana.

M. Hanson and D. Emerson of LLL visited CER personnel and C.H. Atkinson to discuss the WGSP research effort.

C.R. Appledorn, while on a MHF-WGSP review trip to Denver and Grand Junction, Colorado made an evaluation of current fracturing practices. Mr. Appledorn's investigation indicated changes in fracturing technology emphasis. For instance, there has been a marked reduction in the use of Poly E (condensate-water) fracturing fluids and a consequent increase in the use of gelled KCl brines. In part, this has been due to the higher cost of condensate and increasingly strict safety requirements. It is believed that water-based gels give comparable results with new materials that have become available for gel control and clay stabilization.

Most fracs are now using sand-free spacers which may make up as much as one-half of the treatment volume. Foam fracs are gaining in favor, particularly in shallower producing zones, with a few being performed at depths to 9,000 ft. In the Grand Junction area, one company is performing variable rate and variable viscosity fracs with high sand concentrations and inducement of sand-outs during treatment. The use of 100

mesh sand in pads and in initial fracturing stages is apparently widespread. The most widely used fluids are cross-linked, "refined" guar and polysaccharides. These are used in preference to synthetic polymers.

In the northern extensions to the Wattenberg field, many jobs are being performed using 2 percent or 3 percent KCl brine with polysaccharide gelling agents, bactericide, clay stabilizers and other additives. Recently, the use of Poly E fluids which are 2/3 condensate, 1/3 base fluid has been discontinued in preference to 5 percent condensate in the base fluid. This fracturing fluid is said to have excellent fluid loss properties due to the presence of the condensate as a dispersion rather than the previously-used emulsion. Jobs range in size from 100,000 to 400,000 gal with 300,000 to 800,000 lb of sand. As much as 25 percent of the sand volume may be 100 mesh and the remainder 20-40 mesh. The use of larger sand is relatively restricted in eastern Colorado. All jobs are staged with spacers of base fluid.

Other Wattenberg fracs use low pH (4.5 - 6.5 pH) fluids. These jobs are mixed "on the fly", with no premixing of ingredients. Gels range from 10 lb to 40 lb polysaccharides/1,000 gal in 2 percent to 3 percent KCl brine. In one recent job, eleven stages were run following a 25,000 gal 2 percent KCl brine prepad (25 lb guar gel) and a 25,000 gal gel pad. Each stage was separated by a 7,100 gal spacer which had gel ahead of and following the brine for viscosity transition. A total of 227,600 gal were pumped during the treatment, of which 96,600 gal were gel fracturing fluid, 43,600 gal gel spacers, and 37,400 gal of 2 percent KCl brine spacers. Sand at 4 pounds per gallon (ppg) design concentration, was 352,400 lb, of which 50,800 lb was 100 mesh in the first stage, 100,000 lb 10-20 mesh in the tail-in, and 201,600 lb 20-40 mesh. The job was pumped at 20 BPM at 3,700 psi. Clay stabilization chemicals commonly used in these fracs were employed.

These jobs, though only one-half the average size of previous fracs in the same area, are said to result in comparable wells. The cost of these treatments, including acid breakdown, ranges from \$65,000 to \$70,000.

Several "Pillar frac" jobs have been performed in which polyemulsion frac fluid was staged with spacers maintaining spacer viscosity equal to that of the main treatment fluid. In Northern Montana, the use of CO₂ in large concentrations is common, though not all are foam fracs. For treating the subnormally pressured Eagle, Phillips-Greenhorn and Bowdoin, 2 percent and 3 percent KCl brine with surfactants is used as base fluid. The use of gels is held to a minimum because the wells are turned around rapidly and, with the cold fluid, gels do not have time to break. Pumping rates are 30 to 50 BPM and sand concentrations are up to 8 ppg of 20-40 mesh, 5 ppg of 10-20 mesh, and 4 ppg of 8-12 mesh. One company reports the following schedule: 3 percent KCl brine with 30 lb silica flour/1,000 gal for fluid loss, 10 gal demulsifier and 6 gal

clay stabilizer/6,000 gal, and 1 gal surfactant/ 1,000 gal. A total of 17,000 gal of fluid was pumped, carrying 19,000 lb of 10-20 mesh sand and 22,000 lb 8-12 mesh; 300,000 standard cubic feet (SCF) of CO₂ was used during the treatment and the pumping rate was 35 to 36 BPM. The wells clean up rapidly and pre- vs post-frac production ratios of 1:10 are common, however, most of the wells in this area are low capacity.

In the Piceance Basin, recent practice has included fracs of about 100,000 gal and 400,000 lb of sand, with a variable-rate and variable-viscosity technique being tried. In one such recent treatment, the well sanded out twice during the frac. Sand concentrations up to 10 ppg were initially pumped at 40 - 50 BPM, slowing gradually to 24 BPM before sanding out. CO₂ concentrations are such that the wells can usually be flowed back to clean up after sand-out allowing continuation of the treatment.

In fracturing the Mancos "B" on the Douglas Creek Arch, treatments emphasize the use of large volumes of 100 mesh and 10-20 mesh sand. A recent job used 85,000 lb 100 mesh, 130,000 lb 10-20 mesh, and 75,000 gal treating fluid, including spacers. Another was 130,000 lb 100 mesh, 271,000 lb 10-20 mesh and 97,000 gal fluid; CO₂ was used at 850 to 1,250 SCF/BBL giving a 20 percent quality foam pumped at rates of 60 BPM in 5.5 in. casing and 50 BPM in 4.5 in. casing. The average job has a maximum treating pressure of 3,800 psi and an average hydrostatic pressure of 450 psi. Most jobs use the limited entry technique with a design rate of 3 BPM per perforation.

2.2 Technology Transfer

2.2.1 Documentation and Reports

The third Quarterly Basin Activities Report, Logging Program, Project Status Report - Financial Supplement, June 1978, and the Project Plan Document FY 79 are being drafted.

The USGS has released a report by T.F. Tyler, 1978, Preliminary Chart Showing Electric-Log Correlation Section A-A' of Some Upper Cretaceous and Tertiary Rocks, Washakie Basin, Wyoming, USGS Open-File Report 78-703.

2.2.2 Project Data Bank

The bibliography of the Western Gas Sands Project information files is being prepared.

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3. RESOURCE ASSESSMENT

Resource assessment includes geological, geophysical and reservoir evaluation studies to define and characterize the resource base. The USGS is performing the majority of the geological studies for resource assessment. Additional activity, however, primarily in the area of field tests and obtaining and analyzing cores, provides data to support this work.

3.1 U.S. Geological Survey Activities

3.1.1 Greater Green River Basin

The pressure gradient listing has been received from Petroleum Information Well History Control System, and the data is being compiled on maps.

The Wyoming Atomic Stimulation Project (WASP) core photography has been completed.

Field work is underway by B.E. Law in the Western Green River Basin, and L.W. Kitley continued field work on the Tertiary zone of the Sand Wash Basin.

3.1.2 Northern Great Plains Province

D.D. Rice and G. Shurr are conducting field work in central Montana.

A manuscript on low-permeability reservoirs has been submitted to the Montana Geological Society for presentation at the Williston Basin Symposium in September 1978.

3.1.3 Piceance Basin—Uinta Basin

A report is being drafted on the mineralogy of core from the CER Rio Blanco Unit E-01 nuclear emplacement hole, located approximately 31 miles southeast of Rangely, Colorado. The report deals primarily with the genesis of the various matrix materials found in the sandstone units, and will be important in understanding how similar sandstones will react when subjected to various types of stimulation techniques.

In the southern Piceance Basin, two sections of the Cretaceous Mesaverde Formation were measured and sampled. One was measured at Rifle Gap near Rifle, Colorado and the other near Lands End Road on the west side of Grand Mesa.

Carbonate-rich core samples were analyzed from the Pariette Bench Field, located approximately 30 miles southwest of Vernal, Utah.

Core taken from the Humble-Exxon No. 8 Peters Point well, located approximately 40 miles east of Price, Utah, were examined and sampled.

3.1.4 Schedule Status

A milestone chart depicting FY 78 activities and status is shown in Figure 3-1.

3.2 Core Program

The first core under the WGSP Core Program will be obtained during July, 1978*. The location for the core is a Joseph J.C. Paine & Associates well, Midlands Federal 1-0296, Section 2, T29N, R36E, Valley County, Montana, which is in the USGS designated core area "C", Figure 3-4.

