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Western Gas Sands Project Status Report

1 May - 31 May, 1980

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U.S. Department of Energy
Bartlesville Energy Technology Center
Las Vegas Field Office
Compiled by CER Corporation
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SUMMARY

This May, 1980, WGSP Status Report summarizes the progress of the government-sponsored projected directed towards increasing gas production from the low permeability gas sands of the western United States. Background information is provided in the September, 1977, Status Report, NVO-0655-100.

The planning activities for the multi-well experiment continued in May. Bartlesville Energy Technology Center continued formation evaluation and reservoir simulation studies. Lawrence Livermore Laboratory continued calculations of fracturing near interfaces. Los Alamos Scientific Laboratory focused work on the permanent magnet system for NMR logging. Results of the 3-D Seismic Reflection Survey were presented by Sandia Laboratories.

Production and injection experiments continued for the Colorado Interstate Gas Company Miller No. 1 and Sprague No. 1 wells. The DOE Well Test Facility was transported to Las Vegas for repairs and modifications. In situ testing continued at the Nevada Test Site for the Sandia Mineback program.

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SECTION 1

PROJECT MANAGEMENT

TECHNICAL MANAGEMENT

C. H. Atkinson (DOE) met with G. Spencer and K. Smith, Coastal Oil and Gas Corporation (formerly Gas Producing Enterprises), May 22 in Las Vegas, to discuss an additional phase for the Natural Buttes MHF demonstration project in the Uinta Basin.

C. H. Atkinson (DOE) and personnel from CER Corporation and C K GeoEnergy attended a briefing in Las Vegas on May 23 by Sandia Laboratories, concerning the status of seismic mapping of individual sand lenses (Seismic Field Mapping Project in Utah).

C. H. Atkinson and personnel from CER Corporation and Sandia Laboratories participated in a meeting at CER offices in Las Vegas, May 27 and 28, to review the multi-well test status and to update activity networks.

TECHNOLOGY TRANSFER

DOCUMENTATION REPORTS

Structure, isopach and production maps are being drafted of the Bryson Canyon area (Uinta Basin). Work on the production history of the Piceance and Uinta Basins continued. A production map indicating pay zones and cumulative production in the Piceance Basin is nearing completion. Preliminary facies mapping of the Green River Basin continued, with producing areas being spotted and a summary of the maps being prepared.

The *WGSP Financial Supplement for May, 1980*, the *April WGSP Status Report*, and *The Quarterly Basin Activities Report* for first quarter, 1980, have been distributed. Revision continued for the *DOE Well Test Facility Operations Manual*. Compilation of data is nearly complete for the WGSP section of the *DOE Semi-Annual Report for the Unconventional Gas Recovery Program* (period ending March 31, 1980).

PROJECT DATA BANK

The map "Subsurface and Surface Correlation of Some Upper Cretaceous and Tertiary Rocks, Northern Green River Basin, Wyoming, Section A-A', B-B'," by B. E. Law, USGS, 1979, has been added to the WGSP project data bank.

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

ARTICLES AND PUBLICATIONS

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

*Some Relations Between
Diagenesis and Porosity (Real
and Imagined), Sandstones of
Mesaverde Group, Uinta Basin,
Utah*

by C. W. Keighin
USGS

Examination of core and surface samples from several nonmarine sandstones of the Upper Cretaceous Mesaverde Group in the southeastern part of the Uinta Basin, Utah, reveals extensive diagenetic alterations. Diagenesis has significantly altered the porosity characteristics of the sandstones and is thought to have a definite influence on porosity log

calculations and on the interpretation of various other geophysical logs, sometimes leading to erroneous interpretations of reservoir characteristics.

Leaching of rock fragments and carbonates — calcite, dolomite, and ankerite — has resulted in the development of significant amounts of secondary porosity which probably provide the favorable reservoir properties of the sandstones. Formation of authigenic pore-filling kaolinite, and illite, which replace rock fragments and which line pores, has produced microporosity, greatly increased pore surface area, and has created a tortuous pore network. These properties dramatically alter pore geometry and, thus, fluid-flow characteristics which significantly alter the response of resistivity logs and influence the interpretation of sonic and neutron logs. Consequently, erroneous values may be obtained for calculated porosity and water saturation. Interpretation of mercury-injection curves is also influenced by authigenesis.

Bowdoin Dome Area, North-Central Montana — Example of Shallow Biogenic Gas Production from Lower-Permeability Reservoirs

by G. L. Nydegger, D. D. Rice
and C. A. Brown
USGS

Natural gas is currently being produced from shallow, low-permeability, low-pressure reservoirs in the Bowdoin dome area, Phillips and Valley Counties, Montana.

Most of the biogenic gas is stratigraphically entrapped in thin, discontinuous siltstones and sandstones that are enclosed in a thick sequence of shales of Late Cretaceous age. There is some structural influence on the accumulations in more porous zones. The reservoirs and the associated shales were deposited on a shallow-marine shelf and thus present different mapping and recovery problems from most low-permeability reservoirs of nonmarine origin.

Early development, prior to 1960, was on the structurally high part of the dome and covered an area of about 200 sq. mi. (520 sq. km). Production was from depths ranging from 800 to 1,000 ft (240 to 300 m). With the advent of higher gas prices and improved completion technology in the 1970s, the field now includes an area greater than 600 sq. mi. (1,560 sq. km). The reservoirs in the expanded area are lower in permeability, occur at depths ranging from 1,200 to 1,800 ft (360 to 540 m), and require stimulation to provide economic flow rates.

Most of the recent wells have been drilled using conventional rotary rigs and mud systems designed to minimize formation damage. The wells are hydraulically fractured using sand, carbon dioxide, and water. A combination of sonic, neutron, and density logs is an aid in reservoir evaluation, although better logging tools are needed. Production history, which is limited, will probably prove to be the best method of estimating recoverable reserves.

SECTION 2

RESOURCE ASSESSMENT

U.S. GEOLOGICAL SURVEY ACTIVITIES

UINTA-PICEANCE BASINS

Paleontologic data from Price River Canyon was compiled.

Manuscripts are being prepared for reports on reservoir rocks in Southman Canyon and Pariette Bench fields.

Small samples of core were received from Mapco RBU No. 11-17F well in the Uinta Basin. Thin sections are being examined as samples arrive.

Core from a Twin Arrow C & K well, Westwater Canyon in the Bookcliffs, is being examined to determine suitability for reservoir property studies. Initial analysis indicated that almost all of the Mesaverde cores have been extensively altered by near surface weathering conditions, making them unsuitable for direct rock-property and mineralogic comparisons to the deep subsurface at Natural Buttes. However, this core is useful for sedimentologic data.

GREATER GREEN RIVER BASIN

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

Samples from Belco (Inexco) WASP No. A-1 well were submitted for complete geochemical analyses.

X-ray analysis of clays from drill-cuttings from Rainbow Resources Pacific Creek Federal No. 1-34 well were completed.

Reservoir pressure and other data from the Pinedale Unit area, northern Green River Basin are being completed.

Two stratigraphic-engineering log cross sections from the Sand Wash Basin are being reviewed.

Data is being compiled on clay mineralogy and petrography of Tierney wells and will be published as an oil and gas chart.

The report on stratigraphic correlations of Upper Cretaceous rocks in the Rock Springs Uplift and northern Green River Basin has been temporarily suspended until additional field work is completed.

