Western Gas Sands Project Status Report

1 August 1979 - 31 August 1979

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 edition of the WGSP Status Report summarizes August, 1979, progress of the government-sponsored projects directed toward increasing gas production from the low-permeability gas sands of the western United States. Background information is provided in the September, 1977, WGSP Status Report, NVO/0655-100.

C. H. Atkinson (DOE), and G. R. Luetkehans and R. L. Mann (CER) met with Exxon personnel in Denver to discuss the potential use of Exxon acreage in Colorado for the multi-well field test.

C. H. Atkinson and G. R. Luetkehans attended the Fifth Annual DOE Symposium in Tulsa, Oklahoma.

The USGS in Denver continued work toward resources assessment in the four primary study areas of the WGSP.

A second coring operation began in August on the PTS well No. 22-12 Federal in Rio Blanco Cty, Colorado, to recover Mesaverde core.

The PTS well No. 24-19 Federal in Sublette Cty, Wyoming, was logged in August.

Projects of the National Laboratories and Energy Technology Centers progressed on schedule. Work on fracture conductivity, rock-fluid interaction, and log evaluation and interpretation techniques continued at Bartlesville Energy Technology Center. Work funded by the Gas Research Institute commenced on completing, testing and possible hydraulic fracturing of the Rio Blanco Natural Gas Company well No. 397-19-1 Government (on which the DOE Well Facility is being used) and on the evaluation of seismic data for stratigraphic studies of lenticular sands. Lawrence Livermore Laboratory continued experimental and theoretical work on hydraulic fracturing mechanics and analysis of well test data. Los Alamos Scientific Laboratory worked on developing NMR methods to define fluid saturation, porosity, and permeability of western gas sands at *in situ* conditions. M. D. Wood, Inc. was involved in design and site preparation for two hydraulic fracture mapping jobs in the Cotton Valley Trend in Texas. Testing and analyses of the borehole seismic system and borehole hydrophone system continued at Sandia Laboratories.

Field tests and related activities for the WGSP progressed as scheduled in August. Cyclic injection of dehydrated natural gas and production in Colorado Interstate Gas Company's Miller No. 1 and Sprague No. 1 wells continued. The Gas Producing Enterprises, Inc. wells, Natural Buttes Units 9, 14, 18 and 20 flowed to sales. The Mitchell Energy Corporation Muse-Duke No. 1 was shut-in for a 15-day pressure buildup test. Hydraulic fracture containment experiments and activities in the multi-frac test series continued at the Nevada Test Site for Sandia Laboratories' mineback program.

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2. PROJECT MANAGEMENT

2.1 TECHNICAL MONITORING AND EVALUATION

Merle Hanson (LLL) visited C. H. Atkinson (DOE) in Las Vegas, Nevada, on August 1 to discuss LLL's research activities relating to the WGSP.

Ed Talone (Intercomp) visited C. H. Atkinson (DOE) in Las Vegas, Nevada, on August 6 to discuss Intercomp's participation in the WGSP.

C. H. Atkinson (DOE) and G. R. Luetkehans (CER Corporation) attended the 5th Annual DOE Symposium on Enhanced Oil and Gas Recovery in Tulsa, Oklahoma, August 22-24.

C. H. Atkinson (DOE), and G. R. Luetkehans and R. L. Mann (CER Corporation) met with Exxon personnel in Denver, Colorado, on August 31 to discuss Exxon acreage in the Piceance Basin of Colorado as a possible site for the multi-well field test.

2.2 TECHNOLOGY TRANSFER

2.2.1 Documentation and Reports

Data for the WGSP Financial Supplement for July, 1979, was compiled. Work on the WGSP Project Plan for FY 1980 continued. The DOE Well Test Facility Manual was updated. A geologic review of the Northern Great Plains Province by H. E. Newman III of CER Corporation was completed. Data for the DOE Semi-Annual Report for the Unconventional Gas Recovery Program (period ending September 30, 1979) and WGSP Second Quarterly Basin Activities Report, 1979, were compiled.

2.2.2 Project Data Bank

A map entitled "Surface and Subsurface Correlations of some Upper Cretaceous and Tertiary Rocks, Green River Basin, Wyoming", USGS Open file report No. 79-357, section A-A', by B. E. Law, C. W. Spencer and H. W. Roehler, was added to the WGSP data bank. Work continued on the WGSP bibliography.

2.2.3 Articles and Publications

The following articles and publications relate to the WGSP, and abstracts, when available, will be included.

*Pacific Transmission Supply Company, Sand Ridge II Mesaverde Massive
Hydraulic Fracture Project, Uintah County, Utah, Final Report*

D. E. Beardsley and B. W. Allen
Pacific Transmission Supply Company

The Mesaverde Group in the northeast portion of the Uinta Basin is being evaluated to demonstrate the ability of the low permeability reservoirs to economically produce gas after massive hydraulic fracture stimulation. Pre-contract conditions stated that stimulation would be conducted only upon confirmation of minimum reservoir conditions as determined by reservoir evaluation. The evaluation was done by a combination of drillstem testing, logging, coring, mini-fracturing to determine the *in situ* stress field and fracture direction as well as the lab tests on cores. The hydraulic fracturing would be performed only if gas bearing sandstone could be shown to have a gas transmissibility of 0.5 millidarcy-feet in the lower Mesaverde and 1.0 millidarcy-feet in the upper zones. The test well was drilled to a total depth of 9,282 feet. Production casing was run, and eight sandstone zones were perforated to test gas production. These zones were selected from critical analyses of drillstem tests, gas logs and open-hole logs. Although all zones showed gas production in small amounts, each zone produced water in varying amounts. Analysis of flow test data indicated that none of the zones met the minimum transmissibility requirements and therefore no massive hydraulic fracturing was performed in the Mesaverde.

*Development of Techniques for Optimizing Selection and Completion of
Western Tight Gas Sands. Phase II report, 1 January 1979 — 28 February 1979*

C. F. Knutson and C. R. Boardman
C K GeoEnergy Corporation

Phase II work included the measurement of sandstone bed structural elements at 16 outcrop sites on Cretaceous marine marginal sandstone beds and at 16 outcrop sites on beds in a Lower Tertiary lacustrine sequence in eastern Utah. Work was aimed at defining the internal geometrical characteristics of these two types of reservoir rocks.

3. RESOURCE ASSESSMENT

3.1 U.S. GEOLOGICAL SURVEY ACTIVITIES

3.1.1 Uinta-Piceance Basins

Core from the Green River Formation from the Pariette Bench field was sampled and described.

Field work in the Piceance Basin continued.

Core samples of Tertiary rocks from the eastern Uinta Basin were examined.

3.1.2 Greater Green River Basin

Work on the stratigraphic analysis of the Greater Green River Basin continued.

Petrographic analysis of the Tierney wells in the Washakie Basin continued.

Work on describing and sampling core from the PTS well, Sec. 28, T36N, R112W, Sublette County, Wyoming continued.

An east-west cross section through the southern Washakie Basin was submitted for review.

Field work in the Rawlins, Wyoming, area continued.

Field work in the northern Green River Basin was completed.

3.1.3 Northern Great Plains Province

Core from the gas-producing Milk River equivalent in south-eastern Alberta, Canada, was sampled.

Field work on the Eagle sandstone and Mosby (Phillips) sandstone in central Montana was completed.

A paper on the petrology of the Eagle sandstone in the Bearpaw Mountains area was completed.

3.1.4 Schedule Status

Figure 3-1 is a milestone chart depicting USGS status in the WGSP.

3.2 CORE PROGRAM

A 6-1/2 in. diameter core hole (DOE/WGS-GC-1) is being drilled by C K GeoEnergy through about 1,200 ft of the non-marine Mesaverde Group in the Westwater Canyon area of the Book Cliffs in eastern Utah, (senw T17W, R24E, Grand Cty). The core hole is located on a ridge and the section being cored (lower Tuscher, Farrer, Upper Neslen) is exposed along the adjacent valley walls. There has been excellent core recovery to date and 4,400 lbs of 3 in. diameter core has been shipped to the USGS in Denver for description. An additional 600 ft of core will be cut in early September and logging will commence later.

Sandia Laboratories, DOE and GRI are fielding a three-dimensional geophysical shoot covering the area around this well. This project will attempt to define lens size and orientation by geophysical means. Lenses exposed in the outcrops are being mapped at a scale of 1 in. = 400 ft. If the geophysical work indicates some success in defining the lenses, additional mapping (lens location, height, length, and size and orientation of sedimentary structures) will be done on a larger scale.

Coring operation began in August on the Pacific Transmission Supply Company well, No. 22-12 Federal "Barcus Creek", Sec. 12, T1N, R99W, Rio Blanco Cty, Colorado.

Two hundred-eighty ft of Mesaverde core was recovered from this well. Seven cores were cut with 98 percent recovery. The upper 120 ft and lower 100 ft of core was very fine to medium grained, salt and pepper sandstone. The middle 60-ft was predominantly shale and siltstone with small layers of carbonaceous material. Gas was not detected from this Mesaverde section. Selected core samples were plastic sealed and sent to Bartlesville Energy Technology Center, Los Alamos Scientific Laboratory and Lawrence Livermore Laboratory for analyses.

Mapco, Inc. and Exxon were contacted concerning participation in the WGSP for their locations in the Uinta and Piceance Basins. David M. Munson was contacted for a coring contract for a well near Cathedral Bluffs, Rio Blanco Cty, Colorado. B. Pickard, representing Sugar Creek Resources, contacted CER Corporation in response to the WGSP core program publicity in the *Oil and Gas Journal*.

