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Western Gas Sands Project Status Report

1 November 1979 - 30 November 1979

Prepared for
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Bartlesville Energy Technology Center
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Las Vegas, Nevada
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CONTENTS

	Page
1. SUMMARY	1
2. PROJECT MANAGEMENT	3
2.1 Technical Monitoring and Evaluation	3
2.2 Technology Transfer	3
3. RESOURCE ASSESSMENT	5
3.1 U.S. Geological Survey Activities	5
3.2 Core Program	6
3.3 Logging Program	9
3.4 Survey of Basin Activities	9
3.5 C K GeoEnergy Corporation	14
3.6 Multi-Well Experiment	16
4. RESEARCH AND DEVELOPMENT BY ENERGY TECHNOLOGY CENTERS AND NATIONAL LABORATORIES	17
4.1 Bartlesville Energy Technology Center	17
4.2 Gas Research Institute	31
4.3 Lawrence Livermore Laboratory	36
4.4 Los Alamos Scientific Laboratory	38
4.5 Sandia Laboratories	41
5. FIELD TESTS AND DEMONSTRATIONS	53
5.1 Background	53
5.2 CER Corporation	56
5.3 Colorado Interstate Gas Company	58
5.4 DOE Well Test Facility	61
5.5 Gas Producing Enterprises, Inc.	63
5.6 Mitchell Energy Corporation	68
5.7 Mobil Research and Development Corporation	70
5.8 Rio Blanco Natural Gas Company	72
5.9 Sandia Laboratories—Mineback	74

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FIGURES

	Page
Figure 3-1 Milestone Chart — USGS	7
Figure 3-2 Greater Green River Basin Showing Wells of Interest and USGS Designated Core Areas	11
Figure 3-3 Northern Great Plains Province Showing Wells of Interest and USGS Designated Core Areas	12
Figure 3-4 Piceance Basin Showing Wells of Interest and USGS Designated Core Areas	13
Figure 3-5 Uinta Basin Showing Wells of Interest and USGS Designated Core Areas	15
Figure 3-6 Milestone Chart — Multi-well Experiment	16
Figure 4-1 Frequency vs. Cl^- concentration	19
Figure 4-2 Effect of Water Saturation on Gas Permeability	23
Figure 4-3 Effect of Water Saturation and Pore Pressure on Relative Permeability to Gas	25
Figure 4-4 Effect of Water Saturation and Pore Pressure on Relative Permeability to Gas	26
Figure 4-5 Sample Holder — Saturation Chamber	28
Figure 4-6 Milestone Chart — BETC	33
Figure 4-7 Milestone Chart — LLL	39
Figure 4-8 Milestone Chart — LASL	40
Figure 4-9 Borehole Resistivity System	43
Figure 4-10 Depth model of two sandstone lenses underlain by a continuous sandstone layer	45

	Page
Figure 4-11 Normal Incidence "Spike" Reflection Record Section for a Model of Figure 4-10	46
Figure 4-12 Resulting reflection record section utilizing a 40-80 Hz bandwidth wavelet	48
Figure 4-13 Resulting reflection record section utilizing a 60-140 Hz bandwidth wavelet	49
Figure 4-14 Resulting reflection record section utilizing a 80-160 Hz bandwidth wavelet	50
Figure 4-15 Milestone Chart — Sandia	51
Figure 5-1 Production and Injection Volumes and Associated Pressure of CIG Miller No. 1 and Sprague No. 1 Wells	59
Figure 5-2 Flow Rate Performance of Natural Buttes No. 9 Well	64
Figure 5-3 Flow Rate Performance of Natural Buttes No. 14 Well	64
Figure 5-4 Flow Rate Performance of Natural Buttes No. 18 Well	65
Figure 5-5 Flow Rate Performance of Natural Buttes No. 19 Well	65
Figure 5-6 Flow Rate Performance of Natural Buttes No. 20 Well	66
Figure 5-7 Flow Rate Performance of Natural Buttes No. 22 Well	66
Figure 5-8 Results of Exploratory Coring of Hole No. 6	75
Figure 5-9 Milestone Chart — Sandia Mineback	77

TABLES

	Page
Table 3-1 Summary of Wells — Greater Green River Basin	11
Table 3-2 Summary of Wells — Northern Great Plains Province	12
Table 3-3 Summary of Wells — Piceance Basin	13
Table 3-4 Summary of Wells — Uinta Basin	15
Table 4-1 Analysis of Water Samples from the Green River Formation	20
Table 4-2 Analysis of Water Samples from the Ferron Formation	20
Table 4-3 Effect of Water Saturation on Relative Gas Permeability	22
Table 4-4 Effect of Water Saturation and Pore Pressure on Relative Gas Permeability	24
Table 4-5 Maximum Percentages of Selected Molecular Weight Fractions in a 40 lb, Low-Residue Guar Degraded with $(\text{NH}_4)_2\text{S}_2\text{O}_8$	30
Table 4-6 Sample Analyses	32
Table 4-7 Core Analyses of CIGE No. 21 Well	44
Table 5-1 MHF Contract Location and Frac Data	54

1. SUMMARY

This edition of the WGSP Status Report summarizes November, 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.

The USGS in Denver continued work toward resource assessment in the four WGSP primary areas. Coring was completed in the Pacific Transmission Supply Company No. 3-10A Federal well in the Greater Green River Basin, and in the Mapco Rio Blanco Unit No. 11-17F well, Uinta Basin.

Projects of the National Laboratories and Energy Technology Centers progressed on schedule in November. Work on improved pressure coring systems, logging studies, in situ permeability and rock/fluid interaction continued at Bartlesville Energy Technology Center. The Gas Research Institute sponsored work continued the planning of a project to develop a geologic and engineering data base for the tight gas sands basins. Lawrence Livermore Laboratory furthered experimental and theoretical work on hydraulic fracturing mechanics and analyses of well test data. Los Alamos Scientific Laboratory completed three papers for presentation at a meeting of the American Physical Society. The enhanced gas recovery instrumentation and diagnostic program at Sandia Laboratories continued with various experiments.

Interruptions and shutdowns still plagued the Colorado Interstate Gas Company Miller No. 1 and Sprague No. 1 wells. Gas Producing Enterprises, Inc. Natural Buttes Unit wells continued to flow to sales. All testing has been completed at Mitchell Energy Corporation Muse-Duke No. 1 well.

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2. PROJECT MANAGEMENT

2.1 Technical Monitoring and Evaluation

C. H. Atkinson (DOE) and CER Corporation personnel met with D. Ward (DOE/BETC) in Las Vegas, November 8-9, regarding status and plans for the WGSP Multi-well field test and additional project plans.

C. H. Atkinson (DOE) and R. L. Mann (CER Corporation) participated in a BETC Planning Conference, November 26-28, to update the section of the Liquid Fossil Fuel Cycle (LFFC) planning framework which pertains to the WGSP.

2.2 TECHNOLOGY TRANSFER

2.2.1 Documentation Reports

The WGSP Financial Supplement for November, 1979, has been distributed. The draft of the DOE Morgantown Semi-Annual Report, Unconventional Gas Recovery Program (period ending September 30, 1979) is in final stages. The WGSP Project Plan, FY 1980, has been completed and distributed. The DOE Well Test Facility Operations Manual and a report on the WGSP Logging Program are being updated. Work has commenced on the WGSP Greater Green River Basin Review, and data are being compiled for similar reports on the Piceance and Uinta Basins.

2.2.2 Project Data Bank

Updating and cataloging continued on the WGSP bibliography.

2.2.3 Articles and Publications

The following articles and publications relate to the WGSP and are included in the bibliography. Abstracts are included when available.

Remote Production of a Region of Homogeneous Magnetic Field

by R. K. Cooper and J. A. Jackson
Los Alamos Scientific Laboratory

A method has been discovered for producing a region of homogeneous magnetic field remote from the source(s) of the field. Two simple examples are treated. Both are based on the following principle: If two equal field sources are arranged axially so their fields oppose between them, then there exists

a region near the plane perpendicular to the axis midway between the sources where H_r , the radial component of the field, goes through a maximum. Near the maximum, the field is homogeneous within any chosen degree over prescribed regions. Computer calculations describing the H_r versus r curve and measurements confirming it will be discussed. The production of such a field has several potential uses; one is the detection of an NMR signal from this region.

Sensitivity of NMR Detection for External Samples

by L. J. Burnett and J. A. Jackson

Los Alamos Scientific Laboratory

Although there are a variety of geophysical and biomedical applications of NMR (such as NMR well logging and remote NMR imaging) which require the sample to be in a position remote from the spectrometer, very little on the experimental particulars of this configuration has been published. In this work we present results of sensitivity measurements, i.e., measurements of signal amplitude and signal-to-noise ratio, for cylindrically symmetric samples located outside the NMR coil. The results are analyzed in terms of a simple model that may be useful in extrapolating to cases of greater geometrical complexity.