Approximately 400 ft of core will be taken in the Upper Cretaceous sections of the well with an expected TD of approximately 2,000 ft. Core will be taken in the following intervals:

Eagle	approx. 550 - 670 ft and 830 - 920 ft
Bowdoin	approx. 1,390 - 1,540 ft
Greenhorn/Phillips	approx. 1,640 - 1,760 ft

In the event that the sections core faster than anticipated, additional core may be taken. The formations will be cored with a conventional diamond core bit, but, because of the casing size, the core will be limited to 2.5 in. diameter.

The core will be sent to a commercial laboratory in Casper, Wyoming for routine plugs to obtain porosity, saturations, air permeability and grain densities in the sand intervals as specified in the Core Program. In addition, a core gamma will be obtained over the entire core. After routine analyses are run, the core will be shipped to the USGS core library in Denver.

* Core recovery was completed on July 12, 1978.

Figure 3-1 Milestone Chart — USGS

Figure 3-1 Continued

Figure 3-1 Continued

Figure 3-1 Continued

Distribution of core samples to the various labs will be made prior to slabbing and archiving.

The following logs are planned.

DIL/SP/GR
Proximity Microlog
FDC/SN/GR
BHC/GR
Spectral Gamma Ray
SARABAND

3.3 Logging Program

A logging program document, being drafted to define and assist in the implementation of this program, will be distributed to WGSP participants in preparation for a coordination meeting in September*. A Log Quality Control Check List, included in the document, will be used to ensure uniform log quality during the core acquisition effort at the Joseph J.C. Paine and Associates well in Valley County, Montana.

The 19th Annual Meeting and Logging Symposium of the Society of Professional Well Log Analysts (SPWLA) was held at the El Paso Civic Center, June 13-16, 1978, El Paso, Texas. The following papers have possible application to the WGSP Logging Program:

The Determination of Prior Depth of Burial (Uplift and Erosion) Using Interval Transit Time, William H. Lang, Jr., (Union Oil Company of California).

Some Practical Applications to Improve Formation Evaluation of Sandstones in the Mackenzie Delta, W.L. Johnson and W.A. Linke (Chevron Standard Ltd., Calgary, Atla., Canada).

Determination of Logging Parameters in Shaly Sand, Makoto Miyairi and Toshinobu Itoh (Japan Petroleum Exploration Company, Tokyo, Japan).

A Study of the Relationship Between Two Intrinsic Reservoir Parameters, the Lithologic Influence Factor and the Pore Geometrical Factor, A. Barlai, Reda A. Mawla, and Faleh, T. Al-Saadoon (Al-Fateh University, Tripoli, Libya).

* Document completed and distributed, August 14, 1978

Mineral Composition, an Aid in Classical Log Analysis Used in Jurassic Sandstones of the Northern North Sea, O. Nyberg, K. Lien, P.A. Lindberg, and J.K. Smistad (Statoil, Stavanger, Norway).

Relationship Between the Conductivities of Tertiary Water-Bearing Sands and Nearby Shales, Offshore Louisiana, H.J. Ritch and E.S. Pennebaker (Shell Oil Company).

Logging Tests in Porous Media to Evaluate the influence of their Permeability on Acoustic Waveforms, F. Lebreton and J.P. Sarda (Institut Francais du Petrole), F. Trocqueme (Societe Nationale Elf-Aquitaine (Production)), and P. Muller (Laboratoire de Mechanique des Roches de l'Ecole Polytechnique).

Evaluation of Very Low-Porosity Carbonates (Malossa, Italy), J. Suau and C. Boyeldieu (Schlumberger Inland Services, London, England), R. Roccabianca and M. Cigni (AGIP, Milano Italy), and M. Spila (Schlumberger Italiana S.p.A., Milano, Italy).

Well Log Interpretation of Shaly Sands with the Programmable Calculator, Kenneth D. Thompson (Schlumberger Well Services).

The Prediction of Water Saturation and Recoverable Hydrocarbon Volumes in Shaly Sand Reservoirs, Daniel A. Krygowski (Cities Service Company) and G.R. Pickett (Colorado School of Mines).

Log Interpretation of Shaly Formations Using the Velocity Ratio Plot, Richard Leeth (Wexel) and Michael Holmes (Independent Geological Consultant).

The SPWLA Logging Symposium Transactions volume and other SPWLA publications may be obtained by writing to:

P.A. Wichmann, Executive Secretary
Society of Professional Well Log Analysts
806 Main Street, Suite B-1
Houston, Texas 77002

3.4 Study of Basin Activities

Monitoring continues of drilling and testing activities in the four primary areas. Figures 3-2 through 3-6 indicate the four areas and recent wells of significance to the WGSP. The following paragraphs give a brief account of drilling activity.

3.4.1 Greater Green River Basin

Activity within the Greater Green River Basin is focused on the very productive gas fields in Sweetwater and Carbon Counties. The major objectives are the Almond and Ericson Members of the Mesaverde Group. Amoco Production is the most active operator in the area and has staked six wildcat outposts in the Wamsutter Arch area, Carbon County, projected to the upper Mesaverde at 9,480 - 9,715 ft and another deeper Mesaverde test (12,230 ft) nine miles northeast of the Wamsutter Field. In southern Carbon County, Getty Oil drilled a well that opened up a new Mesaverde field located three miles southwest of the shut in Robbers Gulch Field. A sand emulsion fracture treatment was utilized to enhance gas recovery, (Figure 3-2).

Well No. 1

Getty Oil Company
ISW Robbers Gulch
Section 27, T14N, R92W
Unnamed field, Carbon County, Wyoming
Mesaverde production (8,310 - 9,047 ft gross)
Frac: 112,000 gal gel, 157,250 lb sand
IPF: 522 MCFD, 3 BC
Mesaverde discovery - new field

In Sweetwater County, the Lewis Sands are being tested in the Canyon Creek Field by Oil Development of Texas who has staked four tests at 4,066 to 4,420 ft. Wildcat activity is being monitored closely because the information is applicable to the WGSP. Anadarko Production has a wildcat well to test the Almond, 2-1/2 miles west of the Stateline Field, which produces from the Wasatch, and Smokey Oil is active to the north with a wildcat Mesaverde test (Figure 3-2).

Well No. 2

Smokey Oil
2-18 Bluewater-Federal
Section 18, T17N, R96W
Wildcat Field, Sweetwater County, Wyoming
Mesaverde test (12,500 ft)
Status: Staked

Activity in Sublette and Lincoln Counties is predominantly in the development of established gas fields such as Tip Top, Figure Four, Big Piney, Whiskey Buttes and Fontenelle Fields. Belco Petroleum has two new 7,800 ft Frontier tests in the Big Piney Field, Sublette County. On the

Figure 3-2 Greater Green River Basin Showing Wells of Interest and USGS Designated Core Areas

Lincoln/Sweetwater County line, Amoco has a new field discovery on the east flank of the Moxa Arch producing 884 MCFD from the Frontier (Figure 3-2).

Well No. 3

Amoco Production
1 Champlin 359 Amoco-A
Section 9, T20N, R11W
Unnamed field, Sweetwater County, Wyoming
Frontier production (12,412 - 12,571 ft gross)
Frac: 97,020 gal oil, 63,000 lb sand
IPF: 884 MCFD, 12 BC
New field discovery

Koch Explorations plans to drill a 17,500 ft Mesaverde test which is of interest to the WGSP Core Program due to its depth and closeness to the USGS designated core area No. 1. Core from this area would be a significant resource assessment acquisition to the WGSP effort (Figure 3-2).

Well No. 4

Koch Exploration
1 Adobe Town Unit
Section 20, T15N, R97W
Wildcat Field, Sweetwater, County, Wyoming
Mesaverde test (17,500 ft)
Status: On location

The Sand Wash Basin in Moffat County, Colorado, comprises the southernmost part of the Greater Green River Basin. Operators are active in the North Craig Field where Sun Gas Company is developing the Lance and in the Great Divide Field where Northwest Exploration has a wildcat to test the Lewis.