3.3 LOGGING PROGRAM

G. C. Kukal and H. E. Newman (CER Corporation) assisted Pacific Transmission Supply Company in logging the No. 24-19 Federal, Sec. 19, T33N, R114W, Sublette Cty, Wyoming, on August 7:

Figure 3-1 Milestone Chart — USGS

Figure 3-1 Continued

WGSP-USGS	FY-79											
C. PICEANCE BASIN	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Prepare and release cross section relating rock types, lithofacies, engineering data for rocks between DeBeque and Rifle, Colorado												
Prepare and release cross section in style above for southernmost Piceance Basin												
Cross section as above from Cathedral Bluffs to Rio Blanco area												
Report results of analysis of core from Rio Blanco area												

WGSP-USGS	FY-79											
D. UINTA BASIN	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Prepare and release cross section relating rock types, lithofacies, engineering data for rocks from Wasatch Mountains to southcentral Uinta Basin												
Investigate mineralogy and stratigraphy, and rock properties of core from Southman Canyon region of Uinta Basin												
Analyze data from San Arroyo Wash surface exposures of Cretaceous and Tertiary units of the southeast Uinta Basin. Report results as they become available												
Prepare report on diagenetic reactions and controls on Upper Cretaceous gas reservoirs at Southman Canyon Field, to be published in SPE volume												
Core analysis—Upper Cretaceous and Lower Tertiary units, southwest Uinta Basin												
Investigate mineralogy of core from the Sego Sandstone, Upper Cretaceous, southeast Uinta Basin, Utah												

Figure 3-1 Continued

3.4 SURVEY OF BASIN ACTIVITIES

3.4.1 Greater Green River Basin

During August, 47 development wells were completed: 22 produced, 3 were D&A, 15 were suspended and 7 locations were abandoned. Of 8 completed wildcats, 2 produced, 1 was D&A and 5 were suspended.

Producing horizons included the Lewis, Mesaverde, and Frontier and yielded 25,310 MCFD of new gas.

Twenty-six development wells and 9 wildcats were staked during August.

Wells of interest to the WGSP are listed in Table 3-1 and are shown in Figure 3-2.

3.4.2 Northern Great Plains Province

In August, of 29 completed development wells, 15 were producers, 12 were D&A, 2 were suspended and 1 location was abandoned. Of 17 completed wildcats, 3 were producers, 9 were D&A and 5 were suspended.

New gas production totaled 10,455 MCFD from the Eagle, Carlile, and Bow Island horizons.

During the month, 31 development and 13 wildcat wells were staked.

WGSP wells of interest are listed in Table 3-2 and are located on Figure 3-3.

3.4.3 Piceance Basin

In the Piceance Basin, 15 development wells were completed, with 7 producing and 8 suspended. Five wildcats were completed: 2 D&A, 2 suspended and 1 temporarily abandoned.

New gas from Mancos, Cozzette and Corcoran horizons totaled 2,386 MCFD. Of that total, Cozzette and Corcoran commingled production totaled 2,047 MCFD.

Twenty-three development wells and 9 wildcats were staked during August.

Wells of interest to WGSP are listed in Table 3-3 and are shown in Figure 3-4.

Figure 3-2

Greater Green River Basin Showing Wells of Interest and USGS Designated Core Areas (Refer to Table 3-1)

Table 3-1 Summary of Wells — Greater Green River Basin

OPERATOR	WELL NAME	MAP INDEX NO. ¹	LOCATION Sec/T/R	HORIZON ² ft	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Amoco Production	1 Champlin 242 AMOCO-C	1	csw 3/19N/93W Echo Springs Field Carbon Cty, WY	Almond (9,500-9,532)	10,085 PB: 9,896	Acidized w/ 2,520 gal. Fract w/ 133,686 gal water, 315,000 lb sand.	Develop. well comp. 6-23-79, located in Core Area A.	749
John J. Christmann	3-20 Red Gap	2	nenw 28/26N/ 113W South Hogsback Field Lincoln Cty, WY	2nd Frontier (7,750-7,896)	8,142	86,000 gal water 190,000 lb sand	Develop. well comp. 6-2-79. No cores or tests.	1,848
Smokey Oil	2-34 Anderson-Federal	3	csw 34/18N/96W Hansen Draw Field Sweetwater Cty, WY	Mesaverde (11,426-12,225)	13,356	32,500 gal water 40,000 lb sand	Develop. well comp. 10-14-78, located in Core Area A.	617
Amoco Production	1 Champlin 226 AMOCO-A	4	nesw 21/17N/94W Wildcat Field Sweetwater Cty, WY	Mesaverde 12,800	11,556	Acidized w/ 5,285 gal. Fract w/ 464,205 gal emul. 1,034,334 lb sand.	Wildcat well comp. D&A. Located in Core Area A.	

¹Refer to Figure 3-2

²Horizon - projected depth
or producing interval

Figure 3-3 Northern Great Plains Province Showing Wells of Interest
(refer to Table 3-2)

Table 3-2 Summary of Wells — Northern Great Plains Province

OPERATOR	WELL NAME	MAP INDEX NO. ¹	LOCATION Sec/T/R	HORIZON ² ft	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Tricentrol United States	16-16 State	1	sese 16/30N/15E Tiger Ridge Field Hill Cty, MT	Eagle (1,442-1,460)	1,800	30,000 lb sand	Develop. well comp. 7-17-79. No cores or tests.	1,200
Petroquest	1 Margaret Johnson	2	sene 8/37N/6E Sage Creek Field Liberty Cty, MT	Bow Island (2,216-2,220)	2,371		Develop. well comp. 11-26-78. No cores.	439
Balcron Oil	4-30 Iverson Farm	3	senw 30/29N/1W Ledger Field Pondera Cty, MT	Carlile (390-525)	525	open hole	Wildcat well comp. 6-18-79, no cores or tests. Carlile Shallower Pool Discovery.	260
Grace Pet	32-2 Bow & Arrow	4	nwne 32/37N/1E Police Coulee Field Toole Cty, MT	1st Bow Island (10,069-10,079)	1,110		Develop. well comp. 6-14-79.	145

¹ Refer to Figure 3-3

² Horizon - projected depth or producing interval

Figure 3-4

Piceance Basin Showing Wells of Interest and USGS Designated Core Areas (refer to Table 3-3)

Table 3-3 Summary of Wells — Piceance Basin

OPERATOR	WELL NAME	MAP INDEX NO. ¹	LOCATION Sec/T/R	HORIZON ² ft	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Norris Oil	36-2 Federal	1	nwse 36/9S/97W Shire Gulch Field Mesa Cty, CO	Cozzette (2,859-2,871) Corcoran (3,032-3,091)	3,200		Develop. well comp. 5-10-79. No cores or tests. Commingled.	1,573
Adolph Coors	1-32 Acco-Wood	2	sese 32/10S/96W Plateau Field Mesa Cty, CO	Cozzette (3,402-3,440) Corcoran (3,535-3,588)	4,242	269,850 gal water 522,000 lb sand	Develop. well comp. 10-17-78. No cores or tests. Commingled.	474
Northwest Exploration	14 Philadelphia Creek	3	sese 12/2S/101W Cathedral Field Rio Blanco Cty, CO	Mancos B (3,506-3,725)	3,795 PB: 3,749	Acidized w/ 1,000 gal. Fract w/ 56,030 gal emul. 50,000 lb sand.	Develop. well comp. 1-7-79.	116
Teton Energy	23-1 Federal	4	sesw 23/1S/98W Wildcat Field Rio Blanco Cty, CO	12,500 Mancos			Reported 8-21-79, located in Core Area A.	

¹Refer to Figure 3-4

²Horizon - projected depth
or producing interval

Figure 3-5

Uinta Basin Showing
Wells of Interest and
USGS Designated Core
Areas (refer to Table 3-4)

Table 3-4 Summary of Wells — Uinta Basin

OPERATOR	WELL NAME	MAP INDEX NO. ¹	LOCATION Sec/T/R	HORIZON ² ft	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Belco Petroleum	53-3B Natural Buttes Unit	1	sww 3/9S/21E Natural Buttes Field Uintah Cty, UT	Wasatch (5,967-6,409)	7,340 PB: 7,280	79,200 gal water 117,000 lb sand	Develop. well comp. 3-15-79. No cores or tests.	2,810
Piaute Oil & Mining	2 POMCO Monument Butte	2	nwse 18/9S/17E Monument Butte Field Duchesne Cty, UT	Green River 6,000			Reported 8-16-79, located in Core Area B.	
Belco Petroleum	15-27 Stagecoach	3	nwse 27/8S/21E Stagecoach Field Uintah Cty, UT	Wasatch 7,595			Reported 8/14/79.	

¹Refer to Figure 3-5

²Horizon - projected depth or producing interval

3.4.4 Uinta Basin

Twenty-five wells were completed in August, with only one producing (the rest were suspended). New gas production was solely from the Wasatch Formation and totaled 2,810 MCFD.

Wells of interest to WGSP are listed in Table 3-4 and are shown in Figure 3-5.

3.5 C K GEOENERGY

During August, completion of the core hole (swnw Sec. 16, T17S, R24E) in Grand Cty, Utah, was arranged with Himes Drilling Company.

Pressure buildup data from 3 Belco wells (Chapita Wells Nos. 6, 7 and 13) and CIG's 52X well are currently being analyzed to determine the permeability in the Wasatch. Static reservoir pressure data have been obtained for 7 Belco wells and 1 CIG well at various times during their production. Water level determinations have been made in 6 of these wells. The water column height above perforation midpoint depths ranged between 132 and 555 ft. Packers in the remaining two wells rendered water level determinations impossible. An average value will be used as an approximation in these two wells. It will be assumed that all completed zones were productive, since production logging attempts were unfruitful due to the water columns in the wells. These data will be used along with cumulative production figures to determine total reservoir volumes. This analysis will make possible the first check on tight gas reservoir lenticular geometry models developed from outcrop studies.

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

4.1 BARTLESVILLE ENERGY TECHNOLOGY CENTER

4.1.1 Improved Pressure Coring System (Sandia Laboratories et al)

4.1.1.1 Core Retriever Design and Test

Design work to improve the pressure core barrel's seal reliability and to reduce the total number of required O-rings used in the assembly continued in August.

The use of pressure transducers to gage internal pressure in the recovered cores will be incorporated as soon as transducers are obtained.