Detection of NMR in a Remotely Produced Region of Homogeneous Magnetic Field

by J. A. Jackson, L. J. Burnett and J. F. Harman

Los Alamos Scientific Laboratory

The recent discovery of a method of producing a region of homogeneous magnetic field remotely, combined with the recent detection of NMR in samples external to the NMR coil, led to this report of the detection of NMR from a remotely produced toroidal region external to the coil. Using a 4 in. modified laboratory electromagnet, a toroidal region of homogeneous radial magnetic field, 28 cm in diameter with a field strength of 117.5 Gauss, was produced. Proton NMR signals from a variety of cylindrically symmetric samples were detected using NMR coils of 15, 18, 20 and 24 cm in diameter. Criteria for detection of such signals, as well as prospective improvements, will be discussed. Several practical applications of this experimental geometry are obvious. Prominent among these is a new technique for NMR well logging. This development is underway at LASL.

3. RESOURCE ASSESSMENT

3.1 U.S. Geological Survey Activities

3.1.1 Uinta-Piceance Creek Basins

An open file analysis of petrographic data was derived from SEM, x-ray and sedimentation studies of cores from Rio Blanco MHF-3 well, Piceance Basin.

Core was described and sampled of the Tuscher and Farrer Formations from the Tavaputs Plateau, Uinta Basin — Wilkins Ridge area.

A manuscript was revised that discusses the controls on the amount and distribution of porosity and permeability in sandstone core from the Pariette Bench oil field of the south-central part of the Uinta Basin.

3.1.2 Greater Green River Basin

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

L. W. Kiteley published a report entitled "Stratigraphic measured sections of the Upper Cretaceous Mancos Shale (upper part) and Mesaverde Group (lower part), Moffat County, Colorado," as U.S. Geological Survey Open-File Report 79-1306.

Samples from the Tierney No. 1 and Koch Adobe Town wells, Washakie Basin, were submitted for geochemical analyses.

The first draft was completed of a paper entitled "Evaluation of organic matter and subsurface temperature and pressure with regard to gas generation in low-permeability Upper Cretaceous and lower Tertiary sandstones in the Pacific Creek area, Sublette and Sweetwater Counties, Wyoming."

A report is being prepared on clay mineralogy of samples from Tierney wells in the Washakie Basin.

3.1.3 Northern Great Plains Province

Work continued on the resource appraisal of low-permeability, gas-bearing reservoirs of the Northern Great Plains for the National Petroleum Council.

Work continued on a paper on conditions required for the generation and accumulation of biogenic gas.

Work commenced on a regional cross section showing the distribution of tight reservoirs from southeastern Alberta to north-central Montana.

Core was received and sampled for analysis from the Joseph J. C. Paine No. 1-9 well, Little Missouri field, Bowman County, North Dakota.

Petrographic analysis of Milk River core from southeastern Alberta continued.

3.1.4 Schedule Status

Figure 3-1 is a milestone chart depicting the status of all USGS projects within the WGSP.

3.2 CORE PROGRAM

In the Greater Green River Basin, major coring activity took place in the Red Desert Sub-basin, with the coring of Pacific Transmission Supply Company No. 3-10A Federal well, Sec. 10, T22N, R94W, Sweetwater County, Wyoming. About 165 ft of continuous 4 in. core from the Almond Formation was recovered from depths of 11,436 ft to 11,623 ft. The first core recovered included 20-25 ft of good reservoir sand, which was whole-core analyzed. Commercial laboratory core analysis is in progress and selected core samples have been shipped to LLL, LASL, Sandia and BETC for special analysis. Also in Sweetwater County, coring preparations continued at the Rainbow Resources No. 1-3 Federal well, Sec. 3, T26N, R103W. Objectives include cutting 400 ft of 2-5/8 in. core from the Ericson and Rock Springs Formations. Core intervals will begin at about 12,200 ft.

No coring activity occurred this month in the Northern Great Plains Province.

In the Uinta Basin, the coring of Mapco RBU No. 11-17F well, Sec. 17, T10S, R20E, Uintah County, Utah, occupied most of the month. Operations began on November 13 and, due to minor difficulties, continued to November 27. Total core cut was 141.6 ft, with 98.2 ft recovered (70 percent). Two cores were cut in the basal unit of the Wasatch, locally named the Uteland Buttes unit by Mapco, but recovery was poor. The remaining cores were cut in the upper portion of the Mesaverde. The core was comprised mainly of sandstone, siltstone and shale. Pertinent details are contained in the DOE WGSP Core Description, which is available upon request. Samples were taken for BETC and LASL and chips were taken every foot through the sand intervals for Sandia Laboratories.

The Utah project was the first field application for the newly-acquired WGSP Coring Trailer, a self-contained unit equipped to provide a protected work area for special core handling requirements and for winter operations.

For the Piceance Basin, laboratory analysis of core samples from the Pacific Transmission Supply Company No. 22-12 Federal well continued during the month.

Figure 3-1 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 3-1 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 Parlette 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 3-1 Continued

3.3 LOGGING PROGRAM

G. C. Kukal (CER Corporation) assisted in logging operations at PTS No. 3-10A Federal well, Sec. 10, T22N, R94W, Sweetwater County, Wyoming. A circulated mud sample was collected from the flowline. The well was logged beginning November 16 as follows:

Dual Induction Log-SFL-SP-GR (11,966 to 9,436 ft and 9,676 to 1,544 ft); Simultaneous BHC Sonic-Caliper (11,938 to 9,856 ft); Variable Density Log-Full Wave Train Log-Amplitude Log (11,940 to 9,800 ft); Formation Density-Caliper (11,969 to 9,857 ft and 11,969 to 11,424 ft); Simultaneous Compensated Neutron Gamma Ray (11,969 to 9,857 ft and 11,969 to 11,424 ft); Dual Laterolog and Simultaneous Micro-SFL-Caliper-Gamma Ray (11,971 to 9,900 ft and 11,971 to 11,514 ft. Also logged with pad closed from 11,955 to 11,514 ft); and Mud Log (Rxo closed from 10,937 to 11,960 ft).

Field prints of the logs were delivered on location. CYBERLOOK Log was computed over the interval 11,950 to 9,900 ft. The Spectral Gamma Log equipment was unavailable for this well.

3.4 SURVEY OF BASIN ACTIVITIES

3.4.1 Greater Green River Basin

Of the four primary areas of interest to the WGSP, the Greater Green River Basin accounted for the most new gas potential reported for November: 33,227 MCFD. Producing horizons

included the Almond, Lewis, Ericson, undifferentiated Mesaverde, Frontier and second Frontier. The Mesaverde was the largest producer with 13,044 MCFD of potential new gas.

Twenty-seven wells were reported complete this month: 16 development and 3 wildcat wells were reported as producing with 3 development and 5 wildcat wells D&A. Two wildcat locations were abandoned.

By month's end, 20 new development and 4 new wildcat wells were reported.

Wells of interest are summarized in Table 3-1, and Figure 3-2 shows the locations of these wells and the designated core areas.

3.4.2 Northern Great Plains Province

Thirteen development and 4 wildcat wells were reported producers in November. Eight development wells were reported D&A, as well as 7 wildcat wells.

From the 17 reported producers, there was a total of 7,559 MCFD of potential new gas. (6 IPFs were not available from the P.I. Report). The largest producing horizon was Bow Island (4,765 MCFD). Other horizons were the Eagle, Greenhorn, second Bow Island and third Bow Island.

During the month, 17 development and 11 wildcat wells were staked.

Wells of interest are summarized in Table 3-2 and are shown in Figure 3-3.

3.4.3 Piceance Basin

Fourteen wells were reported complete during November: 11 development wells and 1 wildcat well were reported as producers and 1 of each well type was D&A. One development location was abandoned.

From the 12 reported producing wells, there was a total of 6,451 MCFD of new gas potential reported. Producing horizons included the Corcoran, Rollins/Cozzette/Corcoran commingled, undifferentiated Mesaverde, Mancos B and the Emery, which yielded the most reported gas for the month (2,287 MCFD).

Fifteen development and 5 wildcat wells were staked by month's end.

Wells of interest are summarized in Table 3-3, and Figure 3-4 shows the locations of these wells and the designated core areas.

3.4.4 Uinta Basin

Production and activity in the four major areas of primary interest to the WGSP was slowest this month in the Uinta Basin. Four development wells were reported as producers, with a total of 3,417 MCFD of potential new gas. Production was from the undifferentiated Mesaverde Group and the Wasatch Formation.

