Western Gas Sands Project Status Report

1 March - 31 March, 1980

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SUMMARY

The March, 1980 progress of the government-sponsored projects directed towards increasing gas production from the low permeability gas sands of the western United States is summarized in this edition of the WGSP Status Report. The September, 1977 Status Report, NVO/0655-100, provides background information.

A site for the multi-well experiment was approved by the industry review committee; drilling is expected by mid-summer. Bartlesville Energy Technology Center continued work on fracture conductivity, rock/fluid interaction, and log evaluation and interpretation techniques. Lawrence Livermore Laboratory continued experimental and theoretical work on hydraulic fracturing mechanics and analysis of well test data. Analysis of data obtained from a test of the borehole seismic unit by Sandia Laboratories continued.

The DOE Well Test Facility continued bottom-hole pressure buildup measurements at the Colorado Interstate Gas Company Miller No. 1 well.

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SECTION 1

PROJECT MANAGEMENT

TECHNICAL MONITORING AND EVALUATION

C. H. Atkinson (DOE) participated in a meeting with project personnel in Denver, Colorado, March 5, to plan a briefing for the DOE Deputy Assistant Secretary for Oil, Gas and Shale Technology. The briefing took place in Morgantown, West Virginia, on March 11.

D. L. Reese and S. R. Anderson (CER Corporation) attended a symposium entitled, "Natural Gas Resources Development in Mid-Continent Basins: Production and Exploration Techniques," in Tulsa, Oklahoma, March 10-12.

A meeting with the multi-well experiment industry review group was held in Las Vegas, Nevada, March 25-26. Representatives from DOE, BETC, METC, CER Corporation, Sandia Laboratories and industry were present. The Northwest Exploration site was reviewed and approved by the group. (See Section 3, "Multi-well Experiment".)

P. Branagan and G. Cotner (CER Corporation) attended the Third Annual Well Testing Symposium at the Lawrence Berkeley Laboratory, Berkeley, California, March 26-28.

TECHNOLOGY TRANSFER

The *WGSP Financial Supplement* for March 1979 and the February *WGSP Status Report* have been distributed. The *WGSP Logging Program Document* has been submitted for comment. Compilation of data for the quarterly basin activities report for the first quarter, 1980, and the WGSP section of the

DOE semi-annual report for the Unconventional Gas Recovery Program (period ending March 31, 1980) has begun. Revision and updating continued on the *DOE Well Test Facility Operations Manual*. Research for the WGSP Greater Green River Basin review and similar reports for the Piceance and Uinta Basins continued.

Project Data Bank

The following maps have been added to the WGSP data bank:

"Simple Bouguer Gravity Anomaly Map of Utah," by K. L. Cook, J. R. Montgomery, J. T. Smith, and E. F. Gray, Department of Geology and Geophysics, University of Utah, Salt Lake City, Utah, 1975.

"Geologic Map Index of Utah," compiled by L. F. Hintze and L. Boardman, Utah Geological and Mineralogical Survey, 2 sheets, 1964.

"Penetration Chart of Utah Oil and Gas Fields," compiled by J. A. Campbell and R. S. Bacon, Utah Geological and Mineralogical Survey, October 1976.

"Catalog: Sample Library. Consolidated Index to Samples, Cores, Lithologic Logs and Electrical and Other Mechanical Logs on File," compiled by D. C. Mann, Utah Geological and Mineralogical Survey, May 1973.

Updating and cataloging of the WGSP bibliography and map file continued.

Articles and Publications

The following abstracts are from articles of importance to the WGSP and are included in the bibliography.

*Evaluation and Performance
Prediction of Low-Permeability
Gas Wells Stimulated by
Massive Hydraulic Fracturing*

by R. G. Agarwal, R. D. Carter,
and C. B. Pollock
Amoco Production Company

This paper discusses how to analyze past performance and predict future performance of tight gas wells stimulated by massive hydraulic fracturing (MHF) using finite fracture flow-capacity type curves. The limitations of conventional pressure transient analysis and other methods of evaluating MHF treatment are discussed. A set of constant well-rate and well-bore-pressure type curves is presented.

*Ball Sealer Diversion of Matrix
Rate Treatments of a Well*

by S. R. Erbstoesser,
T. W. Muecke, and C. E. Cooke, Jr.
Exxon Production Research
Company

A method for sequential treatment of formation strats when treating fluid is pumped into a well at a matrix rate by temporarily closing perforations in the well casing. The perforations are closed by ball sealers injected into the well during the treatment. The ball sealers are sized to plug the perforations and have a density less than the density of the treating fluid. The treating fluid is injected at a rate which transports the ball sealers to the perforation but which is sufficiently low to prevent formation fracture. 17 claims.

SECTION 2

RESOURCE ASSESSMENT

U.S. GEOLOGICAL SURVEY ACTIVITIES

Uinta-Piceance Basins

SEM and mineralogic studies of reservoir rock cores in both basins continued.

The potential Piceance Basin multi-well experiment site was reviewed as well as other potential coring opportunities.

Greater Green River Basin

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

An 84-ft core was received from TRW, which was from the Belco No. S-29-27 well, Sec. 28, T30N, R113W, Sublette County, Wyoming.

Desorbed methane core samples of the Rainbow Resources No. 1-3 Pacific Creek Federal well (Sec. 3, T26N, R103W), Sweetwater County, Wyoming) were sent to METC for residual gas determination.

A palynological report on surface samples from the Hoback Basin was received.

USGS Core Lab slabbed core from the PTS No. 24-19 Beamers Bluff well (Sec. 19, T33N, R114W) Sublette County, Wyoming.

Northern Great Plains Province

A report was prepared entitled "Physical characteristics, burial history, and reservoir properties of low-permeability, biogenic methane reservoirs in the Northern Great Plains."

Work continued on resource potential of the Northern Great Plains for the National Petroleum Council.

A report was prepared entitled "Revision of Cretaceous nomenclature in Montana and South Dakota," by D. D. Rice, G. W. Shurr and D. L. Gautier for the USGS Bulletin.

A regional cross section from southeastern Alberta to the Bowdoin Dome, north-central Montana, was completed.

Several operators were contacted about obtaining core from the study areas.

Schedule Status

Figure 2-1 is a milestone chart depicting USGS status in the WGSP.

CORE PROGRAM

The core facility for the multi-well experiment is being designed. It is planned as a 24 ft by 60 ft skid-mounted building, completely self-contained for on-site core handling.

SURVEY OF BASIN ACTIVITIES

Greater Green River Basin

During March, 34 wells were reported complete: 20 development wells were reported as producers, 5 wildcat wells were discoveries, and 5 development and 4 wildcat wells were D&A.

From the 25 producers, the total initial potential was 33,542 MCFD new gas. The Frontier horizon was the largest contributor (18,171 MCFD), and other horizons included the Almond, Mesaverde undifferentiated, Lewis, Frontier/Muddy (commingled), and Fox Hills.

Figure 2-1 Milestone Chart — USGS

WGSP — USGS	FY-80											
B. Northern Great Plains Province	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Petrographic examination of producing low-permeability reservoirs of SE Alberta.												
Write paper on origin of biogenic gas accumulations.												
Construct cross-sections from western Canada to north-central Montana.												
Write paper on depositional environments and geometries of Mosby SS (Greenhorn Fm.) of north-central Montana.												
Regional subsurface study of Niobrara Fm. in North and South Dakota.												
Pilot lineament study of Northern Black Hills.												
Subsurface study of Groat sandstone.												
Regional lineament map.												

