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1 July - 31 July, 1980

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Bartlesville Energy Technology Center
Las Vegas Field Office
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SUMMARY

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

A subcontract was approved between Gas Research Institute and M.D. Wood, Inc. to obtain information on hydraulic fracture length. A meeting was held with Superior Oil Company during July to discuss possible sites for the multi-well experiment. Bartlesville Energy Technology Center continued work toward the assessment of fracture fluid effects on post fracture test times. A full report of the Seismic Formation Mapping Program will be issued by Sandia after review and editing have been completed.

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SECTION 1

PROJECT MANAGEMENT

TECHNOLOGY TRANSFER

DOCUMENTATIONS AND REPORTS

The *WGSP Financial Supplement* for July, 1980, and the May *WGSP Status Report* have been distributed. The June *WGSP Status Report* and Second Quarter *Quarterly Basin Activities Report* are being compiled. Statistics and production information from the Piceance and Uinta Basins are being compiled and organized; logs of Wasatch tops in the Uinta Basin are being correlated in preparation of a structure map. Facies maps of the Greater Green River Basin are being finalized. A draft of the WGSP Project Plan Document FY 1981 is being reviewed.

PROJECT DATA BANK

The following maps were added to the WGSP data bank:

"Northern Part of the Uinta Basin," Shell Oil Company Map, Topographic Blueline, Showing Location of Wells; and

"Natural Buttes—Chapita Wells, Uintah County, Utah," Topographic Blueline, Showing Location of Wells.

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.

*Reservoir Characteristics
in Uinta Basin Gas Wells
Final Report, September 1, 1978
— January 31, 1980*

by C. R. Boardman and
C. F. Knutson
CK GeoEnergy

Volumes of 29 lenticular tight gas sandstone reservoirs in the Uinta Basin, Utah, have been approximated from long-term pressure buildups on six wells. Average reservoir volume was interpreted to be about 240,000 ft³ per ft of net pay. Outcrop reservoir geometry studies indicate an average reservoir volume (without any reservoir interconnection assumed) of about 30 percent less than the average based upon production analysis. Therefore, some reservoir interconnection may exist. Results of this study are consistent with the Knutson lenticular reservoir model in which average reservoir width is 22 times the gross sand thickness, length is 10 times the width, and reservoir interconnection is a function of the sand fraction in the productive interval. Apparent reservoir permeabilities, assuming radial flow, range from .009 to .052 millidarcies and actual sandstone matrix permeabilities are interpreted to range from .06 to .21 millidarcies. Fracture half-lengths are interpreted to be about 0.1 ft/BBL of fluid with an average proppant load of 1.2 to 1.7 lb/gal at injection rates of 18 to 24 BPM and injection pressures of 2,500 to 4,600 psi for each 100 ft of gross sand in the fraced interval.

*Demonstration of Massive Hydraulic
Fracturing, Piceance Basin,
Rio Blanco County, Colorado*

by J. L. Fitch, W. L. Medlin
and M. K. Strubbar
Mobil Research and Development

Demonstration of massive fracturing
to provide gas production from tight

gas sands in the Piceance Basin was the objective of this jointly funded Mobil DOE project. This effort has been at least partially successful. The uppermost interval fractured, the Ohio Creek Formation at 7,324 to 7,476 ft, appears to be commercially viable. The remaining sequence to a total depth of 10,800 ft may also be commercially attractive, depending on fractured well costs, gas prices and the risk of failure to achieve production capacity equal to, or greater than, that achieved in the present well. Prior work was performed by Mobil in the Brush Creek Unit, Mesa County, Colorado. The well, Brush Creek 1-25, was drilled to

10,330 ft and given two massive fracturing treatments before the well was plugged and abandoned as noncommercial. It was concluded that formation permeability was too low to justify additional work in the Brush Creek Unit. Piceance Creek well F31-13G was drilled to 10,800 ft. Nine zones were tested in the Mesaverde and Ohio Creek Formations between 7,324 to 10,680 ft. Six massive fracturing treatments were performed covering 7 of the 9 intervals. Average first-year flow potential of the well is estimated at 2.9 MMCFD with 1.1 MMCFD of this amount attributed to the uppermost zone.

SECTION 2

RESOURCE ASSESSMENT

U.S. GEOLOGICAL SURVEY ACTIVITIES

UINTA-PICEANCE BASINS

The compilation of a map continued relating water and/or hydrocarbon recoveries for all Mesaverde Group tests in the Piceance Basin. The data are from analysis of completion zones and drill stem tests.

Surface exposures of Wasatch Formation units along Yellow Creek between Meeker and Rangely Fields in the Piceance Basin were examined. In this area, the Wasatch contains many rocks that were formed in a lacustrine depositional setting; these rocks contain organic matter and are probable sources of gas and/or oil in deeply buried units.

Lithologies of cored units in the Uinta Basin were plotted against geophysical log curves. This was done to relate log response to rock properties determined from SEM, petrographic, and sedimentologic studies. The analysis and data for the Upper Cretaceous Mesaverde Group (including the Neslen, Farrar and Tuscher Formations) at Southman Canyon gas field is being incorporated in a manuscript for publication.