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 261 Amoco-H	1	csw 9/18N/93W Standard Draw Field Carbon Cnty, WY	Almond 8,884-9,226 (gross)	9,470 PB: 9,313	Acidized w/ 7,650 gal Fractured w/144,315 gal emul 545,000 lb sand	Wildcat outpost extension, comp. 8-22-79. No cores or tests. Located in Core Area A.	1,107
Davis Oil	1 Honeycomb Buttes Unit	2	nwse 2/27N/99W Wildcat Field Fremont Cnty, WY	Mesaverde 13,000	13,984		Wildcat well, comp. 10-8-79 D&A. No cores.	
Belco Petroleum	1-22 Mills	3	sese 22/28N/113W Big Piney Field Sublette Cnty, WY	Frontier 6,936-7,126 (gross)	7,300	29,750 gal emul 108,000 lb sand	Develop. well, comp. 9-10-79. No cores.	4,621
Amoco Production	1 USA-Amoco-S	4	cse 22/20N/94W Tierney Field Sweetwater Cnty, WY	Almond 9,816-9,980 (gross)	10,405	Acidized twice w/ total 7,140 gal acid Fractured twice w/ total 418,992 gal gel 928,000 lb sand	Develop. well, comp. 8-20-79. No cores or tests.	679

¹ Refer to Figure 3-2

² Horizon - projected depth or producing interval

Figure 3-3 Northern Great Plains Province Showing Wells of Interest and USGS Designated Core Areas (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
Flare Energy	1 Galt	1	swsw 23/35N/21E Unnamed Field Blaine Cnty, MT	Eagle 1,092-1,390 (open hole) 1,016-1,092 (open-hole, non-producing)	2,086 PB: 1,390		Wildcat well, comp. 10-5-79. Eagle Discovery- New Field. No cores or tests.	126
J. Burns Brown	13-37-13 Brown	2	nwnw 13/37N/13E Unnamed Field Hill Cnty, MT	Greenhorn	2,398		Wildcat well, comp. 8-29-79 as SIGW. Green- horn Discovery- New Field.	N/A
Grace Petroleum	32-7 Heydon	3	swne 32/34N/7E Unnamed Field Liberty Cnty, MT	Bow Island 2,152-2,156	2,271		Wildcat outpost extension, comp. 8-1-79 as SIGW. No cores.	(120)
Dome Petroleum	1-21 BN	4	nene 21/12N/47E Wildcat Field Custer Cnty, MT	Madison 7,700			Wildcat test, reported 11-20-79. Located near Core Area B.	

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
Dome Petroleum	1-17 Baldy Creek Unit	1	senw 17/7S/90W Baldy Creek Field Garfield Cnty, CO	Corcoran 9,974-10,146	10,355	Fractured	Wildcat outpost extension, comp. 9-25-79, no cores.	1,406
Norris Oil	4-1 Federal	2	nwse 4/10S/97W Roberts Canyon Mesa Cnty, CO	Corcoran 2,830	2,675		Wildcat shallow pool, comp. 10-18-79 D&A. No cores or tests.	
Adolph Coors Corporation	1-31 Acco-Nichols et al	3	nwse 31/10S/95W Plateau Field Mesa Cnty, CO	Rollins 4,306-4,330 Cozzette 4,635-4,701 Corcoran 4,780-4,806	4,975 PB: 4,830	Fract three times w/ total 344,400 gal fluid 653,000 lb sand	Develop. well comp. 11-29-77. Commingled production. No cores or tests.	850
Teton Energy	1 Anderson Ranches	3	swsw 7/10S/94W Wildcat Field Mesa Cnty, CO	Corcoran 5,800			Wildcat test, reported 11-19-79. Located in Core Area D.	

¹ Refer to Figure 3-4

² Horizon - projected depth or producing interval

One new development and 1 new wildcat well were reported by the month's end.

Wells of interest are summarized in Table 3-4, and Figure 3-5 shows the locations of the wells and designated core areas.

3.5 C K GEOENERGY CORPORATION

3.5.1 Development of Techniques for Optimizing Completion of Western Tight Gas Sands

3.5.1.1 Coring and Logging Core Hole DOE-GC-1

This experiment will attempt to show that new high resolution dipmeter logging tools can determine paleocurrent directions from small scale sedimentary structures in lenticular sands. It is known that paleocurrent directions correlate with the long axis of sandstone lenses. Thus, if logging direction data correlates with the long axis and the hydraulic fracture direction is known, fracture size can be optimized for lenses from tight gas development wells.

The Himes Drilling Company rig was mobilized to the GC-1 corehole. The fill was blown out and coring started at 663 ft. The hole was conventionally cored to about 800 ft, where an attempt was made to commence cutting 200 ft of oriented core.

Although the oriented core service was supplied by one company, the equipment was jointly owned with another. The two companies weren't coordinating and crossovers didn't match. Additionally, during the oriented coring, repeated equipment failures were experienced. The oriented coring was terminated after approximately 140 ft. To this point cores from the lower Farrer and upper Neslen had been recovered, and penetration was into the relatively continuous Neslen sandstones. Conventional coring was resumed.

Several coal beds were cored in the Neslen, with one 10 ft thick. No indication of this bed had been previously noted. The seam could be reached via an adit and horizontal tunnel from East Canyon.

Coring was terminated at 1,010 ft; recovery was 98 percent. The hole will be reamed to about 6-1/2 in. diameter, mudded up and logged from the TD of 1,200 ft up to 32 ft (bottom of surface pipe).

The core was photographed and generally described at the site before being shipped to USGS in Denver for slabbing and detailed description. A general description, plus a complete core log of the coring and logging operation, will be included in the final phase report. The logging should be completed during the first week of December.

3.5.1.2 Evaluation of Sandstone Outcrops - Green River and Wind River Basins, Wyoming

Field notes were organized and photo panoramas of the outcrops used in field evaluation were assembled.

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
Ensearch Exploration	1-11 Jack Rabbit Federal	1	swne 11/10S/23E Southman Canyon Uintah Cnty, UT	Mesaverde 6,402-7,978 (gross)	8,050	Acidized 4 times: 6,000 gal total. Fract w/ 160,000 gal fluid, 182,000 lb sand	Develop. well comp. 10-23-79 as SIGW.	200
Belco Petroleum	50-19B Natural Buttes Unit	2	swnw 19/9S/21E Natural Buttes Field Uintah Cnty, UT	Wasatch 6,494-7,140 (gross)	7,224 PB: 7,180	36,700 gal emul, 74,200 lb sand	Develop. well comp. 8-10-79. No cores or tests.	101
Del Rio Drilling	30-2A Flat Rock	3	nesw 30/14S/20E Flat Rock Field Uintah Cnty, UT	Wasatch 4,400			Wildcat outpost test, reported 10-30-79. Located in Core Area D.	
Pacific Transmission Supply Co.	11-32 Winter Ridge Unit-State	4	nwnw 32/15S/22E Unnamed Field Uintah Cnty, UT	Morrison 10,000			Wildcat outpost test, reported 11-26-79. Located in Core Area D.	

¹ Refer to Figure 3-5

² Horizon - projected depth or producing interval

3.6 MULTI-WELL EXPERIMENT

Site acquisition efforts have been focused in the Vega Reservoir area, east of Collbran, Colorado. A detailed Phase I - Phase 2 planning meeting will be held January 15-17, 1980, in Albuquerque, New Mexico.

Figure 3-6 is a milestone chart depicting the progress of the Multi-well Experiment program.

Figure 3-6 Milestone Chart — Multi-well Experiment

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

4.1.1.1 Core Retriever Design and Test

Recovery rates for cores under pressure continue to improve. Between 90 and 95 percent recovery rate appears possible when all core barrel modifications are fully implemented under the Sandia/DOWDCO improvement program.

4.1.1.2 Core Fluid Tests

The low-invasion fluid has received acceptance in the oil fields and is now being requested as an aid in obtaining better cores. The fluid used now is deaerated before injection into the inner barrel, controlling low-invasion fluid compressibility during tripping into the hole. The inner barrel piston prevents contamination of the low invasion fluid during tripping and ensures extrusion of the fluid when coring starts.

4.1.1.3 Bit Design and Fabrication

A two-piece diamond compax core bit design, fully interchangeable with the Sandia one-piece design, has been completed. Two one-piece and two two-piece diamond compax core bits are being fabricated and laboratory testing will begin in March, 1980. Field tests will begin when laboratory tests have been completed.

Industry response to the improved coring capabilities of the single piece diamond compax core bit continues to be good. A version of this bit will continue to be offered by DOWDCO as an option for standard coring operations.

4.1.1.4 Polycrystalline Diamond Core Bit Tests

The single-piece bit design developed in the Sandia/DOWDCO pressure coring improvement program is being manufactured and marketed as a coring service through DOWDCO Pressure Coring, Inc.

4.1.2 Logging Studies

4.1.2.1 Interface Conductivity Effects on Electric Logging

The cation exchange capacity (CEC) has been determined for 33 samples from cores of Joseph J. C. Paine No. 1-0296 Federal well and Twin Arrow C&K No. 4-14 well. These values will be correlated with the gamma ray log, clay analysis and surface area data.

In general, the CECs for samples from the J. J. C. Paine well are high, whereas those from the Twin Arrow well are relatively low. The standard ammonium acetate technique (pH 7.0) was used for all CEC determinations.

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

Data supplied by the Bartlesville office included analyses of 136 waters obtained from flow streams of producing gas wells in the Uinta Basin. The salinities of these waters were compared on the basis of chloride content and a histogram of the results appears in Figure 4-1. The agreement with the corresponding histogram constructed from drill stem test waters was quite unexpected. A study using the bicarbonate ion as indicator is being conducted.

Six drill stem test water analyses, which bore the analyst's statement that the water correlated with the water typifying the formation tested, are of interest. Three samples were from the Green River Formation and three from the Ferron Formation. The analyses appear on Tables 4-1 and 4-2. Both waters contain large amounts of bicarbonate ion relative to chloride.

Sample C in Table 4-1 appears suspect because of the presence of a significant quantity of carbonate ion. Until the advent of modern analytical devices, carbonate and bicarbonate were never found to coexist in natural oil field brines. Using present procedures, trace amounts of one may be found in the presence of the other. But an anomaly of this magnitude is unusual. Since sodium carbonate is a common drilling fluid additive, it appears likely that the sample was diluted with mud filtrate, which would explain the lower concentration of bicarbonate in the sample.