3.4.2 Northern Great Plains Province

Drilling activity is concentrated in and around the gas fields in the northern Montana Counties of Hill, Blaine, Phillips and Valley. In Hill County the major operator is J. Burns Brown and in Blaine County the operators are Fuel Resources Development, J. Burns Brown, Tricentrol United States and Xeno Inc. Joseph J. C. Paine & Associates, Trio Petro Inc., Midlands Gas Company and Anschutz Corp are all active in Phillips County and in Valley County the operators are Joseph J. C. Paine & Associates, Falcon-Colorado Exploration and Xeno Inc.

Figure 3-3 Northern Great Plains Province Showing Wells of Interest and USGS Designated Core Areas

Figure 3-4 Detail of USGS Designated Core Areas and Wells of Interest, Northern Great Plains Province

Gas production during the month from the untreated Eagle Sands in Tiger Ridge Field, Blaine County totaled 5,174 MCFD. Tricentrol United States was the major operator. Fulton Producing completed a well in Toole County producing 253 MCFD from commingled Fish Scales/Bow Island Formation (Lower Cretaceous). This well represents a shallower pool discovery in the Miners Coulee Field.

The completions of most interest to the WGSP are the Midlands Gas Inc wells, which are producing from the Phillips, Bowdoin and Greenhorn Sands, and utilized fracture treatments to enhance gas recovery. These wells are located in Phillips County (Well No. 1) and produced 1,192 MCFD. Joseph J.C. Paine also completed a well in this area using a fracture treatment which brings the total production for five wells to 1,639 MCFD.

Well No. 1

Midlands Gas Company
1 Hellie 0560
Section 5, T36N, R30E
Bowdoin Field
Phillips County, Montana
Bowdoin production (1,294 - 1,349 ft)
Frac: 15,078 gal water, 40,000 lb sand,
137,584 SCF Nitrogen
IPF: 288 MCFD
Development Gas Well

Joseph J.C. Paine and Associates has staked seven Phillips tests in Phillips and Valley Counties. These wells are significant to the WGSP Core Program due to their location within the Core Site "C" (Well No. 2). Trio Petro Inc. has staked a Phillips and two Muddy tests near Core Site "D". Plans call for testing the Eagle, Bowdoin and Phillips in all three wells (Well No. 3).

Well No. 2

Joseph J. C. Paine & Associates
1-3406 Porteen
Section 34, T30N, R36E
Wildcat field
Valley County, Montana
Phillips test (1,900 ft)
Status: On location
Wildcat

Well No. 3

Trio Petro Inc.
1 Nylander
Section 1, T31N, R27E
Wildcat field
Phillips County, Montana
Phillips test (2,300 ft)
Status: On location
Wildcat

Tricentrol United States has five new locations in the Sherard Field, Blaine County, projected to the Eagle at 1,900 ft. In Phillips County, Anschutz Corp. has three wildcat ventures scheduled to the Phillips at 1,900 ft. These wells are close to Core Site "D" and will be monitored accordingly. To the south, in Chouteau County, Montana Power has three Eagle tests planned. Two are projected to 3,500 ft and the third to 1,700 ft.

Parts of North and South Dakota make up the eastern boundary of the Province. The Cretaceous test, reported last month by Cabot Corp., in Tripp County, South Dakota has been abandoned, and drilling has not yet started on the three Niobrara tests by Montana Dakota Utilities in Haakon County, South Dakota.

3.4.3 Piceance Basin

Drilling activity in the Piceance Basin is concentrated in proven gas fields located in Rio Blanco, Mesa and Garfield Counties. Wildcats, however, staked within the basin boundaries are of most interest to the WGSP and will be monitored accordingly. During this reporting period, several operators have staked wildcat ventures.

Amoco Production has a well in Gunnison County to test the Rollins sandstone member of the Mesaverde (Figure 3-7, Well No. 1). Ralston Oil and Gas Company completed a gas well in this area last year with significant commingled Cozzette/Corcoran production utilizing a fracture treatment.

Well No. 1

Amoco Production
1 Hotchkiss Ranches
Section 20, T12S, R89W
Wildcat Field
Gunnison County, Colorado
Rollins test (2,600 ft)
Status: On location

Figure 3-5 Piceance Basin Showing Wells of Interest and USGS Core Areas

David M. Munson currently has four wells on the Sagebrush Hills Unit. A recently staked wildcat southeast of an indicated Mancos discovery is scheduled to test the Mancos (Figure 3-5, Well No. 2). Last year he drilled a well to test the Mesaverde and abandoned it at 8,550 ft. Current plans are to workover that well to test the Mancos at 9,600 ft.

Well No. 2

David M. Munson
5-2-99 Federal
SWNW, Section 5, T2S, R99W
Wildcat Field
Rio Blanco County, Colorado
9,300 ft test
Status: On location

Of interest to the WGSP Coring Program are Houston Oil and Minerals plans to drill a 10,700 ft wildcat, 22 miles northeast of Rangely, Rio Blanco County. This well is on the northern margin of the designated core area (Figure 3-5, Well No. 3).

Well No. 3

Houston Oil and Minerals
24X-21 Federal
Section 21, T3N, R98W
Wildcat Field
Rio Blanco County, Colorado
10,700 ft test
Status: On location

In the Dragon Trail Field, Chandler and Associates have staked nine Mancos tests at depths ranging from 2,250 ft to 3,390 ft.

3.4.4 Uinta Basin

Activity in the Uinta Basin is concentrated in the Southman Canyon, Natural Buttes and Island Fields of Uintah County. Companies with new locations of interest to the WGSP include Continental Oil, Belco Petroleum and Taiga Energy. Continental Oil has four Mesaverde tests and Belco Petroleum has staked seven Wasatch tests in the Natural Buttes Field (Well No. 1 and 2). Taiga Energy has five Mancos wildcat wells located in southeastern Uintah County. Taiga recently completed a Mancos field discovery in the immediate vicinity of their new wells (Well No. 3)

Figure 3-6 Uinta Basin Showing Wells of Interest and USGS Designated Core Areas

Well No. 1

Continental Oil
35-8 Conoco - Ute Tribal
Section 35, T8S, R20E
Natural Buttes Field
Uintah County, Utah
Mesaverde test (11,743 ft)
Status: On location
Development well

Well No. 2

Belco Petroleum
2-10 Duck Creek
Section 10, T9S, R20E
Natural Buttes Field
Uintah County, Utah
Wasatch test (7,500 ft)
Status: On location
Development well

Well No. 3

Taiga Energy
1L-23
Section 23, T14S, R24E
Wildcat field
Uintah County, Utah
Mancos Production (5,416 - 5,804 ft)
Frac: 50,000 gal emulsion, 180,000 lb sand
IPF: 288 MCFD
New field discovery

Other companies with wells on stream are Belco Petroleum and Enserch Inc. Belco Petroleum has five wells producing from the Wasatch in the Natural Buttes Field totaling 8,039 MCFD. Enserch has two wells with commingled Wasatch/Mesaverde production also in the Natural Buttes Field. All seven wells placed on stream utilized massive hydraulic fracture treatments to increase gas production.

Of interest to the WGSP Coring Program are the two Anschutz Corp. wells in Grand County. The wells are projected to the Entrada at 9,210 ft and 10,500 ft, and are within Core Site "D" (Well No. 4).

Well No. 4

Anschutz Corp.
1 State - 95
Section 17, T16S, R22E
Unnamed field
Grand County, Utah
Entrada test (10,500 ft)
Status: On location
Deeper pool wildcat

4. RESEARCH AND DEVELOPMENT BY ENERGY TECHNOLOGY CENTERS AND NATIONAL LABORATORIES

4.1 Bartlesville Energy Technology Center

4.1.1 Improved Pressure Coring System

4.1.1.1 Core Retriever Design

Maurer Engineering has completed the detailed layout drawing for the retriever and a working model of the ball valve, and its actuating mechanism has been prepared for demonstration. Current work involves preparation of piece-part drawings, pressure vessel safety calculations, and materials specifications. The following features have been incorporated.

- mud pressure actuation of the ball valve
- pressure pulse signaling of specific system operations
- core position locator interlocked to the ball valve
- mechanical or fluid pressure opening of the ball valve after system depressurization
- retriever pressure maintenance system utilizing dry nitrogen

4.1.1.2 Coring Fluid Selection

Three different experimental tests are being used to evaluate the required properties necessary for the special coring fluid to be used in this system. Dynamic invasion by the test fluid candidates of a sandstone specimen is used to determine the ability of the fluid to seal and protect the core during cutting and while encapsulated. In this test, overbalance pressures (up to 500 psi) are maintained for various time intervals up to 24 hours and then the fluid penetration is examined. The best results to date have been obtained with a high viscosity polymer, Dow-Corning^R 200 (60,000 cs). Twenty-four hour tests have shown approximately a 1 cm depth of core invasion. This polymer is non-reacting with oil, gas, and water and has excellent high temperature stability.