WGSP — USGS	FY-80											
C. Piceance Basin	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Report results of core analysis from Rio Blanco area.												
Structure contour map of top of Cretaceous.												
Isopach map of rocks in interval from top of Cretaceous to Rollins sandstone.												
Prepare results of outcrop section of Mesaverde and lower Tertiary sequence at Rifle Gap.												
Continue studies of mineralogy, diagenesis, stratigraphy and sedimentology of cores from Twin Arrow, Mobil and Ralstov Production Company.												

Figure 2-1 Continued

WGSP — USGS	FY-80											
D. Uinta Basin	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Geologic and engineering cross section from Wasatch Plateau to south central Uinta Basin.												
Sedimentology, stratigraphy and mineralogy study of Tertiary core from Southman Canyon region												
Analyze stratigraphy, sedimentology, and diagenesis of core from Pariette Bench field Tertiary rocks.												
Continue analysis of CIGE NBU No. 21 core as available.												
Prepare analysis of sedimentology, stratigraphy, and mineralogy of Late Cretaceous and lower Tertiary rocks at Price River Canyon.												

Figure 2-1 Continued

Newly staked locations totaled 30: 22 development and 8 wildcat wells.

Table 2-1 is a sample of wells and tests located in the basin. Figure 2-2 shows the location of the wells and the USGS designated core areas.

Northern Great Plains Province

By month's end, 36 wells were reported complete: 26 development wells were reported as producers, 1 wildcat well was a discovery, and 2 development and 7 wildcat wells were D&A. Six development and two wildcat locations were temporarily abandoned.

The Eagle Formation was the largest contributor, with the total initial potential flow of 6,584 MCFD. Other horizons included the Bow Island, Bowdoin, White Specks, Dakota, Phillips, Frontier, Niobrara/Bow Island (com-

mingled), and Bow Island/Sunburst (comingled). The total initial potential flow was 17,018 MCFD.

Eleven new locations were staked during March: 7 development and 4 wildcat wells.

Table 2-2 is a sample of wells located in the Northern Great Plains Province, and Figure 2-3 shows the locations of these wells.

Piceance Basin

Twenty wells were reported complete: 17 development wells were reported as producers, 2 development wells were D&A, and 1 development well was completed as a shut-in gas well. There were no wildcat discoveries reported during the month.

Total initial potential flow was 5,692 MCFD: the Mancos B contributed 4,134 MCFD (1 IPF was not available). Other horizons

Figure 2-2 Greater Green River Basin
Showing Wells of Interest
and USGS Designated Core
Areas (refer to Table 2-1)

Table 2-1 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
Houston Oil & Minerals	21-27 Federal	1	nenw 27/12N/94W Wildcat Field Moffat Cnty, CO	Mesaverde 8,500	9,009		Wildcat well, comp. 10-10-79 D&A. Tested, no cores.	
Texas Oil & Gas	1 Antelope Flats State	2	nesw 36/17N/99W Bitter Creek Field Sweetwater Cnty, WY	Fox Hills 7,191-7,274	7,557 PB: 7,416	Acidized w/ 3,000 gal; fractured w/ 92,610 gal gel, 139,612 lb sand.	Wildcat shallower pool discovery, comp. 2-4-80. No cores or tests.	675
Amoco Production	1 Champlin 149B	3	senw 9/18N/112W Bruff Field Uinta Cnty, WY	Frontier 11,527-11,544	11,784	Acidized w/ 20,000 gal; fractured w/ 137,634 gal oil, 562,400 lb sand.	Develop. well, comp. 8-30-79. Cored and tested.	300
Pacific Transmission Supply	3-2A Federal	4	csw 2/20N/91W Wildcat Field Sweetwater Cnty, WY	Mesaverde 12,000			Wildcat test, reported 3-5-80. Located in Core Area B1.	

¹ Refer to Figure 2-2

² Projected depth or producing interval

Figure 2-3 Northern Great Plains Province Showing Wells of Interest and USGS Designated Core Areas (refer to Table 2-2)

Table 2-2 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
Petroleum Incorporated	2 Miles	1	sese 29/35N/7E Unnamed Field Liberty Cnty, MT	Niobrara 2,022-2,026 Bow Island 2,137-2,176 (commingled)	3,345		Develop. well, comp. 7-28-79. Tested, no cores. Spud: 1-9-76.	860
P&M Management	34-19 Fee (Walter B Sales et Ux)	2	swse 19/8S/46E Wildcat Field Powder River Cnty, MT	Parkman 4,700	4,461		Wildcat test, comp. 1-2-80 D&A. Tested, no cores.	
General Well Service	1 Benjamin	3	nesw 21/31N/2E Unnamed Field Toole Cnty, MT	Bow Island 871-881 (gross)	2,487 PB: 965		Wildcat field discovery, comp. 7-25-79. Tested, no cores.	312
Staman Exploration & Production	1-8 Werner	4	cnw 8/27N/50E Wildcat Field Roosevelt Cnty, MT	Judith River 1,065			Wildcat test, reported 3-19-80.	

¹ Refer to Figure 2-3

² Projected depth or producing interval

Figure 2-4 Piceance Basin Showing Wells of Interest and USGS Designated Core Areas (refer to Table 2-3)

Table 2-3 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
Chandler & Associates	9-19-1-1 Fork Unit	1	nese 19/1S/101W Douglas Creek North Field Rio Blanco Cnty, CO	Mancos B 2,308-2,426	2,645	Acidized w/ 1,500 gal; fractured w/ 98,700 gal water, 288,000 lb sand.	Develop. well, comp. 2-10-80. No cores or tests.	350
Norris Oil	4-1 Federal	2	nwse 4/10S/97W Roberts Canyon Field Mesa Cnty, CO	Mesaverde 2,675			Wildcat shallow pool test, reported 2-29-80. Old well worked over: comp. 10-18-79 D&A.	
Teton Energy	23-2 Walck	3	nwnw 23/10S/93W Plateau Field Mesa Cnty, CO	Cozzette 5,476			Develop. test, reported 3-18-80. Located in Core Area D.	

¹ Refer to Figure 2-4

² Projected depth or producing interval

Figure 2-5 Uinta Basin Showing Wells of Interest and USGS Designated Core Areas (refer to Table 2-4)

Table 2-4 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
Gulf Oil	3-29-2C Skitz Canyon Ute	1	sene 29/4S/6W Wildcat Field Duchesne Cnty, UT	Wasatch 8,000	6,300 PB: 6,254	Acidized 4 times w/ total 12,200 gal	Wildcat well, comp. 8-16-79, temp. abnd Cored and tested.	
Sun Gas	3 Utah-Federal-D	2	nwnw 25/7S/24E Powder Springs Field Uintah Cnty, UT	Green River 5,112-5,126	5,399 PB: 5,361		Develop. well, comp. 1-14-80. No cores or tests.	1,200
Enserch Exploration	1 Eight Mile Flat	3	nwnw 23/9S/18E Wildcat Field Uintah Cnty, UT	Green River 6,000			Wildcat test, reported 3-7-80.	

¹ Refer to Figure 2-5

² Projected depth or producing interval

included the Castlegate (also known as Mancos A), Corcoran, Cozzette/Corcoran (commingled), Rollins/Corcoran (commingled), Frontier/Dakota (commingled) and the Wasatch.

One newly staked wildcat and 16 development locations were reported during March.