Sample G in Table 4-2 was taken at the flare line, rather than from a drill stem test. It has a lower concentration of ions than the other two Ferron samples. This may be explained by the observation that water vapor from the reservoir condenses at the choke and moves to the flare where it is collected with the formation water.

The large amount of bicarbonate in the Green River and Ferron Formations may explain some of the confusion in relating the self potential (SP) to R_w . Alger states¹, "In many fresh waters the predominant anion is bicarbonate, HCO_3^- . If the accompanying cation is sodium, Na^+ , the activity of the solution and thus the effect on an SP curve is usually close to that for an NaCl solution having the same Na^+ concentration. That is, the activity of the

¹ "Interpretation of Electric Logs in Fresh Water Wells in Unconsolidated Formations," Schlumberger Well Surveying Corporation, in-house publication.

Figure 4-1 Frequency vs. Cl^- concentration

Table 4-1 Analysis of Water Samples from the Green River Formation

Ion	Sample					
	A		B		C	
	PPM	MEQ	PPM	MEQ	PPM	MEQ
Sodium	1,233	53.64	2,346	102.03	1,213	52.78
Calcium	9	0.45	12	0.60	24	1.20
Magnesium	11	0.90	4	0.33	4	0.33
Sulfate	—	—	45	0.94	12	0.25
Chloride	60	1.69	140	3.95	70	1.07
Carbonate	Trace	—	—	—	146	4.88
Bicarbonate	3,250	53.30	5,980	98.07	2,880	47.28

Table 4-2 Analysis of Water Samples from the Ferron Formation

Ion	Sample					
	E		F		G	
	PPM	MEQ	PPM	MEQ	PPM	MEQ
Sodium	1,730	75.27	1,876	81.59	1,344	58.45
Potassium	10	0.26	10	0.26	—	—
Calcium	14	0.70	17	0.85	14	0.7
Magnesium	10	0.82	3	0.25	Trace	—
Sulfate	Trace	—	0	—	16	0.33
Chloride	1,150	32.40	1,700	47.94	859	23.22
Bicarbonate	2,721	44.62	2,135	35.01	1,960	32.14

solution is primarily dependent on the cation concentration. However, the resistivities of NaCl and NaHCO₃ solutions (of the same Na⁺ concentrations) are different. The HCO₃⁻ ion contributes only 27 percent as much conductivity as an equal weight of Cl⁻ ion. Or, in other words, the R_w of a NaHCO₃ solution is 1.75 times greater than R_w of a NaCl solution having the same Na⁺ concentration."

In the Uinta Basin, industry practice is to drill with a non-dispersed mud having an API fluid loss between 8 and 15 cc. Such fluids consist of an approximately 7 wt percent slurry of Wyoming bentonite in fresh water. No dispersing agents such as quebracho, phosphates or lignosulphonates are used. Fluid loss is usually controlled by the addition of starch. When this is required, it is necessary to hold the Ph of the mud above 9.0 to prevent fermentation by adding caustic soda or sodium carbonate. If evaporite beds are encountered, the drilling fluid is converted to a salt water base by adding sodium chloride.

The running of self potential logs in the Uinta Basin is current practice, but they are difficult to read because of drift. C. F. Knutson and C. R. Boardman have utilized this drift in differentiating between fluviial and lacustrine sediments in "Continuity and Permeability Development in the Tight Western Gas Sands of the Eastern Uinta Basin, Utah," Final Report to U.S. Department of Energy Contract No. EW-78-X-08-0011. They state,

"Based on the work of Visher in the reconstruction of sedimentary environments, it would be expected that SP curves for fluvial sands would be asymmetrical with sharp gradients below the peak and gradual gradients above (indicating an increase in clay and silt-size particles from the peak upward, or "fining" up.) On the other hand, lacustrine sands should exhibit asymmetrical SP curves with sharp gradients above the peak and gradual gradients below (indicating an increase in clay and silt-size particles from the peak downward, or "fining" down). These criteria are applicable to the ideal case. Variations due to interruption of ideal sedimentary cycles are to be expected. Such variations could result in roughly symmetrical or irregularly fluctuating SP curves."

Examples of "fining" up and "fining" down were presented.

If their postulate is valid, the peak value of the SP curves could be used with confidence in the calculation of R_w values. In order to determine R_w from values of the self potential, the in situ temperature must be known. This is ordinarily calculated from the mean annual temperature of the area and the earth's temperature gradient at the site. Such information is readily available in Texas and adjoining states, but none can be found for the Uinta Basin area.

A maximum-reading thermometer is always run with logging tools, and its reading is always recorded on the log. However, at the time of logging, the bottomhole temperature is always lower than that of the undisturbed formation. Usually the discrepancy is between 10 and 20°F. Therefore, it appears likely that by use of temperatures obtained from logs, the error caused by the temperature dependency would be less than 5 percent. This is due primarily to the fact that absolute temperature is the parameter which relates R_w to SP.

4.1.3 In Situ Permeability

4.1.3.1 Measurement of Formation Characteristics for Western Tight Sands - Institute of Gas Technology

The relative gas permeability of cores Nos. 5172, 5205 and 5220 from the Pacific Transmission Supply Company No. 24-19 Federal well, Sec. 19, T33N, R114W, Sublette County, Wyoming, was measured. The results are listed in Table 4-3 and shown in Figure 4-2. The relative permeability curves exhibited trends similar to those observed in cores from the Mobil PCU F31-13G and Canyon Largo No. 256 wells in the Piceance Basin. Different water saturations were established by evaporation of water from a core that was initially saturated.

Table 4-3 Effect of Water Saturation on Relative Gas Permeability

Core Depth, ft	Water Saturation, percent	K _{rg} , md	K _{rg} K _{eff} = K _o g
5,172	0.0	1.50 x 10 ⁻¹	1.0000
	24.8	8.24 x 10 ⁻²	0.5500
	39.3	4.73 x 10 ⁻²	0.3200
	52.6	9.40 x 10 ⁻³	0.0630
	70.0	1.80 x 10 ⁻³	0.0120
	87.1	2.04 x 10 ⁻⁴	0.0014
5,205	0.0	3.31 x 10 ⁻¹	1.0000
	9.1	2.78 x 10 ⁻¹	0.8400
	20.9	2.26 x 10 ⁻¹	0.0680
	61.7	7.38 x 10 ⁻³	0.0220
	74.3	4.45 x 10 ⁻³	0.0130
5,220	0.0	4.80 x 10 ⁻¹	1.0000
	5.9	4.39 x 10 ⁻¹	0.9100
	19.8	3.39 x 10 ⁻¹	0.7100
	37.5	2.29 x 10 ⁻¹	0.4800
	58.5	7.94 x 10 ⁻²	0.1600
	73.2	3.39 x 10 ⁻³	0.0070

NOTE: Listed permeabilities correspond to mean pore pressures of 34.7 psi.

Well: Pacific Transmission Supply Co. No. 24-19 Federal

Figure 4-2 Effect of Water Saturation on Gas Permeability

To study the effect of partial water saturation on gas slippage effects, relative gas permeability was measured at different water saturations as a function of mean pore pressure for cores Nos. 5172 and 5220. The results are shown in Figures 4-3 and 4-4, respectively, as a plot of measured permeability versus reciprocal mean pore pressure. An increase in partial water saturation results in reducing slippage effects. The slope of the straight line relating relative gas permeability and reciprocal mean pore pressure decreases as partial water saturation increases.

The slope and intercept of each line are shown in Table 4-4. The value of 'b', the constant associated with Klinkenberg's equation to account for gas slippage effects, increased with increasing water saturation for core No. 5220. There was an initial decrease in the value of b for core No. 5172, from a value of 3.23 atm at 0 percent water saturation to 1.75 atm at 24.8 percent water saturation, followed by a monotonic increase with increasing water saturation.

Table 4-4 Effect of Water Saturation and Pore Pressure on Relative Gas Permeability (PTS No. 24-19 Well)

Core Depth, ft	Water Saturation, percent	Slope (md) (psi)	Intercept, md	'b', atm
5,172	0.0	3.01	6.32×10^{-2}	3.23
	24.8	1.22	4.73×10^{-2}	1.75
	52.6	0.82	2.38×10^{-2}	2.34
	70.0	0.70	7.39×10^{-3}	6.43
5,220	0.0	4.92	3.38×10^{-1}	0.99
	5.9	4.85	2.99×10^{-1}	1.10
	19.8	4.71	2.03×10^{-1}	1.58
	37.5	1.28	1.92×10^{-1}	4.53
	58.5	0.50	6.50×10^{-2}	5.22

NOTE: $K_g = K_{\infty} \left(1 + \frac{b}{P_M}\right)$

Intercept = K_{∞}

Slope = $(b) (K_{\infty})$

These observations, along with the results of experimental measurements of gas permeability at high confining pressures, indicate that high water saturations and high confining pressures reduce gas-slippage effects. It is possible that high confining pressure closes small pores, which are mainly responsible for gas-slippage effects. In the case of partial water saturation, it appears that the saturation technique was effective in saturating small pores also.

Gas drive experiments will be conducted to obtain relative permeability curves to compare with those obtained by the evaporation technique.