Surface exposures of Upper Cretaceous Mesaverde Group sandstones in the south central part of the Uinta Basin were described. In this area, many of the units reflect changing depositional facies, which may form a regional boundary of potentially recoverable natural gas.

The following paper was approved for publication:

Keighin, C. W., and K. Sampath, in press, "Evaluation of pore geometry of some low-permeability sandstones, Uinta Basin, Utah," Society of Petroleum Engineers, Paper 9251.

GREATER GREEN RIVER BASIN

Work continued on geologic and engineering cross sections.

Field work was conducted in northern Green River and Rock Springs areas and northern Uinta Mountain foothills.

Pressure and temperature data is being compiled for Pinedale Unit wells, T29N to T33N, R108W to R110W, Sublette County, Wyoming.

Petrographic data from Tierney area wells is in review as a USGS Oil and Gas Chart.

NORTHERN GREAT PLAINS PROVINCE

Field work is being conducted in central and southeastern Montana.

Northern Great Plains lineament and fracture data is being compiled.

SCHEDULE STATUS

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

CORE PROGRAM

Several operators were contacted during July concerning possible coring operations. In the Piceance Basin, contacts included CSG Exploration, Adolph Coors Co., Teton Energy, Dome Petroleum, Texas Eastern and

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.												
Cation and x-ray studies of clays in Gammon Shale reservoirs												

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.												
Prepare overview summary report on USGS Tight Gas Sands research and conclusions to date.												

Figure 2-1 Continued

Bow Valley Exploration. Others were Cotton Petroleum (Uinta Basin), Pacific Transmission Supply Co. (Uinta Basin), Mountain Fuel Supply Co. (Greater Green River Basin) and Falcon Oil & Gas Co. (Northern Great Plains Province).

SURVEY OF BASIN ACTIVITIES

GREATER GREEN RIVER BASIN

No D&A wells were reported this month. Seven development wells were producers and two wildcats were discoveries. Total initial potential flow of these 9 completions was 12,393 MCFD. Contributing horizons included the Almond, Lewis, Mesaverde undifferentiated, Fort Union and Frontier, the horizon which contributed the most (5,160 MCFD).

Davis Oil will drill a projected 10,700-ft Mesaverde test at No. 12 Siberia Ridge

Unit, Sec. 28, T22N, R95W, Sweetwater County, Wyoming. This test is 3 miles southeast of Texas Oil & Gas's No. 1 Federal-H gas discovery in Sec. 18, and 6 miles west of the Siberia Ridge field. Both produce from the Mesaverde.

Location has been staked by Exxon Corporation at No. 1 Mayberry Springs Unit, Sec. 31, T11N, R94W, Moffat County. This 10,500-ft wildcat test is 4 miles northwest of the Big Hole gas field, which produces from the Lewis Formation, and 8 miles southeast of the abandoned Little Snake Field. Closest comparable drilling depth is in Davis Oil's No. 1 Verna-Federal, Sec. 27, a 9,400-ft dry hole 3½ miles east of the location.

During the month, 39 new locations were staked: 25 development and 14 wildcat.

Table 2-1 presents a summary of wells and newly-staked locations in the basin, and Figure 2-2 shows their locations.

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
Belco Petroleum	27-32 East Labarge Unit	1	nwn 32/27N/112W East Labarge Field Sublette Cnty, WY	Frontier 6,898-7,237 (gross)	7,352	69,700 gal water, 131,740 lb sand	Develop. well, comp. 5-27-80. No cores; drill stem tested.	610
Koch Exploration	1 Federal-Twin Fork	2	nws 28/14N/97W Unnamed Field Sweetwater Cnty, WY	Fort Union 11,495-11,533	11,594 PB: 11,551	Acidized w/ 10,000 gal; sand fractured w/ 100,000 lbs.	Wildcat field discovery, comp. 2-18-80. No cores; drill stem tested. OWWO: Spud 2-10-79; re-entered 3-3-79; re-entered 10-24-79.	3,700 (112 BCPD)
Anadarko Production	2 Cottonwood Gulch-State-A	3	nws 36/8N/91W Craig North Field Moffat Cnty, CO	Lewis 3,278-3,334 (gross)	3,460		Develop. well, comp. 2-12-80. No cores; drill stem tested.	856
Energetics Inc.	1 Fordyce-Federal	4	nws 26/22N/113W Wildcat Field Lincoln Cnty, WY	Frontier 11,175			Wildcat test, reported 7-1-80.	
Wexpro Co.	1 The Mesa	5	nene 7/32N/109W Wildcat Field Sublette Cnty, WY	Fort Union 12,000			Wildcat test, reported 6-24-80. Located in Core Area B3.	
Forest Oil	1 Jonah Gulch	6	sesw 9/26N/107W Wildcat Field Sweetwater Cnty, WY	Mesaverde 10,570			Wildcat test, reported 7-22-80. OWWO: OTD 10,570; comp. 1-21-80 D&A. Located in Core Area B1.	