A sample of wells and tests in the Piceance Basin is in Table 2-3, and Figure 2-4 shows the locations of the wells and the USGS designated core areas.

Uinta Basin

Activity was slow during March: 3 development wells were reported as producers, 1 wildcat location was temporarily abandoned, and 1 of each type well was D&A. Initial potential flow of the new gas totaled 3,526 MCFD. The contributing horizons included the Wasatch, Green River and Mesaverde undifferentiated.

Six new locations were staked by month's end: 5 development and 1 wildcat wells.

Table 2-4 is a sample of wells and locations in the basin, and Figure 2-5 shows the locations of these wells.

C K GEOENERGY

The final report has been issued for contract No. ET-78-C-08-1601 (Reservoir Characteristics in Uinta Basin Gas Wells).

For contract No. DE-AC08-79BC10005 (Development of Techniques for Optimizing Selection and Completion of Western Gas Sands), data processing continued for the Green River and Wind River Sandstone Geometry Study. Corehole DOE-GC-1 infor-

mation is being coordinated with Seismic International and Sandia Laboratories' Seismic Program. Additional field work to tie in the seismic work should be completed by the end of April.

MULTI-WELL EXPERIMENT

A meeting of the Multi-Well Industry Review Committee was held at CER Corporation in Las Vegas, March 25 and 26, 1980 with representatives from DOE, BETC, METC, Sandia Laboratories, CER Corporation and industry.

The primary purpose of the meeting was to choose a well site for the multi-well experiment and review the preliminary plans. CER had investigated a number of potential sites, but had narrowed the site selection to three locations.

After a review of the geology and offset well data, a Northwest Exploration Company site was selected as the most suitable from a geologic standpoint and from a year around operational basis. The site is located in Sec. 20, T6S, R94W, Garfield County, Colorado (in the Colorado River Valley, near the town of Rifle). The Committee unanimously agreed on the Northwest Exploration Company site as the best location for the experiment.

Plans for drilling, logging and formation evaluation were reviewed by CER Corporation personnel. D. R. Van Alstine of Sierra Geophysics, Inc. (Arcadia, CA) presented a technique for orienting core using paleomagnetism either in conjunction with conventional orienting techniques or as an alternative method. Sandia Laboratories presented their plans for core handling and analysis and preliminary plans for running stress tests in the second well.

Figure 2-6 Milestone Chart - Multi-Well Experiment

Coring of the first well is expected to begin by August.

Other multi-well activities during the month included:

- designing utility routes for the location;
- designing the crew change room and the core handling facility;
- filling out Garfield County Environmental Impact forms;

- working on a "Federal type" environmentally oriented 13-point surface use plan and safety oriented 10-point operations plan; and
- writing a draft surface use plan that included a 1 in. = 50 ft scaled plat showing the well site pad with all future facilities.

Schedule Status

Figure 2-6 is a milestone chart depicting the multi-well experiment progress.

SECTION 3

RESEARCH & DEVELOPMENT BY ENERGY TECHNOLOGY CENTERS & NATIONAL LABORATORIES

BARTLESVILLE ENERGY TECHNOLOGY CENTER

Improved Pressure Coring System — Sandia Laboratories

Core Retriever Design and Test

When Stratapax® bits are used, the core breaks much closer to the bottom of the hole, and in a few instances, the resulting longer core has prevented proper closure of the ball valve mechanism. Several components of the pressure coring system have been redesigned to permit increased downward travel of the ball valve. This redesign has been field tested, and the longer cores now do not interfere with the ball valve.

Core Fluid Testing

A number of tests have been conducted to optimize the low-invasion fluid for field use. The CaCl_2 brine eutectic, with a freezing point of -60°F , has been replaced by CaBr_2 eutectic, which has a freezing point of -117°F . Since the bromide eutectic is non-freezing at dry ice temperatures (-110°F), the viscous, bromide-based low-invasion fluid should have good core-handling characteristics. This was verified experimentally by pushing a "frozen" core out of a core barrel and easily removing the low-invasion fluid from the core at dry ice temperatures. These improved low-temperature properties should

further reduce the handling costs and difficulties associated with pressure coring. The bromide eutectic (46.6 percent by weight) appears to have all the good features of the chloride eutectic, and the bromide ion should be a very good tracer to accurately quantify the amount of invasion which takes place during coring.

Viscosity testing to optimize particle and polymer concentrations of the low-invasion fluid has been completed. The particle concentration was increased from 100 lb/BBL of CaCO_3 to 300 lb/BBL to improve the formation pore bridging and surface filter cake properties of the fluid. The 300 lb/BBL particle concentration represents a practical upper limit based upon mixing properties, and the increase in particle concentration also increases the viscosity significantly. To keep the viscosity within design limits, the HEC polymer concentration was reduced from 15 lb/BBL to 10 lb/BBL.

Preliminary core analysis data have been received on the Bennet Ranch Unit No. 310 well, which was cored in October, 1979. These data indicate that the low-invasion fluid is doing a good job protecting the core from the conventional drilling fluid. Tritium isotope tracer data on depressurized cores indicates that less than 4 percent of the core water was drilling fluid filtrate.

Bit Design and Fabrication

The Sandia redesigned bits with improved hydraulics will be available for testing in June. These one- and two-piece core bits will be equipped with diamond compax cutters diffusion-bonded to steel studs. This will permit the field replacement of damaged cutters to rebuild the core bits for reuse.

Polycrystalline Diamond Core Bit Tests

One advantage of the improved PDC pressure coring system is that excellent cores from

lightly consolidated formations can be obtained where core recovery was very poor in the past.

In Situ Permeability

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

Investigation of the effect of net confining pressure on the gas slippage effect confirms that the slope of the straight line relating reciprocal mean pore pressure and gas permeability is a function of confining pressure.

Measurements on core sample Nos. 8290.4, 8290.9 and 8365.4 from the Mapco RBU No. 11-17F well, Sec. 17, T10S, R20E, Uintah County, Utah indicate that the slope of the Klinkenberg plots decreases with increasing confining pressure. The results are summarized in Tables 3-1 to 3-3, respectively. Graphic representations of the data are shown in Figures 3-1 to 3-3. The cores were subjected to net confining pressures up to 5,000 psi. For core No. 8290.4, the slope decreased from 1.23 (md)(psi) at a net confining pressure of 120 psi to 0.178 (md)(psi) at 5,000 psi net confining pressure. For core No. 8290.9, the reduction was from 3.44 (md)(psi) to 0.337 (md)(psi); and for core No. 8365.4, the slope dropped from 0.875 (md)(psi) to 0.0135 (md)(psi) at 5,000 psi. The value of b , the constant in the Klinkenberg equation, does not exhibit any trend.

The equation proposed by Klinkenberg to explain gas flow through porous media consists of two contributions, one due to viscous flow and the other due to molecular flow. Observations made during this reporting period and earlier ones indicate that the two contributions are affected to different extents by confining pressure and partial water saturations. This behavior might be explained by effectively decoupling the two contributions and evaluating the variables' effect on the flow behavior. The dependence

of the viscous flow contribution on confining pressure may be evaluated to confirm earlier conclusions. Eliminating the molecular flow component would be one way to decouple the two contributions.

Logging Studies

Mapping and Contouring Water Resistivities in Tight Western Gas Sands — Texas A&M University

Most gas wells producing from a formation which has a water drive ultimately begin to produce significant amounts of formation water. Reliable values of R_w can be obtained if the effects of dilution by water which entered the well in the vapor phase are taken into account.