NORTHERN GREAT PLAINS PROVINCE

Work continued on resource appraisal of natural gas in shallow, tight reservoirs of the Northern Great Plains.

Core is being solicited from operators from the Bowdoin Dome area in northcentral Montana and West Shore Pine Hills field in northwestern South Dakota.

Cation-exchange work on clays from Gammon Shale in southwestern North Dakota is progressing.

The paper, "Major gas resources in shallow, tight pays seen for Northern Great Plains," by D. D. Rice and G. W. Shurr was published in *Oil and Gas Journal*.

SCHEDULE STATUS

Figure 2-1 is a milestone chart depicting USGS WGSP progress.

CORE PROGRAM

Few operators were contacted concerning WGSP coring jobs. However, discussions were held with Coastal Oil and Gas Corpora-

Figure 2-1 Milestone Chart — USGS

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

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

Figure 2-1 Continued

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

Figure 2-1 Continued

tion concerning coring, logging, testing and fracturing a well with WGSP support in the Natural Buttes area in the Uinta Basin.

SURVEY OF BASIN ACTIVITIES

GREATER GREEN RIVER BASIN

Twelve completed wells were reported during the month: 4 development wells were producers, two development wells were D&A, and 6 wildcat wells were D&A. Total new initial potential flow was 4,676 MCFD, with the Frontier, Lewis and Almond horizons contributing.

Twenty new locations were staked by month's end: 13 development and 7 wildcat.

Table 2-1 is a summary of wells and new locations for the Greater Green River Basin, and Figure 2-2 shows their locations.

NORTHERN GREAT PLAINS PROVINCE

Twenty-five completed wells were reported during May for the province: 14 development wells were producers, 2 wildcats were discoveries, 1 development well and 7 wildcats were D&A, and 1 development well was completed shut-in.

A total 5,279 MCFD of potential new gas production was reported this month. The contributing horizons included the Eagle, Bowdoin, Phillips, Blackleaf and Bow Island. Twenty-six new locations were staked: 15 development and 11 wildcat.

Table 2-2 is a summary of wells and new locations from the province, and Figure 2-3 shows their locations.

PICEANCE BASIN

Reported activity was limited in this basin during May: 7 completed wells were re-

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

Table 2-1 Summary of Wells — Greater Green River Basin

OPERATOR	WELL NAME	MAP INDEX NO. ¹	LOCATION Sec/T/R	HORIZON ² ft	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Davis Oil	1 Seturn Unit	1	senw 27/13N/93W Wildcat Field Carbon Cnty, WY	Mesaverde 10,500	10,665		Wildcat well D&A, comp. 3-3-80. Drill stem tested; no cores.	
Wexpro	28-1 Lansdale- Federal	2	senw 28/19N/ 112W Bruff Field Lincoln Cnty, WY	Frontier 11,296- 11,318	11,450 PB: 11,385	201,800 gal gel, 460,000 lb sand.	Develop. well, comp. 11-15-79. Drill stem tested; no cores.	1,823
Getty Oil	14-2 McPherson Springs	3	nwn 14/13N/94W McPherson Springs Field Sweetwater Cnty, WY	Mesaverde 13,000			Wildcat deeper pool location, reported 5-15-80.	
Anadarko- Production	1 Black Mountain- Federal	4	swne 27/10N/90W Black Mountain Field Moffat Cnty, CO	Lewis 5,100			Develop. location, reported 5-23-80.

Figure 2-3 Northern Great Plains Province Showing Wells of Interest and USGS Designated Core Areas

Table 2-2 Summary of Wells – Northern Great Plains Province

OPERATOR	WELL NAME	MAP INDEX NO. ¹	LOCATION Sec/T/R	HORIZON ² ft	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
CIG Exploration	1 BN	1	sese 17/3N/45E Wildcat Field Custer Cnty, MT	Niobrara 3,850	4,496	Acidized 3 times w/ total 15,040 gal.	Wildcat well D&A, comp. 11-28-79. No cores or tests.	
Midlands Gas	1 Federal 1760	2	nese 17/36N/30E Unnamed Field Phillips Cnty, MT	Bowdoin 1,471-1,531	N/A	12,180 gal water, 40,000 lb sand.	Wildcat outpost extension, comp. 10-15-79. No cores or tests.	83
Canada Northwest Land	LTD 3-12 CNW Oils- Scarboro- AHC Cornwell	3	nenw 12/2N/42E Wildcat Field Rosebud Cnty, MT	Shannon 3,000			Wildcat location, reported 5-1-80.	
Brownlie, Wallace, Armstrong & Bander	9-22 Erickson	4	senw 9/154N/ 101W Wildcat Field Williams Cnty, ND	3,400 ft Cretaceous test			Wildcat location, reported 5-6-80.

Figure 2-4 Piceance Basin Showing Wells of Interest and USGS Designated Core Areas

Table 2-3 Summary of Wells – Piceance Basin

OPERATOR	WELL NAME	MAP INDEX NO. ¹	LOCATION Sec/T/R	HORIZON ² ft	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Coseka Resources	7-9-5-101 Harold S. Quick	1	nwse 9/5S/101W Trail Canyon Field Garfield Cnty, CO	Mancos B 4,035-4,072 (gross)	4,850 PB: 4,502	15,900 gal water, 40,500 lb sand.	Wildcat outpost extension, comp. 3-11-79. No cores or tests.	124
Chandler & Assoc.	2-17 Jenacaro	2	nwne 17/10S/96W Plateau Field Mesa Cnty, CO	Cozzette 3,034-3,040	3,460	Acidized twice w/ total 1,300 gal; fractured twice w/total 93,034 gal water, 239,000 lb sand.	Develop. well comp. 10-15-79. No cores or tests.	1,010
Wexpro Co.	8-1 MFS-Federal	3	nwse 8/2S/103W Lower Horse Draw Field Rio Blanco Cnty, CO	Mancos B 4,009-4,171 (gross)	4,325 PB: 4,275	Acidized w/ 1,000 gal; fractured w/ 69,000 gal gel, 232,000 lb sand.	Develop. well, comp. 1-30-80. No cores or tests.	847

Figure 2-5 Uinta Basin Showing Wells of Interest and USGS Designated Core Areas

Table 2-4 Summary of Wells — Uinta Basin

OPERATOR	WELL NAME	MAP INDEX NO.1	LOCATION Sec/T/R	HORIZON ² ft	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Belco Petroleum	45-25 Chapita Wells Unit	1	swse 25/9S/22E Natural Buttes Field Uintah Cnty, UT	Wasatch 5,893-7,374 (gross)	7,471	81,060 gal water, 184,000 lb sand.	Develop. well, comp. 1-22-80. No cores or tests.	2,250
Gas Producing Enterprises	36-Y CIGE	2	sene 30/9S/21E Natural Buttes Field Uintah Cnty, UT	Wasatch 5,538-6,846 (gross)	6,920 PB: 6,886	Acidized w/ 4,544 gal; fractured w/ 102,140 gal gel, 285,000 lb sand.	Develop. well, comp. 3-18-80. No cores or tests.	2,000
Cotton Petroleum	1-18 Love Unit-A	3	sesw 18/11S/22E Natural Buttes Field Uintah Cnty, UT	Mesaverde 6,400			Wildcat outpost location, reported 5-23-80.	

ported, with 6 development wells being producers and 1 wildcat a discovery. Total initial potential flow was 2,707 MCFD of new gas, with the Mancos B and Cozzette as the contributing horizons. Twenty-one new locations were staked by month's end: 20 development and 1 wildcat.