NORTHERN GREAT PLAINS PROVINCE

Forty-five wells were reported this month: 14 development wells were producers, 2 wildcats were discoveries, 2 development and 11 wildcat wells were D&A, and 14 development and 2 wildcat wells were completed and shut in. Total initial potential flow was 3,506 MCFD, with 16 IPFs not available due to the shut in wells. The producing horizons included the Phillips, Bowdoin, Bow Island/Dakota commingled, Bowdoin/Phillips commingled and Eagle, the horizon to which all the shut in wells were completed.

Sixty-eight newly-staked locations were reported during the month: 60 development and 8 wildcat. Falcon-Colorado Exploration will drill a 1,400 ft Phillips test at No. 1-1 Swanson Ranch, Sec. 1, T31N, R35E, Valley County, Montana. The outpost is about 2 miles east and 2 miles north of Cretaceous gas producers in the Bowdoin Field.

Table 2-2 is a summary of completions and newly-staked locations in the province, and Figure 2-3 shows their locations.

PICEANCE BASIN

Reported activity was slow during July: 4 development wells were reported as producers and 1 was D&A. Total initial potential flow was 1,960 MCFD, with production from Mancos B, Corcoran and Corcoran/Cozzette commingled. Twenty-one new locations were staked: 12 development and 9 wildcat.

One of these new locations was Exxon Corporation's No. 1 Kinney Creek, Sec. 9, T11S, R93W, Mesa County, an 8,700 ft test. That test is 6 miles northeast of Nebraska Driller's No. 1 Michelson-Government, Sec. 15, T11S, R94W, a 1958 Mesaverde discovery flowing 1,536 MCFD between 5,712 and 5,806 ft.

Table 2-3 presents a summary of completed wells and new locations, and Figure 2-4 shows their locations.

UINTA BASIN

Conoco Inc. has staked two Wasatch wildcats in Uintah County: No. 4-23K Snow Knight, Sec. 4, T9S, R20E (7,620-ft test) and No. 2-5 Agnacio, in Sec. 2 (7,520 test). The locations are 1½ miles northwest and 1½ miles north, respectively, of the Natural Buttes Field, where production is from the Wasatch, Mesaverde and Castlegate horizons.

Ten newly-staked locations were reported by month's end: 6 development and 4 wildcat. Nine wells were reported as drilled or completed: 5 development wells were producers, 1 wildcat was a discovery and 3 development wells were D&A. Total initial potential flow was 7,148 MCFD, with all production from the Wasatch Formation.

Table 2-4 is a summary of completions and newly-staked locations, and Figure 2-5 shows their locations.

GAS RESEARCH INSTITUTE SPONSORED PROJECTS

Work continued on the development of a matrix or information model to identify the state-of-the-art in tight gas sands technology as well as resource evaluation. A proposed matrix format was developed and presented to the GRI Project Advisors at their meeting in July. Further refinement is continuing.

A comprehensive Annual Report is in preparation, covering all project activities during the period from project inception in early 1979 through June 1980.

EVALUATION OF SEISMIC DATA FOR DETAILED STRATIGRAPHIC STUDIES OF LENTICULAR SANDS

A final report is being prepared and will be issued as a Sandia Laboratories Report. A summary report was submitted to the project advisors.

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
Balcron Oil	1-32 Sprague	1	swne 32/30N/2W Unnamed Field Pondera Cnty, WY	McCracken (Mowry-Upper Blackleaf ?) 1,050-1,085 (open hole)	1,085		Wildcat field discovery, comp. 4-8-80. No cores or tests.	317
Canada Northwest Land Ltd.	3-12 CNW Oils-Scarboro- AHC Cornwell	2	nenw 12/2N/42E Wildcat Field Rosebud Cnty, MT	Shannon 3,000	2,995		Wildcat well, comp. 5-7-80 D&A. No cores or tests.	
Marquis Petroleum	6-13 Wilcox	3	sww 6/33N/2W Southwest Keven Field Toole Cnty, MT	Bow Island 590-775 (gross) Dakota 915-928 (gross)	1,652 PB: 1,580	Acidized w/ 250 gal.	Wildcat outpost extension, comp. 12-21-79. No cores or tests. Commingled production.	37
Burton- Hawks	6-1 State	4	sese 6/15N/6E Wildcat Field Harding Cnty, SD	Shannon 1,500	1,650		Wildcat well, comp. 5-27-80 D&A.	
Grae Exploration	4D-18 Neyland	5	nwnw 18/25N/4E Wildcat Field Chouteau Cnty, MT	Bow Island 1,200			Wildcat test, reported 6-30-80.	
Fiemac Resources	1-7 Fiemac- State	6	nwse 7/2N/20E Wildcat Field Haakon Cnty, SD	Niobrara 2,100			Wildcat test, reported 7-17-80.