Since all conventional hydrocarbon reservoirs contain connate water which is considered to be immobile, vapor phase water is always a natural gas contaminant. The mole fraction of water in reservoir gas can be approximated from its vapor pressure and the reservoir pressure by

$$Y_w = \frac{P_{vw}}{P}$$

However, this relationship is inaccurate at elevated pressure where the ideal gas laws do not apply. At higher pressures the empirical correlations of McCarthy et al are useful.¹

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

Velocity measurements have been made for three cores from the CIGE NBU No. 21 well, Uinta Basin. Physical properties of each sample are listed in Table 3-4. A plug of each core

¹ McCarthy, E. I., W. L. Boyd and L. S. Reid, "The Water Vapor Content of Essentially Nitrogen Free Natural Gas Saturated at Various Conditions of Temperature and Pressure," Trans AIME, 1950, p. 189.

Figure 3-1 Effect of Net Confining Pressure on Gas Slippage

Table 3-1 Effect of Net Confining Pressure on Gas Slippage

Well: Mapco RBU No. 11-17F, Uintah County Core No: 8290.4			
Net Confining Pressure, psi	Slope (md)(psi)	Intercept K_{∞} , md	b, atm
120	1.230	0.1540	0.544
1,000	0.855	0.0421	2.327
1,500	0.670	0.0250	1.824
2,500	0.348	0.0158	1.499
3,500	0.250	0.0093	1.829
5,000	0.178	0.0048	2.523

Figure 3-2 Effect of Net Confining Pressure on Gas Slippage

Table 3-2 Effect of Net Confining Pressure on Gas Slippage

Well: Mapco RBU No. 11-17F, Uintah County Core No: 8290.9			
Net Confining Pressure, psi	Slope (md)/(psi)	Intercept K_{∞} , md	b, atm
120	3.440	0.1770	1.323
1,000	1.910	0.0536	2.425
2,500	0.657	0.0190	2.353
3,500	0.350	0.0110	2.268
5,000	0.337	0.0028	8.190

Figure 3-3 Effect of Net Confining Pressure on Gas Slippage

Table 3-3 Effect of Net Confining Pressure on Gas Slippage

Well: Mapco RBU No. 11-17F, Uintah County Core No: 8365.4			
Net Confining Pressure, psi	Slope (md)(psi)	Intercept K_{∞} , md	b, atm
120	0.875	0.05770	1.032
1,000	0.306	0.02520	0.826
1,500	0.451	0.00950	3.230
2,500	0.303	0.00280	7.364
3,500	0.143	0.00250	3.892
5,000	0.135	0.00035	26.246

was saturated with water and a transducer (piezoelectric chip) was attached to each end which allowed the velocity of a generated pulse to be measured as it passed through the sample. Each sample was coated with epoxy to prevent the fluid in the pressure vessel from permeating. Travel times were measured and recorded for pressures from 0 to 4,000 psi. Figure 3-4 shows the plot of matrix travel time versus pressure. Matrix travel times were calculated from the measured velocities and the known porosities of each sample.

Sample No. 28 provided the most useful data. The elastic wave propagation theory indicates that a material 100 percent saturated with an incompressible fluid will maintain a nearly constant matrix travel time over a wide range of pressures. A compressible saturating fluid would allow the porosity to decrease with increasing pressures. Water was the saturating fluid for these three samples.

Sample No. 28 responded as expected to changes in pressure. Sample Nos. 17 and 33 showed a large variation in matrix travel times with changing pressure. Because each sample had to be exposed to air when the transducers were cemented on and the epoxy coat applied, it is likely that sample Nos. 17 and 33 were not 100 percent saturated with water. These samples are being remeasured.

Sample No. 28 also indicated that the presence of the carbonate cement might not affect matrix travel times as expected. Normally, a carbonate has a matrix travel time of 43 to 47 μsec per foot. Sample No. 28 has a carbonate content of 58 percent (from petrographic analysis). However, the matrix travel time was 63 μsec per foot. Some other factor which cannot be readily identified (possibly the presence of shales) controls matrix travel times. Data from the resaturated samples plus other unexamined samples should provide the information.

Advanced Logging Techniques and Interpretations

Dielectric Constant Measurement for Formation Evaluation

Although the dielectric constant bridge was very difficult to balance at higher frequencies, this problem was solved by using a different capacitance standard and a low pass filter in the detection circuit. One remaining electrical problem, a capacitance-conductance interaction, is now being studied.

Developments and Applications of a Wide Band Laboratory Dielectric Constant Measurement System — Colorado School of Mines

Construction of the dielectric measurement sample holder and fluid saturation chamber has been completed.

Use of Sonic Techniques to Measure In Situ Stresses — Lawrence Livermore Laboratory

Preliminary experiments were conducted to evaluate several different ways of detecting uniaxial stress by acoustic velocity measurements. A pulse generator was used to send a square pulse to a transducer-sample-transducer assemblage. The output signal was processed with a spectrum analyzer and displayed on an oscilloscope. The sample was a 10 cm thick Nugget sandstone cube, which has strong anisotropic velocities. Shear transducers were used with the polarization direction 45° to the fast velocity direction. Uniaxial stress was added to the sample in the direction normal to the propagation direction. The initial anisotropy of the sample produced a minimum in the frequency domain on the spectrum analyzer due to interference of the two shear waves.

Figure 3-4 Sample Data for Matrix Travel Time Measurements

Table 3-4 Sample Data for Matrix Travel Time Measurements

Sample No.	Depth (ft)	Porosity (percent)	Matrix Density (gm/cc)	Carbonate (percent)
28	7,476.67	3.2	2.772	58
17	6,472.00	8.5	2.645	13
33	7,482.00	6.2	2.698	31

When uniaxial stress was added, the frequency minimum was shifted due to the change in the shear velocities.

For a continuous wave method, the frequency synthesizer sent a sine wave to the transducer-sample-transducer assemblage. The sample signal and the original signal were simultaneously displayed on the oscilloscope. Initially, the frequency was adjusted so that the two signals were in phase as a reference condition. When the uniaxial stress was added, the sample signal was shifted. The frequency difference to make the two signals in phase again was proportional to the velocity change due to stress.

Reservoir Simulation Studies

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

Final drafting on a set of short flow time type curves is in progress. The curves will be used in analyzing pressure buildup data from fractured, low permeability gas reservoirs.

A computer model of a fractured gas well was used to develop test problems for use with the type curves. The pressure buildup data from the model appears to match more than one of the type curves in some cases. This results in values for permeability, k , and fracture half-length, X_f , that are not unique. The multiple matches are covered by the similar shapes of the curves.

When the calculated values of k and X_f , using the wrong type curves, are used in the model, the original buildup curve is not reproduced. The model generates a unique set of data for a given k and X_f . Attempts will be made to find a test for uniqueness to use with the type curves.

Rock-Fluid Interaction

Proppant Studies: Acid-Base Inertness of Sintered Bauxite

To test the chemical inertness of sintered bauxite to the potentially harsh environment of drilling and fracturing fluids, a 20 to 40 mesh proppant was placed in various concentrations of HCl and NaOH. The pH of the test solutions ranged from 1 to 13. The proppant was exposed to three time-intervals (24 hrs, 3 days and 7 days at 24° C). Chemical attack was determined by measuring the percent of dry weight loss.