The coring fluid must also serve as a lubricant to clean and cool the coring bit. Laboratory drilling experiments conducted in sandstone, using a NQ size Stratapax core bit, have shown that the polymer provides adequate cooling and excellent chip "pick-up" and removal. Minimum fluid flow rates of 75-100 in.³/min are necessary to prevent bit balling.

It is standard practice to freeze pressure cores with dry ice to immobilize fluids. The low thermal conductivity of the Dow Corning Polymer has made possible a method in which the core retriever is heated with water and the core then removed still encapsulated in the frozen fluid.

Although these tests indicate that Dow-Corning^R 200 would serve as an acceptable pressure coring fluid in many reservoirs, other types of fluids are being evaluated. These fluids include both oil and water based drilling muds, emulsions, suspensions, and fluorosilicon polymers. Initial results show oil based native coring fluids to be unacceptable because of high core invasion rates.

4.1.1.3 Bit Design

The developmental work on Stratapax diamond cutters currently in progress at Sandia has been applied to the design of a special coring bit for use with the pressure coring system. These cutters are especially unique in this application. Since they allow a 10 ft core to be cut in about 20 minutes, core washing is reduced. In addition, their drag-bit cutting action permits acceptable cleaning and cooling with low coring fluid flow rates.

Features incorporated in the presently designed bit are:

- replaceable pilot section that is extended below the main bit body which utilizes matrix mounted Stratapax
- high angle crown profile using computer positioned stud mounted Stratapax
- fluid porting designed to minimize invasion

A core bit of NQ size has been laboratory tested using Dow-Corning^R 200 as a coring fluid. Bit weights of 1,200 lb have been used to core Berea sandstone and bit cooling and chip removal appear good. A core bit of HQ dimensions is presently being constructed to further evaluate the Stratapax low invasion fluid coring capabilities. In addition, shop drawings of the full 8.5 in. bit are near completion.

4.1.1.4 Measurement of Formation Core Characteristics

A proposal from the Institute of Gas Technology entitled Measurement of Formation Characteristics for Western Tight Gas Sands is being processed through the BETC panel for acceptance.

A proposal was received from Terra Tek, Inc. to perform rock mechanics analysis and in situ stress work on cores from wells in the WGSP. However funds are not currently available to perform this work.

4.1.2 Interface Conductivity Effects on Electric Logging

Several test runs were made of the conductivity apparatus with trial cores. Core resistivity and permeability was found to be very sensitive to overburden pressure. Usually the flow rate and resistivity for a given flow rate cannot be duplicated at a different time. To minimize these effects, it was decided to use an overburden pressure of 1,500 psi and a pore pressure of 1,000 psi.

Several authors have reported that it may take several weeks or months for equilibrium to occur for resistivity measurements in a tight core. Based on the observed sensitivity of core resistance to overburden pressure, it is possible that nearly 100 percent saturation and most of the matrix deformation occurs in a short time. The long time to equilibrium may be due to gradual clay swelling.

Suppose that clay swelling does not appreciably change the lengths of the core conductive paths, but does reduce their size. Once saturation is achieved, core resistance can be measured and related to permeability as shown in Figure 4-1. Plots like Figure 4-1 should allow all resistance measurements to be corrected for permeability (or pore size) changes.

Saturation is assumed after 10 pore volumes have been pumped through the core. Runs are made at five different KCl concentrations (2, 3.5, 5, 7, and 8.5 percent) and two temperatures (70°C and 80°C). Figure 4-2 illustrates the results.

4.1.3 Mapping and Contouring Formation Water Resistivity(R_w)

Water resistivity data gathered from Petroleum Information (Denver) and Gypsy (Norman, Oklahoma) data banks were used in completing the cross section. Resistivities were measured by numerous laboratories used by the operators and drillers of the wells involved, and in some cases the analysis was performed by BETC. Resistivity was reported in standard ohm-meters.

Figure 4-1 Core Resistance vs. Permeability as a Function of Saturation and Rock Equilibrium

Figure 4-2 Rock Conductivity vs. Solution Conductivity at Constant Temperature

All data is from drill stem tests conducted on the Green River Formation unless otherwise labeled, ie: production, swab, Mesaverde. Locations of the tested wells were derived from the test report sheets, and elevations of the wells were taken from USGS topographic sheets.

This cross section involves 64 wells with each well selected having R_w data reported, and a location closest to the cross section line in each quarter section. This allows well location at the cross section line or as distant as 6 miles south of that line.

4.1.4 Logging Techniques and Interpretation

On June 8, 1978, an information meeting was held at BETC with Sandia personnel to discuss the objectives of the project task as related to the WGSP needs and to on-going investigations at BETC and at other institutions.

R_w is one of the most basic quantities required to assess the fluid saturation and producibility of hydrocarbon reservoirs, yet it is often the formation parameter which is least accurately known. Current determinations of R_w are based on either direct or inferred measurements. Both measurements require a sample of the water. Inferred measurements range from regional water analysis catalogs to the measurement of physical parameters in situ (well logging) whose values are dependent upon, among other quantities, R_w . The major deterrent to both measurements is the presence of the flushed-invaded zone where both matrix properties and fluid content have been changed by drilling. As the depth of invasion increases, so too does the complexity of R_w analysis. The task objectives then are to 1) investigate current sampling and logging procedures, 2) evaluate current and proposed research aimed at overcoming the limitations imposed by current technologies, and 3) develop alternate methodologies (both direct and inferred) which may enable accurate determination of R_w .

The initial stage of this investigation has been started with the continuing compilation of reference materials from petroleum-related journals and publications, as well as information from well logging organizations.

4.1.5 Rock-Fluid Interaction

Permeability and porosity measurements on several tight gas sands core plugs were made as a function of overburden pressure. Liquid permeabilities were measured with a 2 percent KCl solution.

Figure 4-3 Milestone Chart — BETC

Figure 4-3 Continued

4.1.6 Schedule Status

A milestone chart depicting FY 78 activities is shown in Figure 4-3 and includes status through June 30, 1978.

4.2 Lawrence Livermore Laboratory

4.2.1 Theoretical and Experimental Model Development and Application

During the past month, LLL continued calculations of the stress intensity factor near the tip of a pressurized crack in the neighborhood of an interface between two materials. As reported previously*, LLL assumed that the interface was well bonded; e.g., relative motion between the materials on either side of the interface did not occur. In the calculation performed this month, the geometry shown in Figure 4-4 was used.

Figure 4-4 Geometry of Fracture near Interface

The material on the left side of the interface was assigned a value of Young's modulus equal to twice that on the right side of the interface. In these calculations the crack length, $2a$, has been kept constant. The right crack tip has been positioned at various distances from the interface to include the cases where the crack is completely contained in the material to the left of the interface and where the crack bridges the interface.

*WGSP Status Report NVO/0655-107, May 1, 1978, p 21

Figure 4-5 Computed Normalized Stress Intensity Factor as a Function of Normalized Distance from the Interface

The computed normalized stress intensity factor at the right tip of the crack as a function of normalized distance from the interface is shown in Figure 4-5. The stress intensity factor is normalized by the factor $P/\sqrt{a}$, and the distance of the crack tip from the interface is normalized by $2a$ where P is the fluid pressure in the crack and a is the semi-major axis of the fracture ellipse. The calculations show that as the crack tip approaches the interface from the side of the higher modulus material, the stress intensity factor drastically increases. However, as the fracture tip penetrates the interface, the stress intensity factor is significantly decreased. These calculations indicate that a pressurized crack will be drawn toward an interface with material of modulus lower than that of the material in which the crack initiated. Then, having crossed the interface, further growth of the crack in the lower modulus material will be impeded.

4.2.2 Experimental Program

Calculations have been performed to analyze the tendency for growth in a pressurized crack which initially bridges an interface between two different materials.* During the month of June, some preliminary experiments were begun in which the experimental geometry was similar to that of the calculational model. An injection tube was epoxied in the standard manner down a hole drilled along an interface between Indiana limestone and Nugget sandstone, as shown in Figure 4-6.