4.1.1.2 Core Fluid Tests

The low-invasion coring fluid was field tested in a well near Denver City, Texas. The fluid was used to cut 19 ft of pressure core using the modified Stratapax coring bit. A methanol tracer was used in the conventional drilling fluid and a sodium nitrate tracer was used in the low-invasion coring fluid. Although core analysis has not been completed, the test appears to be very successful and the cores appear to have much higher oil saturations than the conventional pressure cores. Handling of frozen cores may be greatly simplified by the low-invasion fluid. A major reduction in the expense of handling pressure cores can be achieved by thawing the outer layer of coring fluid, pushing the frozen core out of the barrel, and cutting and peeling the low-invasion fluid from the frozen core. No major problems were encountered in any phase of the field test and the overall system worked well.

4.1.1.3 Bit Design and Fabrication

Two pilot bit redesigns were completed. One pilot bit designed to improve only the hydraulics can be used with the existing main bit body and will be tested in early November.

The other redesign included a reduction in the bit size to reduce the amount of formation cut by the pilot bit. This will require modification of the main bit body and will not be available for testing before December.

4.1.1.4 Polycrystalline Diamond Core Bits

Laboratory and field tests have been conducted for two different polycrystalline diamond core bits. They have been designed and fabricated under a joint industry/Sandia program to improve the present technology of pressure coring.

A two-piece coring bit cut sandstone core at rates up to 50 ft per hour, but exhibited plugging action in the pilot section. As a result of this laboratory test, the pilot section will be redesigned to improve the hydraulics.

A single piece coring bit was tested in the laboratory. Limestone cores were cut at 128 ft per hour using Sandia's special low-invasion coring fluid. Based on this test, a field coring experiment was arranged with Shell Oil Company in the Wasson Field near Denver City, Texas. Coring was conducted at a depth of 5,200 ft in a dolomite/anhydrite formation. Two coring runs were made the first day with 100 percent core recovery. The first core examined was found to be in perfect condition and completely encapsulated in the low-invasion fluid. The second core was frozen in dry ice and cut into three segments for shipment for analyses. The cut-off flushing head end of the core barrel contained a short segment of frozen core which was used to evaluate the stripping characteristics of the low-invasion fluid. The stripping characteristics were excellent. Core analysis for coring fluid invasion is currently underway. Penetration rates were from 7 to 10 times faster than those normally obtained. No bit wear was observed.

These are the first oil field cores which were cut with this improved system. A major oil company in the area has requested that all future pressure cores in this field be taken with diamond compax core bits. To date, nineteen cores have been recovered.

4.1.2 Interface Conductivity Effects on Electric Logging

A study of prospective gas zones was made using conventional log analysis for the Natural Buttes Unit No. 21 well. Sonic versus neutron cross plots were used to identify potential gas-bearing zones. Density versus sonic cross plots were made to estimate the shaliness of the sand intervals. Only one zone of eleven prospective sands indicated gas. However, this zone was considered nonproductive because of its high shale content and excessive water saturation. These results were confirmed by previous production tests which showed no commercial gas present within this Mesaverde zone. Further studies of other wells are in progress to establish the applicability of current logging techniques for tight gas sands.

4.1.3 In Situ Permeability

Measurement of Formation Characteristics of Western Tight Sands — Institute of Gas Technology.

Figure 4-1 Effect of Net Confining Pressure on Klinkenberg Permeabilities: Experiment No. 1

4.1.3.1 Pressure Dependence of Single-Phase Permeability

The effect of net confining pressure on Klinkenberg permeability and gas permeability was examined. The results of measurements on core No. 9998A from the Mobil PCU F31-13G well are summarized in Figures 4-1 and 4-2. Figure 4-1 shows the measurements made during the first set of experiments. It was noted that at net confining pressures up to about 1,000 psi, the measured permeability values were considerably higher than the initial permeability value measured months ago. Subsequently, the core was heated to 90° C under a vacuum and maintained at that temperature for 3 days. Permeability measurements were made again, 3 weeks after the first series of measurements. The values had dropped to the values measured initially (after the plug had been drilled out of the core).

The core, which was saturated with brine subsequent to initial permeability measurements in February, was also used in the brine flow experiments. In both sets of experiments

Figure 4-2 Effect of Net Confining Pressure on Klinkenberg Permeabilities: Experiment No. 2

conducted this month, Klinkenberg permeabilities decreased with increasing confining pressure. This behavior is consistent with that reported for core No. 6475.5 from the Uinta Basin last month.

Figure 4-3 presents the results of experiments conducted on core No. 7011 from the Canyon Largo well No. 256, Dakota Formation, Farmington, New Mexico. This figure shows the effect of net confining pressure on a tight gas sandstone core at low and high mean pore pressures. The low and high pore pressure measurements follow similar trends at high net confining pressures. The initial permeability values (at a net confining pressure of 120 psi) are different; at low pore pressure, k equals 0.067 md and at high pore pressure (at a net confining pressure of 120 psi) k equals 0.038 md. This is probably due to the Klinkenberg effect. It is surprising that the low and high pore pressure measurements agree so closely since the low pore pressure measurements have not been corrected for gas slippage effects.

Figure 4-3 Effect of Net Confining Pressure on Gas Permeability at High and Low Pore Pressures

Figure 4-4 shows the reduction in permeability as a function of net confining pressure at both low and high pore pressures. The two curves are different due to the difference in initial permeability values.

Figure 4-4 Effect of Net Confining Pressure on Reduction In Gas Permeability at High and Low Pressures

4.1.3.2 Relative Permeability

Burdine and Purcell independently studied the relation between capillary pressure data and empirical permeability data.^{1,2} Results from these studies (Core Laboratories Special Analysis Manual) yield the following relationships:

$$\frac{K_{rnw}}{K} = \frac{K_{rg}}{K_g^0} = \left[\frac{1 - S_L}{S_L - S_{wi}} \right]^2 \int_{S_{wi}}^{1.0} \frac{dS_w}{(P_c^2)}$$

where

K_{rnw} = K_{rg} = relative permeability to gas (non-wetting phase)
 S_{wi} = irreducible water saturation
 S_L = liquid saturation (1 - gas saturation)
 S_w = mercury saturation from mercury injection test data
 P_c = capillary pressure from mercury injection tests
 K = absolute permeability

Equation 1 is applicable only to cases where the initial saturation of the core is at irreducible levels. The absolute permeability can be calculated from the following:

$$K = 0.66 F f \int_0^{100} \frac{d\rho_w}{(P_c)^2}$$

where

K = permeability (md)
 f = percent porosity
 ρ_w = mercury saturation (from mercury injection tests), percent
 P_c = capillary pressure (from mercury injection tests)
 F = empirical factor (assumed to be 0.1)

The values of K calculated from mercury injection tests are shown in Table 4-1.

¹ Burdine, N. T., "Relative Permeability Calculations from Pore Size Distribution Data," Trans. AIME (1953), 198, 71-78.

² Purcell, W. R., "Capillary Pressures — Their Measurements Using Mercury and the Calculation of Permeability Therefrom," Trans. AIME (Feb. 1949), 39-48.

Table 4-1 Relative Permeability

Mobil Well PCU F31-13G

Core Depth: 8,498 Feet

S _L , Percent	Relative Permeability		Absolute Permeability	
	K _{rg} /K (calculated)	K _{rg} /K _g ^o (measured)	(calculated), md	K _g ^o (measured), md
0.1	1.82 x 10 ⁻²	8.70 x 10 ⁻¹	7.35 x 10 ⁻¹	2.76 x 10 ⁻²
0.2	7.55 x 10 ⁻³	7.43 x 10 ⁻¹		
0.3	2.80 x 10 ⁻³	5.80 x 10 ⁻¹		
0.4	1.01 x 10 ⁻³	4.35 x 10 ⁻¹		
0.5	2.87 x 10 ⁻⁴	2.97 x 10 ⁻¹		
0.6	6.78 x 10 ⁻⁵	1.81 x 10 ⁻¹		
0.7	1.35 x 10 ⁻⁵	—		
0.8	1.99 x 10 ⁻⁶	—		
0.9	1.25 x 10 ⁻⁷	—		

Core Depth: 9,998 Feet

0.1	1.15 x 10 ⁻²	9.52 x 10 ⁻¹	8.31 x 10 ⁻¹	3.15 x 10 ⁻²
0.2	4.60 x 10 ⁻³	8.57 x 10 ⁻¹		
0.3	1.73 x 10 ⁻³	7.30 x 10 ⁻¹		
0.4	4.84 x 10 ⁻⁴	5.78 x 10 ⁻¹		
0.5	1.48 x 10 ⁻⁴	4.13 x 10 ⁻¹		
0.6	4.83 x 10 ⁻⁵	2.54 x 10 ⁻¹		
0.7	1.25 x 10 ⁻⁵	—		
0.8	2.01 x 10 ⁻⁶	—		
0.9	1.26 x 10 ⁻⁷	—		

Core Depth: 9,957 Feet

0.1	5.56 x 10 ⁻²	8.64 x 10 ⁻¹	1.25	1.10 x 10 ⁻¹
0.2	2.36 x 10 ⁻²	6.91 x 10 ⁻¹		
0.3	9.15 x 10 ⁻³	5.82 x 10 ⁻¹		
0.4	2.97 x 10 ⁻³	3.45 x 10 ⁻¹		
0.5	6.07 x 10 ⁻⁴	2.00 x 10 ⁻¹		
0.6	7.46 x 10 ⁻⁵	2.55 x 10 ⁻²		
0.7	1.46 x 10 ⁻⁵	—		
0.8	1.74 x 10 ⁻⁶	—		
0.9	2.17 x 10 ⁻⁷	—		

Canyon Largo Well No. 256, Dakota Formation

Core Depth: 7,011 Feet

0.1	2.4045 x 10 ⁻²	7.49 x 10 ⁻¹	1.3	6.21 x 10 ⁻²
0.2	1.0355 x 10 ⁻²	5.31 x 10 ⁻¹		
0.3	4.7853 x 10 ⁻³	3.62 x 10 ⁻¹		
0.4	2.1129 x 10 ⁻³	2.25 x 10 ⁻¹		
0.5	7.5635 x 10 ⁻⁴	1.26 x 10 ⁻¹		
0.6	2.0911 x 10 ⁻⁴	6.12 x 10 ⁻²		
0.7	4.1387 x 10 ⁻⁵	—		
0.8	3.3884 x 10 ⁻⁶	—		
0.9	1.2102 x 10 ⁻⁷	—		

The relative permeability to gas of cores No. 8498, 9957, and 9998 from the Mobil PCU F31-13G well and core No. 7011 from the Canyon Largo well No. 256 was calculated at different brine saturation levels assuming irreducible water saturation was zero. Results are tabulated in Table 4-1. Relative gas permeability values measured by establishing different water saturation levels by evaporation are also presented for comparison. The absolute permeability (for the measurements) was assumed to be the gas permeability at zero water saturation. The values estimated using capillary pressure data are consistently lower than the measured values, the difference being rather marked at high saturation levels. The difference could be due to the fact that S_{wi} may have a value higher than zero and that the measurements were made by desaturation.