The results of these tests did not show any significant chemical attack on the sintered bauxite. The length of time of chemical exposure appeared to have little effect. At the more neutral pHs (5.0 to 9.0), there was no weight change. At the lower and higher pH values, a very slight weight change was observed but the percent change was so small (<0.02 percent) that it would be difficult to assign this weight change to dissolution, especially when the time of exposure had no effect. Based on these tests, there seems to be little problem with chemical attack on the sintered bauxite proppant.

Schedule Status

Figure 3-5 is a milestone chart showing BETC's WGSP progress.

GAS RESEARCH INSTITUTE

Preliminary discussions were held concerning a proposed joint GRI/DOE cooperative coring and logging field project at a Northwest Exploration Company well site, Garfield County, Colorado. This location is near

the planned site of the multi-well experiment, and information gained from it will aid in the planning of the MWX as well as contribute to the overall DOE/WGSP Coring/Logging Program.

LAWRENCE LIVERMORE LABORATORY

Theoretical Analysis

In the October, 1979 WGSP status report, the dynamics of crack propagation near an interface that separates materials of differing elastic moduli were analyzed. There was a special case where the crack propagated up to and stopped at the interface ($c/L = 1.0$ in Figure 3-6, where c is the final crack half length). The dynamics for a crack that stops before the interface and for a crack that penetrates the interface before stopping also need to be determined. In March, the case where the crack stopped short of the interface ($c/L = 0.6$) was examined. This geometry is drawn nearly to scale in Figure 3-6. As shown on Figure 3-7, three calculations were made that corresponded to three values of the Lamé constants for material 2: 10, 30, and 90 GPa. These constants for material 1 were maintained at 30 GPa for each calculation and the densities, ρ_1 and ρ_2 , were 2.7 gm/cm^3 for the calculations.

In Figure 3-7, the normalized vertical displacement of a point just behind the final position of the right crack tip (Figure 3-6) is plotted against nondimensional time, i.e., the problem time t is divided by the time elapsed from crack initiation to stopping, t_b . There is a variation in the material response which begins after the crack stops. This variation is less than 7 percent of the maximum displacement and is not large when compared to the large change in elastic moduli.

Experimental Program

During March, experiments continued on crack growth across lubricated interfaces in Nugget sandstone, and pressure-volume

measurements on Mesaverde sandstone from Colorado were completed. Construction continued on the apparatus for simultaneous measurement of ultrasonic sound speed in multiple directions under a confining pressure. Preparations continued on Mesaverde sandstone and shale specimens for ultrasonic measurements.

Logging and Geology

The performance of the borehole seismic reflection system was studied and a displacement transducer observing the transmitter indicated that most of the energy was below 1.5 kHz, dropping off at about 4 kHz. The downhole amplifier will overload unless a high-pass filter with a cutoff of 1.0 or 1.5 kHz is installed. The isolator between the transmitter and receiver transmits signals with frequencies below about 1.5 kHz with energies about 20 db greater than those observed without the isolator. When the filter is installed, the effect from the presence of the isolator will no longer be observed. For normal use it isolates effectively, but small signals transmitted through air in the borehole can be seen if the transmitter is not properly coupled to the borehole.

A review of the fracture and structure patterns of the Piceance and Uinta Basins continued during March. Natural fractures will often follow the axes of folds except when they turn to follow structure contours on plunging noses.

Schedule Status

Figure 3-8 is a milestone chart depicting LLL's WGSP progress.

LOS ALAMOS SCIENTIFIC LABORATORY

The purpose of this research is to develop methods to define fluid saturation, porosity, and permeability in Western gas sands as

WGSP — BETC	FY-80											
RESOURCE ASSESSMENT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
FORMATION EVALUATION												
IMPROVED PRESSURE CORING SYSTEM												
Core Retriever Design & Test												
Core Fluid Testing												
Bit Design & Fabrication												
Bit Tests												
IN SITU PERMEABILITY												
Measurement of Formation Characteristics												
LEGEND												
▽ Scheduled Start and Completion of Task												
▼ Completed Milestone												
===== Projected Schedule												
===== Task Progressing												
===== Task Progress Not Reported												
===== Delay in Work on Task												

WGSP — BETC	FY-80											
RESOURCE ASSESSMENT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
IN SITU PERMEABILITY (Continued)												
Permeability of Interbedding Material Measurement												
Development of Standardized Core Analysis												
ADVANCED LOGGING TECHNIQUES AND INTERPRETATION												
Measurement of Interface Conductivity Effects on Electric Logging												
Dielectric Constant Measurements												
Mapping and Contouring Water Resistivities Study												
Study of Sonic, Neutron and Density Logging of Low Permeability Gas Sands												

Figure 3-5 Milestone Chart - BETC

WGSP — BETC	FY-80											
RESOURCE ASSESSMENT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
STIMULATION MECHANICS & METHODS												
RESERVOIR MODELING AND STIMULATION												
Perform Analysis of MHF Test Data and Engineering Studies												
ROCK-FLUID INTERACTION												
Physical Measurements												
PROPPANT AND PROPPANT TRANSPORT												
Evaluation of Particle Transport in Proppant Beds												
Evaluation of Proppant Embedment in Tight Gas Sands												
Study of Proppant Settling												
Light Weight Proppant Feasibility Study												

WGSP — BETC	FY-80											
RESOURCE ASSESSMENT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
ROCK MECHANICS												
IN SITU STRESS												
Development of Wire-Line In Situ Stress Tool												
Study on Measurement of Stress in Cores												

Figure 3-5 Continued

Figure 3-6 Geometry for Time Dependent Crack Propagation Near an Interface

Figure 3-7 Vertical Displacement of a Point Behind Final Position of Right Crack Tip

Figure 3-8 Milestone Chart - LLL

found under in situ reservoir conditions. These analyses will then be correlated with nuclear magnetic resonance studies to ultimately lead to the design of an improved downhole NMR tool.

In March, the annual report for FY 1979 (April, 1979 to March 31, 1980) entitled "Remote Characterization of Fluid Saturation in Western Sands," was published. The report is to BETC and is written by E. B. Nuckols and J. Jackson.

Permeability and Porosity Determinations on Core Samples

A complete laboratory has been set up and an experimental program has been designed to address the objectives of this task. These goals, which are complementary to the central NMR investigation, are to enable routine measurement of porosity and permeability (nano Darcy range) of synthetic and natural core samples employed in NMR studies. They are also to possess the capability to investigate the effects of such variables as microscale structure, temperature, pressure, water saturation, and pore throat obstruction on the bulk porosity and permeability of reservoir samples. By elucidating the physical microstructures of the various lithologies and their response to varying conditions of temperature, fluid saturation, pressure, etc., more useful information can be obtained for developing the NMR tool. Ultimately, the macroscale behavior of fluids in formations of interest will be better understood, predicted, and controlled.

Table 3-5 shows the response of a core from the Pacific Transmission Supply Company No. 3-10A well, Sweetwater County, Wyoming, to varying confining pressures.

Table 3-5 Response of PTS Core to Varying Confining Pressures

Confining Pressure, psia (20 min)	Permeability, md + SD% (6,414.1 ft)
200	.674 + 1.6%
400	.488 + 1.6%
600	.422 + 0.8%
800	.386 + 3.1%
1,000	.348 + 2.2%
1,200	.327 + 2.5%
1,400	.299 + 1.0%
1,600	.280 + 0.6%
1,800	.270 + 3.0%
2,000	.254 + 0.7%
2,200	.246 + 0.7%
2,400	.237 + 0.7%
2,600	.277 + 1.3%
2,800	.222 + 1.0%

Additional capabilities of the porosity/permeability laboratory include the ability to determine virtual and real core density and pore-size distributions for those pores with throat diameters as small as 120A. From this information, data on connected-pore surface areas can be obtained and estimates of the distribution of pore throat radii can be made. This type of information will prove to be critical in any attempt to understand the relative importance of flow through a rock's porous fabric versus flow along fracture channels. Another apparatus is also available for analyzing triaxial dilation (or contraction) and changes in liquid/gas permeabilities as core specimens are subjected to varying conditions of temperature and pressure.