Figure 4-6 Placement of Injection Tube Along Sandstone Limestone Interface

*WGSP Status Report, NVO/0655-107, May 1, 1978, p 21

The limestone-sandstone interface was bonded with epoxy as in earlier experiments. In these first experiments, no initial crack was present at the bottom of the borehole. In one experiment there was no applied stress load across the interface. In another experiment a 750 psi load was applied across the interface. In the experiment on the loaded block, the crack grew perpendicular to the interface and broke the bonded block into two congruent pieces. In the experiment on the unloaded block, the crack grew at an angle to the interface. The time history of the hydraulic fluid pressure as it was raised up to the point of fracture and terminal observation of the fracture show evidence that a crack may have initiated in the Nugget sandstone before initiating in the Indiana limestone. This conjecture is certainly not conclusive at present, but it is consistent with the results of calculations which predict a higher stress concentration factor in the less permeable medium having a lower Poisson's ratio.

Calculation*

$$\begin{array}{rcl} K_b & = & 4k_a \\ E_b & = & E_a \\ \nu_b & = & 0.35 \\ \nu_a & = & 0.20 \end{array}$$

More experiments of this type are planned.

4.2.3 Logging Program

The dry hole acoustic system constructed by Southwest Research Institute performs satisfactorily in the laboratory, and has been sent to the Nevada Test Site for acceptance testing.

4.2.4 Environmental Assessment

Various environmental assessment reports are being prepared or scheduled to be prepared for the DOE Enhanced Gas Recovery Program. Below is a list of projects for which reports are being prepared and their status.

- Colorado Interstate Gas -- Project in Wattenberg Field is progressing. Assessment is in preparation and should be complete by the end of July.
- MHF in Texas -- Awaiting further details on project before assessment can begin.

*WGSP Status Report, NVO/0655-107, May 1, 1978, p 21

Figure 4-7 Milestone Chart — LLL

4.2.5 Schedule Status

A milestone chart of LLL FY 78 activities is shown in Figure 4-7. Status for these tasks is not available.

4.3 Sandia Laboratories

4.3.1 Hydraulic Fracture Mapping

4.3.1.1 Wattenberg Fracturing Equipment. — Seismic Data Analysis

In January of 1978, Sandia participated in the first fracturing experiments utilizing the wire line seismic package with Amoco in the Wattenberg area.

On the first experiment, the borehole seismic package was lowered and clamped in position in the open hole section prior to the initiation of pumping from the surface. The package remained in the hole during the entire breakdown pump, which contained only fluid and no proppant. After the initial breakdown was achieved, the breakdown pump was divided into three 5,000 gal phases with a quiet period inserted after each phase. A quiet period was also inserted immediately after the breakdown and also during flowback. Any amount of fluid flow caused sufficient seismic disturbances so that seismic signals in the presence of this noise would have been undetectable. During the shutdowns, several seismic signals were observed and the determination of their sources is being investigated.

The seismic signals observed appeared to fall into three classes or categories of signals. The first category appears to be a high frequency impulsive type of signal which is arriving at the geophone package and causing either the geophones or their mounts to go into a resonance mode of oscillation. The origin of these impulsive signals is not understood but has been speculated to be caused by either thermal cracking, fault slippage along the fracture face, or closing motions of the fracture face. If the resonance problems in the geophones and mounts could be resolved, then the direction to these signal sources could be determined, and if a P-wave and S-wave are present, the distance to the origin could also be determined.

The second category of signals appears to be associated with these impulsive signals but has evidently had the higher frequencies attenuated to a low enough level so as not to cause the packages to go into resonance. These signals appear to have created pressure waves within the fracture fluid which are refracting from the fracture edges and oscillating from

Figure 4-8 Test No. 1 Example of Low Frequency Oscillation

Figure 4-9 Test No. 1 Example of High Frequency Oscillation

one end to the other, or from the top to the bottom of the fracture. If this supposition is correct, the frequency of the oscillations can be directly related to the fracture height and fracture length. That is, a pressure wave would travel through the fracture as an increase in pressure until it reached a boundary. Here it would be refracted as a decrease in pressure. Thus, one cycle of pressure change would require two traverses of the fracture face. Figures 4-8 and 4-9 are examples of this oscillatory type signal. The supposition is that the low frequency component (Figure 4-8) is governed by the fracture length and the higher frequency (Figure 4-9) by the fracture height. If one uses a velocity of propagation for fluids slightly reduced because of the containment, the approximate fracture size is 75 x 250 ft.

An interesting side note is that the size did not change dramatically between pumps. Apparently, the total size was essentially achieved during the initial 5,000 gal phase and the next two pumps only inflated the original fracture.

The third category of signals occurred only following the shut-in after breakdown occurred. These signals appear to be measuring the near field fracture displacements as the fracture is closing during shut-in. The fracture orientation obtained by wellbore televiewer agrees with the orientation obtained by these displacements. Figure 4-10 is a representative example of this seismic motion.

Figure 4-10 Test No. 1 Example of Near Field Displacement Signal

If the area is integrated under the curve of particle velocity, the displacement is obtained which is in the order of one-micro inch for each of these signals. With a total of approximately 100 signals during this shut in period, total fracture face motion is probably in the neighborhood of 100 microinches. This appears to be a reasonable number and could be accounted for by fracture tip extension or leak-off from the fracture face.

The two types of signals observed in this experiment would seem to indicate that a great deal of additional testing should be conducted to evaluate the borehole seismic system. Provided the assumptions are true, the fracture orientation and size, for at least small fractures, can be directly determined using seismic signals. The validity of these assumptions will have to be verified through additional testing and laboratory modeling.

The second experiment using the borehole seismic system was conducted in March, 1978. The seismic system was located in a lubricator above the wellhead during the main fracture pump of approximately 124,000 gal of fluid, and 228,000 lb of sand. At the conclusion of the main pump, the borehole seismic package was lowered to a depth of 50 ft above the fracture interval in the cased portion of the hole. The system was then clamped into position and data recording initiated. During the data recording period, no flowback occurred as the well was shut in. Data recording continued for six hours and numerous signals were recorded that appeared to be similar to the category 1 and 2 signals seen during the first experiment. It should be noted that the category 3 signals were seen in only the first experiment after a small volume of fluid had been pumped for the initial breakdown and were not seen after 5,000 gal had been pumped. On this experiment, none of these signals was found after the entire pumping operation was completed. The category 2 signals that occurred in this experiment arrived at the geophones with a different orientation relative to the geophone mount compared to Test No. 1. As the apparent orientation of these signals changed, it suggests that the signals are external to the seismic system and not related to the method of mounting. Figure 4-11 is an example of one of the signals received during the second experiment. The frequency of this signal suggests that it was created by the fracture oscillating from the top to the bottom of the fracture with a fracture height of approximately 50 ft.

The data analysis has not been completed on either of these experiments and considerable tape searching, digitizing, filtering and correlations remain to be done before this data analysis is completed.

Figure 4-11 Test No. 2 Example of High Frequency Oscillation

4.3.2 Mobile Well Test Facility

The mobile instrumentation system for use in the WGSP has been completed. Instrumentation installed in the trailer includes a PDP 11/10 computer and a Hewlett-Packard pressure gauge which is to be used for extended time BHP recording. BHP is to be the primary quantity to be measured in this program. A grease injection system was mounted on the mast truck after arrival at Sandia in Albuquerque.

The trailer, mast truck, and generators were checked out as a system and then shipped to Rio Blanco, Colorado to be tested as a system by CER Corporation prior to use (see Section 5.7 for field status).

4.3.3 Other Program Related Activities

D.A. Northrop briefed R.W. Taft and R.W. Newman, DOE/NV on the fossil energy-related experiments being conducted in G tunnel, Nevada Test Site, on June 8, 1978, at DOE's Nevada Operations Office, Las Vegas, Nevada.

R.A. Schmidt attended the 19th U.S. National Rock Mechanics Symposium held at Lake Tahoe on April 30 - May 3, 1978, and presented a paper for C.W. Smith entitled "Puff 'N Tuff, A Residual Stress-Gas Fracturing Experiment," by C.W. Smith, R.C. Bass, and L.D. Tyler.