Further, permeability values calculated from capillary tests are consistently higher than the measured K_g^0 values. The applicability of the equations for tight sandstones is questionable and further evaluation is needed.

4.1.4 Advanced Logging Techniques and Interpretation

4.1.4.1 Dielectric Constant Measurements for Formation Evaluation

The development of an accurate laboratory method for measurement of dielectric constant in rock samples is in progress. The method will be used to investigate the effects of anisotropy, matrix material, salinity and wettability on dielectric constant measurements. Presently, a system has been tested which uses rock samples as part of a resonant Q meter circuit. This technique does not have the sensitivity required to investigate dielectric constant properties, therefore, another system which will utilize phase shift measurements is being considered. This system will be more sensitive and will result in accurate measurements.

4.1.4.2 Study of Sonic, Neutron, and Density Logging in Low Permeability Gas Sands — Texas A & M University

The porosity of samples from the Natural Buttes Unit No. 21 well has been analyzed using the helium porosimeter in two different ways and by determining the difference in dry weight and saturated weight using kerosene as a saturating fluid. The porosities obtained by these three methods are presented in Table 4-2.

From these measurements, the matrix density of the reservoir rock samples was calculated. These values are presented in Figure 4-5. The unexpected feature of these measurements is that the matrix density is considerably higher than the 2.65 gm/cc value normally expected for sandstone. However, this may be due to the presence of carbonates in the matrix. In some cases, the rock contained gypsum. A plot of the matrix density versus the porosity is presented in Figure 4-5. For the higher porosity (about 10 percent), the density of the matrix approaches 2.65 gm/cc. However, for samples with lower porosity, the matrix density was higher.

The cores were grouped to correspond to readings that could be obtained from the log (see Table 4-3). The matrix density of each interval was averaged and used with the bulk density

Table 4-2 Core from Natural Buttes No. 21

Core	Depth in Feet	Porosity - Helium & Matrix Cup (%)	Porosity - Sat. Method (%)	Porosity - Helium Porosimeter (%)
1	4,441 ft 4.5 in.	5.2	2.9	4.6
2	4,441 ft 6.5 in.	4.6	4.2	4.8
3	4,441 ft 9.5 in.	3.0	2.0	3.3
4	4,442 ft	2.7	2.2	3.0
5	4,457 ft	2.8	1.7	3.1
6	4,457 ft 6.0 in.	3.9	3.6	4.5
7	4,453 ft 10 in.	4.4	4.2	5.3
8	4,450 ft 1.0 in.	5.2	4.1	5.2
9	4,460 ft 6.0 in.	5.0	4.4	5.5
10	4,463 ft 8.0 in.	3.6	1.9	3.3
11	4,463 ft 11 in.	3.3	2.9	3.9
12	4,465 ft 10 in.	4.2	3.4	5.0
13	6,405 ft	4.4	4.9	4.8
14	6,405 ft 10 in.	6.4	5.7	7.2
15	6,406 ft	6.2	5.4	5.6
16	6,423 ft 3.0 in.	5.1	4.3	5.5
17	6,472 ft 1.0 in.	8.5	8.0	8.1
18	6,472 ft 9.0 in.	5.5	4.8	5.6
19	6,473 ft 1.0 in.	7.2	6.1	7.1
20	6,473 ft 10 in.	10.8	10.3	10.0
21	7,423 ft	5.2	4.7	5.6
22	7,424 ft	5.9	5.4	6.2
23	7,425 ft 6.0 in.	6.5	5.9	7.1
24	7,426 ft	6.5	6.0	7.1
25	7,426 ft 11 in.	7.5	7.1	7.8
26	7,429 ft	8.7	8.7	8.4
27	7,430 ft	9.0	8.4	8.4
28	7,475 ft 3.0 in.	3.2	—	3.2
29	7,478 ft 1.0 in.	3.2	2.1	2.8
30	7,479 ft 3.0 in.	3.2	2.3	3.1
31	7,479 ft 6.0 in.	3.0	2.5	2.9
32	7,481 ft	5.6	5.6	5.5
33	7,482 ft	6.2	5.7	6.0
34	7,482 ft	5.8	5.4	6.0
35	8,425 ft	4.0	2.9	4.5
36	8,425 ft	3.7	2.8	3.9
37	8,434 ft 6.0 in.	8.7	7.6	8.7
38	8,434 ft 4.0 in.	9.8	9.2	9.2
39	8,436 ft 1.0 in.	9.0	7.4	8.8
40	8,437 ft	9.5	9.0	9.1
41	8,438 ft 2.0 in.	9.3	8.5	9.4
42	8,439 ft	7.2	6.6	6.4
43	8,483 ft	2.6	2.3	3.3
44	8,510 ft	4.1	3.4	3.7
45	8,512 ft 3.0 in.	4.3	3.8	5.0
46	8,513 ft	3.8	2.5	3.4
47	8,514 ft	6.4	5.5	6.3
48	8,515 ft 3.0 in.	10.0	9.1	9.6

Figure 4-5 Matrix Density versus Porosity for Cores from Natural Buttes No. 21

Table 4-3 Coding samples from Natural Buttes No. 21

Plug No.	Log Depth	Zone	Plug No.	Log Depth	Zone
1	4,441 ft 4.5 in.	A	28	7,476 ft 3.0 in.	G
2	4,441 ft 6.5 in.		29	7,478 ft 1.0 in.	
3	4,441 ft 9.5 in.		30	7,479 ft 3.0 in.	
4	4,442 ft		31	7,479 ft 6.0 in.	
5	4,457 ft	B	32	7,481 ft	H
6	4,457 ft 6.0 in.		33	7,482 ft	
7	4,458 ft 10 in.		34	7,482 ft 1.0 in.	
8	4,459 ft 1.0 in.		35	8,425 ft	I
9	4,460 ft 6.0 in.	C	36	8,425 ft 11 in.	
10	4,463 ft 8.0 in.		37	8,434 ft 6.0 in.	
11	4,463 ft 11 in.		38	8,435 ft 4.0 in.	
12	4,465 ft 10 in.	D	39	8,436 ft 1.0 in.	J
13	6,405 ft		40	8,437 ft	
14	6,405 ft 10 in.		41	8,438 ft 2.0 in.	
15	6,406 ft		42	8,439 ft	K
16	6,423 ft 8.0 in.	E	43	8,483 ft	
17	6,472 ft 1.0 in.		44	8,510 ft	
18	6,472 ft 9.0 in.		45	8,512 ft 3.0 in.	
19	6,473 ft 1.0 in.	F	46	8,513 ft	
20	6,473 ft 10 in.		47	8,514 ft	
21	7,423 ft		48	8,515 ft 3.0 in.	
22	7,424 ft				
23	7,425 ft 6.0 in.				
24	7,426 ft				
25	7,426 ft 11 in.				
26	7,429 ft				
27	7,430 ft				

read from the density log to yield a porosity. Figure 4-6 is a plot of the porosity obtained from the density log together with the average porosity for the cores in the interval being analyzed. Agreement between the core porosity and the log porosity may be improved if more complete laboratory measurements of porosity are obtained for the cores. Therefore, porosity of the whole core interval must be measured.

Some samples from the Natural Buttes Unit No. 21 well were extracted before the porosities were determined. Others were placed in an oven, dried, and porosity was subsequently measured. There was essentially no difference between the porosity for the samples which were extracted and that of the samples which were not extracted.

4.1.5 Reservoir Simulation Studies

Parametric Analysis of MHF Test Data and Engineering Studies of Western Gas Sands — Intercomp.

The post-fracture pressure transient test data from zones 1 and 3 in the Mobil PCU F31-13G well were analyzed. The results of the new analyses are given in Table 4-4, and Figures 4-7 through 4-10. The consistency between reservoir parameters calculated from pre-fracture pressure transient test data and those used in the post-fracture analysis is much better than in earlier analyses. The new analysis gave a much lower fracture permeability than was used earlier. Previously the fracture permeability was assumed to be 50,000 md.

4.1.6 Rock-Fluid Interaction

The interactions (filtration, adsorption, chemical reaction) between a formation and the fracturing fluid (gel) can be more easily understood if the molecular weight distribution of the unbroken and broken gel is determined.

At 40 lb, low-residue guar was prepared at pH 9.0 to aid in dispersion. The pH was then dropped to 6.0 to obtain dispersion. Two portions of the gel were separated for breakdown. The first was broken enzymatically and the second with $(\text{NH}_4)_2 \text{S}_2\text{O}_8$. Both degraded to a viscosity of about 3.5 cp. The samples were then examined by gel permeation chromatography. Preliminary results for the unbroken gel indicated that most of the gel had a molecular weight above the exclusion limit of 2,000,000. After breakdown in both techniques, there was only minor structural change in the high molecular weight peak, with no obvious low molecular weight products, although the molecular weight analysis between 20,000 and 3,000 was somewhat uncertain. This work was preliminary, but it was evident that an appreciable amount of high molecular weight material remained after breakdown by either technique. This could cause formation damage, especially through physical plugging of the small pores in tight formations.