Figure 4-3 Effect of Water Saturation and Pore Pressure on Relative Permeability to Gas

Figure 4-4 Effect of Water Saturation and Pore Pressure on Relative Permeability to Gas

4.1.4 Advanced Logging Techniques and Interpretation

4.1.4.1 Dielectric Constant Measurements for Formation Evaluation

The dielectric constant sample holder has been completed and the plumbing connections to the sample holder have been tested. A test sample was mounted in the holder and fluid saturation was successfully performed. Electrical connections were made to the Anzac voltage standing-wave-ratio bridge, and it appears that the sample holder itself does not cause any severe electrical problems. Work is continuing to solve some experimental procedure problems and on tests with the old sample holder.

The hardware and software interface between the PDP-11 computer and the HP 9825 calculator has been developed and will enable the interchange of data files between the systems. This interface has the capability of plotting data from PDP-11 files.

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

A sample holder-saturation chamber has been designed, as shown in Figure 4-5. This is designed to operate at low pressure (not to exceed 10 psi) and room temperature. The chamber will accommodate a disc-shaped sample of diameter 1.5 in. and thickness 0.5 in. It is equipped with provisions which enable saturation under air-tight conditions, and with a guard ring.

A saturating fluid reservoir under proper pressure will be utilized for saturating samples. The fluid inlet and outlet are laterally displaced to ensure maximum efficiency, and an O-ring will be utilized to hydraulically isolate the high and low pressure sides during saturation.

A power supply has been designed and built to actuate a mechanical beam exterior access shutter for the laser beam. The laser beam mode has been adjusted to accomplish the most uniform heating energy intensity on sample. An HP pulse generator is being integrated to develop capability of a pulsed laser beam.

Porous sandstone samples have been selected and coring is continuing. Prepared samples will be washed in distilled water and dried in an oven under 105°C until weight losses are minimized.

A capacitance bridge is being prepared and tested for measuring capacitance of samples at low frequency range. In addition, a capacitance bridge is being acquired (General Radio) for measurements at the intermediate frequency range.

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

Several preparatory steps needed for the evaluation of the sonic log have been started. Whole core analyses are being performed and core plugs were obtained for analysis by Scanning Electron Microscopy.

Figure 4-5 Sample Holder — Saturation Chamber

Plugs of core samples, taken from the CIGE Natural Buttes Unit No. 21 well, had been used to determine the average porosity of selected intervals in the well. These average porosities were used to correlate core depths to log depths. The density log was used as the correlation log because it has been found to give the most accurate measurement of porosity. Once the proper intervals were located on the density log, they could be picked on the sonic and neutron logs.

To insure that the laboratory properties obtained from the plugs are representative of reservoir properties, whole core analysis has begun. Parts of the core are still in the process of extraction and the parts that have been extracted and dried are being measured for porosity and permeability.

New plugs were taken from the same intervals that had undergone petrographic analysis and were examined by Scanning Electron Microscopy. The electron microscope should provide needed information about the structure and composition of cementing material in tight sandstones.

When evaluating the sonic log, Schlumberger has assumed a matrix travel time (Δt_m) of 52.6 microseconds per foot. Previous core analysis has shown that the zones under examination have varying amounts of shale. The presence of shale should increase the matrix travel time. Using laboratory measured porosities and sonic log travel times (Δt_{log}), actual matrix travel times were calculated. These matrix travel times are greater than 52.6 microseconds per foot. The Δt_m values for the selected intervals range from 53.2 to 69.8 microseconds per foot. Methods are being considered for correlating these travel times in individual zones and throughout the western sands.

The porosity of the core sections that have been measured differ significantly from the porosity of the plugs taken from these cores.

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

The literature review is continuing and should be completed by mid-January.

No effort was expended on analytical studies this month. By mid-February, the theoretical limits of resolution of shear stress will be indicated based on idealized measurement uncertainties and rock parameters from the literature. The analytical work will continue at a low rate throughout FY 1980 instead of stopping in February.

The measurement system is complete. The data acquisition software is being written and will be tested with the hardware by mid-January.

4.1.5 Reservoir Simulator Studies

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

The uniqueness of reservoir and fracture parameters, obtained from the computer matching of pressure transient test data from a fractured gas well, was investigated. Unique values for fracture half length, gas permeability and fracture flow capacity are obtained if several reservoir parameters are known from some independent measurements. These are:

- net gas pay thickness,
- porosity,
- initial reservoir pressure,
- reservoir temperature,
- gas viscosity, and
- system compressibility.

A non-unique solution can result if any of these parameters are treated as unknowns during the analysis of the test data.

Intercomp's fractured-gas-well simulation program has been modified to simulate the behavior of a well having multiple vertical fractures. The program will not simulate the pressure transient behavior of a wellbore intersecting two fractures of equal length. It assumes the two fractures intersect at an angle of 90°.

The feasibility of conducting a multiple-well test in the Western Gas Sands is being studied. The test will involve two wells. The first will be alternately produced and shut in, which will cause a series of pressure pulses to be sent through the reservoir. The second well will be used as an observation point in the reservoir. The pressure pulses caused by the active well will be measured at the observation well. Reservoir permeability and porosity-compressibility product of the reservoir can be calculated from the arrival time and amplitude of the pressure pulses.

The simulator is being used to model this type of test. The length of the pulse and the pressure amplitude at the observation well will be determined for a series of reservoir parameters and well spacing.

4.1.6 Rock-Fluid Interaction

4.1.6.1 Gel Fracture Fluid Characterization

A significant percentage of the material in a degraded, or broken, 40 lb (0.48 wt percent) low-residue guar still has a molecular weight of 10^6 or greater. Improved resolution in the 2×10^3 to 2×10^6 molecular weight region indicates that the percentage remaining above a molecular weight of 10^6 may be even greater than previously assumed. Table 4-5 contains maximum possible percentages of certain molecular weight fractions contained in a 40 lb, low-residue guar degraded with $(\text{NH}_4)_2\text{S}_2\text{O}_8$. The high molecular weight of the fracturing gel remaining after breaking may prove to be one of the reasons for lower-than-expected production rates after stimulation.

Table 4-5 Maximum Percentages of Selected Molecular Weight Fractions in a 40 lb, Low-Residue Guar Degraded with $(\text{NH}_4)_2\text{S}_2\text{O}_8$

Molecular Weight	Maximum Percent
5.0×10^5	27.0
7.0×10^4	3.9
4.0×10^4	2.3
1.0×10^4	1.8
1.5×10^1	1.1

An effort must be made to examine the molecular weight distribution above 2×10^6 , in addition to improving the resolution and quantifying the region below a molecular weight of 10^6 .

4.1.6.2 Proppant Embedment

Efforts are now underway to examine the embedment of 20-40 and 40-60 mesh sintered bauxite proppant into formations of various hardnesses. This will supplement data previously reported with 12-20 mesh on rock from the Mesaverde Group.

4.1.6.3 Drilling Mud Particle Size Distribution

Measurement continues of particle-size distributions of several different concentrations of available drilling muds in 2 percent KCl solutions, including two recent field samples. During the measurements, the particle concentrations of these mixtures was kept within a narrow range to insure the most accurate results with the Coulter TA II Particle Counter. However, such extreme dilutions were needed at times to achieve this that the results are often more reflective of the 2 percent KCl solution rather than the suspended mud particles. In such instances, a more concentrated mud mixture was sometimes used.

Although several additional samples of Drilling Mud No. 6325 were run to confirm last month's results, much of the data was measured at unacceptable levels of particle concentration. However, one completely new mud sample and the 2 percent KCl solution used to dilute it were effectively investigated. The sample was Drilling Mud No. 6494, another field sample similar to Drilling Mud No. 6325. Also, the results of a "Modified Sample" of Drilling Mud No. 6325 were examined and two particle-size distribution plots were prepared. These and similar plots for the other mixtures are available. The results of this analysis and those of samples of Drilling Mud No. 6494 are listed in Table 4-6. The first part of this table shows the results of an attempt to produce a particle-size distribution of Drilling Mud No. 6325, which reflects only the mud particles present in the mixture. The second and third parts of the table concern the Drilling Mud No. 6494 mixture. The Population means and modes of samples of this mud mixture are generally lower than those of Drilling Mud No. 6325. However, the Volume means, modes, and medians are generally somewhat higher.

4.1.7 Schedule Status

Figure 4-6 is a milestone chart of BETC WGSP activities.