A summary of wells and new locations is in Table 2-3, and their locations are shown in Figure 2-4.

UINTA BASIN

Seven completed wells were reported during May, all of them development wells: 4 were producers, 1 was D&A, and 2 were completed shut-in. Initial new gas potential totaled 6,563 MCFD, with most of the gas being contributed by the Wasatch Formation. The Mesaverde Group undifferentiated also contributed a small portion to that figure.

Eight locations were staked during the month: 7 development and 1 wildcat.

Table 2-4 is a summary of wells and new locations for the basin, and their locations are shown in Figure 2-5.

CK GEOENERGY

During the month, CK GeoEnergy and Schlumberger reviewed the interpretation of the DOE-GC-1 corehole logs. Schlumberger will continue to make refined interpretations, which will be completed by early June.

Additional field work is required to tie in the Seismic International work. Also, the DOE-GC-1 corehole will be relogged to adequately tie in the borehole information.

GAS RESEARCH INSTITUTE

Work continued on the development of a matrix or information model to identify the state-of-the-art in tight gas sands tech-

nology as well as resource evaluation. A proposed matrix format has been developed and will be presented to the GRI Project Manager in June.

EVALUATION OF SEISMIC DATA FOR DETAILED STRATIGRAPHIC STUDIES OF LENTICULAR SANDS

All processing of the Bryson Canyon seismic data has been completed. A final report is in preparation and will be incorporated in the Annual Report.

SECONDARY BASIN STUDIES

A draft report has been prepared reviewing the geology of the potential tight gas areas in the Arkoma Basin and Ouachita Mountains Province of Oklahoma and Arkansas. Work on a geologic review of the Raton Basin of New Mexico and Colorado continued.

INFORMATION MANAGEMENT

An annual report is in preparation, covering all project activities during the period from project inception in early 1979 through March, 1980.

MULTI-WELL EXPERIMENT

Planning activities continued for the MWX, including:

- Designing modifications to the site personnel change room and core handling facility.
- Initiating action on obtaining equipment, structures and services for the experiment.
- Compiling data needed for a suitable design for three identical skid-mounted close-coupled (motor to pump) centrifugal pumps for operational use.

Figure 2-6 Milestone Chart – Multi-Well Experiment

- Advancing a multiplex system designed to operate a number of downhole instruments for the in situ stress measurements. This system will permit all or selected instruments to be monitored and/or controlled by computer with manual override.
- Discussing the MWX 2 well (stress well), that centered on the hardware systems to be fabricated to implement the perforations and mini-fractures made in the stress well. Two instrumentation systems will be available in the field for use in the production of these small fractures. One tool is a developmental assembly, which will combine perforation and fracturing operation hardware in a single assembly. The other will be an assembly which, while requiring separate trips in the well for perforation and for fracturing is somewhat simpler in concept.
- Revising and expanding the MWX network charts, including site selection, drilling and coring, core program, log program and stress testing.
- Revising core handling and processing procedures.
- Selecting core through portions of the Mesaverde Group from the USGS core library for a pilot study of paleomagnetism by Sierra Geophysics, Inc. This core included the major rock types (sand, shale, siltstone, transition rock) anticipated from the MWX wells. Information on magnetic signal strength and direction for these core samples has a potential use in orienting the core.

Figure 2-6 is the schedule status of the multi-well experiment.

SECTION 3

RESEARCH & DEVELOPMENT BY ENERGY TECHNOLOGY CENTERS & NATIONAL LABORATORIES

BARTLESVILLE ENERGY TECHNOLOGY CENTER

IN SITU PERMEABILITY

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

Liquid permeabilities for Core No. 6475.5 from the CIGE NBU No. 21 well, Uinta Basin, were measured. Liquid flow was maintained using a hydraulic cylinder and applying gas pressure on a piston which separated the gas from the liquid. A 2 percent KCl/2 percent NaCl brine was used as the flowing fluid. Differential pressures were maintained at approximately 80 psi. These permeability values were compared with the Klinkenberg permeabilities determined by gas flow measurements. The results are shown in Figure 3-1 as a plot of permeability versus net confining pressure. The figure shows that the liquid permeability values are consistently lower than the corresponding Klinkenberg at each net confining pressure. The ratio of the values remained approximately constant. Porosity was measured to be 0.102.

Pore volume compressibility of the core was measured by monitoring the amount of water displaced from the core as confining pressure increased. The decrease in pore volume was only 3.3 percent of initial pore volume when confining pressure increased to approximately

in situ values (20.7 MPa or 3,000 psi). Pore volume compressibility (expressed as change in pore volume per unit pore volume per megapascal) was $1.64 \times 10^{-3} \text{ (MPa)}^{-1}$. Porosity, determined by saturation, was 0.102.

These observations indicate that while permeability is a strong function of net confining pressure, porosity for the core investigated is not greatly affected.

Permeability of Interbedding Material of Tight Western Gas Sands — Lawrence Livermore Laboratories

The permeability system calibration was completed, and the first four samples were loaded into the pressure vessel and pressurized. A literature search was begun to determine the compressibility and viscosity of the pore fluid (Argon) at pressure (1-50 MPa) and temperature (20-350°C).

The literature search is scheduled to be completed by the end of June. A parameter study began of the permeability determination for use in data reduction. Permeability measurements will also be made at pressure (10-20 MPa) and ambient temperature.

LOGGING STUDIES

Interface Conductivity Effects on Electric Logging

Preliminary experiments have begun to determine cation exchange capacities (CEC) using a semi-automated method modified from one developed by A. E. Worthington¹. After exchange ions on rock samples are replaced with barium ions, the amount of barium on the clay is analyzed by conductometric titration with magnesium sulfate (MgSO_4). In addition to the forward titration, the feasibility of adding an excess amount of

¹ Worthington, A.E., *Geophysics*, Vol. 38, No. 1, 1973 pp. 140-153.

Figure 3-1 Comparison of Klinkenberg Permeability and Liquid Permeability

MgSO₄ and back titrating with barium ions will be investigated. The CEC of bentonite was measured to be .82 meq/g. The forward

and back titration of one sample gave the same value. This CEC compares with .711 meq/g from Worthington and .755 meq/g as measured in the lab using the ammonium acetate method.

A rather simplistic experiment has been conducted to see what effect the temperature may have on the cation exchange capacity (CEC) of clays. In the past, most CEC values have been measured at room temperature but applied at reservoir temperatures. A moderate variation of the CEC with temperature could significantly affect interpretation of electric logs in shaly formations. Due to the complexity of the cation exchange phenomenon, possible errors in the procedure used here have only allowed detection of + 50 percent change. From 23° C to 73° C, no difference has been seen within this error limit. One problem is that the clay must be maintained in a relatively high brine concentration to ensure cation saturation. Also, it cannot be assumed that standard techniques applicable at room temperature will apply at elevated temperature. These problems must be overcome to better evaluate the temperature dependence of the cation exchange capacity.

A sample from a Uinta Basin well was used as an initial test sample to measure liquid permeability and electrical conductivity of tight gas core material as a function of overburden pressure. Permeability decreased as expected with increased overburden pressure. However, conductivity increased rather than decreased as expected. Several changes in core preparation and experimental procedures have been proposed to solve this problem. Testing of these procedures will begin in June with each sample requiring about two weeks to complete.