4.1.7 Schedule Status

Figure 4-11 is a milestone chart depicting BETC's WGSP progress.

Figure 4-6 Porosity from Density Log and Core Analysis for Natural Buttes No. 21

Table 4-4 Reservoir Parameters Utilized in Radial Gas Simulator

Parameter	Zone 1		Zone 2	
	Pre-Frac	Post-Frac	Pre-Frac	Post-Frac
Initial pressure, psia	4,975	4,975	4,070	4,070
Hydrocarbon Porosity	0.036	0.036	0.036	0.036
Permeability, md	0.0109	0.0109	0.0215	0.0215
Thickness, ft	20	20	61	30
Wellbore vol., ft ³	234	1,952	312	312
Fracture half-length, ft	100	504	56	432
Fracture width, in	0.2	1.0	0.2	1.0
Fracture Permeability, md	738	300	129	1,000
Fracture skin	0.267	0	0	0.25

Figure 4-7 Post-Fracture Pressure Buildup Test - Zone No. 1

Figure 4-8 Post-Fracture Pressure Buildup Type Curve - Zone No. 1

Figure 4-9 Post-Fracture Pressure Buildup Test - Zone No. 3

Figure 4-10 Post-Fracture Pressure Buildup Type Curve - Zone No. 3

Figure 4-11 Milestone Chart — BETC

Figure 4-11 Continued

WGSP—BETC	FY-79											
C. LOGGING TECHNIQUES	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1. MAPPING & CONTOUR OF R _w												
Review current research												
Study of current logs												
Internal report												
Extant data assembly												
Isoresistivity maps												
Computer contours												
Annual report												
Report on contour of R _w & water components in Uinta Basin												
Examine and contour R _w & water components in Piceance Basin												

WGSP—BETC	FY-79											
C. LOGGING TECHNIQUES	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
2. LOGGING EVALUATION												
Effects of interface conductivity on electric logging												
Physical measurements												
Core preparation & selection												
Resistivity												
Data correlations												
Conductivities from Rink & Shopper equation												
Permeabilities												
Report												
Study of Logging Techniques												
Neutron log data evaluation												
Acoustic log data evaluation												

Figure 4-11 Continued

Figure 4-11 Continued

4.2 GAS RESEARCH INSTITUTE

Three projects were approved for funding in July and work has commenced. These projects include the hydraulic fracturing and testing of the Rio Blanco Natural Gas Company well, No. 397-19-1 Government, evaluation of seismic data for detailed stratigraphic studies of lenticular sands, and coring and logging of the Pacific Transmission Supply Company well, No. 22-12 Federal.

In addition, a proposal is in preparation to develop a geological and engineering data base for tight gas sand basins not presently under investigation by DOE. Some work has been done in one geologic area to aid in the planning of future studies. It is anticipated that this proposal will provide for broad access and convenient data retrieval by industry.

4.2.1 Hydraulic Fracturing and Testing of the Rio Blanco Natural Gas Company No. 397-19-1 Government

A fracturing and testing experiment on the RBNG No. 397-19-1 Government has been approved for funding by GRI, and operations commenced in July. The fracture stimulation experiment, tentatively scheduled for August 20, 1979, was postponed when pre-fracture tests indicated insufficient flow capacity due to perforation placement. Additional perforations will be made in September, followed by repeat testing. Assuming that satisfactory results are obtained, the frac-job will take place in late September.

See section 5.3 for details on the testing of the RBNG No. 397-19-1 Government well.

4.2.2 Evaluation of Seismic Data for Detailed Stratigraphic Studies of Lenticular Sands

A project has been funded to perform seismic research using recently developed techniques to determine if the geometry 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 program proposed by Sandia Laboratories is to:

- Locate an optimum site having the following characteristics:
 - Mesaverde depth range: surface outcrop to 5,000 ft
 - Known channel (lenticular sand) existence
 - Adequate well log control
 - Production history preferred (i.e., known gas resources);
- Construct a preliminary model using known geologic controls;
- Perform seismic modeling based on the geologic model and log control; perform sensitivity analysis;
- Perform a seismic reflection survey, map sand lenses, define the geologic section and trends of lenses. Explain production irregularities where production data are available, and modify the current geologic model.

A contract has been negotiated with Seismic International Research, Inc., to perform a twelve-fold survey in the eastern Uinta Basin, Utah. This survey will use an existing core hole and existing outcrop control to delineate sand lenses to a depth of 500 ft.

During August, the proposed site for the field experiment was finalized, well log data near the site were obtained and assimilated, and time spent in obtaining approval from the Bureau of Land Management and posting requisite bonds. At the end of the month, a land surveyor was retained to lay out shot point and geophone locations.

The seismic crew assigned to the project was detained longer than expected by a previous contractor, and commencement of the seismic shooting will be delayed until late September.

A follow-up survey, Phase II of the project, funded by DOE, will extend the seismic work down dip into the basin. Logs of existing wells and the first GRI-funded work will control this survey. Extensions of this research will be performed in the future at the site of the multi-well fracturing experiment. DOE is supporting this research, and will finance additional studies to determine the physical characteristics, geometry, and orientation of lenticular sands in the western basins.

4.2.3 Coring and Logging of the Pacific Transmission Supply Company No. 22-12 Federal

GRI approved a subcontract to obtain core from this well to supplement DOE participation under the Western Gas Sands Project core program. The well is located in a deep part of the Piceance Basin of Colorado, in an area designated by the U.S. Geological Survey as in need of tight sand core data.

The PTS No. 22-12 Federal well was spudded July 7, 1979, and is targeted to the Dakota Formation at 14,500 ft. Coring of the Mesaverde commenced August 17 and was completed in four days. (See section 3-2, Coring Program, for further details). Coring of the Mancos B should take place in late September. Approximately 120 ft of 4-in. core is planned within the interval 10,460 - 11,000 ft, the exact depths to be determined on the basis of information available at that time.

Logging operations will take place after the completion of all coring activities.

4.3 LAWRENCE LIVERMORE LABORATORY

4.3.1 Theoretical Analysis

The dynamic finite element model to enhance analysis of the behavior of hydrofractures that propagate up to an interface separating materials of differing elastic moduli is being modified. The expansion of the model to include half-plane symmetry has been completed and will allow unilateral and bilateral fractures near a single interface to be studied. Previously, a bilateral crack in a material which was sandwiched between layers of a second

material was analyzed. Only early time effects could be analyzed on one interface because reflected waves from the opposite interface, which arrived shortly after the crack stopped, did not allow for a sufficient amount of time to determine the material rebound characteristics. With the expanded model, the likelihood of cracking into the second material can be determined by analyzing the late-time effects due to the propagating and stopping of the crack.

Currently, a set of calculations is being performed to determine the amount of overshoot in the stress intensity of the leading crack tip as a function of the relative values of the elastic moduli of the two materials. The effect of the relative values of the elastic moduli on the likelihood of subsequent penetration of the crack into the second material and the time, relative to the stopping of the crack, will be determined.

In addition, three sets of calculations with a pressurized fracture moving toward a frictional interface have been completed with a quasistatic model. In these calculations, the ratio of the initial frictional stress to the effective pressure in the fracture, (τ_f/P_c) , varied with values of 0.033, 0.067 and 0.1. The material characteristics on either side of the frictional interface were identical. Although the results from these calculations have not been completely analyzed, some observations can be reported.

When the scaled distance of the crack from the interface is greater than 1.0, the effects of the frictional interface on the fracture are very small. Motion along the interface increases as the pressurized fracture approaches the interface and as the frictional coefficient decreases. Additionally, the frictional stress along the interface changes as the fracture approaches the interface. The largest change in the frictional stress along this interface occurs directly ahead of the crack tip decreasing to very small values when the scaled distance between the fracture tip and the interface is less than 0.2.

Results of these calculations will be further reduced and compared with experimental values to determine the magnitudes of frictional stress in the tip region which will stop the crack or permit penetration of the frictional interface.

4.3.2 Experimental Program

During August, experiments were begun to study hydraulic crack growth in limestone near interfaces which were intersected by cracks. This phenomenon has been modeled theoretically and the stress intensity factor near the tip of the pressurized crack has been computed as the crack approaches an interface which is intersected by 0, 1, and 2 pre-existing cracks.¹ To experimentally model this geometry, the standard setup to study crack growth was modified as shown in Figure 4-12. The setup consisted of a sandwich of three 4 in. x 4 in. x 2 in. limestone blocks with the fluid pressurized crack initiated and driven in the center block. A load was applied so that a normal stress was set up across interfaces I₁ and I₂. In these experiments, however, the upper block consisted of three blocks which were precisely

¹ Hanson, M. E., G. D. Anderson, R. J. Shaffer, L. D. Thorson and D. N. Montan, "Theoretical and Experimental Analysis of Hydraulic Fracturing and Some Reservoir Response to the Stimulation," Proc. Fifth Annual DOE Symp. on Enhanced Oil and Gas Recovery and Improved Drilling Technology, Vol. 3, Tulsa, Oklahoma, August 22-24, 1979.

Figure 4-12
Experimental Setup for Fracture Growth
(C_1 , C_2) near Interfaces I_1 and I_2

machined and aligned adjacent to one another to give the effect of pre-existing cracks, C_1 and C_2 , which intersected the interface I_1 at right angles. In an initial experiment in which the applied load, W , exceeded the threshold stress for crack growth across unbonded interfaces in limestone (~ 650 psi), the pressurized crack crossed the interface I_2 from the central block in which it was initiated into the lower single block. It failed to cross the interface I_1 which was intersected by cracks C_1 and C_2 . This result is consistent with the predictions of the mathematical model if the mode I stress intensity factor is used as a criterion for predicting crack growth. However, this result must now be considered preliminary and subject to further modification as it is based on one observation. Further experiments are planned to establish a definite trend.