4.2 GAS RESEARCH INSTITUTE

Preparation continued of a proposal for a Tight Gas Sands Data Base Project. This proposal will:

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

Table 4-6 Sample Analyses

Modified Drilling Mud No. 6325

Run No.	Total Concentrations Per ml	Population Mean, microns, (μ)	Pop Mode, μ	Pop Median, μ	Pop Standard Deviations, μ	Volume Mean, μ	Vol Mode, μ	Vol Med, μ	Vol SD μ
1	183,690	5.40	6.69	5.76	1.68	12.25	9.00	10.94	1.82

**2 Percent KCl Solution
(Used to Dilute Drilling Mud No. 6494)**

1	3,884	1.87	1.41	1.63	1.48	1.79	1.41	1.60	1.35
2	3,804	1.86	1.41	1.63	1.49	1.79	1.41	1.60	1.37
3	4,270	1.89	1.41	1.68	1.48	1.81	1.41	1.65	1.36
4	3,798	1.85	1.41	1.66	1.42	1.79	1.41	1.64	1.34

**Drilling Mud No. 6494
(In 2 Percent KCl Solution)**

1	96,420	2.65	1.41	2.29	1.82	11.62	14.63	12.40	1.91
2	90,706	2.84	1.41	2.48	1.87	11.51	16.56	12.43	1.82
3	98,376	2.70	1.41	2.34	1.85	11.09	16.00	11.98	1.81
4	100,066	2.70	1.41	2.32	1.85	11.16	15.28	12.07	1.81
5	99,384	2.69	1.41	2.32	1.84	11.20	14.97	12.21	1.80
6	100,440	2.63	1.41	2.28	1.81	11.63	16.06	12.34	1.92

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												
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												
Sonic Techniques to Measure In Situ Stress												
Literature Review												
Analytical Studies												

Figure 4-6 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 4-6 Continued

A proposal was prepared and approved for GRI to cooperatively fund a coring/logging field project with DOE at the Pacific Transmission Supply Company No. 3-10A Federal well, Sweetwater County, Wyoming. It was proposed that DOE pay for coring 240 ft in the Mesaverde plus all core analysis, and that GRI will pay for selected additional well logs and provide a contingency fund.

A proposal is in preparation for a cooperative GRI-operator coring/logging field project at the Rainbow Resources, Inc., No. 1-3 Federal well, Sweetwater County, Wyoming. It is contemplated that GRI will pay for coring services, logging services, rig time for logging, and a portion of rig time for coring; the operator would pay for the balance. It is proposed that 420 ft of Mesaverde core be cut below 12,000 ft.

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

Production and pressure build-up tests conducted from July to October in preparation for the fracture stimulation treatment indicated insufficient reservoir flow capacity to warrant a meaningful experiment. Consequently, plans for further operations have been suspended. Negotiations are pending regarding subcontract cancellation.

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

The Seismic Modeling Group spent a week at USGS in Denver working on the seismic computer model, and work was completed on a seismic model study of channel sandstone bodies representative of those at the study site in the Uinta Basin. The model study incorporated various channel sizes, numbers of channels, and separations between the channels. Results of the study will be used in interpretation of the results of the forthcoming seismic survey.

Topographic surveying was completed during November at the Bryson Canyon site. The seismic crew arrived in the field November 30 in preparation of acquiring field data.

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

Coring and logging operations at this well in Colorado were completed in October with no complications. Laboratory core analysis and data evaluation are in progress.

4.2.4 Coring and Logging of Pacific Transmission Supply Company No. 3-10A Federal Well

DOE-funded coring of 187 ft of the Mesaverde in this Sweetwater County, Wyoming, well was successfully conducted November 9 through 13, with recovery of 166.7 ft (89 percent). Logging operations, funded in part by GRI, were carried out immediately thereafter without problems. Core analysis, as well as log and other data evaluation, is in progress.

4.3 LAWRENCE LIVERMORE LABORATORY

4.3.1 Theoretical Analysis

4.3.1.1 Dynamic Crack Growth

In the numerical analyses of a crack propagating in the neighborhood of an interface, the dynamic effects resulting from a variation in the crack propagation velocity have been studied. The elastic constants on either side of the interface have been varied to determine interface penetration characteristics. In addition to these analyses, the effects of varying density across the interface will be studied.

Like the variation in crack propagation velocity, a variation in density must be analyzed with a dynamic model because static models cannot account for density. To accomplish this, the dynamic finite element model was modified. Since the model is quite sophisticated (using a mass matrix which is derived from the finite element basis function), a variation in density is achieved by reconstructing the global mass matrix. The coding has been done and the model is currently being debugged.

4.3.1.2 Fluid Flow-Crack Growth Interaction

The development of a theoretical model to calculate the flow and pressure distribution in a propagating hydraulic crack has been continued. As part of the model, the fracture aperture and shape have to be determined to define the boundaries of the flow regime in the crack. The Sneddon² relations

$$U_y(x,0) = b \int_{x/c}^1 \frac{t q_1(t) dt}{\sqrt{t^2 - x^2/c^2}} \quad (1)$$

where

$$b = \frac{2(1-\eta^2)P_0c}{E}, \text{ and} \quad (2)$$

$$q_1(t) = \frac{2}{\pi} \int_0^t \frac{P_1(u) du}{\sqrt{t^2 - u^2}} \quad (3)$$

² Sneddon, I. N., and M. Lowengrub, "Crack Problems in the Classical Theory of Elasticity," John Wiley & Sons, Inc., 1969.

have been written in numerical form and in FORTRAN. E is Young's modulus, η is Poisson's ratio, c is the crack half length, $U_y(x,0)$ is the aperture of the crack and $P_1(x)$ is an even function of x which can take values from 0 to 1 and is defined by $P_1(x)P_0$ where P_0 is a constant pressure. These equations have been coded and debugged on the computer and compare well with the analytic solution where $P_1(x)$ is a constant over the length of the crack. In that case the analytic solution shows that the crack has an elliptical shape, e.g., $U^2/b^2 + x^2/c^2 = 1$.

To calculate the fluid motion in the crack the problem was approached along similar lines as Viecelli.³ In this approach,

$$\frac{\partial u}{\partial t} + \frac{\partial u^2}{\partial x} + \frac{\partial uv}{\partial y} = - \frac{\partial P}{\partial x} + \frac{1}{Re} \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) \quad (4)$$

$$\frac{\partial v}{\partial t} + \frac{\partial uv}{\partial x} + \frac{\partial v^2}{\partial y} = - \frac{\partial P}{\partial y} + \frac{1}{Re} \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) \quad (5)$$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (6)$$

for the velocities, u and v , and the pressure p . Here Re is the Reynolds number. The idea of using the vorticity and stream function formulation of the equations has been set aside because of problems specifying the boundary conditions on the crack face. Solving directly for the pressure simplifies the calculation of the flux into the rock. Work has begun on a code that will solve equations (4) through (6) in a bounded region.

4.3.2 Experimental Program

4.3.2.1 Crack Growth Across Unbonded Interfaces

In the laboratory hydraulic fracture experiments performed to study crack growth across unbonded interfaces, two types of interfaces have been used to vary friction: a smooth machined surface and a surface roughened by sandblasting. During November, experiments were performed to find suitable lubricants which would lower the frictional characteristics of the interfaces below those of the smooth machined surfaces. Two or three lubricants have been found and experiments are in progress to further assess their effects on crack growth near unbonded interfaces.

³ Viecelli, J. A., "A Computing Method for Incompressible Flows Bounded by Moving Walls," J. Comp. Phys. 8, 119-143 (1971).

4.3.2.2 Rock Mechanics Measurements

Measurement of the relation between pressure and volume (confining pressure up to 1.2 GPa) was completed for the Mesaverde shale from Rio Blanco County, Colorado. Data reduction will be completed during December. Measurement of the failure envelope has been completed for Wyoming Mesaverde sandstone loaded parallel to the bedding. Similar measurements on this material loaded perpendicular to the bedding will be performed in December.

The plumbing of the high pressure system for simultaneous ultrasonic velocity measurements in multiple directions up to confining pressures of 1.0 GPa is almost complete.

4.3.3 Geology and Geophysics

A bibliography has been compiled and reprints of papers have been collected on the structure and fracture patterns in the western tight gas sand basins. There is disagreement on the origin of the fracturing and its relation to local and regional structure and stress. It appears that there are two types of fracturing: one whose origin is obscure, and another with an apparent systematic relationship to structure. The question still remains as to the relation of original fractures, which were not sufficient for commercial production, to new induced fractures. The literature on this subject is presently being abstracted and a review and synthesis of the state of the art for fracture-structure-stress studies is in preparation.

4.3.4 Schedule Status

Figure 4-7 is a milestone chart depicting LLL's WGSP status.

4.4 LOS ALAMOS SCIENTIFIC LABORATORY

Activities in November for Nuclear Magnetic Resonance (NMR) studies were centered around completing three papers for presentation at the Chicago meeting of the American Physical Society on January 21-24, 1980. The papers are:

"Detection of NMR in a Remotely Produced Region of Homogeneous Magnetic Field."

"Sensitivity of NMR Detection for External Samples," and

"Remote Production of a Region of Homogeneous Magnetic Field."

See section 2.2.3 for the abstracts of these papers.

Figure 4-8 is a milestone chart depicting LASL's WGSP status.

Figure 4-7 Milestone Chart — LLL

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 4-8 Milestone Chart - LASL

Figure 4-8 Continued

4.5 SANDIA LABORATORIES

4.5.1 EGR Instrumentation and Diagnostic Program

4.5.1.1 Hydraulic Fracture Characterization

In November, a borehole seismic experiment was performed on Amoco's Burnett Brothers No. 12 gas well near Carthage, Texas. Because of high temperatures in the well, a thermistor was used to monitor the temperature inside the borehole seismic unit. The intent was to pump fluid to cool the unit when destructive temperatures were approached. However, the seismic unit began to fail at about the 7,000 ft level, producing erroneous temperature readings considerably below what was actually present. The unit failed to respond to the clamping control signals when it reached 9,490 ft, 2 ft above the top of the perforations. As the unit was extracted from the well, all electronics failed.