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
Northwest Exploration	10 Clough	1	nwnw 22/6S/94W Rulison Field Garfield Cnty, CO	Wasatch 2,750	375		Develop. well, comp. 5-13-80 junked & abandoned. No casing set; no logs run; no tops picked; no cores or tests.	
Chandler & Associates	6-22 Barnard	2	senw 22/10S/96W Plateau Field Mesa Cnty, CO	Cozzette 3,193-3,298 Corcoran 3,298-3,378	3,585	92,988 gal water, 355,000 lb sand	Develop. well, comp. 1-8-80. No cores or tests. Commingled production.	601
Twin Arrow	2-32 Shenandoah-Federal	3	sene 32/2S/100W Cathedral Field Rio Blanco Cnty, CO	Mancos B 4,280-4,310 (gross)	4,646		Develop. well, comp. 4-26-80. No cores or tests.	384
Dome Petroleum	3-28 Federal	4	swnw 28/7S/90W Wildcat Field Garfield Cnty, CO	10,150 Cretaceous test			Wildcat test, reported 7-22-80.	
Adolph Coors	1-14 HC USA	5	sese 14/9S/98W Wildcat Field Mesa Cnty, CO	7,020 Cretaceous test			Wildcat test, reported 6-25-80. Near Core Area C.

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
Pacific Transmission Supply Co.	14-10 Devil's Playground-Federal	1	sww 10/9S/24E Natural Buttes Uintah Cnty, UT	Mesaverde 6,200	6,163	Acidized three times w/total 7,000 gal.	Develop. well, comp. 6-19-80 D&A. No cores; drill stem tested.	
CIG Exploration	31-1-10-22 Natural Buttes Unit	2	sene 1/10S/22E Natural Buttes Field Uintah Cnty, UT	Wasatch 4,949-7,060 (gross)	7,308 PB: 7,275	Acidized w/ 3,400 gal; fractured w/ 122,300 gal gel, 275,000 lb sand.	Develop. well, comp. 5-20-80. No cores or tests.	2,400
Pacific Transmission Supply Co.	24-22 Federal	3	sesw 22/8S/22E Natural Buttes Field Uintah Cnty, UT	Wasatch 6,382-8,140	8,088 PB: 8,655	Acidized three times w/total 4,500 gal; fractured twice w/total 68,120 gal water, 87,000 lb sand.	Wildcat outpost extension, comp. 4-10-80. No cores or tests.	1,366 (2 BWPD)
Coseka Resources	11-2-15-22 Wolf Unit-State	4	senw 2/15S/22E Wildcat Field Uintah Cnty, UT	Mancos 7,000			Wildcat test, reported 7-15-80. Located in Core Area D.	
Amoco Production	1 MA Smith Oil Investment	5	nws 16/3S/9W Wildcat Field Wasatch Cnty, UT	Wasatch 12,500			Wildcat test, reported 7-23-80.

Figure 2-6 Milestone Chart — MWX

SECONDARY BASIN STUDIES

A draft is in review on a geologic report of the tight gas potential in the Arkoma Basin/Ouachita Mountains Province in Oklahoma and Arkansas. Geologic review continued on the Raton Basin of New Mexico and Colorado. Preliminary background work has begun for the Anadarko Basin of Oklahoma and Texas, and the Wind River and Big Horn Basins of Wyoming.

HYDRAULIC FRACTURE CHARACTERIZATION

Site selection and planning are underway for the first field project under an M.D. Wood, Inc. subcontract to furnish FRAC-MAP services for two sites in the Wattenberg Field, Colorado. Amoco Production Company will provide the sites and certain required well stimulation data. The purpose of the subcontract is to obtain information on hydraulic fracture length.

MULTI-WELL EXPERIMENT

GENERAL

DOE, CER and Sandia personnel visited proposed Superior Oil Company MWX sites in Colorado. A field evaluation was performed and a list of mineral owners was compiled. A meeting was held with Superior Oil Company during July in Houston, Texas, to discuss the possible sites.

CORE PROGRAM

The possibility of setting up a core inventory facility at the DOE's Grand Junction facility is being explored. A cost estimate will be provided for storage space, display and laboratory space and help in running the facility. Personnel in the mineralogy-petrology, analytical chemistry and logging groups at the facility were contacted concerning the possibility of collaboration in appropriate phases of the program.

The design of a tool to measure the dip and strike of bedding, fractures and joints during the field processing of core was approved. Drawings will be finalized and the tool will be fabricated. Revisions were also made on the design of the core gamma apparatus.

A drilling fluid invasion study was designed. The first test will investigate invasion in various dry sandstones by an oil-base drilling fluid at a 250 psi overbalance condition for 3 to 4 hours. The dry sandstones are more prone to invasion, and thus provide a worst case test. These results should help indicate how extensive an experiment matrix (in terms of rock saturations and use of filter cake) is needed to put limits on the amount of invasion, and to help provide data for use in log

interpretation. The rocks to be used in the study are:

Sandstone Type	ϕ (%)	k (md)
Berea	~ 17	~ 200
Nugget	~ 3	~ 0.30
Tennessee	~ 1	~ 0.10
"Tight"	~ 5	~ 0.01

Accurate measurements will be made of k and ϕ for the sandstones used.

SCHEDULE STATUS

Figure 2-6 is a milestone depicting the MWX progress.