Experiments are continuing to measure the pressure-volume response of Mesaverde shale and sandstone up to a pressure of 1.0 GPa. Assembly of a high pressure vessel for simultaneous measurement of ultrasonic sound speed in multiple directions has been completed. Assembly has begun on a system to measure hot gas permeability.

4.3.3 Geology and Geophysics

Work has begun on the compiling of regional stratigraphy and tectonic information and maps of the Western gas sands area. This will give geologic information on stratigraphic controls for reservoir properties and local and regional information that may relate to fracturing and *in situ* stress in the rocks. Information sources so far include the American Association of Petroleum Geologists, the Rocky Mountain Association of Geologists, and the Wyoming Geological Association.

4.3.4 Schedule Status

Figure 4-13 is a milestone chart depicting LLL project status through August, 1979.

4.4 LOS ALAMOS SCIENTIFIC LABORATORY

4.4.1 Nuclear Magnetic Resonance Studies

In order to establish the scientific feasibility of NMR logging using the remotely-produced region of homogeneous field, it was necessary to investigate the sensitivity of NMR detection to samples outside the coil.

This was first tested at 20 MHz in a 9 in. electromagnet using a 1 cm diameter sample coil. The 1 cm hole was bored in a neoprene stopper. A plug was inserted in the coil and used to obtain a reference signal. The remaining annular part of the stopper was placed around the coil. A signal from the exterior annulus was obtained when the radio frequency pulse length was increased from that used to obtain the interior signal. This was necessary due to the reduced strength of the radio frequency field outside the coil.

A larger coil (approximately 1.5 cm x 4 cm) was wound to resonate at the logging density frequency of approximately 0.5 MHz. Since the lower frequency limit of the NMR preamp and receiver used for the 20 MHz was 2 MHz, it was necessary to design and build a suitable system capable of operating at 0.5 MHz. The new coil and radio frequency system were used successfully to detect signals from the sample exterior to the coil at 0.5 MHz in the laboratory electromagnet.

To remove the influence of the large iron pole, pieces of the electromagnet and a pair of 10 in. diameter coils were wound and arranged to form a Helmholtz pair. This provided a uniform field so that annular samples of one to two inches in diameter could be studied. A 1-in. diameter radio frequency coil was wound, and with a set of concentric pyrex cups. This allowed the 1 in. diameter coil to be centered in annuli of various diameters and thicknesses.

Figure 4-13 Milestone Chart — LLL

An extensive set of measurements (using glycerol as the sample material) was made on the signal size of various annular samples relative to a standard sample internal to the coil.

4.4.2 Remote Production of a Region of Homogeneous Magnetic Field

Computer calculations were made to study the variation of this field with change in various parameters. Figure 4-14 summarizes the results for the field in a plane perpendicular to the axis midway between the two field producing elements. B_r is the value of the radial field, r is the radial distance from the central axis, a is the radius of the coil (or magnet), and h is the half-separation of the two field producing elements. As h/a increases, the peak value decreases, and the peak moves further from the axis. The homogeneous region near the peak becomes wider as h/a increases.

To test these calculations, a pair of 8-in. diameter coils were wound and powered with a borrowed supply. As h/a varied, the field was mapped using a Gaussmeter and was found to agree with the calculations.

- B_r - Relative value of radial field
- a - Radius of coil (or magnet)
- r - Radial distance from central axis
- h - Half separation of two field producing elements

Figure 4-14 Results for a Homogenous Magnetic Field Perpendicular to an Axis between two producing Elements

Similar measurements were made using bar magnets. The results are shown in Figure 4-15.

Figure 4-16 shows how the position and value of the peak field vary with separation $D(=2h)$ for bar magnets.

4.4.3 Schedule Status

Figure 4-17 is a milestone chart depicting LASL's progress in the WGSP.

4.5 M. D. WOOD, INCORPORATED

During August, M. D. Wood, Inc. was involved in design and site preparation for two hydraulic fracture mapping jobs in the Cotton Valley Trend area of Texas. The stimulations will be massive hydraulic fractures on wells belonging to Shell and Amoco. The work is being supported by Sandia Laboratories and will be accomplished using the technology pioneered by MDWI where the ground deformations produced by fracture growth will be monitored with an array of sensors (tiltmeters) in shallow boreholes.

4.6 SANDIA LABORATORIES

4.6.1 EGR Instrumentation and Diagnostic Program

4.6.1.1 Hydraulic Fracture Characterization

The Amoco Burnett Bros No. 12 well, located approximately 60 miles east of Tyler, Texas, will be drilled to 9,500 ft and will be ready for fracturing in mid-October.

Experimental measurements from oriented coring, tiltmeters, and borehole seismic are planned for this well. After site inspection, it was recommended that the surface potential measurements be eliminated because of the dense forest in the area and the lack of access to areas requiring surface instrumentation and cabling.

4.6.1.2 Borehole Seismic System

Data analysis from the borehole seismic system evaluation test at the NTS has been completed. Even though the system has resonances, the p-wave and s-wave arrivals can be determined as accurately as with a grouted system, and vertical angles of up to 70 degrees present no serious problems provided the signal is relatively large.

The Shell Oil Company test on the Texas-Oklahoma border has been delayed until October. Additional seismic monitoring tests have been added to the experiment. A second borehole seismic system will be placed in an adjacent well (No. 309) about 600 ft from the well to be completed (No. 343); this well will be in line with the natural faults that exist in this area. Seismic activity will be monitored in both wells during the breakdown phase. During the main fracture treatment, the seismic unit that was used in well No. 343 will be moved to well No. 333, which is also about 600 ft away but to the north rather than to the east.

Figure 4-15 Results for a Magnetic Field with varying distance from the Bar Magnet

Figure 4-16 Magnet Separation D , cm

Figure 4-17 Milestone Chart -- LASL

4.6.1.3 Borehole Hydrophone System

The hydrophone system was tested in the Sandia borehole located in Area Y at the Sandia base. The bottom of the 6-in. diameter hole was determined to be at 243 ft. The bottom of the 6-in. diameter casing was 200 ft. The water level was detected at a depth of 142 ft. Two types of tests were made on the system. One consisted of a series of hammer blows on the surface at various distances from the well. The second included a small vibrator placed at a distance of approximately 40 ft from the well which was driven at cw frequencies from 30 to 500 Hz. A driving frequency of 100 Hz was chosen in recording the hydrophone output signals. In addition to recording the output on a paper recorder, the differences in phase between all hydrophones was measured on an oscilloscope. These measurements were made with the top of the hydrophone tool varying from a depth of 150 to 170 ft in 2-ft increments. Preliminary analysis of the data indicates that multiple reflections from the formation or standing waves in the borehole may be causing the measured formation velocity to be in the range of 1,000 to 2,000 feet-per-second. Since it is believed that the formation velocity should be in the order of 5,000 feet-per-second, another test in the borehole is being scheduled in order to determine if the reflection or standing wave interference is causing problems. The hammer blow testing was done only to determine if the differences in the time of arrival at the hydrophones could be detected. An accurate measurement was not made.

The hardware needed to complete a 30-ft ITC hydrophone system is expected to be delivered in September.

4.6.1.4 Formation Mapping

Field work at site No. 1 (Bryson Canyon Gas Field) has been limited to initial topographic surveying of the shot point and geophone pattern locations. Final approval from the Bureau of Land Management offices, including posting of bonds and archaeological releases, was given at the end of August. Surveying has continued.

4.6.1.5 Nuclear Magnetism Logging

Core analyses of eleven samples were started and are still in progress at Petroleum Testing Service, Santa Fe Springs, California. NMR analysis of these same samples will follow the initial tests and will be performed at Chevron Oil Field Research Company laboratories. Sandia will participate in the NMR experiments.

4.6.1.6 Advanced Electromagnetic Logging Techniques

A computer program for analytical calculations for the inductive coupling between single turn coils in a homogenous medium is now being used.

Parametric curves indicate that, under the point-source assumption, an error as large as 25 percent of the correct values can exist for coils whose diameters are less than 0.1 wavelength. When these coils are assumed to be point sources, the induced voltages are always larger than those from solutions, and their errors decrease in proportion to separation distances. For errors to be less than 1 percent of the correct values, the coils need to be

separated by a distance of 10 coil-diameters or greater. This separation distance is commonly assumed in the analyses of induction logging devices. When this separation is designed into tools, the probes suffer a loss of sensitivity and may suffer a lack of capability for the determination of the constitutive parameters.

Parametric curves on response sensitivities have been prepared for probe design purposes. After coil diameters are specified and the receiver dynamic ranges are determined, the coil separations can be quickly established according to operating frequencies. For a coil diameter of 2.5 cm, operating frequencies may vary from about 120 kHz to 1.2 GHz in free space. The high frequency limit is reduced in inverse proportion to the refractive index of a medium. Due to the absence of a theory for multi-turn coils, the present results are only applicable to single-turn systems. Multi-turn coils require careful calibrations to assure the accuracy of constitutive parameters in the inversion process.

Receiving-coil responses as functions of constitutive parameters of rocks are being obtained. Inherently low sensitivity is known for low-frequency operations. Better sensitivity can be obtained for frequencies up to 1.2 GHz for small coils. However, gas-oil production parameters will have to have better correlation with constitutive parameters before the most suitable frequencies of operation can be found.

Electrical constitutive relations are those functions that interrelate the electrical parameters E , D , B , H , and J (standard notations are used herein). These functions are analogous to equations-of-state. However, electrical systems are dissipative, so the functions describe thermo-dynamically irreversible processes. The frequency dependence of the conductivity, the dielectric constant and the magnetic permeability will be related to hydrocarbon production parameters.

Recently Poley, Nooteboom and deWall published data on the frequency-dependent electrical response of saturated sandstone cores. In their experiments, the measured current was due to conduction and displacement currents. In the model of these experiments, Archie's equation was used to describe the conductivity, whereas a Maxwell, Wagner, Sillars system governed the dielectric response. Some aspects of the Poley, et al data are well represented by such a model. However, a continuum of Maxwell, Wagner, Sillars systems describing a continuum of pore shapes will be required to model all aspects of the data. Dielectric measurements yield information over and above simple porosity determinations, and this information may be relatable to fluid flow permeabilities through the Kozeny equation.