A second seismic unit, which did not have the capability of monitoring temperature, was then used for the experiment. Consequently, the unit was clamped at about 7,000 ft and water was pumped in for cooling purposes. The borehole seismic unit was then clamped at 9,490 ft and a slow pump rate was begun while an explosive charge was prepared. This charge was to produce a seismic signal at a known location, which could be used to determine the unit's orientation. After pumping was stopped for about 10 min, a 5-lb shot was detonated 9,000 ft from the well. The shot was detected but was of fairly low amplitude.

A 15-lb shot was also detonated at this location but produced only a small increase in amplitude. Two more 5-lb shots were detonated in different locations, each at a distance of 9,000 ft from the treatment well. Both produced low amplitude signals. A water pump was activated between all shots to keep the seismic system temperature below a destructive level. Seismic activity before and after the explosive shots was recorded for fracture mapping. Background noise was very high in this well, but with appropriate filtering useful seismic signals can be obtained and tool orientation from the explosive shots can be accomplished.

In an attempt to remove the borehole seismic unit, it became stuck while still in the fracture valves, so the well could not be shut in to remove it. The well was allowed to flow back but did not reduce pressure sufficiently to remove the seismic unit. The wireline attached to the seismic unit broke and allowed the unit to fall to the 9,600-ft level. Attempts failed to kill the well with 10- and 10.5-lb water. Finally, 11-lb water succeeded in keeping well head pressure down. A fishing trip was made and the seismic unit was removed from the well, but was dropped and broken after removal.

The first seismic unit is presently undergoing repair but nothing has been learned as to why it failed. However, several semiconductors did fail and the unit still fails at elevated temperatures. The unit retrieved from the well was examined and extensive cleaning and checking will be needed as all internal units were discolored and covered with an oily film. The electronics will be cleaned and thoroughly tested, the orientation units will be reconditioned, and the clamping mechanism will be repaired.

4.5.1.2 Electrical Resistivity System

Utilization of the surface electrical resistivity system has decreased significantly during the past months. As a result of this and the increased emphasis on formation evaluation, a portion of this effort is being redirected to a borehole resistivity system. This system would be capable of ascertaining the resistivity profile surrounding a single wellbore.

The formation resistivity is assumed to possess axial symmetry where resistivity is a function of the depth coordinate, Z , and the radial distance from the borehole, r . The determined resistivity profile will be used to:

- ascertain the radial extent of the borehole fluid invasion zone;
- determine the virgin formation resistivity exterior to the invaded zone, from which porosity can be estimated if a value of formation water resistivity is assumed; and
- investigate applications in coal gasification and oil shale programs.

The borehole mechanism will be a long cylinder with cylindrical electrodes placed at regular intervals along the exterior wall. An electric current will be injected at one electrode, with the current return at either the surface of the earth or another electrode. Potential data will be recorded at the remaining electrodes. The entire system will then be raised one electrode spacing and the sequence repeated. A large amount of potential data is gathered, which will be used to obtain the resistivity profile. The borehole system is shown in Figure 4-9.

Figure 4-9 Borehole Resistivity System

4.5.1.3 Nuclear Magnetism Logging

Initial analysis of the eleven cores from Colorado Interstate Gas Exploration No. 21, Uinta Basin, has been completed by Petroleum Testing Services. The results of the core analyses are given in the following table.

Table 4-7 Core Analyses of CIGE No. 21 Well

Sample Depth (ft)	Helium Porosity (percent)	"A" Brine Wet Porosity (percent)	Air Permeability (md)	Apparent Sand Grain Density (gm/cc)
4,403.3	8.8	8.7	0.05	2.72
4,303.8	9.2	9.2	0.90	2.66
4,478.3	7.0	7.0	0.20	2.69
4,478.3	4.7	4.5	<0.05	2.68
6,492.0	9.6	9.6	0.30	2.65
6,493.0	9.8	9.6	0.20	2.65
7,469.0	3.7	3.7	<0.05	2.70
7,469.0	4.7	4.7	<0.05	2.70
8,492.0	9.4	9.1	0.10	2.67
8,496.5	2.7	2.6	0.20	2.47
8,525.0	6.1	6.0	<0.05	2.67

The samples represent a range of small permeabilities, from less than 50 μ d up to 300 μ d. This is typical of permeabilities encountered in numerous other tight western gas sand tests. The lack of correlation between measured porosity and permeability indicates non-connected porosity, probably due to variable amounts and distribution of clay minerals.

4.5.1.4 High Resolution Seismic Formation Mapping

The seismic modeling segment of this project was completed in November. Sixteen subsurface models were submitted to a normal incidence ray tracing program at the Phoenix computer facility of the USGS seismic stratigraphy group, Denver. The purpose of the modeling exercise was to evaluate seismic field parameters, such as sandstone channel thickness, multi-channel separation and seismic pulse bandwidth, and their effects on the resulting seismic record sections. Models included 50- and 20-ft thick channels in a variety of configurations. A deeper, continuous bed (representing the continuous Sego or Castlegate sandstones) was included to evaluate the effects of channeling on deeper horizon reflections. A sandstone velocity of 11,800 ft/sec and a shale/silt velocity of 10,500 ft/sec were used; these values were obtained from a sonic log from the Horse Point Gas Field site.

An example of a modeled section is given in Figures 4-10 through 4-14. Figure 4-10 is a display of the depth model: two 50-ft thick sand channels superimposed and separated by 400 ft. Figure 4-11 represents the reflection arrival times from each surface, excluding diffractions from the channel edges. The upper (convex) channel surfaces cause a spread out (diverging) reflection pattern while the bottom (concave) surfaces are shortened (focused).

DEPTH MODEL 3

WGSP SEISMIC MODELING PROJECT

Figure 4-10 Depth model of two sandstone lenses underlain by a continuous sandstone layer

Figure 4-11 Normal Incidence "Spike" Reflection Record Section for a Model of Figure 4-10

In fact, the focal point of the bottom surface of the lower channel is actually below the ground surface, which results in the complex crossing reflection pattern commonly referred to as a "buried focus". The "velocity pull-up" or upward warping of the flat reflection is caused by the local higher velocity zones represented by the channels. Such a presentation is a simplified means of looking at reflections; the actual recording consists of a convolution of a source wavelet with this figure, including the effects of reflection coefficients at each interface. Figures 4-12 through 4-14 show the resulting record sections for three different source wavelets. Figure 4-12 uses a 40-80 Hz bandwidth wavelet, Figure 4-13 uses a 60-140 Hz wavelet and Figure 4-14 uses an 80-160 Hz wavelet. All three sections exhibit sufficient resolution to distinctly "see" both channels and the horizontal bed. In addition, some edge focusing effects cause amplitude increases locally on the flat reflector, which may aid in locating edges of actual channels. The ultimate resolving power is gained with the highest frequency wavelet (Figure 4-14). Here, individual top and bottom reflections are observed, whereas thickness indication on the lower frequency records may be made only through analysis of the amplitudes of composite top and bottom reflections. Later models, having considerably less separation between channels, illustrate the need for a higher frequency pulse to be able to separate the numerous, interfering events.

Analysis of the modeled results is continuing; however, certain preliminary observations should be made. As in the case of any study of relatively thin bodies, a higher frequency wavelet is desirable. The initial segment of field operations will optimize primacord length and coupling parameters to raise the frequency content of the impulse. Secondly, the lens-like behavior of the channels (divergence and focusing) will require a migration step in data processing to remove these effects and present a more correct "picture" of the subsurface. Thirdly, analysis of deeper, continuous reflections may prove useful in interpreting the presence and trends of channels in the overlying section. Further analyses of models will evaluate geometrical considerations and their effects on expected resolution.

4.5.1.5 Electromagnetic Logging

Efforts have been directed toward evaluating the overall program feasibility and merit. Specifically, seminars concerning the modeling of the dielectric and ohmic constitutive relations were presented at BETC, Amoco, Welx, and Dresser-Atlas; and a short talk was given at IGT. Comments and criticisms concerning the modeling work as well as the merit of Sandia's involvement in this electromagnetic logging program were solicited. The important industry responses to date are:

- No one is aware of an electromagnetic approach similar to Sandia's, although all parties are interested. However, parallel acoustic programs do exist. The bottom line for both studies should be the same, i.e., a description of pore geometries leading toward permeability predictions. This means the electromagnetic and acoustic concepts can be tested against each other.
- Clays will be a problem. There is a need first to understand simple (clay-free) rocks.
- A proper DOE role is one of research. Most companies are not willing to expend the resources needed to solve the electromagnetic problem, but they are willing to help out in their areas of expertise. One-on-one involvements with DOE/industry researchers are likely.

Figure 4-12 Resulting reflection record section utilizing
a 40-80 Hz bandwidth wavelet

*Figure 4-13 Resulting reflection record section utilizing
a 60-140 Hz bandwidth wavelet*

*Figure 4-14 Resulting reflection record section utilizing
a 80-160 Hz bandwidth wavelet*

Figure 4-15 Milestone Chart — Sandia

- Even if instrumentation problems preclude sonde development, the program may yield a valuable laboratory tool.
- Prototype sondes exist that provide some of the required electromagnetic data. Furthermore, logging companies have an interest in working with the DOE on the multi-well test.
- In all, the program was received well. The previous point may mean that industry can be persuaded to build a multi-frequency electromagnetic sonde. This question will be addressed at a later date when more information and data are available.