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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

Work has begun on the meaning and measurement of anisotropy in western tight sands. True anisotropical conditions are confirmed when lab and/or field measurements indicate that permeability has the form of the symmetric second-rank tensor, $k_{ij} = k_{ji}$. The consequences of the existence of anisotropy is that the flux vector is not necessarily colinear with the potential gradient vector. The hypothesis is being tested that certain types of heterogeneity in otherwise locally isotropic sediments will give rise to flow patterns that are similar (perhaps identical) to those that would be observed in homogeneously anisotropic media. This prospect will be considered further as a first step towards developing methodologies for laboratory measurement of the directional properties of western tight gas sands.

Permeability of Interbedding Material of Tight Western Gas Sands — Lawrence Liver- more Laboratories

During July, progress was delayed mainly by a component failure in the instrumentation

system. The failure has been isolated and repairs should be completed during August. Permeability measurements will resume on four samples at ambient temperature and effective pressures to 50 MPa (approximately 7,250 psi).

LOGGING STUDIES

Interface Conductivity Studies

Klinkenberg permeabilities of four Uinta Basin samples, measured at 1,000 psi, ranged from 15 to 200 microdarcies. Liquid permeability and resistivity were measured at confining pressures from 300 to 3,200 psi. The data were in agreement with the empirical model by Jones and Owens.¹ The data were also used to evaluate a theoretical rock geometry model based on thick-wall capillary tubes. The data fit to this model appears to be marginal. A third permeability model was derived, based on rectangular slits or rectangularly-shaped capillaries. The permeability data fitted to the rectangular model show improvement over a thick-wall capillary tube model. The results indicate rock capillaries are not round but tend to be slits or rectangular.

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

Reliable water samples from Uinta Basin Upper Cretaceous formations are virtually nonexistent. This is primarily because water production from such formations is a rare occurrence and because fluids from multiple zones are commingled routinely. As a result, no mathematical relationship between the SP log and the resistivity ratio, R_w/R_{mf} , has been established.

¹ Jones, F. O. and W. W. Owens, "A Laboratory Study of Low Permeability Sands," SPE 7551, 1979 SPE Symposium on Low Permeability Gas Reservoirs, May 20-22, Denver, p. 325-334.

In June, it was reported that a useful analysis was obtained of water produced from the Tuscher/Farrar Formation of the Mesaverde Group. However, the USGS has stated that the high sodium chloride content reported appears inconsistent with the perceived geochemistry of the Tuscher/Farrar Formation.

A list of nine operators who have drilled or are drilling in the Mesaverde was received from Mapco Production Company. The possibility of resolving the R_w problem through more sophisticated approaches will be initiated with these operators.

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

The porosity logs of the Mapco RBU No. 11-17F well, Uintah County, Utah, are being evaluated similarly to the evaluation of the CIGE NBU No. 21 well, Uintah County. Core data includes porosity, permeability and matrix density. These properties were measured on 54 one-ft samples. Log depths were correlated to core depths, and corresponding readings from the density, sonic, neutron and gamma ray logs were obtained for each sample.

Figure 3-1 is a plot of bulk density versus lab measured porosity. Bulk density was calculated from the porosity and matrix density of each sample and best fit least squares lines drawn through the data. Although the data does not demonstrate a clearly variable matrix density, as did the same plot for the CIGE No. 21, the data does indicate that the best "average" value for matrix density is 2.665 or 2.67 gm/cc. This is particularly apparent for porosities greater than 6 percent where the majority of the samples have a matrix density of 2.67 gm/cc or less.

Figure 3-2 is a plot of neutron porosity versus lab porosity. The scatter of the data about the matrix lines is due to the varying amounts of carbonate cement and shale.

Figure 3-3 is a plot of sonic porosity versus lab measured porosity. The sonic log indicates a porosity that is higher than the measured porosity. This indicates that the assumed matrix travel time of 52.6 micro-seconds per foot is too low. Figure 3-4 shows a plot of log travel-time versus lab porosity, while Figure 3-5 is a plot of calculated matrix travel-time versus lab porosity. The matrix travel times have been calculated using the log travel times and the lab porosities. For Figures 3-4 and 3-5, only those samples with a gamma ray reading of less than 60 were plotted to evaluate cleaner, high porosity sands. In these figures, a least squares line was drawn through the data.

These preliminary results are very similar to the results of the evaluation of CIGE No. 21. The detailed results of the Mapco RBU No. 11-17F evaluation will be compiled in the upcoming annual report.

ADVANCED LOGGING TECHNIQUES AND INTERPRETATIONS

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

The data acquisition and fast Fourier transform analysis programs for the LSI-11 computer were completed. These programs can provide an accurate analysis of the acoustic birefringence phenomenon. The programs have been successfully tested on Nugget sandstone and oil shale for the acoustic transmission mode. A theory for the borehole application of the technique has been developed. Work has begun to test the theory on Nugget sandstone and oil shale using a same face mode.

It is apparent that transducer design will be a critical part of the design of a borehole stress tool.