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

Shell Oil Company and Conoco will assist in obtaining produced waters in the Uinta Basin area. Western contacts were also established with Amoco, Exxon and Tenneco, none of which have any production from the Upper Cretaceous formations in the Uinta Basin. Texaco is a gas producer, but none of their wells produce water.

Measurements will begin in June, with the resistivities of produced waters measured as obtained.

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

Porosity, matrix densities and bulk densities have been calculated and recorded (Table 3-1) for the samples to be used in the travel-time experiments.

The Mitchell No. 1 Muse-Duke samples have very little porosity and an almost constant matrix density. The PTS No. 24-19 Federal samples have a wider range of porosities and a seemingly variable matrix density. Density logs from the Mitchell No. 1 Muse-Duke well could be easily interpreted using a constant matrix density of 2.69 gm/cc. Further work is needed to best determine how to analyze the logs from the PTS No. 24-19 Federal well.

The densities measured on the CIGE No. 21 samples are in accord with the results obtained from other CIGE core sections. The lower porosity samples have a matrix density of 2.66 gm/cc or greater. The higher porosity samples have a matrix density of 2.65 gm/cc or less.

Table 3-1 Laboratory Measured Densities

	Sample No.	Porosity, Percent	Bulk Density, gm/cc	Matrix Density, gm/cc
CIGE No. 21	A12	3.2	2.60	2.66
	A48	10.9	2.46	2.64
	A41	9.8	2.47	2.63
	A47	7.3	2.53	2.65
	A6	4.4	2.59	2.67
	A25	7.7	2.57	2.69
	A39	10.3	2.46	2.63
PTS No. 24-19 Federal	P1	12.4	2.42	2.62
	P2	11.9	2.49	2.69
	P3	5.6	2.55	2.64
	P4	13.6	2.44	2.67
	P5	13.4	2.44	2.66
	P6	14.1	2.42	2.68
Mitchell No. 1 Muse-Duke	M1	2.4	2.64	2.68
	M2	2.8	2.64	2.69
	M3	2.5	2.65	2.69
	M4	1.7	2.67	2.69
	M5	2.0	2.66	2.69
	M6	2.1	2.66	2.69
	M7	1.8	2.67	2.71
	M8	2.3	2.72	2.76
	M9	2.3	2.65	2.69
	M10	1.8	2.66	2.69

USGS has studied thin sections of 38 Mesa-verde samples from the Shell No. 7, Southman Canyon Field in the Uinta Basin. This well is approximately seven miles east of the CIGE No. 21 well and about 500 ft up-structure. Their findings verify the data already collected on the CIGE No. 21.

An observation that should help log interpretation is the shale-sand contacts appear to be more heavily cemented than other areas within the particular sand body. This is illustrated in Figure 3-2, showing a section of the density log from CIGE No. 21. A well-developed sand body is located between 4,545 ft and 4,590 ft (as defined by the gamma ray section). Zones A and B indicate the increased bulk densities are due to the increased carbonate which occurs at shale-sand contacts. Zone C represents a thin shale section that appreciably alters the bulk density of the surrounding sand. Normally shales are expected to decrease the bulk density readings; here the bulk density increased. Normal logging techniques would interpret the high bulk densities of Zones A, B and C to have a lower porosity than the rest of the sand body. Figure 3-3 illustrates that the presence of carbonate controls the matrix density of the formation. Shale-sand contacts have more carbonate present, thereby causing the matrix density to be greater, which reads as a larger bulk density on the log. Thus, the causes of the density changes in Zones A, B and C have been identified, but a sure method of correctly calculating porosity is not yet available.

ADVANCED LOGGING TECHNIQUES AND INTERPRETATIONS

Dielectric Constant Measurement for Formation Evaluation

Work continued on the interaction of capacitance and conductance in the dielectric constant measurement system. It was decided to eliminate the distributed transmission line correction which was required by the sample

holder. The sample holder was modified so the terminals of the measurement system were directly connected to the sample electrodes. The modified measurement system was tested on artificial samples. Results were accurate to ± 2 percent for 500 kHz to 20 MHz and ± 5 percent for 30 MHz. The data measurements are reliable enough that a calibration curve can be used to achieve increased accuracy. Work on a calibration curve will continue in June.

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

Theoretical analysis of velocities around a borehole in a stressed medium is in progress.

A preliminary comparison of three measurement approaches was completed: continuous wave phase matching and interference techniques will be pursued and natural resonance techniques will not.

Development and Application of a Wide Band Laboratory Dielectric Constant Measurement System — Colorado School of Mines

Dielectric constant measurements have been made at low frequencies (500 to 10 kHz) on 20 low-loss rock samples. Construction and testing has been completed on the saturation chamber and sample holder unit. Sandstone samples are now being ground to proper thickness for the holder. A review of the induction heating procedure to be used in the high frequency dielectric measurement method is being compiled.

ROCK-FLUID INTERACTION

Proppant Embedment Studies

To establish a standard, work began on the embedment of sintered bauxite into berea sandstone. Replicate experiments with 12-20 mesh proppant have shown that the initial

Figure 3-2 Log Section from CIGE NBU No. 21

Figure 3-3 Matrix Density vs Percent Carbonate
CIGE NBU No. 21

embedment (from 0 to 1,500 psi) is quite variable. This is probably due to the relatively small number of large proppant (0.6 percent of 12-14 mesh) in a sample. Consequently, unless the proppant is sorted by size and a sample is reconstructed in the exact quantity needed for each experiment, the random differences in grain distribution from one sample to the next will lead to variable percentages of the largest proppant. To overcome this problem, results were averaged from several identical experiments.

Embedment in one area of the berea block may be greater than some other area (differential embedment) due to variations in rock hardness or random differences in the proppant size distribution. The new method for measuring embedment has allowed the differential embedment to be estimated. Occasionally, large differences have been noticed. Results from these experiments are discarded since they would not be representative of reservoir conditions where the two rock faces must be held basically parallel.

Simulated Fracture Conductivity

A long-term stressed-proppant experiment was completed during May. A 2 percent KCl solution was continuously injected at a constant rate of 2 mls per minute into a simulated fracture between tight core halves packed with 40-60 mesh sand and subjected to a constant 5,000 psig overburden pressure. Effluent particle-liquid samples were collected periodically for analysis with a Model TA II Coulter Particle Counter. Samples collected were analyzed to determine their particle concentrations for the first 72 hours of the experiment.

It appeared that a large number of particles were created initially upon overburden pressure application. The number of particles per unit volume found in the effluent increased rapidly within the first few hours of the experiment, peaked and dropped off after the first 24 hours. After 48 hours particle concentration was down to 1/3 of the peak

concentration. The curve shape of a plot of particle concentration vs time indicates most of the particles were created initially as overburden pressure was applied.

RESERVOIR SIMULATION STUDIES

Parametric Analysis of MHF Test Data: An Engineering Study of Western Gas Sands

Further study was conducted during the month of the uniqueness of reservoir and fracture parameters obtained from pressure transient analysis. Work also centered on the effect of fracture skin and wellbore storage on the pressure responses of wells.