When combined with the above investigations, a systematic study of the microstructure of tight gas sands reservoir lithologies utilizing scanning electron and optical microscopy will aid in elucidating the relationship between rock microstructure and the porosity and permeability (or lack thereof) of

typical Western gas sands. Investigations with the SEM will include pore geometry and connected-pore characterization, and correlation of microstructural lithologic features (intergranular recrystallization, pore throat obstruction by micro particles, etc.) with the bulk permeability and porosity of core samples. Optical microscopy will provide information on depositional environment, lithologic texture, mineralogy, post-depositional lithification and/or dissolution features that will aid in understanding the structure of fluid flow pathways in porous rock fabrics.

All of these studies are designed to enhance the ability to design a workable porosity/permeability NMR tool by providing pertinent information on how fluids are incorporated in, interact with, and are transported through a tight gas sand reservoir.

GEOLOGICAL SUPPORT STUDIES

The activities of comparing laboratory measurements against existing geophysical log suites and core descriptions have been temporarily delayed until more extensive laboratory work can be accomplished.

NUCLEAR MAGNETIC RESONANCE STUDIES

During March, work began on the measurement of water in the pore spaces of solid, porous samples, using magnetic resonance techniques. These measurements will be taken from an inverse geometry instrument. Three different samples will be used: packed sea sand of varying sieve sizes, sintered alumina solids and one core from a Western gas sands formation.

Schedule Status

Figure 3-9 is a milestone chart depicting LASL's progress in the WGSP.

SANDIA LABORATORIES

EGR Instrumentation and Diagnostic Program

Hydraulic Fracture Characterization

The data obtained in the Shell Oil Company experiment in Big Mineral Creek field near Sherman, Texas, is being analyzed. The analysis has been complicated by the shortness of the fracture and the large seismic background levels. Pressure and flow data have been analyzed for comparison with tiltmeter and electrical potential data.

The main fracture treatment ran for one hr and twenty-three min on February 27. For the first 56 min, flow rates ranged from 11 to 16 BPM. Then, the average pumping pressure of approximately 3,600 psi began to increase to a maximum value of 4,150 psi while flow rates decreased to a value averaging 4 BPM. The treatment was terminated since the sand had apparently begun to cover the casing perforations. Even though Sandia's current injection probe was located approximately 100 ft above the perforations, it required several hundred pounds of extra force to break free from the sand.

The seismic signals that occurred from well No. 343 during the breakdown pumping have been given a preliminary scan. A large number of seismic signals were recorded and a much closer examination of this data will be necessary to gain a definite conclusion as to the fracture orientation. All seismic signals from the test have been digitized but examination of these signals has not yet been made.

The next planned mapping test will be a breakdown test in April on Amoco's Patricia Pope Whaley Gas Unit No. 1 in the Cotton Valley Trend near Marshall, Texas.

WGSP — LASL	FY-80											
REMOTE CHARACTERIZATION OF FLUID SATURATIONS	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
PERMEABILITY AND POROSITY DETERMINATIONS ON CORE SAMPLES												
GEOLOGICAL STUDIES: Correlation Studies between Log Suites, Core Sections, and Lab Measurements.												
LEGEND												
▽ Scheduled Start and Completion of Task												
▼ Completed Milestone												
===== Projected Schedule												
===== Task Progressing												
===== Task Progress Not Reported												
===== Delay in Work on Task												

WGSP—LASL	FY-80											
REMOTE CHARACTERIZATIONS OF FLUID SATURATIONS	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NUCLEAR MAGNETIC RESONANCE STUDIES												
THEORETICAL STUDIES												
Toroidal Magnetic Field												
Signal Detection												
Reservoir Fluid Characteristics by NMR												
LABORATORY STUDIES												
Feasibility of Remote NMR Detection												
Remote Detection of NMR in Focused Toroidal Magnetic Field												
Remote NMR Signal Detection Improvements												
Reservoir Fluid NMR Characteristics												

Figure 3-9 Milestone Chart - LASL

Figure 3-9 Continued

Borehole Resistivity System

The numerical solution to the forward layered one-dimensional borehole resistivity problem was programmed and compared with the continuous solution. Figure 3-10 shows a comparison of the continuous solution with three layers of approximations. The continuous profile is presumed to represent a 3-in. diameter probe emersed in a fluid-filled 6-in. diameter wellbore, surrounded by an invaded zone with a hyperbolic tangent type transition to the virgin formation. The apparent resistivity as a function of position along the surface of the probe is given. The two-layer and continuous solutions agree closely but the one- and zero-layer approximations show visually recognizable discrepancies (note that optimization of layer locations has not been attempted). This comparison gives an indication of the resolution in obtaining the location of invasion front with typical field measurement accuracies.

Electromagnetic Impedance Sonde

Dielectric Modeling

It was previously reported that work was being directed toward determining water saturations from dielectric measurements. This month computer programs have been developed that augment that task.

At higher frequencies (10^6 to 10^9 Hz) the dielectric response of rocks is particularly sensitive to:

- the water saturation, S_w ;
- the location of the water if $S_w < 100$ percent; and
- the pore geometry.

To define all of these parameters, good fits are required between the model responses and the experimental data for both the real and

Figure 3-10 Comparison of the Continuous Solution with Three Layer Approximations

imaginary components of the current. Past fitting techniques were unsatisfactory since the form of the distribution function, $A(k)$, did not allow for rapid changes in the dielectric response with frequency. The new fitting technique eliminates this problem.

Presently, distribution functions based on the data of Poley, et al are being used to generate responses for $S_w < 100$ percent.

Laboratory Work

A thorough study of the dielectric properties of rocks must determine the relationship of rock characteristics, such as porosity, permeability, and pore geometry, to dielectric properties. The work of Poley, Nooteboom, and de Waal (The Log Analyst, May-June, 1978, p. 8) measured the dielectric properties of "nearly clay-free" sandstones as a function of rock porosity and saturating water salinity. This and other studies are complicated by the unknown effect of impurities such as clays. Therefore, the use of a known matrix of materials to simulate the pore geometry of rocks is being investigated.

Finite-Difference Modeling

A computer code is being developed to model mathematically the response of a horizontally and vertically layered earth to a magnetic induction logging tool. Horizontal layers are formed by the geologic structure. Vertical layers are formed by the borehole fluid and by its invasion into the surrounding structure. Understanding the response of the layered earth is expected to aid in determining the permeability of tight gas sand reservoirs.

The source is assumed to be a point magnetic dipole radiating at a constant frequency (or at a set of frequencies) in an azimuthally symmetric, layered earth. The differential equation describing the complex-valued electric field intensity is a second-order elliptic type equation. A unique solution exists in a

bounded region of space and can be calculated if the boundary conditions at the edges of the space are known. These boundary conditions provide the major difficulty in finding a general finite-difference solution to the equation. Once the electric field intensity is found, the magnetic fields can be calculated by differentiation. With the electromagnetic fields known, receiver response can be obtained. Sensitivity studies are then possible to determine response variation with the conductivity and dielectric constant of the various layers of earth.