Figure 3-1 Bulk Density Vs. Laboratory Derived Porosity, Mapco RBU No. 11-17F

Figure 3-2 Neutron Log Porosity Vs. Laboratory Derived Porosity, Mapco RBU No. 11-17F

Figure 3-4 Sonic Log Travel Times, Mapco RBU No. 11-17F

Figure 3-5 Calculated Matrix Travel Times, Mapco RBU No. 11-17F

HYDRAULIC FRACTURING AND FRACTURE CONDUCTIVITY

Proppant Embedment in Hydraulically Fractured Reservoirs

Proppant Embedment Studies

To further investigate the results of propping fractures in deep gas wells with sintered bauxite, the study has been extended to include embedment between fractured surfaces. Previous work has been concentrated on rocks with smooth (cut) surfaces. Figure 3-6 compares embedment in fractured grey berea blocks and embedment in smooth grey berea blocks using 12/20 mesh sintered bauxite. The rate of embedment for the fractured block is much more rapid at low closure pressures and is still somewhat faster at higher pressures. This is probably due to a reduced proppant-block contact and a less well-supported embedment surface. However, the initial fracture width of the propped fractured blocks is much greater, and only at higher pressures does it approach that of the smooth block case. It appears that although smooth blocks may be useful in studying the effects of proppant coverage, mesh size, size distribution, etc, absolute estimates of fracture conductivity should be based on fractured rock.

Proppant Transport in Massive Hydraulic Fracturing — University of Tulsa

This report covers recent experimental studies on the settling velocities of sand particles in aqueous slurries of hydroxypropyl guar.

Three plexiglass vessels were constructed to measure the settling rates of sand particles in fracture fluids. Height and length were 12 in. and separation can be 1/2 in., 1/4 in. or 1/8 in.

Ottawa sand of 20/40 mesh was selected as the proppant; however, because of the large size variation, further screening was necessary to obtain 28 to 35 mesh. Absolute density of the sand was measured using a pycnometer. Published values were used for both density and specific gravity. The densities of the hydroxypropyl guar solutions were measured by weighing. These values are listed in Section A of the following Results.

A RVT Wells-Brookfield Micro viscometer was used to measure slurry viscosity. Since non-Newtonian behavior was expected, viscosity measurements were made at different rpm and consequently at different shear stresses. Viscosity data were collected for two temperatures, 30°C and 35°C, and the results are tabulated in Section B of the Results.

About 300 readings were taken to develop experimental techniques to measure single-particle settling time. Single particles would not submerge when dropped at the surface because of surface tension. Tweezers had to be used to immerse the particles below the surface of the liquid before releasing them. The time taken for the particle to settle between two lines 8 in. apart was recorded. The settling times were recorded not only in water but for different concentrations of the hydroxypropyl guar in water. These settling times are given in Table 3-1. Table 3-2 shows the settling rates. The readings were taken for plate separations of 1/2 in., 1/4 in. and 1/8 in.

Horizontal lines at 1/2-in. intervals were etched on the front wall of the settling chambers to measure bulk settling rates in sand-water slurries. In these settling studies, a homogeneous slurry of 1 lb sand per gallon was prepared by placing the appropriate sand and water in the settling chamber (suitably covered) and vigorously shaking the chamber. The chamber was set abruptly upright on the bench and the time it took for the sand to fill the lower portion of the chamber between the

Figure 3-6 Fracture Closure Vs. Closure Pressure with Various Fractions of Monolayer Coverage Using 12/20 Mesh Sintered Bauxite Proppant Between Smooth and Fractured Berea Blocks

Table 3-1 Mean Single Particle Settling Times, secs

Fluid	.125 in.	Plate Separation .25 in.	.50 in.
Water			
Settling in sec	3.4 + 0.2	3.2 + 0.3	3.0 + 0.3
No. of experiments	30	50	130
Temp. (°C)	28	29	32
Hydroxypropyl Guar Solution (1.2 gm/liter)			
Settling in sec	6.7 + 0.4	5.4 + 0.4	4.7 + 0.4
No. of experiments	20	20	20
Temp. (°C)	28	28	28
Hydroxypropyl Guar Solution (2.4 gm/liter)			
Settling in sec	18.12 + 0.6	13.54 + 1.0	9.9 + 1.5
No. of experiments	20	20	20
Temp. (°C)	30	30	30

Table 3-2 Mean Single Particle Settling Rates, cm/sec

Fluid	.125 in.	Plate Separation .25 in.	.50 in.
Water	6.01	6.37	6.73
Hydroxypropyl Guar Solution (1.2 gm/liter)	3.06	3.80	4.31
Hydroxypropyl Guar Solution (2.4 gm/liter)	2.06	1.50	1.12

bottom and the first horizontal mark was recorded.

A 1.2 gm/liter (corresponding to 10 lb/1,000 gal) solution of hydroxypropyl guar in water was prepared in a blender. An anti-foamant was added. Different amounts of sand (28 to 35 mesh) were added to the solution and settling times were measured as previously described. A similar procedure was used for a 2.4 gm/liter solution (20 lb/1,000 gal) and these results are tabulated in Table 3-3. Table 3-4 gives the times the sand took to settle to specific etch marks on the plexiglass vessels.