The base case model used in the first uniqueness study consisted of two ten-ft producing zones with 5 percent hydrocarbon porosity and .10 md permeability. The top zone contained a fracture with a half-length of 100 ft and fracture conductivity of 1.57×10^3 md-ft. The bottom zone contained a 40-ft fracture with the same fracture conductivity. A match of the pressure transient response of the two-layer model was obtained with a model having a single 20-ft producing zone with .097 md permeability, 5 percent hydrocarbon porosity, and a single fracture with half-length equal to 76 ft and fracture conductivity equal to the base case. Drawdown and build-up curves of the two cases show agreement is very good with only slight discrepancies noted in the middle portions. A comparison of the production forecasts for the two models also shows very close agreement.

The second study used a base case model also containing two 10-ft zones with 5 percent hydrocarbon porosity. The upper zone had a permeability of .10 md and a single fracture with half-length of 100 ft and a fracture conductivity of 1.57×10^3 md-ft. The lower zone had a permeability of .05 md and a single fracture with half-length of 40 ft and a fracture conductivity of 6.3×10^2 md-ft. A match of the two-layer pressure transient

response was obtained with a single 20-ft zone with .0755 md permeability, 5 percent hydrocarbon porosity, and a fracture with a half-length of 76 ft and fracture conductivity of 1.57×10^3 md-ft. Drawdown and build-up curves of the two cases show good agreement of the pressure response and production forecast curves.

An additional study was performed using the single layer model from the second uniqueness study to see if the production history could be matched with a model having enhanced permeability around the wellbore instead of a fracture. Cinco, Samaniego and Dominguez presented in their article on "Transient Pressure Behavior for a Well with a Finite-Conductivity Vertical Fracture" published in the August, 1978 SPE Journal, a relationship for a pseudo-skin factor for a well having a finite-conductivity fracture. A figure in the article showed a graph of $(s_f + 1.1 \ln x_f/r_w)$ vs $(W_f D K_f D)$. The fracture and reservoir characteristics used in the model placed it on the flat part of the curve where the quantity $(s_f + 1.1 \ln x_f/r_w)$ was approximately equal to .70. Using the following equation:

$$s_f = \left(\frac{k}{k_s} - 1 \right) 1.1 \ln \frac{r_s}{r_w}$$

and substituting values of r_s and solving for k_s , it was found that a negative skin factor of 4.75 would approximate the fractured well model.

Figure 3-4 shows a plot of the production forecasts from the fractured model and the enhanced permeability model. The forecasts of the two models are relatively close in early years but deviate in later years. This comparison shows that a fractured well could be simulated by a non-fractured well model if the simulation were based on the early production history.

The effects of fracture skin and wellbore storage on the pressure transient responses of a single layer model were also studied during the month. Figures 3-5 and 3-6 show

the effect of fracture skin, "s", on the drawdown and build-up curves of a model having a 20-ft producing zone with .1 md permeability, 5 percent hydrocarbon porosity, and a single fracture of 100-ft half-length and fracture conductivity of 1.57×10^3 md-ft. As shown, the fracture skin greatly affects the drawdown curves but has no effect on the build-up curves. Wellbore storage was introduced into the model having a fracture skin of 1.0. It can be seen that wellbore storage changes the shape of the early portion of both the drawdown and build-up curves but the curves become concurrent later in time. Figures 3-7 and 3-8 show the pressure responses, on an expanded scale, of the model with a fracture skin of .10, with and without wellbore storage. It can be seen that the effect of wellbore storage becomes less noticable as the skin factor decreases. Figures 3-9 and 3-10 show the effect of wellbore storage on the single layer model having a fracture skin of .10, but having a lower formation permeability of .05 md. The effect of wellbore storage increases in the lower permeability reservoir as expected.

In the future, a two-phase simulation model will be used to study the effect of fracture face damage on well performance.

SCHEDULE STATUS

Figure 3-11 is the status of BETC projects in the WGSP.

LAWRENCE LIVERMORE LABORATORY

THEORETICAL ANALYSIS

Calculations continued of fracturing near interfaces to quantify the effects of existing cracks near well bonded interfaces. Effects of friction along interfaces and penetration of frictional interfaces are also being analyzed. The effects of existing cracks near well bonded interfaces have been the subject of previous analyses where a pressurized fracture

Figure 3-4 Production Forecast

Figure 3-5 Effect of Fracture Skin on Drawdown with 0.1 md Permeability

Figure 3-6 Effect of Fracture Skin on Build-up with 0.1 md Permeability

Figure 3-7 Effect of Wellbore Storage on Drawdown with Fracture Skin of 0.1 md and 0.1 md Permeability

Figure 3-8 Effect of Wellbore Storage on Build-up with Fracture Skin of 0.1 md and 0.1 md Permeability

Figure 3-9 Effect of Wellbore Storage on Drawdown with Skin Factor of 0.1 md and 0.05 md Permeability

Figure 3-10 Effect of Wellbore Storage on Build-up with Skin Factor of 0.1 and 0.05 md Permeability

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

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

Figure 3-11 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												
Evaluation of Particle Transport in Proppant Beds												
Evaluation of Proppant Embedment in Tight Gas Sands												
Study of Proppant Settling												
Light Weight Proppant Feasibility Study												

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

Figure 3-11 Continued

is propagating in a lower modulus material toward an interface with a higher modulus material. Those results showed that a possible barrier effect to the propagation of a pressurized fracture is reduced by existing fractures in the higher modulus material. Presently, a set of calculations is being completed where the pressurized fracture is propagating in a higher modulus material toward and through an interface with a lower modulus material. The concentration is on the effects of existing fractures across the interface in the lower modulus material, where previous findings² need to be verified.

Figure 3-12 shows the geometry of the problems analyzed. In these calculations, the modulus E_1 was equal to $2E_2$ and Poisson's ratio for the material on both sides of the interface was equal to $1/4$. Three separate cases were analyzed for comparison and to determine if existing cracks significantly alter the results obtained as opposed to when there are no existing cracks (Case I).

Case I, which is not shown in Figure 3-12, has the same geometry for the pressurized crack and the interface as in Case II and III, but does not contain any existing cracks. Figure 3-13 shows the results of the calculation in terms of the normalized stress intensity factor $\bar{K}_I$ and δ is the distance of the crack tip from the interface normalized with respect to the pressurized fracture length $2a$. The stress intensity factor $\bar{K}_I$ has been normalized by the stress intensity factor for a pressurized crack in an infinite, isotropic medium, $P\sqrt{a}$, where P is the pressure (constant) in the crack and a is the crack half length. The stress intensity factor increases as the fracture approaches the interface from the left, which means that the fracture would be drawn toward the interface. The existing cracks across the interface, Cases II and III, tend to result in a slight increase in the stress intensity as the crack approaches the interface. Cases II and III produce approximately the same results as the pressurized crack approaches the

interfaces, but did not appreciably change the results in this region. In Case I, as the crack propagates through the interface to the higher modulus material on the right side, the critical stress intensity factor is significantly reduced. This shows that the tendency to break is reduced and hence propagation will not be as likely if the critical breakage characteristics are similar. A curve for Case II is not shown on the right side of the interface because as the crack extends, it propagates into the existing crack and follows the curve for Case I. Case III is more complicated but the magnitude is comparable to Case I. Hence, the effect of existing fractures near an interface does not significantly change the results obtained as when no existing fractures are present.

In these results, only the rock mechanics related to fracturing across well bonded interfaces are considered, not how changes in mechanical properties affect the in situ stress field. Stress field variations due to changes in mechanical properties may dominate fracture propagation in the neighborhood of interfaces and is the subject of future research.