Probe and Formation Modeling

The effectiveness of electromagnetic (EM) logging is enhanced by the availability of ancillary relations that accurately express EM parameters in terms of formation parameters.

One pair of such relations has been empirically formulated for 20 to 80 MHz logging based on the published data by Poley, et al. Sandstones of varying porosity saturated by water of different salinities are characterized as parametric equations to determine the sensitivity range of the EM probe. As it stands, the parametric charts for borehole-coil couplings are able to delineate specific response regions for gas/oil saturated sandstones or limestones. With partial saturations, no ancillary relations are available. However, the loci of sandstones with varying porosity and saturating waters of varying salinity are available on the refractive index charts specifically constructed for coil responses.

Borehole effects (due to changes in borehole size, shape, and fluid) have a large number of combinational possibilities. Systematic studies have been started from the worst-case scenario; i.e., the borehole is assumed to be flooded by fluid of salinity equal to that of sea water. Coils are first assumed to be immersed in this borehole fluid. Data on 20, 40, and 80 MHz operations have indicated a clear trend of larger borehole effects toward higher logging frequencies. Analytical and

Figure 3-11 Milestone Chart - Sandia Laboratories

WGSP — SANDIA	FY-80											
EGR — INSTRUMENTATION DIAGNOSTICS	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
FORMATION EVALUATION												
ELECTROMAGNETIC IMPEDENCE SONDE												
Feasibility Study												
Electrical Description												
Geological Description												
Prototype Development												
ELECTROPOTENTIAL SONDE												
Feasibility Study												
Parametric Description												
Prototype Development												

Figure 3-11 Continued

numerical evaluations become rapidly more complex as the number of borehole zones are increased.

Schedule Status

Sandia Laboratories' WGSP is depicted in Figure 3-11.

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SECTION 4

FIELD TESTS & DEMONSTRATIONS

BACKGROUND

Field tests are essential to verify the findings of laboratory tests and modeling studies. The field test and demonstration program involves cooperation between industry and government and also interacts geologic studies with laboratory research and development. The following projects are 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, and
- a mineback testing program by Sandia Laboratories.

Table 4-1 summarizes WGSP MHF treatments. Progress of these projects is presented in the following sections.

Table 4-1 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		
							Before	After	Ratio
AUSTRAL Piceance, Mesaverde	7S/94W/Sec 3 Garfield Cty, Colorado	Federal 3-94	6,198-6,333	8-13-76	420,000	226 Gel	35	62	1.8
			5,170-5,630	8-25-76	720,000	316 Gel			
CONSORTIUM MANAGED BY CER CORPORATION Piceance, Mesaverde	3S/98W/Sec 11 Rio Blanco Cty, Colorado	RB-MHF-3	8,048-8,078	10-23-74	400,000	117 Gel	60	60	—
			7,760-7,864	05-02-75	880,000	285 Gel	—	40	—
			5,925-6,016	04-04-76	815,000	400 Gel	42	160	3.8
			5,851-5,869	11-03-76	448,000	228 Gel	57	70	1.2
DALLAS PRODUCTION Fort Worth, Bend Cong.	Ben D. Smith Survey A-779 Wise Cty, Texas	Ferguson A-1	5,957-6,794	09-16-76	506,000	139 Foam 198 Emul	40	15	—
EL PASO NATURAL GAS Northern Green River, Fort Union	30N/108W/Sec 5 Sublette Cty, Wyoming	Pinedale Unit No. 5	10,950-11,180	07-02-75	518,000	183 Emul 8 Gel	150	340	2.3
			10,120-10,790	10-20-75	1,422,000	459 Gel	—	150	—
GAS PRODUCING ENTERPRISES, INC. Uinta, Wasatch and Mesaverde	10S/22E/Sec 10 Uintah Cty, Utah	Natural Buttes No. 18	6,490-8,952	09-22-76	1,480,000	745 Gel	—	1,400	—
	10S/21E/Sec 21 Uintah Cty, Utah	Natural Buttes No. 19	8,909-9,664 7,224-8,676	09-21-76 09-28-76	424,000 784,000	280 Gel 364 Gel	—	166	—
	9S/21E/Sec 22 Uintah Cty, Utah	Natural Buttes No. 14	6,646-8,004	03-15-77	1,093,000	544 Gel	38	800	21.0
	9S/21E/Sec 28 Uintah Cty, Utah	Natural Buttes No. 20	8,498-9,476	06-22-77	826,000	322 Gel	75	1,200	16.0
	10S/22E/Sec 18 Uintah Cty, Utah	Natural Buttes No. 22	6,838-8,550	11-21-77	1,151,000	499 Gel	—	700	—
	9S/22E/Sec 19 Uintah Cty, Utah	Natural Buttes No. 9	5,661-8,934	03-27-78	554,000	349 Gel	140	540	3.9
	10S/21E/Sec 29 Uintah Cty, Utah	CIGE No. 2	9,237-9,653 7,251-8,774	06-22-78 08-08-78	170,500 1,965,000	203 Gel 722 Gel	—	Water	—
	10S/22E/Sec 7 Uintah Cty, Utah	Natural Buttes No. 23	5,080-6,294	10-04-78	470,000	240 Gel	—	800	—
MITCHELL ENERGY Cotton Valley, Limestone Trend	Limestone Cty, Texas	Muse-Duke No. 1	11,235-11,418	11-15-78	2,800,000	891 Gel	2,000	6,600	3.3
MOBIL Piceance, Mesaverde	2S/97W/Sec 13 Rio Blanco Cty, Colorado	F31-13G	10,549-10,680	06-22-77	580,000	316 Gel	300	800	2.7
			9,392-9,538	08-24-77	600,000	260 Gel	700	2,600	3.7
			8,765-8,972	05-10-78	388,000	150 Gel	479	430	—
			8,163-8,650	07-06-78	660,000	288 Gel	—	360	—
			7,704-7,794	09-07-78	218,000	120 Gel	—	180	—
			7,324-7,476	11-15-78	700,000	365 Gel	1,000	2,000	2.0
PACIFIC TRANSMISSION Uinta, Mesaverde	8S/23E/Sec 25 Uintah Cty, Utah	Federal 23-25	NO FRACTURES PERFORMED						
RIO BLANCO NATURAL GAS Piceance, Mesaverde	4S/98W/Sec 4 Rio Blanco Cty, Colorado	Federal 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

DE-AC08-77ET12046

Colorado Interstate Gas Company
Colorado Springs, Colorado
Status: Active

Contract Date:	September 1, 1977
Anticipated Completion Date:	March 1, 1981
Total Project Cost (estimated):	DOE \$ 75,000
	CIG \$319,754
	Total \$394,754
Principal Investigator:	David Wilson
Technical Project Officer for DOE:	C. H. Atkinson

OBJECTIVE

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

COLORADO INTERSTATE GAS COMPANY

Measurement of bottom-hole pressure continued at the Miller No. 1 and Sprague No. 1 cyclic dry gas injection experiment sites. At Miller No. 1, the DOE Well Test Facility began measuring the bottom-hole pressure February 1 and continued to March 7. For comparison, the well was drawn down again

from March 7 to 15 for a second BHP buildup measurement. The buildup curves were similar.

Cable Inc. continued to measure the BHP buildup at the Sprague No. 1 well; no data was available for this well.