Results

A. Densities

1. Ottawa sand 20/40 mesh

The following data were obtained from the literature:

Actual density = 21.929 lb/gal
Specific gravity = 2.63

Absolute density was measured by pycnometer:

Absolute density = 2.645 gm/ml =
22.02 lb/gal.

Table 3-3 Mean Single Particle Settling Times, secs

SOLUTION	Solution Height, in.	Sand Added to Solution, gm/liter of solution	Total Height Sand + Solution, in.	Temp. (°C)	Mean Time for Sand to Settle Completely, sec	No. of Observations
Hydroxypropyl Guar 1.2 gm/liter	10	120	10.4	37	6.46	15
		360	11.0	35	8.26	15
		720		35	11.80	20
Hydroxypropyl Guar 2.4 gm/liter	10	120	10.5	33	24.75	10
		360	11.1	33	26.00	20
		720		33	28.50	10

Table 3-4 Mean Single Particle Settling Rates, cm/sec

Solution: Hydroxypropyl Guar, 2.4 gm/liter

Sand: 120 gm/liter of Solution (Total height 10.5 in.)

Time required for sand to settle to the first mark (0.5 in.)	5.85 sec
Time required for sand to settle completely (1.6 marks; 0.8 in.)	24.75 sec

Sand: 360 gm/liter of Solution

Time required for sand to settle to the 3rd mark (1.5 in.)	10.51 sec
Time required for sand to settle to the 4th mark (2.0 in.)	18.72 sec
Time required for sand to settle to the 5th mark (2.5 in.)	26.00 sec

2. Solutions

Because of the low concentrations used, the densities of the solutions were almost identical to those of water at the same temperatures.

B. Viscosities

1.2 gm/liter Hydroxypropyl Guar

30°C	at 20 rpm	$\mu = 9.60$ cp
	at 50 rpm	$\mu = 7.55$ cp
	at 100 rpm	$\mu = 6.27$ cp

35°C	at 20 rpm	$\mu = 4.00$ cp
	at 50 rpm	$\mu = 7.87$ cp
	at 100 rpm	$\mu = 8.57$ cp

2.4 gm/liter Hydroxypropyl Guar

30°C	at 20 rpm	$\mu = 14.72$ cp
	at 50 rpm	$\mu = 10.32$ cp
	at 100 rpm	$\mu = 10.75$ cp

35°C	at 20 rpm	$\mu = 8.32$ cp
	at 50 rpm	$\mu = 12.00$ cp
	at 100 rpm	$\mu = 10.88$ cp

RESERVOIR SIMULATION STUDIES

Reservoir Simulator for Hydraulically Fractured Gas Wells in Lenticular Formations — University of Oklahoma

During this reporting period, effort was directed toward the completion of the two-dimensional gas reservoir simulator. All additions to the program have been completed which reflect the effects of non-continuous sand lenses, non-Darcy flow, wellbore and fracture storage and pressure drop in the production string. Considerable effort was expended in developing the computer logic associated with these additions in order to conserve computer storage.

Debugging is still in progress but it is anticipated that a workable simulator program will evolve by the end of August.

Parametric Analysis of MHF Test Data: An Engineering Study of Western Gas Sands — Intercomp, Inc.

During July, work was performed on the task determining how fracture fluid remaining around the fracture affects the post fracture test periods. To perform this study, it was necessary to use the Single Well Radial Flow Simulator in conjunction with the new Two-Phase Fracture Propagation Model.

Before beginning work with the fracture models, a non-fractured reservoir was simulated to determine whether the two models would calculate the same pressure transient responses to a given set of reservoir parameters. Although the parameters in both simulators were identical, it was not possible to match the transient responses. Further work on Task 2 will be delayed until the differences between the two models can be resolved and can match the pressure transient responses on a non-fractured reservoir.

SCHEDULE STATUS

Figure 3-7 is a BETC milestone chart.

LAWRENCE LIVERMORE NATIONAL LABORATORY

THEORETICAL ANALYSIS

Finite Element Technique Development for Stimulation Models

New time-efficient solution techniques are being developed for simulation models designed for a wider range of stimulation phenomena. One promising technique takes advantage of the regularity of the stiffness matrix when rectangular finite elements are

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 3-7 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 3-7 Continued

used. The stiffness matrix, which relates nodal forces (F) to displacements (x), can be partitioned in the form

$$\begin{array}{c}
 K_{11} \quad K_{12} \\
 [K] = K_{21} \quad K_{22} \quad K_{12} \quad (\text{all zeroes}) \\
 K_{21} \quad K_{22} \quad K_{12} \\
 K_{21} \quad K_{22} \quad K_{12} \\
 (\text{all zeroes})
 \end{array} \quad (1)$$

The equation

$$\{F\} = [K] \{x\} \quad (2)$$

is used to find the nodal displacements when the nodal forces {F} are given. The displacements are found by inverting the stiffness matrix which yields

$$\{x\} = [K]^{-1} \{F\} = [A] \{F\} \quad (3)$$

where [A] is called the flexibility matrix and

$$AK = KA = I \quad (4)$$

where I is the identity matrix.