4.6.2 Schedule Status

Figure 4-18 is a milestone chart depicting Sandia's progress in WGSP activities.

Figure 4-18 Milestone Chart — Sandia

5. FIELD TESTS AND DEMONSTRATIONS

5.1 BACKGROUND

Specific field tests are essential to verify the findings of laboratory tests and modeling studies. The field test and demonstration program involves cooperation between industry and government and also interacts geologic studies with laboratory research and development. The following projects are active in the WGSP:

- A dry gas injection experiment in the Wattenberg Field, Colorado, by Colorado Interstate Gas Company,
- MHF demonstrations by Gas Producing Enterprises in the Uinta Basin, Utah,
- MHF treatment of the Cotton Valley Limestone Formation in Limestone County, Texas, by Mitchell Energy Corporation,
- 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 5-1 summarizes completed and active WGSP MHF treatments. Progress of these projects is presented in the following sections.

Table 5-1 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 5,170-5,630	8-13-76 8-25-76	420,000 720,000	226 Gel 316 Gel	35	62	1.8
CONSORTIUM MANAGED BY CER CORPORATION Piceance, Mesaverde	3S/98W/Sec 11 Rio Blanco Cty, Colorado	RB-MHF-3	8,048-8,078	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
			10,120-10,790	10-20-75	1,422,000	459 Gel	—	150	—
GAS PRODUCING ENTERPRISES, INC. Uinta, Wasatch and Mesaverde	10S/22E/Sec 10 Uintah Cty, Utah	Natural Buttes No. 18	6,490-8,952	09-22-76	1,480,000	745 Gel	—	1,400	—
	10S/21E/Sec 21 Uintah Cty, Utah	Natural Buttes No. 19	8,909-9,664	09-21-76	424,000	280 Gel	—	166	—
			7,224-8,676	09-28-76	784,000	364 Gel	—	—	—
	9S/21E/Sec 22 Uintah Cty, Utah	Natural Buttes No. 14	6,646-8,004	03-15-77	1,093,000	544 Gel	38	800	21.0
	9S/21E/Sec 28 Uintah Cty, Utah	Natural Buttes No. 20	8,498-9,476	06-22-77	826,000	322 Gel	75	1,200	16.0
	10S/22E/Sec 18 Uintah Cty, Utah	Natural Buttes No. 22	6,838-8,550	11-21-77	1,151,000	499 Gel	—	700	—
	9S/22E/Sec 19 Uintah Cty, Utah	Natural Buttes No. 9	5,661-8,934	03-27-78	554,000	349 Gel	140	540	3.9
	10S/21E/Sec 29 Uintah Cty, Utah	CIGE No. 2	9,237-9,653 7,251-8,774	06-22-78 08-08-78	170,500 1,965,000	203 Gel 722 Gel	—	—	—
	10S/22E/Sec 7 Uintah Cty, Utah	Natural Buttes No. 23	5,080-6,294	10-04-78	470,000	240 Gel	—	800	—
MITCHELL ENERGY Cotton Valley, Limestone Trend	Limestone Cty, Texas	Muse-Duke No. 1	11,235-11,418	11-15-78	2,800,000	891 Gel	2,000	6,600	3.3
MOBIL Piceance, Mesaverde	2S/97W/Sec 13 Rio Blanco Cty, Colorado	F31-13G	10,549-10,680	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 498-4-1	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	—

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: David L. 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.

5.2 COLORADO INTERSTATE GAS COMPANY

Cyclic injection of dehydrated gas and production continued at the Miller No. 1 and Sprague No. 1 wells. The period of each injection production cycle has been lengthened to two weeks with the direction of flow being reversed every other Friday.

The ball valve on the inlet side of the compressor is not working properly, and it may be necessary to change the orifice on the controller so that it will be compatible with the positioner. Work is continuing so that the ball valves will work automatically.

DOE WELL TEST FACILITY

EY-76-C-08-0623

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.

5.3 DOE WELL TEST FACILITY

The DOE Well Test Facility has been relocated to the Rio Blanco Natural Gas Company well site No. 379-19-1 Government, Rio Blanco County, Colorado. The facility has been acquiring reservoir data and providing analytic support for the proposed joint GRI/RBNG fracture experiment.

Following a small breakdown, (approximately 5,000 gal, 15 percent MSR acid), a short pressure buildup test of the RBNG well No. 397-19-1 Government was conducted during mid-July. This BHP test indicated that the formation flow capacity was less than $7.0 \mu\text{d-ft}$ and that the extrapolated formation pressure was approximately 4,030 psia. A subsequent flow test was unsuccessful due to excessive fluid buildup that killed the well. Following the swabbing, another BHP test commenced on August 4. The results of this test, which lasted 25 days, confirmed those obtained during the short test in July, and indicated the formation flow capacity was approximately $8.0 \mu\text{d-ft}$ and the extrapolated formation pressure was approximately 3,910 psia.

Perforation of the casing into the sands at 8,502-8,516 ft and 8,534-8,558 ft was conducted on July 14 with little gas show. These perforations were located toward the center of the sands in order to reduce the possibility of going out of the zone during the fracture. Unfortunately, this perforation selection was not optimum for the formation testing necessary to adequately assess the results of the fracture experimentation. Consequently, it was recommended that these sands be perforated at locations of maximum permeability, as shown in Figure 5-1.

The formation and well data from the BHP buildup test conducted in July are tabulated in Table 5-2. Figure 5-2 is a Horner plot of that BHP data. Similarly the BHP buildup data for the August test are shown in Table 5-3, while a Horner plot of the BHP data is shown in Figure 5-3. Prior to each buildup the flow rate was low, 25 MCFD and 15 MCFD for the July and August tests, respectively. The total production for July and August was 10 MCF and 62 MCF, respectively. However, production resulted in substantial bottom-hole pressure reductions which substantiate the extremely low permeability values derived in the analysis.

Figure 5-1 Perforation Locations and Recommended Perforation Locations for
RBNG 397-19-1 Government

Table 5-2 Bottom-hole Pressure Buildup Test Commencing July 21, 1979,
RBNG 397-19-1 Government

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: 10.00 hrs.
Flow Rate: 25.00 MCFD

Time (ΔT) (hrs)	Horner Time	Pressure (psi)	Slope (psi/ cycle)	P-Star (psi)	kh (μ d-ft)	Skin
3.50	3.86	639.0	179.0	1,048.	500.100	-2.24
6.00	2.67	1,257.0	3,728.0	2,828.	22.430	-1.41
7.00	2.43	1,378.0	3,138.0	2,592.	26.360	-1.46
8.00	2.25	1,489.0	3,512.0	2,730.	23.330	-1.44
9.00	2.11	1,592.0	3,847.0	2,843.	21.120	-1.43
10.00	2.00	1,686.0	4,251.0	2,970.	18.980	-1.42
11.00	1.91	1,778.0	4,655.0	3,087.	17.210	-1.40
12.00	1.83	1,862.0	4,930.0	3,161.	16.160	-1.40
13.00	1.77	1,941.0	5,177.0	3,225.	15.300	-1.39
14.00	1.71	2,013.0	5,627.0	3,333.	14.010	-1.38
16.00	1.63	2,148.0	5,989.0	3,414.	13.050	-1.37
18.00	1.56	2,266.0	6,436.0	3,504.	12.050	-1.37
20.00	1.50	2,372.0	6,888.0	3,587.	11.190	-1.36
22.00	1.45	2,467.0	7,247.0	3,648.	10.580	-1.35
24.00	1.42	2,552.0	7,584.0	3,700.	10.070	-1.35
28.00	1.36	2,695.0	7,774.0	3,727.	9.751	-1.35
32.00	1.31	2,810.0	7,947.0	3,749.	9.487	-1.35
36.00	1.28	2,903.0	8,340.0	3,794.	9.001	-1.35
40.00	1.25	2,987.0	8,406.0	3,799.	8.897	-1.35
44.00	1.23	3,050.0	8,539.0	3,813.	8.736	-1.35
48.00	1.21	3,113.0	9,099.0	3,860.	8.178	-1.35
54.00	1.19	3,188.0	9,114.0	3,862.	8.140	-1.35
60.00	1.17	3,252.0	9,425.0	3,883.	7.852	-1.35
66.00	1.15	3,306.0	9,527.0	3,890.	7.751	-1.35
70.50	1.14	3,341.0	9,915.0	3,913.	7.439	-1.35
73.00	1.14	3,361.0	.1059E+05	3,951.	6.957	-1.33
75.50	1.13	3,379.0	.1032E+05	3,936.	7.137	-1.34
78.50	1.13	3,399.0	.1062E+05	3,952.	6.931	-1.34
92.50	1.11	3,479.0	.1061E+05	3,952.	6.918	-1.34
95.00	1.11	3,490.0	.1069E+05	3,955.	6.863	-1.34
96.50	1.10	3,498.0	.1099E+05	3,968.	6.672	-1.33
100.00	1.10	3,513.0	.1051E+05	3,948.	6.979	-1.34
104.00	1.10	3,529.0	.1216E+05	4,015.	6.026	-1.32
116.00	1.09	3,579.0	.1255E+05	4,030.	5.828	-1.31
120.00	1.08	3,593.0	.1255E+05	4,030.	5.826	-1.31

Figure 5-2 Horner Plot for July 21, 1979 Bottom-hole Pressure Test,
RBNG 397-19-1 Government

**Table 5-3 Bottom-hole Pressure Buildup Test Commencing August 4, 1979,
RBNG 397-19-1 Government**

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: 100.00 hrs.
Flow Rate: 15.00 MCFD