In the past, this program has concentrated on modeling the dielectric properties of saturated rocks as an assemblage of conducting spheroids imbedded in a nonconducting (quartz) matrix. This model did not attempt to account for the presence of clays. Clays may be present in the form of large "particles" filling spaces between quartz grains or as a thin coating on the surfaces of otherwise clay-free pores. The former problem can be easily modeled using a three-compound Sillars' model of an inhomogeneous dielectric, i.e., quartz and clay and water-filled inclusions. The latter problem is currently being worked on.

4.5.2 Schedule Status

Figure 4-15 is a milestone chart depicting Sandia Laboratories' WGSP progress.

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

Figure 4-15 Continued

5. FIELD TESTS AND DEMONSTRATIONS

5.1 BACKGROUND

Field tests are essential to verify the findings of laboratory tests and modeling studies. The field test and demonstration program involves cooperation between industry and government and also interacts geologic studies with laboratory research and development. The following projects are 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	06-22-78	170,500	203 Gel	—	Water	—
			7,251-8,774	08-08-78	1,965,000	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	—

RIO BLANCO MASSIVE HYDRAULIC FRACTURING EXPERIMENT

DE - AC08 - 76RA00623

CER Corporation
Las Vegas, Nevada

Interagency Agreement Date: June 19, 1974
Anticipated Completion Date: July 1, 1979 (Closing)

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

Principal Investigator: G. R. Luetkehans
Technical Advisor for DOE: C. H. Atkinson

OBJECTIVE

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

5.2 CER CORPORATION

DOE Contract No. DE-AC08-76RA00623 was awarded to CER Corporation in March, 1974. The original contract provided for the drilling of a new well and two MHF treatments. Contract modifications added two additional MHF treatments and extended the terms of the contract.

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

The transfer is still pending.

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	99,000
	Total	\$174,000

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.

5.3 COLORADO INTERSTATE GAS COMPANY

Cyclic injection of dehydrated gas and production continued at the Miller No. 1 and Sprague No. 1 wells; shutdowns also continued. Line freezes, primarily in the gas line between the Miller No. 1 well and the compressor, occurred most often when the Miller No. 1 well was on production.

Four gravity-feed methanol drip tanks were delivered to the site, along with the Textstream regulator, and will be installed in late December or early January.

Both wells are scheduled to be shut-in in mid-January for 60 days to measure BHP build-up. It is anticipated that the DOE's well test trailer will be available for measuring and recording the BHP at the Miller well. Cable, Inc. of Sterling, Colorado will measure BHP at the Sprague well.

Figure 5-1 illustrates production and injection volumes and associated pressures of these wells.

A table detailing these figures is available upon request. This table also includes the volume of makeup gas obtained from CIG's gathering system, the number of hours the compressor was operating and the amount of fuel used.

Figure 5-1 Production and Injection Volumes and Associated Pressure of CIG Miller No. 1 and Sprague No. 1 Wells

DOE WELL TEST FACILITY

DE-AC08-79-BG01569

CER Corporation
Las Vegas, Nevada

Status: Operational

Principal Investigator:
Technical Advisor for DOE:

R. L. Mann
C. H. Atkinson

OBJECTIVE

The DOE Well Test Facility, consisting of two vehicles, will provide a deep well instrumentation and investigation system to monitor and evaluate the productive potential of all types of wells.

5.4 DOE WELL TEST FACILITY

The DOE Well Test Facility is in temporary storage at the DOE facility in Grand Junction, Colorado.

NATURAL BUTTES UNIT, UINTAH COUNTY, DE-AC08-76 ET 12060 UTAH MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

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

Status: Active

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

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

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

OBJECTIVE

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

5.5 GAS PRODUCING ENTERPRISES

GPE's Natural Buttes Unit Nos. 9, 14, 18 and 20 flowed to sales during November. Natural Buttes Unit No. 19 was shut in for pipeline proration and Natural Buttes Unit No. 21 was temporarily abandoned in the Mesaverde horizon. NBU No. 22 was shut in because it was flowing water. Figures 5-2 through 5-7 show the production histories of these seven wells.

A comprehensive final report is in preparation.

Figure 5-2
Flow Rate Performance of
Natural Buttes No. 9 Well

Figure 5-3
Flow Rate Performance of
Natural Buttes No. 14 Well

Figure 5-6
Flow Rate Performance of
Natural Buttes No. 20 Well

Figure 5-7
Flow Rate Performance of
Natural Buttes No. 22 Well

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

DE - AC08 - 78ET12150

Mitchell Energy Corporation
Houston, Texas

Status: Active

Contract Date:

March 15, 1978

Anticipated Completion:

April 30, 1979 (Extension being processed)

Total Project Cost (estimated):

DOE \$ 553,771

Industry 1,074,550

Total \$1,628,321

Principal Investigator:

F. D. Covey

Technical Project Officer for DOE:

C. H. Atkinson

OBJECTIVE

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

5.6 MITCHELL ENERGY CORPORATION

By month's end, the Mitchell Energy Corporation Muse-Duke No. 1 was flowing 3,400 MCFD and 12 BWPD with a flowing tubing pressure of 1,050 psig through a 25/64 in. choke. All testing has been completed. The well will be produced for a year after it reaches constant line pressure of 650 psi before another check will be made on reservoir performance.

The final report is being prepared and the draft should be finished by mid-January.

PICEANCE CREEK FIELD, COLORADO, MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

DE - AC08 - 76ET12062

Mobil Research and Development Corporation
Dallas, Texas

Status: Active

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

Total Project Cost (estimated):	DOE	\$2,510,000
	Contractor (prior costs)	2,376,485
	Contractor (new costs)	1,590,515
	Total	<u>\$6,477,000</u>

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.

5.7 MOBIL RESEARCH AND DEVELOPMENT

A draft of the final report was submitted to DOE for comments. The report has been returned to Mobil for printing.

RIO BLANCO COUNTY, COLORADO MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

DE - AC08 - 76ET12148

Rio Blanco Natural Gas Company
Denver, Colorado

Status: Active

Contract Date: August 1, 1976
Anticipated Completion: July 31, 1979

Total Project Cost (estimated):	DOE	\$ 410,000
	Contractor	593,000
	Total	\$1,003,000

Principal Investigator: Robert E. Chancellor
Technical Project Officer for DOE: C. H. Atkinson

OBJECTIVE

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

5.8 RIO BLANCO NATURAL GAS COMPANY

DOE Contract No. DE-AC08-76ET12148 was signed with Rio Blanco Natural Gas Company in June, 1976. The first MHF treatment was performed on October 22, 1976. A supplemental agreement, effective October 1, 1977, provided for a second MHF treatment which was performed on November 30, 1977.

The final report is 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 mine-back for direct observation and evaluation.

5.9 SANDIA — MINEBACK

5.9.1 Hydraulic Fracturing Containment Experiments

5.9.1.1 Hole No. 6 Formation Interface Fracture Experiment

Coring began on Corehole EV6-28, shown in Figure 5-8. This is part of an exploratory program to determine the general shape of the fractures. In turn, this will reflect the influence of the interface and in situ stress on overall fracture propagation and behavior. Twenty-two coreholes have been completed to date.

5.9.1.2 Interface Test Series

Twenty fractures have been initiated in the region near the interface, as well as eleven minifracs for in situ stress measurements. The results show that fractures will consistently cross an interface from a low modulus material to a high modulus material; but they will terminate in layers where there is a sharp increase in the minimum principal stress. Flow rate apparently has no effect on containment other than controlling the fluid pressure, which may induce a fracture to propagate into a higher stressed region.

These experiments show that in situ stress is the dominant mechanism controlling hydraulic fracture propagation. The fractures show little or no change as they approach and cross the material property interface, but the unfavorable stress gradients near the peak readily terminate fracture growth.

5.9.1.3 Rock Mechanics

To investigate the origin of the stress variations observed in the interface test series, finite elements will be used to calculate the in situ stress in a linear elastic and isotropic material. Calculations will continue in December.

5.9.1.4 Fluid Mechanics

The fluid mechanics modeling effort involves understanding the phenomena associated with flow through hydraulic fractures (pressure drop, proppant transport, etc.) as well as porous media processes associated with fracturing, production and in situ testing. The major effort has been the development of an interactive rock mechanics/fluid mechanics model of the propagation of a hydraulic fracture. Other modeling activities are in support of mineback experiments conducted at the Nevada Test Site.

5.9.2 Geochemistry and Petrology

Current geological and petroleum engineering literature has established that clay mineralogy is an important factor in determining sandstone reservoir quality. Moreover, it is equally important from geochemical and petrologic studies to determine whether these clays are allogenic (detrital) in origin or authigenic (having formed in place).

Figure 5-8 Results of Exploratory Coring of Hole No. 6

Samples of the Mesaverde Group were recently received by Division 4732. These samples, from Mapco RBU No. 11-17F well in the Uinta Basin, are the first true representatives of the tight gas sands received for petrographic work. A comprehensive investigation is underway to characterize the mineralogy, texture, and diagenetic history of these rocks.

5.9.3 Schedule Status

Figure 5-9 is a milestone chart depicting Sandia mineback WGSP progress.

Figure 5-9 Milestone Chart — Sandia Mineback