R.A. Schmidt presented a paper and chaired two sessions at the 11th National Symposium on Fracture Mechanics held at Blacksburg, Virginia, on June 12 - 14. The paper is entitled K_{IC} and J_{IC} of Westerly Granite-- Effects of Thickness and In-Plane Dimensions, by R.A. Schmidt and T.J. Lutz.

4.3.4 Schedule Status

Figure 4-12 shows a milestone chart of Sandia's FY 78 activities. Status for these tasks is not available.

4.4 U.S. Geological Survey Borehole Gravity Meter

The borehole gravity meter circuitry is undergoing tests at LaCoste Laboratory in Austin, Texas.

4.5 M.D. Wood, Inc., Tiltmeter

The principal activity during June consisted of interpreting the results of a multiple hydraulic fracture sequence at the Talley Energy Systems, Incorporated (TESI) site near Rock Springs, Wyoming. M.D. Wood, Inc. selected, prepared and instrumented tilt sites during the later part of March, 1978 (Figure 4-13 and Table 4-1), and during the period of April through May 15, participated with Sandia Laboratories in monitoring this one-well, four hydraulic fracture sequence. The orientation, geometry and dimensions of the fracture were determined using the bulk properties of the material, the injection parameters, pressure and rate, the total volume of injected material, the depth of the injection, and the values of the tilt at the surface. The three largest and the deepest of the four fractures appeared well defined within the constraints of these parameters. The fourth fracture appeared much smaller than the others, and encountered extremely anomalous flow conditions. It did not appear to fit the constraints as did the previous three fractures.

Figure 4-12 Milestone Chart — Sandia

Figure 4-13 Instrumentation Geometry for Test Site 17

Table 4-1 Tiltmeter Array, Test Site 17

SITE	RADIAL DISTANCE (FEET)	AZIMUTH (DEGREES)	INSTRUMENT SERIAL NUMBER
1	160	N3°E	211
2	160	48	212
3	160	92	213
4	160	133	0028B
5	160	180	0088B
6	160	232	108
7	160	274	105
8	160	312	242
9	240	155	0098B

Table 4-2 Fracture Statistics, Test Site 17

FRAC	DATE	BREAK DOWN Hr/Min	STOP Hr/Min	DEPTH (Feet)	VOL (BBLS)	AVG PRES. (PSI)	AVG RATE (BPM)
I	4/19/78	9:51	11:02	407	146.08	625	2.06
II	4/30/78	10:46	11:13	349.8	104.05	900	3.45
III	5/07/78	10:54	11:32	393.5	85.44	875	2.24
IV	5/14/78	13:46	14:30	385.7	96.23	1000	2.18

The relative geometry deduced for the four fractures is shown in Figure 4-14 and Table 4-2 summarizes the statistics for each fracture. Figures 4-15 through 4-18 show the contours of maximum raw tilt for each fracture, a predominant extension to the northwest, and a somewhat corresponding concavity at the antipode. Figure 4-19 shows a composite superposition of the tilt isochrones.

Plans for the remainder of the fiscal year involve one scheduled monitoring experiment at the TESI site 17 with the Oil Shale Project. M. D. Wood, Inc. will monitor the explosive phase of stage two in this experiment. The field effort will occupy the approximate period July through August 15. The analysis of these results should be completed by the end of August. The instrumentation will be free to monitor other experiments as requested by the DOE following this activity. In addition to field activity, the remainder of the fiscal year will be used to complete data reduction analysis and write up on all past experiments undertaken on behalf of the DOE.

Figure 4-14 *Perspective Drawing of Relative Geometry of the Four Fractures*

Figure 4-15 Fracture 1

Figure 4-17 Fracture 3

Figure 4-18 Fracture 4

Figure 4-19 Tilt Isochrone Composite

5. FIELD TESTS AND DEMONSTRATIONS

5.1 Background

Improved stimulation technology is being developed by joint DOE/Industry field tests and demonstrations to expand commercial development of the western tight gas sands. These joint activities provide a method of technology transfer to industry for commercial usage.

Active field tests and demonstrations are: MHF demonstrations in the Uinta Basin, Utah by Gas Producing Enterprises, Incorporated; a dry gas injection experiment in the Wattenberg Field, Colorado by Colorado Interstate Gas Company; and two MHF tests in Colorado's Piceance Basin by Mobil Research and Development Corporation and Rio Blanco Natural Gas Company. Sandia Laboratories is conducting mineback testing at the Nevada Test Site, and Mitchell Energy Corporation will conduct a MHF demonstration in the Fallon-North Personville Field in Texas.

The Mobile Well Test Facility is undergoing checkout and testing at the CER Corporation RB-MHF 3 well in Rio Blanco County, Colorado.

Table 5-1 summarizes both completed and active Western Gas Sands Project MHF treatments. Progress of ongoing projects is described in the following sections.

Table 5-1 MHF Contract Locations and Frac Data

COMPANY, BASIN AND FORMATION	LOCATION	WELL	INTERVAL FRACTURED	FRAC. DATE	FRAC. TREATMENT	FLUID INJECTED
	T / R / Sec		Feet		Lbs. of Sand	10 ³ Gal.
AUSTRAL Piceance, Mesaverde	7S, 94W, S3 Garfield Co. Colorado	Federal 3-94	5,170- 6,333	8-25-76	1,140,000	542 Gel Gel H O
CONSORTIUM MANAGED BY CER CORPORATION Piceance, Mesaverde	3S, 98W, S11 Rio Blanco Co. Colorado	RB-MHF-3	8,048- 8,078	10-23-74	400,000	117 Gel
			7,760- 7,864	5- 2-75	880,000	285 Gel
			5,925- 6,016	5- 4-76	815,000	400 Gel
			5,851- 5,869	11- 3-76	448,000	228 Gel
GAS PRODUCING ENTERPRISES, INC. Uinta, Wasatch and Mesaverde	10S, 22E, S10 Uintah County Utah	Natural Buttes No. 18	6,490- 8,952	9-22-76	1,480,000	745 Gel
	10S, 21E, S21 Uintah County Utah	Natural Buttes No. 19	8,909- 9,664	9-21-76	424,000	280 Gel
			7,224- 8,676	9-28-76	784,000	365 Gel
	9S, 21E, S22 Uintah County Utah	Natural Buttes No. 14	6,646- 8,004	3-15-77	1,093,000	544 Gel
	9S, 21E, S28 Uintah County Utah	Natural Buttes No. 20	8,498- 9,476	6-22-77	826,000	322 Gel
	10S, 22E, S18 Uintah County Utah	Natural Buttes No. 22	6,858- 8,550	11-21-77	1,091,000	479 Gel
	9S, 21E, S19 Uintah County Utah	Natural Buttes No. 9	5,661- 8,934	3-27-78	554,000	349 Gel
	10S, 21E, S29 Uintah County Utah	Natural Buttes No. 2	9,237- 9,653	6-22-78	170,500	203 Gel.
DALLAS PRODUCTION Forth Worth, Bend Cong.	Ben D. Smith Survey A-779 Wise County, Texas	Ferguson A-1	5,957- 6,794	9-10-76	506,000	139 Foam 198 Emul.
EL PASO NATL. GAS Northern Green River, Fort Union	30N, 108W, S5 Sublette Co. Wyoming	Pinedale Unit No. 5	10-950-11,180	7- 2-75	518,000	183 Emul. 8 Gel
			10,120-10,790	10-20-75	1,422,000	459 Gel
MOBIL Piceance, Mesaverde	2S, 97W, S13 Rio Blanco Co. Colorado	F 31 13G	10,549-10,680	6-22-77	580,000	316 Gel
			9,392- 9,534	8-24-77	600,000	260 Gel
			8,765- 8,972	5-10-78	332,300	166 Gel
PACIFIC TRANSMISSION Uinta, Mesaverde	8S, 23E, S25 Uintah County Utah	Fed. 23-25	NO FRACS PERFORMED			
RIO BLANCO NATL. GAS Piceance, Mesaverde	4S, 98W, S4 Rio Blanco Co. Colorado	Fed. 498-4-1	6,150- 6,312	10-22-76	766,000	276 Gel
			5,376- 5,960	11-30-77	243,000 + 22,500 Beads	164 Gel
WESTCO Uinta, Mesaverde	10S, 19E, S34 Uintah County Utah	Home Fed. No. 1	7,826- 9,437	12-21-76	500,000	412 Gel
			10,014-10,202	10- 1-76	600,000	248 Gel

RIO BLANCO MASSIVE HYDRAULIC FRACTURING EXPERIMENT

EY-76-C-08-0623

CER Corp.
Las Vegas, Nevada

Status: Awaiting Advisory
Committee Decision

Interagency Agreement Date: June 19, 1974

Anticipated Completion Date: September 30, 1978

Project Cost (estimated):	DOE	\$1,975,000
	Industry	1,630,000
	Total	\$3,605,000

Principal Investigator: G. R. Luetkehans

Technical Advisor for DOE: C. H. Atkinson

OBJECTIVE

This stimulation experiment is being conducted in low-permeability, massive gas-bearing sandstone reservoirs in the Piceance Basin in western Colorado, to test advanced hydraulic fracturing technology where it has not been possible to obtain commercial production rates. This test is located about 1 mile from the 1973 Rio Blanco nuclear stimulation site to permit comparison of nuclear and hydraulic fracturing techniques in this area.