LABORATORY EXPERIMENTS

During the past month, experiments have continued in which pressurized fluid is driven between loaded interfaces in PMMA. The preliminary experimental design has not been satisfactory because when the fluid is pumped through the PMMA block, it has repeatedly fractured prior to significant growth of the fluid ring. A more viscous fluid is required for this type of experiment compared to the fracture fluid used in the conventional hydrofracture experiments.

A set of Brazil tests for measurement of tensile strength of Mesaverde shale from Wyoming has been completed. Work has begun to study the failure envelope of this material under tri-axial compression.

SCHEDULE STATUS

A milestone chart, depicting LLL's progress within the WGSP, is in Figure 3-14.

² Hanson, M. E., G. D. Anderson and R. J. Shaffer, Effects of Various Parameters on Hydraulic Fracture Geometry, LLNL, Report UCRL-83784 (1980).

Figure 3-12 Geometries for the Calculations Containing Interfaces and Existing Cracks

Figure 3-13 Stress Intensity Factor for Fractures Approaching an Interface

Figure 3-14 Milestone Chart — LLL

LOS ALAMOS SCIENTIFIC LABORATORY

Activities in instrument development were focused on the construction of a permanent magnet system. A new mount was constructed of non-magnetic materials for the permanent magnet pair. The mount clamps the lower magnet in place while the upper magnet is held in a gimbal, permitting fine adjustments so the projected magnetic field can be optimized. Magnetic field mapping along the horizontal plane between the two magnets indicates that this new mount will be adequate for the next series of experiments. A digital pulsed spectrometer and a high powered RF transmitter will improve the signal-to-noise ratio of subsequent measurements.

Other studies this month have concentrated on defining the pore size distribution within tight gas sands core samples. This is necessary since the proton resonance relaxation time might be an indication of the pore size distribution.

Figure 3-15 shows the schedule status of LASL progress.

SANDIA LABORATORIES

HYDRAULIC FRACTURE CHARACTERIZATION

A first step analysis of the surface electrical potential system (SEPS) data (reported in April Status Report) required new software, which used the digitized analog pulse data files as if they were real-time. The fracture event can be re-run in several ways. During the Shell Unit No. 343 fracture experiment, one calibrate and four analog pulse data files were written. Two of these files were used in the first step analysis. The remaining two files are still under analysis. Other approaches to data analysis, such as the potential gradient between Radius 1 and 2, are also being considered.

Modifications to the seismic analysis program, which will allow corrections for vertical angle to the Shell Big Mineral Creek data, are nearly complete. All design changes to the new seismic hardware have been completed. Leaks in the clamp package have caused problems in the past, but it has been determined that the leaks are due to a faulty seal in the arm shaft. This will be repaired.

Two downhole hydrophone systems, one using the Edo Western transducers and the other using the ITC transducers, have undergone a series of tests in the Sandia WHIPP No. 13 borehole at Carlsbad, New Mexico. The tests included a vibrator which produced cw audio signals at the surface from 30 Hz to 120 Hz and a series of surface explosive shots at distances of approximately 100 ft to 500 ft from the borehole. Data was collected using both systems at depths of 730 ft, 830 ft, 1,800 ft and 3,200 ft from the surface. In addition, data was collected in the vibrator tests at 10-ft intervals from 1,650 ft to 1,850 ft.

Analysis of the explosive shot data indicates that a difference is discernible in arrival times to the transducers and that determining the shot location is feasible. However, the accuracy of locating the shot position has not as yet been determined.

For the cw vibrator data, analysis indicates that multiple signal paths to the hydrophone transducers do exist. Codes have been developed that determine the phase difference between the audio signals received by two downhole hydrophones and plot this difference versus frequency from 30 Hz to 120 Hz. A comparison of this phase difference with theoretical models, which considers the various paths taken by the surface generated signal, should help in determining the formation velocity.

A downhole tool which has four hydrophone transducers located at the same depth in a borehole has been designed and fabricated

Figure 3-15 Milestone Chart — LASL

for testing. This should yield information on variation in phase of a received cw audio signal between transducers.

BOREHOLE RESISTIVITY SYSTEM

The study of the one-dimensional forward problem has been completed. The effect of finite current injecting electrode dimensions has been quantitatively ascertained by solving the mixed boundary value problem which mathematically represents the band electrode configuration exactly. The physical model is a cylindrical insulating probe of infinite length with a finite length current injecting band electrode at its center. The probe radius is 0.0381 meters with the electrode half length also 0.0381 meters. The probe was assumed to be immersed in a homogeneous space of 1 ohm/m conductivity with 1 ampere of current being injected at the electrode. Figure 3-16 shows the resulting potential along the surface of the probe as a function of distance from the center of the current injecting electrode. Both the exact solution to the mixed boundary value problem and the uniform current density approximation (on the current injecting electrode) are given. The potential resulting from a point current source is also given. The predicted potentials agree closely for the uniform current density approximation and the solution to the mixed boundary value problem for distances greater than 0.12 meters. (Note: the roughness of the mixed boundary value curve results from the integration routine used to obtain potentials. This particular integration routine is an adaptive routine which is not well-suited to the integration of oscillatory integrands.)

The discrepancy of the point source approximation is more significant. The first potential measurement point on the probe will be located at least 0.2 meters away from the current electrode. Therefore, the uniform current density approximation affords suitable accuracy for modeling the potential on all electrodes except the current injecting electrode. Figure 3-17 shows the corresponding apparent resistivity curves. Note that the mixed boundary value problem solution can

also be found when the material surrounding the probe is radially inhomogeneous. However, since the borehole fluid is presumed to be homogeneous, variations outside of this zone will probably only result in small differences in the mixed boundary value problem solution from that presented.

Figure 3-18 shows the uniform current density and point source approximations on a different length scale. The difference between these curves results from the finite versus zero electrode dimensions and from the absence of the insulating probe in the point source approximation. When a borehole region is present (surrounding the probe), the presence of the insulating probe would be expected to be more significant. This results from current being focused in the annular region of the conductive borehole fluid with the probe present versus current being focused into the entire borehole region in the absence of the probe. Figure 3-19 shows the apparent resistivity curves for the uniform current density approximation along with the point source approximation when a borehole region is present. In the uniform current density approximation, the current injecting electrode also had a half length of 0.0381 meters with a probe radius of 0.0381 meters.

One ampere of current was injected in both cases and the borehole fluid conductivity was 1 ohm/m with the homogeneous formation conductivity equal to 0.05 ohm/m. The borehole radius was 0.0762 meters. To be noted: the difference in apparent resistivity extended out to 4 meters. Thus, in this instance, the presence of the insulating probe is of considerable importance in modeling apparent resistivities out to large distances.

Although not shown in Figure 3-19, a 0.001 meter radius probe was also used. This thin probe gave essentially the same potentials as the point source approximation, thus, confirming the fact that finite electrode length is not the significant factor in explaining the difference in apparent resistivities (shown in Figure 3-19).

Figure 3-16 Potential Along Surface of Probe

Figure 3-17 Corresponding Apparent Resistivity Curves of Figure 3-16

Figure 3-18 Uniform Current Density and Point Source Approximation

Figure 3-19 Apparent Resistivity Curves for Uniform Current Density Approximation

HIGH RESOLUTION SEISMIC FORMATION MAPPING

Results of the 3-D seismic reflection survey at the Bryson Canyon site were presented to DOE, CER Corporation and CK GeoEnergy. Included in the discussion were the results from the synthetic model study, comparison of model results with observed field data and an interpretation of the survey data.