**DOE WELL
TEST FACILITY**

DE-AC08-79-BGO1569

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.

DOE WELL TEST FACILITY

The DOE Well Test Facility continued to provide technical support to the joint DOE/CIG multi-well cyclic dry gas injection experiment, being conducted at the Miller No. 1 and Sprague No. 1 wells in the Wattenberg Field, Colorado.

A bottom-hole pressure build-up test that was being performed on Miller No. 1 since January 30 was completed on March 7. The total build-up time was about 600 hrs in mid-March, followed by another BHP buildup

test. This redundant testing was necessary to assure that perturbations which occurred in the initial drawdown did not adversely affect the build-up results, and thus hamper later testing comparisons. The two buildup curves are similar, and a composite of the build-up data is shown in Figure 4-1.

A modified isochronal test began at the Miller No. 1 site during the last week of March and is expected to be completed the first week of April.

Figure 4-1 Composite ΔP^2 for Miller No. 1 Well BHP Buildup Test, January through March 1980

**NATURAL BUTTES
UINTAH COUNTY, UTAH**

DE-AC08-76 ET 12060

**Massive Hydraulic Fracturing
Demonstration**

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

Contract Date:	July 1, 1976
Anticipated Completion:	March 31, 1980

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

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

OBJECTIVE

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

GAS PRODUCING ENTERPRISES, INC.

GPE Natural Buttes Unit Nos. 9, 14, 18, 19, 20 and 22 flowed during March with a total of 58,452 MCF. NBU No. 21 was reper-

forated and acidized March 24 and clean up is continuing. Figures 4-2 through 4-7 show the production histories of these wells.

Figure 4-2 Flow Rate Performance of Natural Buttes No. 9 Well

Figure 4-3 Flow Rate Performance of Natural Buttes No. 14 Well

**FALLON-NORTH
PERSONVILLE FIELD, TEXAS**

DE-AC08-78ET12150

**Massive Hydraulic Fracturing
Demonstration**

Mitchell Energy Corporation
Houston, Texas

Status: Active

Contract Date:	March 15, 1978
Anticipated Completion:	April 30, 1979 (Extension being processed)
Total Project Cost (estimated):	DOE \$ 553,771 Industry 1,074,550 Total \$1,628,321
Principal Investigator:	F. D. Covey
Technical Project Officer for DOE:	C. H. Atkinson

OBJECTIVE

To test massive hydraulic fracturing in the Cotton Valley Limestone Formation.

MITCHELL ENERGY CORPORATION

The final report is still in preparation.

**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.

SANDIA MINEBACK

Hydraulic Fracturing

Formation Interface Fracture Experiment

A total of 31 coreholes have been completed, including EV6-34, EV6-35, and EV6-36 in March. The locations of these holes are shown in Figure 4-8. This completes the coring program, and an attempt will be made to use this data to plot fracture width contours. The final work to be performed on this experiment will be several minifrac in two or three of these coreholes in order to determine the in situ stresses in relation to crack growth.

Interface Test Series

Work on this activity has been completed.

Fluid Mechanics and Proppant Transport Experiments

The process of hydraulic fracturing is recognized to be a complex interaction between rock mechanics and fluid mechanics considerations. However, the fluid mechanics aspects of fracturing are generally less understood than the global rock mechanics considerations, such as dilation of the crack under a pressure load. The important fluid mechanics processes associated with fracturing can be broadly divided into two categories. The first is basic phenomena, such as the pressure distribution and the width in a propagating fracture. Experiments to measure the pressure and width at various locations during fracture propagation are being planned. The second area is proppant transport and the resultant conductivity. An in-tunnel pump system is under construction which will pump high viscosity gels sand concentrations up to 3 ppg. A site for these experiments is presently being prepared, and these tests should begin this year.

In Situ Stress Measurement by Hydraulic Fracturing Through Perforations

Mineback experiments have shown that the most important factor governing containment of hydraulic fractures is differences in the minimum principal in situ stress. Material property differences and interface characteristics (friction) appear to be insignificant. In the multi-well experiment in the Piceance Basin, the distribution of minimum in situ stress will be measured through the Mesa-verde horizon. A large number of in situ stress measurements will be obtained by conducting minifrac through perforations.

To be certain that performing these tests through perforations will yield accurate data, an experiment will be conducted in G-tunnel so fracturing through perforations and in an open hole can be compared. Approximately five zones in a cased, horizontal borehole will be fractured with less than 10 gal of dyed water through perforations oriented at different directions to the in situ stress. Important pressure data will be recorded. Afterwards, another hole will be drilled 6 to 8 ft from the cased hole, and five comparable zones will be fractured open hole. Differences in the instantaneous shut-in pressure (if any) will be compared with the dissimilarities in fracture behavior observed during mineback. At present, it is not expected that there will be any significant difference; however, due to perforating, the damaged zone may result in anomalous fracture behavior near the wellbore and a higher observed closure stress or shut-in pressure.

Rock Mechanics

Finite element analyses were made to evaluate the stress distributions resulting from various laboratory experiments for hydraulic fracture propagation in layered media. Whenever an overburden pressure is applied to layered samples with differing strengths, the horizontal stress state is quite variable with marked contrasts in stress occurring across

Figure 4-8 Results of Exploratory Coring of Hole No. 6

the boundaries. For example, if a "soft" rock ($E = 4.5 \times 10^6$ psi) is sandwiched between "hard" rocks ($E = 9 \times 10^6$ psi), the horizontal stress in the center of the soft rock will be compressional (16 percent of overburden pressure) whereas a tensional horizontal stress (13 percent of the overburden pressure) will occur in the hard rocks. The stress across the interface will change by a total 30 percent of the overburden pressure. If the applied stress is hydrostatic, the horizontal stress of the soft rock is compressional (84 percent of hydrostatic pressure) with even greater compression in the hard rock (110 percent of hydrostatic pressure). Since in situ stresses are important in controlling fracture propagation, the results from the apparently simple experiments described above may be difficult to interpret if the in situ stresses are not considered.

In situ stress measurements by an overcoring technique have been made in the G-tunnel to determine the influence of in situ and residual stresses on the containment of hydraulic fractures. Nine sites were instrumented with delta strain rosettes (three sites on three separate bedding horizons which were 0.28 meters apart). This was on the central portion of a tunnel wall within one meter of an exposed mined-back hydraulic fracture from the interface test series. All of the sites were

in a single bed of ashfall tuff. The lowest bedding horizon corresponded to the horizon in which the hydraulic fracture abruptly terminated. After overcoring, eight of the nine gages were still operational.

Preliminary analysis of the data indicates a significant and consistent increase in the minimum principal strain, ϵ_3 , from 80 $\mu\epsilon$ tension at the upper horizon, to 140 $\mu\epsilon$ compression at the middle horizon, to 980 $\mu\epsilon$ compression at the lower horizon. In all cases, ϵ_3 was essentially normal to the plane of the hydraulic fracture. The maximum principal strain showed no significant variation between the three horizons, with an average strain of 2,650 $\mu\epsilon$ compression. Stress calculations from these measured strains will be made once the elastic properties of each core are determined from laboratory compression tests. The results suggest a strong correlation between the large compressive increase in ϵ_3 and the termination of the hydraulic fracture. Additional work will involve residual stress measurements on each of the cores.

Schedule Status

Figure 4-9 is a milestone chart showing Sandia Mineback WGSP progress.

Figure 4-9 Milestone Chart - Sandia Mineback