5.2 CER Corporation

5.2.1 Summary of Past Activities

DOE contract 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 term of the contract until September 30, 1978.

5.2.2 Current Status

Field activities on RB-MHF 3 well have been suspended. Negotiations have taken place with an outside party to complete the commingling of the fractured gas zones and to perform additional tests in return for the well and subsequent gas production. Legal documents are being prepared for distribution to the project participants for their concurrence.

WATTENBERG FIELD

EY-77-C-08-1514

Colorado Interstate Gas Company
Colorado Springs, Colorado

Status: Active

Contract Date: September 1, 1977
Anticipated Completion Date: March 1, 1981

Total Project Cost: (Estimated)	DOE	\$ 75,000
	CIG	99,000
	Total	\$174,000

Principal Investigator: Howard Fredrickson
Technical Project Officer for DOE: C. H. Atkinson

OBJECTIVE

Cyclic injection of dry natural gas is the method to be used to increase productivity of tight gas sands.

5.3 Colorado Interstate Gas Company

5.3.1 Scope of Work

DOE and Colorado Interstate Gas Company (CIG) entered into Contract No. EY-77-C-08-1514 on September 1, 1977. The experiment will determine if productivity of wells completed in low permeability natural gas reservoirs can be improved by reducing the interstitial water saturation by cyclic injection of dry natural gas. In addition, cyclic injection of dry natural gas may improve productivity by dehydrating matrix clays and by removal of formation damage adjacent to the surfaces of induced fractures.

5.3.2 Current Status

A special compressor has been ordered with delivery expected in December, 1978. One additional month is required for completion of site preparation and BHP buildup, and the first cyclic injection-withdrawal is expected to begin around February 1, 1979.

NATURAL BUTTES UNIT, UINTAH COUNTY, EY-76-C-08-0681
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:	Sept. 30, 1978	
Total Project Cost: (Estimated)	DOE	\$2,827,000
	Industry (prior costs)	1,881,000
	Industry (new costs)	<u>3,051,000</u>
	Total	\$7,759,000

Principal Investigator: W. E. Spencer
Technical Project Officer: 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.

5.4 Gas Producing Enterprises, Inc.

5.4.1 Summary of Past Activities

Gas Producing Enterprises was awarded DOE Contract EY-76-C-08-0681 in July 1976. Originally, two old wells, Natural Buttes Unit Wells 14 and 18, and four new wells, 19, 20, 21, and 22 were to receive MHF treatments. Three contract modifications have been entered into, adding one old well, Natural Buttes Unit No. 9, two new wells, 23 and CIGE 2-29-10-21, and increasing the scope of work for Natural Buttes Unit Well No. 21.

5.4.2 Current Status

Natural Buttes Unit Wells No. 9, 14, 18, 19, 20, and 22 were flowing to sales during June. Specific production data on these wells appears in Figures 5-1 through 5-6.

Natural Buttes Unit Well No. 21 was perforated at 8,509, 8,510, 8,511, 8,512, and 8,513 ft and a breakdown treatment performed with 3 percent KCl water and ball sealers. The interval produced 100 BBL of water per day with no measurable amount of gas, and was abandoned. Additional individual sand tests will follow.

CIGE No. 2 was treated by MHF on June 22, 1978, after being perforated and acidized. The perforation depths are:

9,237'	9,396'	9,525'
9,239'	9,397'	9,574'
9,279'	9,427'	9,576'
9,281'	9,429'	9,606'
9,300'	9,488'	9,608'
9,302'	9,490'	9,650'
9,343'	9,523'	9,653'
9,345'	9,523'	9,653'

The well was acidized with 3,000 gal of 15 percent MSR acid at a rate of 7.5 BPM. The well balled out and pressure increased to 5,000 psig.

The MHF treatment consisted of 33,000 gal of 2 percent KCl guar gum pad, 162,000 gal 2 percent KCl guar gum, 8,000 gal flush, 30,000 lb of 100 mesh sand, and 140,500 lb of 40/60 mesh sand.

Natural Buttes Unit Well No. 23 was drilled to 9,560 ft. Logs are being studied and the MHF treatment is being designed.

Figure 5-1 Flow Rate Performance of Natural Buttes No. 9 Well

Figure 5-2 Flow Rate Performance of Natural Buttes No. 14 Well

Figure 5-3 Flow Rate Performance of Natural Buttes No. 18 Well

Figure 5-4 Flow Rate Performance of Natural Buttes No. 19 Well

Figure 5-5 Flow Rate Performance of Natural Buttes No. 20 Well

Figure 5-6 Flow Rate Performance of Natural Buttes No. 22 Well

**FALLON-NORTH PERSONVILLE FIELD,
TEXAS, MASSIVE HYDRAULIC FRACTURING
DEMONSTRATION**

EF-78-C-08-1547

Mitchell Energy Corporation
Houston, Texas

Status: Active

Contract Date:	March 15, 1978
Anticipated Completion:	April 30, 1979
Total Project Cost: (Estimated)	DOE \$ 553,771
	Industry <u>1,074,550</u>
	Total <u>\$1,628,321</u>
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

5.5 Mitchell Energy Corporation

5.5.1 Scope of Work

DOE Contract EF-78-C-08-1547 was signed with Mitchell Energy Corporation in March 1978. The scope of work includes drilling, coring, logging and testing a new well, Muse-Duke No. 1, treating with MHF and evaluating results.

5.5.2 Current Status

The well for the Cotton Valley Lime massive hydraulic fracture test was spudded July 7, 1978. The name and location of the well has been changed from that originally proposed. Its name is now Mitchell Energy Corporation Muse-Duke No. 1, and it is located 6,688 ft FNSL and 14,760 ft FNEL of the Juan N. Acosta Survey A-1, Limestone County, Texas.

Total depth is estimated to be 11,650 ft. and as of July 17, the well was drilling at 4,873 ft. Surface casing (9-5/8 in.) was set at 4,520 ft and cemented to the surface.

The spudding of the test was delayed 22 days because of problems during the last stages of completing another well. Total drilling time is not expected to exceed the original schedule by more than 10 days.

**PICEANCE CREEK FIELD, COLORADO,
MASSIVE HYDRAULIC FRACTURING
DEMONSTRATION**

EY-76-C-08-0678

Mobil Research and Development Corporation
Dallas, Texas

Status: Active

Contract Date:	July 1, 1976	
Anticipated Completion:	December 31, 1978	
Total Project Cost: (Estimated)	DOE	\$2,510,000
	Contractor (prior costs)	2,376,485
	Contractor (new costs)	<u>1,590,515</u>
	Total	\$6,477,000

Principal Investigator:	John L. Fitch
Technical Project Officer:	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.

5.6 Mobil Research and Development Corporation

5.6.1 Summary of Past Activities

Mobil was awarded DOE Contract EY-76-C-08-0678 in July 1976, to perform up to six MHF treatments in a new well in Rio Blanco County, Colorado. The well was drilled by Signal Drilling Company under separate DOE Contract EY-77-C-08-1504. Two treatments were performed in 1977, one in June on zone 1 and the second in August on zone 3. Zones 2 and 4 did not meet frac requirements and were abandoned. The two treated zones were commingled and produced to sales during the winter. The third MHF treatment was performed in May, 1978 on zone 5.