Figures 3-20 and 3-21 review the typical results of modeling a sandstone channel. The reflection response is characterized by the divergent upper surface reflection and the convergent lower surface reflection, the peak-to-peak thickening over the central lense section and by the distortion of deeper continuous horizons. Figure 3-22 shows a sample of a two-dimensional, vertical slice of the actual field data. A reflection response showing similar characteristics to the model response is indicated. This and other channel-like responses may be followed from this section to others across the site; in this way the channels may be mapped. An alternate way of viewing the data is a three-dimensional time slice where the data presented are sliced horizontally at a given value of reflection time. A gray scale represents the peaks and troughs of the seismic data in this format. Figure 3-23 shows a time slice at 0.128 second. The unit labeled "C2" in the figure represents a channel trending to the upper right of the figure. The data from additional slices also show components of dip to the left and bottom which explains why the entire channel does not show on this single time slice. Projecting the trends and calculated dips of several different channel responses to the outcrop area at this site, candidate channels are found at those locations.

Although total agreement has not been achieved with geologic observations, the seismic interpretations are encouraging enough to merit continuation of this program. In that regard, it was suggested and approved at the meeting that experimental site No. 2 (Horse Canyon Gas Field) be deleted from the program plan and the

seismic survey be transferred to the site of the upcoming multi-well experiment.

A detailed report on both the seismic modeling and field data acquisition/interpretation is now being prepared.

ELECTROMAGNETIC LOGGING

Laboratory Investigations

Previous reports have discussed the usefulness of experimentation on synthetic rocks, i.e., samples prepared in the laboratory to simulate rock properties such as pore geometry and fluid flow. A program has begun at Sandia to attempt to produce such samples. In preliminary experiments, 40- μ m and 1.5-mm diameter spheres were placed in ceramic molds and heated at 800°C for one hour. The small spheres produced a consolidated sample but the large spheres gave a friable sample indicating that identical preparation methods cannot be used for different sphere sizes.

A more thorough procedure using only the small sphere size will be implemented. Large diameter (up to 2 in.) samples will be made from the spheres at several temperatures. Then several smaller samples will be cored from the large sample and a surface area analysis will be done. This will not only provide surface area data, but will also give an average pore size distribution and the connected volume porosity. By taking several small samples from the large one, the homogeneity of the large sample can be determined. If it is possible to produce a homogeneous sample, the next step would be to check the procedure to see if a reproducible porosity can be obtained.

Sonde Modeling

The analytical solutions for homogeneous and two-zone cases have been computed this month for low-frequency (20 kHz and 2

Figure 3-22 Two-dimensional Record Section taken at Bryson Canyon Site

$T = 0.128 \text{ sec}$

*Figure 3-23 Three-dimensional Time Slice at $T=0.128 \text{ sec}$.
(Area labeled "C2" is interpreted as a channel.)*

MHz) interrogations. Results were run to provide comparisons with those being obtained through the finite-difference-equation approach. For 20 kHz coupling with two coils spaced less than 3 coil-diameters, the results of two approaches agree to less than 1 percent of correct values. However, results for large coil springs and higher frequencies by the finite-difference-equation approach have not become available.

Results are expected next month for the four-zone case programming.

SCHEDULE STATUS

Figure 3-24 is a milestone chart showing Sandia's WGSP progress.

Figure 3-24 Milestone Chart — Sandia Laboratories

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

Figure 3-24 Continued

SECTION 4

FIELD TESTS & DEMONSTRATIONS

BACKGROUND

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

- a dry gas injection experiment in the Wattenberg Field, Colorado, by Colorado Interstate Gas Company,
- MHF demonstrations by Gas Producing Enterprises in the Uinta Basin, Utah,
- MHF treatment of the Cotton Valley Limestone Formation in Limestone County, Texas, by Mitchell Energy Corporation, and
- a mineback testing program by Sandia Laboratories.

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

Table 4-1 MHF Contract Location and Frac Data

Company Basin & Formation	Location T/R/Sec	Well	Interval Fractured ft	Fracture Date	Fracture Treatment Lb of Sand	Injected Fluid 10 ³ Gal	Production Rates MCFD		Ratio
							Before	After	
AUSTRAL Piceance, Mesaverde	7S/94W/Sec 3 Garfield Cty, Colorado	Federal 3-94	6,198-6,333	8-13-76	420,000	226 Gel	35	62	1.8
			5,170-5,630	8-25-76	720,000	316 Gel			
CONSORTIUM MANAGED BY CER CORPORATION Piceance, Mesaverde	3S/98W/Sec 11 Rio Blanco Cty, Colorado	RB-MHF-3	8,048-8,078	10-23-74	400,000	117 Gel	60	60	—
			7,760-7,864	05-02-75	880,000	285 Gel	—	40	—
			5,925-6,016	04-04-76	815,000	400 Gel	42	160	3.8
			5,851-5,869	11-03-76	448,000	228 Gel	57	70	1.2
DALLAS PRODUCTION Fort Worth, Bend Cong.	Ben D. Smith Survey A-779 Wise Cty, Texas	Ferguson A-1	5,957-6,794	09-16-76	506,000	139 Foam 198 Emul	40	15	—
EL PASO NATURAL GAS Northern Green River, Fort Union	30N/108W/Sec 5 Sublette Cty, Wyoming	Pinedale Unit No. 5	10,950-11,180	07-02-75	518,000	183 Emul 8 Gel	150	340	2.3
			10,120-10,790	10-20-75	1,422,000	459 Gel	—	150	—
GAS PRODUCING ENTERPRISES, INC. Uinta, Wasatch and Mesaverde	10S/22E/Sec 10 Uintah Cty, Utah	Natural Buttes No. 18	6,490-8,952	09-22-76	1,480,000	745 Gel	—	1,400	—
	10S/21E/Sec 21 Uintah Cty, Utah	Natural Buttes No. 19	8,909-9,664 7,224-8,676	09-21-76 09-28-76	424,000 784,000	280 Gel 364 Gel	—	166	—
	9S/21E/Sec 22 Uintah Cty, Utah	Natural Buttes No. 14	6,646-8,004	03-15-77	1,093,000	544 Gel	38	800	21.0
	9S/21E/Sec 28 Uintah Cty, Utah	Natural Buttes No. 20	8,498-9,476	06-22-77	826,000	322 Gel	75	1,200	16.0
	10S/22E/Sec 18 Uintah Cty, Utah	Natural Buttes No. 22	6,838-8,550	11-21-77	1,151,000	499 Gel	—	700	—
	9S/22E/Sec 19 Uintah Cty, Utah	Natural Buttes No. 9	5,661-8,934	03-27-78	554,000	349 Gel	140	540	3.9
	10S/21E/Sec 29 Uintah Cty, Utah	CIGE No. 2	9,237-9,653 7,251-8,774	06-22-78 08-08-78	170,500 1,965,000	203 Gel 722 Gel	— —	Water Water	— —
	10S/22E/Sec 7 Uintah Cty, Utah	Natural Buttes No. 23	5,080-6,294	10-04-78	470,000	240 Gel	—	800	—
MITCHELL ENERGY Cotton Valley, Limestone Trend	Limestone Cty, Texas	Muse-Duke No. 1	11,235-11,418	11-15-78	2,800,000	891 Gel	2,000	6,600	3.3
MOBIL Piceance, Mesaverde	2S/97W/Sec 13 Rio Blanco Cty, Colorado	F31-13G	10,549-10,680	06-22-77	580,000	316 Gel	300	800	2.7
			9,392-9,538	08-24-77	600,000	260 Gel	700	2,600	3.7
			8,765-8,972	05-10-78	388,000	150 Gel	479	430	—
			8,163-8,650	07-06-78	660,000	288 Gel	—	360	—
			7,704-7,794	09-07-78	218,000	120 Gel	—	180	—
			7,324-7,476	11-15-78	700,000	365 Gel	1,000	2,000	2.0
PACIFIC TRANSMISSION Uinta, Mesaverde	8S/23E/Sec 25 Uintah Cty, Utah	Federal 23-25	NO FRACTURES PERFORMED						
RIO BLANCO NATURAL GAS Piceance, Mesaverde	4S/98W/Sec 4 Rio Blanco Cty, Colorado	Federal 498-4-1	6,150-6,312	10-22-76	766,000	276 Gel	57	130	2.3
			5,376-5,960	11-30-77	243,000+ 22,500 Beads	164 Gel	80	350	4.4
WESTCO Uinta, Mesaverde	10S/19E/Sec 34 Uintah Cty, Utah	Home Fed. No. 1	10,014-10,202	12-21-76	500,000	248 Gel	33	155	4.7
			7,826-9,437	10-01-76	600,000	412 Gel	40	Water	—