Time (ΔT) (hrs)	Horner Time	Pressure (psi)	Slope (psi/ cycle)	P-Star (psi)	kh (μ d-ft)	Skin
.50	201.00	980.0	27.43	1,055.	1,924.00	-1.38
1.00	101.00	1,010.0	122.10	1,260.	430.70	-1.77
1.50	67.67	1,039.0	190.40	1,390.	275.40	-1.79
2.00	51.00	1,067.0	247.20	1,491.	211.40	-1.79
2.50	41.00	1,093.0	328.00	1,625.	158.80	-1.81
3.50	29.57	1,144.0	406.30	1,746.	127.50	-1.82
4.50	23.22	1,194.0	509.20	1,892.	101.20	-1.83
5.50	19.18	1,240.0	654.10	2,084.	78.39	-1.85
7.50	14.33	1,330.0	774.00	2,231.	65.63	-1.86
9.50	11.53	1,412.0	944.80	2,420.	53.32	-1.87
11.50	9.70	1,491.0	1,107.00	2,586.	45.17	-1.88
13.50	8.41	1,564.0	1,284.00	2,755.	38.70	-1.90
17.50	6.71	1,695.0	1,427.00	2,881.	34.43	-1.91
21.50	5.65	1,811.0	1,613.00	3,028.	30.18	-1.93
25.50	4.92	1,913.0	1,757.00	3,132.	27.49	-1.94
29.50	4.39	2,004.0	1,854.00	3,196.	25.88	-1.95
33.50	3.99	2,083.0	1,905.00	3,228.	25.04	-1.96
37.50	3.67	2,153.0	1,949.00	3,253.	24.37	-1.97
41.50	3.41	2,215.0	1,985.00	3,273.	23.82	-1.98
45.50	3.20	2,271.0	2,161.00	3,365.	21.80	-2.00
49.50	3.02	2,329.0	2,002.00	3,285.	23.44	-1.98
53.50	2.87	2,365.0	1,812.00	3,197.	25.85	-1.95
57.50	2.74	2,406.0	2,003.00	3,282.	23.33	-1.99
61.50	2.63	2,442.0	1,996.00	3,279.	23.35	-1.99
65.50	2.53	2,476.0	2,024.00	3,291.	22.98	-2.00
69.50	2.44	2,507.0	2,064.00	3,307.	22.50	-2.01
77.50	2.29	2,569.0	2,061.00	3,307.	22.45	-2.00
85.50	2.17	2,612.0	2,051.00	3,302.	22.50	-2.01
93.50	2.07	2,657.0	2,238.00	3,363.	20.58	-2.05
101.50	1.99	2,697.0	2,177.00	3,345.	21.10	-2.04
109.50	1.91	2,732.0	2,356.00	3,396.	19.47	-2.07
121.50	1.82	2,783.0	2,373.00	3,401.	19.27	-2.07
133.50	1.75	2,825.0	2,508.00	3,434.	18.20	-2.10
145.50	1.69	2,865.0	2,465.00	3,425.	18.48	-2.09
157.50	1.63	2,898.0	2,641.00	3,463.	17.22	-2.12
181.50	1.55	2,959.0	2,659.00	3,467.	17.05	-2.13
217.50	1.46	3,034.0	2,945.00	3,518.	15.34	-2.17
253.50	1.39	3,093.0	3,305.00	3,572.	13.63	-2.20
289.50	1.35	3,151.0	4,093.00	3,680.	10.98	-2.24
325.50	1.31	3,206.0	4,592.00	3,741.	9.765	-2.26
361.50	1.28	3,260.0	5,436.00	3,836.	8.231	-2.26
397.50	1.25	3,304.0	4,821.00	3,773.	9.264	-2.26
471.50	1.21	3,390.0	5,599.00	3,848.	7.950	-2.27
535.50	1.19	3,417.0	4,624.00	3,766.	9.616	-2.26

Figure 5-3 Horner Plot for August 4, 1979 Bottom-hole Pressure Test,
RBNG 397-19-1 Government

**NATURAL BUTTES UNIT, UINTAH COUNTY,
UTAH MASSIVE HYDRAULIC FRACTURING
DEMONSTRATION**

EY-76-C-08-0681

Gas Producing Enterprises, Inc.
Subsidiary of Coastal States Gas Co.
Houston, Texas

Status: Active

Contract Date: July 1, 1976
Anticipated Completion: September 30, 1979

Total Project Cost (estimated):	DOE	\$2,827,000
	Industry (prior costs)	1,881,000
	Industry (new costs)	3,051,000
	Total	\$7,759,000

Principal Investigator: W. E. Spencer
Technical Project Officer for DOE: C. H. Atkinson

OBJECTIVE

To evaluate the effectiveness of massive hydraulic fracturing for stimulating natural gas production from thick, deep sandstone reservoirs having low-permeability.

5.4 GAS PRODUCING ENTERPRISES, INC.

The GPE wells, Natural Buttes Unit Nos. 9, 14, 18 and 20 flowed to sales during August. Natural Buttes Unit Nos. 19 and 22 were shut-in all month. Figures 5-4 through 5-9 show production histories.

A comprehensive final report is being prepared.

Figure 5-4
Flow Rate Performance of
Natural Buttes No. 9 Well

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

Figure 5-8
Flow Rate Performance of
Natural Buttes No. 20 Well

Figure 5-9
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	\$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.

5.5 MITCHELL ENERGY CORPORATION

The Mitchell Energy Corporation Muse-Duke No. 1 was shut in August 8, 1979 for a 15+ day pressure buildup test. The effectiveness of the massive hydraulic fracture treatment performed on November 15, 1978, will be determined through this pressure survey.

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: June 1st 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.

**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.

5.7 SANDIA LABORATORIES — MINEBACK

5.7.1 Summary of Past Activities

Exploratory coring of corehole EV6-25 failed to detect grout at approximately 110 ft below the ashfall tuff interface, but grout was detected 60 ft below the interface in corehole EV6-26.

Mineback of the four remaining fracture zones of the CFE-2 hole of the interface test series was completed in July and the results were used for defining the stress state near the interface.

5.7.2 Hydraulic Fracture Containment Experiments

5.7.2.1 Formation Interface Fracture Experiment (Hole No. 6)

The exploratory coring program for the delineation of the Hole No. 6 fractures continued in August with the completion of one additional hole. As shown in Figure 5-10, corehole EV6-27 intersected a green and black grout fracture (~ 4 mm thick) in the welded tuff, about 20 ft above the interface. Further coring will be undertaken in this area to determine the upper limits of the fractures.

5.7.2.2 Interface Test Series

The third hole of this series (CFE-3) was drilled to a total depth of 146.2 ft and 8 zones in the hole were hydraulically fractured with 150 gal of dyed water at 8 gpm. Each zone was at a different distance from the welded tuff/ash-fall tuff interface in a region where the stresses below the interface had significant variations in magnitude. These fractures will be mined back in September to observe the fracture behavior under these conditions. The recorded data from these experiments are shown in Table 5-4.

To further define the *in situ* stresses in this region, another hole (CFE-4) was drilled approximately 5 ft away from CFE-3 and 11 zones were fractured with small volumes of dyed water to determine the shut-in pressure (the minimum principal *in situ* stress) for a localized area around the borehole. These data are shown in Table 5-5. During mineback of the CFE-3, some fractures from the CFE-4 will also be observed.

Previous tests in this region have shown that a steep gradient in the *in situ* stresses has limited fracture growth. These experiments will further evaluate the stress distribution and its effect on containment of hydraulic fractures.

Figure 5-10 Results of Exploratory Coring of Hole No. 6

Table 5-4 CFE-3 Hydrofracture Data

Zone (ft)	BREAKDOWN PUMP				RECYCLE 1			FULL PUMP		
	P _c (psi)	P _f (psi)	P _{isi} (psi)	Vol (gal)	P _f (psi)	P _{isi} (psi)	Vol (gal)	P _f (psi)	P _{isi} (psi)	Vol (gal)
19	750	665	510	7.0	670	510	4.7	685-1,015	665	138.3
42	1,075	700	535	6.7	675	535	3.0	670	540	140.3
55	1,050	835	600	10.5	790	570	3.6	815-1,190	800	135.9
68	1,150	680	520	7.6	625	515	4.6	600-700	525	139.8
83	1,090	850	550	5.7	750	585	2.8	700	600	90.0
98	1,365	725	585	5.6	700	585	3.7	680-1,420	1,140	140.7
113	1,290	790	610	9.0	735	585	3.2	770-1,230	850	137.8
126	900	710	635	7.7	750	640	4.5	650	600	137.8

Table 5-5 CFE-4 Hydrofracture Data

Zone (ft)	BREAKDOWN PUMP			RECYCLE 1			RECYCLE 2		
	P _c (psi)	P _f (psi)	Vol (gal)	P _f (psi)	P _{isi} (psi)	Vol (gal)	P _f (psi)	P _{isi} (psi)	Vol (gal)
16	948	532	3.6	539	470	1.9	545	475	2.0
26	1,193	832	4.6	920	670	2.0	950	700	2.4
33	1,193	1,118	4.2	1,300	1,010	2.0	982	765	2.1
50	873	702	5.1	668	485	2.1	675	520	2.1
65	954	614	5.4	580	505	1.9	580	490	2.1
80	1,125	627	5.2	586	475	2.1	580	485	2.2
94	1,132	614	5.3	597	425	2.3	600	425	2.1
107	1,173	1,077	6.0	838	585	2.1	850	600	2.2
119	1,028	676	6.4	600	440	2.3	545	435	2.6
129	580	470	3.8	464	300	2.6	457	295	2.3
139	—	—	8.0	470	380	4.2	416	360	3.0

5.7.3 Explosive Fracturing Experiments

Several activities in the multi-frac test series are underway. All experiment hole positions were surveyed and marked. A drill rig was set up and coring and reaming operations have begun. Casing, flanges, and bulkhead material have been received at NTS and machining is underway.

A caliper device that is capable of accurate measurements in a horizontal borehole was obtained. Typical calipers are too heavy for convenient use in horizontal holes and are accurate only to $\pm .25$ in. The caliper which will be used is light weight and capable of accuracies of $\pm .001$ in.

5.7.4 Schedule Status

Figure 5-11 is a milestone chart depicting Sandia mineback progress.

Figure 5-11 Milestone Chart — Sandia Mineback