5.6.2 Current Status

Technical Progress

Zone 7, 8,163 - 8,372 ft, overall, was perforated on June 12 with 40 Hyper-Jet charges using a 4 in. outside diameter (O.D.) centralized, hollow carrier. The shot spacing was 2 ft in the intervals 8,163 - 8,181, 8,210 - 8,226, 8,250 - 8,266, 8,279 - 8,285, 8,349 - 8,355 and 8,366 - 83872 ft. No flow was observed after perforating. The perfs were broken down on June 13 with KCl water with good ball action being observed. Instantaneous shut-in pressure was 1,100 psi, but flow could not be sustained after breakdown. Wellhead pressures observed after perforating and breakdown indicate that reservoir pressure in zone 7 is about 500 psi below hydrostatic. The well was swabbed on June 14. The gas flow rate was not sufficient to provide a steady flow in the presence of a substantial water flow and occasional swabbing was required. This made rate measurements difficult. The rate was about constant at 250 MCFD during the period June 14 - 16. Estimated water production was 80 BBL greater than the load, indicating that the zone is making formation water. A sample of this water is presently being analyzed.

The well was shut-in for pressure buildup on June 16. Preliminary analysis of the buildup gives an intermediate slope of 0.8 md-ft and a final slope of 0.3 md-ft. The preliminary buildup plot is shown in Figure 5-7, and flow data for zones 5 and 6 are shown in Figure 5-8.

Figure 5-7 Pressure Build-up after Breakdown—Mobil F-31-13G Well, Zone 7

Forward Plans

As of June 30, the well was prepared for fracturing of zones 6 and 7. The frac plan calls for 900,000 lb of sand carried by Western's Polaris Gel-40 containing 5 percent lease condensate at 15 BPM.

Figure 5-8 Flow Data, after breakdown, Mobil Well No. F-31-13G

Note: The frac job was performed on July 6. Pumping pressure increase was observed from 1,000 psi initially to 2,600 psi just prior to screen-out, which occurred after pumping 660,000 lb of sand and 288,000 gal of fluid. As of July 13 the well was flowing approximately 400 MCF of gas and 600 BBL of water per day. About 25 percent of the 7,000 BBL of load had been recovered at that time.

Figure 5-9 Mobil F-31-13G Well showing Sands Fractured

MOBILE WELL TEST FACILITY

EY-76-C-08-0623

CER Corporation
Las Vegas, Nevada

Status: Equipment checkout
and test to commence
in July, 1978

Principal Investigator: R. L. Mann

Technical Advisor: C. H. Atkinson

OBJECTIVE

The DOE Mobile 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.

5.7 Mobile Well Test Facility

5.7.1 Background

A modification to CER's DOE Contract EY-76-C-08-0655, provides for the operation of the Mobile Well Test Facility at various locations selected by DOE. The facility is comprised of a 10 ft x 50 ft trailer, a two-ton truck mounting a 50 ft telescoping hydraulically controlled mast, and two trailer-mounted 30 and 90 KW electric generators.

5.7.2 Current Status

The Mobile Well Test Facility was transported to RB-MHF 3, (Rio Blanco, Colorado) to complete a systems check on a familiar well location. The facility will be subjected to a simulated well test and analysis.

CER personnel are writing maintenance and operation manuals for the test facility and a complete check out of the system will continue until late August (see Figure 5-12).

A program for the PDP-11/10 computer was finalized which will allow the operator to designate when and how often the computer will interrogate the various transducers, and store the data on the RK-05 discpack. This data acquisition program is performed in the "foreground", is continuously operational, and allows the operator the option of performing other programming in the "background." This allows optimum use of computer time and will permit continuous surveillance of the well while the operator performs other computer operations.

CER is preparing software to perform well test analysis from build-up pressure data and Dr. Steve Holditch (Sovereign Engineering, College Station, Texas) is preparing an automatic type curve history matching program.

Figure 5-10 Mobile Well Test Facility Mast Truck .

Figure 5-11 Mobile Well Test Facility Instrument Trailer

**RIO BLANCO COUNTY, COLORADO
MASSIVE HYDRAULIC FRACTURING
DEMONSTRATION**

EY-76-C-08-0677

Rio Blanco Natural Gas Company
Denver, Colorado

Status: Active

Contract Date:	August 1, 1976	
Anticipated Completion:	March 31, 1978	
Total Project Cost:	DOE	\$ 410,000
	Contractor	593,000
	Total	\$1,003,000
Principal Investigator:	Robert E. Chancellor	
Technical Project Officer:	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.

5.8 Rio Blanco Natural Gas Company

5.8.1 Summary of Past Activities

DOE Contract EY-76-C-08-0677 was signed with Rio Blanco Natural Gas Company in June 1976. The first MHF treatment was performed on October 22, 1976. A supplemental agreement, effective October 1, 1977, provided for a second MHF treatment, which was performed on November 30, 1977.

5.8.2 Current Status

Gas flow continued to be restricted due to persistent cyclical water production. The present production rate is 200 MCFD plus water with the well being flowed for further clean up.

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.

5.9 Sandia Laboratories—Mineback

5.9.1 Summary of Past Activities

The objective of the project is to develop an understanding of the fracturing process for stimulation and thereby improve the production of natural gas from low permeability reservoirs. This is accomplished by conducting controlled fracture experiments which are accessible by mineback for direct observation and evaluation.

5.9.2 Current Status

Both fractures of the Hole #6 interface experiment have now been found. The lower fracture, which was initiated in the ash fall tuff with green and black grout, was intercepted in May and the upper fracture, which was initiated in the densely welded tuff with blue grout, was detected in June. The concentration of blue dye in the cement of the upper fracture, however, was less than originally planned and the grout's appearance upon mineback is actually gray. The location of this region in relation to the tunnel complex is shown in Figure 5-13.

The lower fracture is well behaved in the ash fall tuff formation and a single thick (4-10 mm) fracture was usually observed, although occasional stranding is seen. This fracture, however, breaks through the transition zone into the densely welded tuff and, in these regions, the fracture geometry often becomes quite complex. This fracture also appears to have propagated out some distance and then fractured back through the borehole above the packed-off interval, possibly through a natural fracture. The green and black grout is observed at the wellbore in the interval where the upper fracture was initiated and the gray cement is observed alongside it. Once it was discovered that the upper frac is actually gray, it was realized that this gray grout had been observed in places alongside the lower fracture. There are, however, many areas where the gray fracture is not coexistent with the black and green grout.

The 10-12 ft high tunnel was essentially driven along the transition zone with the lower ash fall and upper welded tuffs visible on the exposed face. At the borehole, a 6 x 6 ft raise was blasted out to about 20 ft above the tunnel in order to examine the upper fracture interval. In this region, there were abundant natural fractures that affected the hydrofracs by off-setting them and in some cases terminating individual strands. Presently, plans are being made to investigate the lower fracture interval by coring down along the borehole to a depth of 15 ft with a 12 in. core barrel.

Figure 5-13 Current Mineback Activities, G Tunnel, Nevada Test Site

Figure 5-14 shows a plan view of the mineback through June. The location of the primary fracture(s) is indicated as well as the dip at various locations. Section C-C, shown in Figure 5-15, is a cross section through the borehole. In general, the transition region can be divided into three zones: (1) a basal, medium soft, ash flow zone, (2) a vitric moderately welded ash flow zone, and (3) a non-welded zone characterized by a soft orange matrix with abundant hard lithics. Shown in the figure, the width of the fracture is considerably affected by the different zones. Section D-D in Figure 5-16 is a face map approximately 25 ft past the borehole. This is indicative of the complex behavior often observed in the transition and welded regions. In the hard zones (densely welded tuff and vitric ash flow zone), stranding is often observed and in the soft orange matrix region, the fractures usually meander to avoid the hard lithics, although they occasionally split them. It is quite interesting that the lower fracture broke through the interface. Most theories predict that the order of magnitude difference in elastic moduli would be sufficient to keep the fracture bonded.

No additional mining activity is planned at present once the end of the fracture is found at this elevation. Material property measurements at specific locations and in situ stress measurements in both zones will be undertaken to further characterize the nature of the interface. In addition, alcoves will be cut at three locations where the upper and lower boundaries of the fractures will be sought by coring in fan-like patterns.

A milestone chart of mineback activities during FY 78 is shown in Figure 5-17. Status for these tasks is not available.

Figure 5-14 EV-6 Plan View

Figure 5-15 Section C-C of EV-6 (CS5 + 14.5 ft.)

Figure 5-16 Section D-D of EV-6 (CS5 + 39)