WATTENBERG FIELD

DE-AC08-77ET12046

Colorado Interstate Gas Company
Colorado Springs, Colorado
Status: Active

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

Total Project Cost (estimated):	DOE	\$ 75,000
	CIG	\$355,495
	Total	\$430,495

Principal Investigator: David Wilson
Technical Project Officer for DOE: C. H. Atkinson

OBJECTIVE

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

COLORADO INTERSTATE GAS COMPANY

Production from Sprague No. 1 well and injection into the Miller No. 1 well began May 7 and continued until May 15. The direction of the cycle was reversed and production from the Miller and injection into the Sprague started May 15 and will continue into June. This longer than normal cycle is an attempt to inject as much gas as possible into the Sprague. However, the three-week cycle might use too much make-up gas so

there could be a return to the two-week schedule. The injection and production cycles and the new ethylene glycol dehydrators are working well. The water content of the gas being injected remains a constant 3.5 lb of water per MMCF.

Figure 4-1 illustrates production and injection and associated pressures of these wells.

Figure 4-1 Production and Injection Volumes and Associated Pressures of CIG Miller No. 1 and Sprague No. 1 Wells

**DOE WELL
TEST FACILITY**

DE-AC08-79-BGO1569

CER Corporation
Las Vegas, Nevada

Status: Operational

Principal Investigator:
Technical Advisor for DOE:

R. L. Mann
C. H. Atkinson

OBJECTIVE

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

DOE WELL TEST FACILITY

Bottom-hole pressure data gathered from the CIG Miller No. 1 well, Wattenberg Field, Colorado, is being analyzed. From the preliminary results derived from the linear analysis, improvement of the zone surround-

ing the fracture appears to be substantial.

The instrumentation trailer and 30 kw generator were transported to Las Vegas during the month for repairs and modifications.

**NATURAL BUTTES
UINTAH COUNTY, UTAH**

DE-AC08-76 ET 12060

**Massive Hydraulic Fracturing
Demonstration**

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

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

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

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

OBJECTIVE

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

GAS PRODUCING ENTERPRISES

During May, GPE Natural Buttes Unit Nos. 9, 14, 18, 19 and 20 flowed to sales a total 43,617 MCF. NBU Nos. 21 and 22 were shut in. The production histories of these wells are

shown in Figures 4-2 through 4-7.

A final report is in preparation.

Figure 4-4 Flow Rate Performance of Natural Buttes No. 18 Well

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

Figure 4-6 Flow Rate Performance of Natural Buttes No. 20 Well

Figure 4-7 Flow Rate Performance of Natural Buttes No. 22 Well

**FALLON-NORTH
PERSONVILLE FIELD, TEXAS**

DE-AC08-78ET12150

**Massive Hydraulic Fracturing
Demonstration**

Mitchell Energy Corporation
Houston, Texas

Status: Active

Contract Date:

March 15, 1978

Anticipated Completion:

Project completed, waiting on final report.

Total Project Cost (estimated):

DOE \$ 553,771

Industry 1,074,550

Total \$1,628,321

Principal Investigator:

F. D. Covey

Technical Project Officer for DOE:

C. H. Atkinson

OBJECTIVE

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

MITCHELL ENERGY CORPORATION

A draft of the final report is expected in August.

**NEVADA TEST SITE
NYE COUNTY, NEVADA**

Mineback Testing

Sandia Laboratories
Albuquerque, New Mexico
Status: Active

Principal Investigator:

D. A. Northrop

OBJECTIVE

To develop an understanding of the fracturing process for stimulation and thereby improve the production of natural gas from low-permeability reservoirs. This will be accomplished by conducting controlled fracture experiments which are accessible by mineback for direct observation and evaluation.

SANDIA MINEBACK

HYDRAULIC FRACTURING

Hole No. 6 Formation Interface Fracture Experiment

The data from the exploratory coring program and the mineback have been used to draw width contours of the combined Hole No. 6 fractures, as shown in Figure 4-8. The observed fractures are of relatively uniform width in the center, and they rapidly taper to zero near the crack tip. In fact, the contour through section A-A', which runs through the mineback region and has the most abundant width data near the fracture tip, shows the steepest tapering at the fracture tip. Because there is limited data in most other areas, the contouring routine probably smooths out the steep gradients probably existing on all edges of the fracture. The width data through section A-A' are shown in Figure 4-9. The relatively flat center and steep gradients at the tip are obvious here, with the fracture width varying so markedly in the center. However, this may be associated with the stranding that is observed throughout the fracture. An effort is underway to separate the different colored grout components of the fracture and to obtain width contours.

Fluid Mechanics/Proppant Transport Experiments

The important fluid mechanics processes associated with fracturing can be broadly divided into two categories. The first is

basic phenomena, such as the pressure distribution. Experiments to measure pressure and width at various locations in a fracture during propagation are being planned. The second area is proppant transport and the resultant conductivity.

Two types of instrumentation packages are being designed for these experiments. The first is a displacement transducer/pressure transducer package which will be used to measure the width and pressure at various locations in a fracture. The second is a fracture detection device which will be emplaced ahead of the fracture so that the length of the fracture as a function of time can be correlated with width and pressure data.

A site for these experiments is ready and an evaluation of the in situ stress magnitudes and orientation will be conducted in June or July.

In Situ Stress Measurement by Hydraulic Fracturing Through Perforations

The initial experiments conducted in G-tunnel (reported in the April Status Report) to compare fracturing through perforations to an open hole fracturing were inconclusive due to poor perforations. A second hole, PERF 2, is planned for the same area, and the experiment will be conducted with stronger perforation charges.

SCHEDULE STATUS

Progress of the Sandia Mineback programs is shown in Figure 4-10.

Figure 4-8 Hole No. 6 Formation Interface Experiment Width Contour Plot — Longitudinal View

Figure 4-9 Width of Fracture Through Section A-A' (Mineback Data)

Figure 4-10 Milestone Chart - Sandia Mineback