It is usually too costly in computer time to invert the stiffness matrix; instead, Equation (2) is solved by means of one of several iteration schemes. Since these schemes require a large amount of computer storage and computer time for large grids, the size of a finite element grid is always limited by the available computer time. An infinite grid is useless with these methods.

If the A matrix is partitioned in the same manner as the K matrix (Equation (1)) and Equation (4) is used, the partial result is the equations

$$\begin{array}{l}
 A_{11} K_{11} + A_{12} K_{21} = 1 \\
 A_{11} K_{12} + A_{12} K_{22} + A_{13} K_{21} = 0 \\
 A_{12} K_{12} + A_{13} K_{22} + A_{14} K_{21} = 0 \\
 \text{etc.}
 \end{array} \quad (5)$$

If the grid is infinite, there are an infinite number of equations in (5). Solving and substituting in Equations (5) results in the expression for the Nth term:

$$A_{1N} = -A_{1(N-1)} K_{12} B_N \quad (6)$$

where B_N is the recursion relation

$$B_N = (K_{22} - K_{12} B_{N-1} K_{21})^{-1} \quad (7)$$

As the grid becomes infinite, B_N converges to B_{N-1} , Equation (7) can be solved, then Equation (6), and finally, the A s in Equation (5) can be determined. Once these are found, Equation (3) can be solved for the displacements. This method has worked on simple beam and plate problems that can be hand calculated.

However, Equation (7) is generally difficult to solve for more complex problems and an efficient method to solve it is being investigated.

Effects of Frictional Interfaces on Crack Growth

Analyses of frictional interfaces near fractures continued. In previous reports, the variation in strain energy density directly across a frictional interface from a pressurized fracture was discussed. As expected, the strain energy density across the interface increased with the magnitude of shear stress that the interface could support. The increase in strain energy density with the magnitude of frictional stress that the interface can support, was seen to be approximately linear over the range analyzed. These calculations assumed a constant pressure over the length of the pressurized fracture. Further analysis may be required when a realistic pressure distribution in the fracture can be determined.

The effects of varying friction along the interface continues to be analyzed. Experiments have been conducted where a varying friction exists along the interface. The results show an abrupt offset in the fracture path as

the fracture crosses the interface. During July, the code has been modified and debugged to quantify these effects.

LABORATORY EXPERIMENTS

The PMMA blocks designed and constructed in June to study fluid flow in cracks were tested in July. The design appears satisfactory at low levels of closure stress (~ 250 psi) and fluid pressure ($\sim 1,000$ psi). Only preliminary experiments have been performed so far. Tests were also initiated to study crack growth across heterogeneous rock plates consisting of sandstone, limestone and dolomite.

During July, measurements were completed of the failure envelope under triaxial compression of Mesaverde shale, as well as pressure-volume measurements of Mesaverde sandstone. The results will be documented later. Specimen preparations for pressure-volume and uniaxial strain measurements of Mesaverde shale were also completed.

GEOLOGY AND GEOPHYSICS

During July cores were examined in the USGS core library. Critical parts of a core from the deep Mesaverde test, Inexco WASP No. A-1, Sec. 28, T36N, R112W, Sublette County, Wyoming, were observed.

Mineral-filled (or partially filled) fractures have the geometry, offsets and terminations at and across beddings very similar to those predicted by computations. They appear to be natural hydraulic fractures. A large quantity of data from this well is now being reviewed.

Study continued of the time versus depth relationship for the burial of Mesaverde reservoirs and of the stress variations with time.

SCHEDULE STATUS

The milestone chart for LLNL is shown in Figure 3-8.

LOS ALAMOS SCIENTIFIC LABORATORY

The use of nuclear magnetic resonance (NMR) techniques using special and novel instrumentation techniques is being studied. During this month, a series of NMR measurements on Western gas sands samples was completed.

SAMPLE PREPARATION

Samples of core taken from Mapco RBU No. 11-17F, PTS No. 12-22 and PTS No. 24-19 wells were prepared for NMR measurements. The first samples selected visually appeared to be clay free. The absence of clay was confirmed in the following manner.

A 360 g sample was cleaned, crushed and leached with deaerated water at 92°C . Clay was not detected in the effluent, which had remained clear. With the absence of clay and its complications, a method for sandstone saturation, proven from other studies at LASL, was applied. The samples, cut from core using water as coolant, were

- washed in toluene and then acetone;
- dried in a hard vacuum for 22 hours at 100°C ;
- exposed to vapor at 20°C for 2 hours, then covered with liquid;
- placed in a high pressure chamber and maintained at 11,000 psig for 20 hours; and
- removed from the high pressure chamber and delivered covered with the saturating liquid for measurement.

Two sets of samples were prepared by this method, one set with deionized water and the other with methyl alcohol. Bulk densities for each sample were calculated based on an assumed grain density ratio of 2.65. Porosities ranging from 3 to 13 percent were represented in the sample sets.

Figure 3-8 Milestone Chart – LLNL

NMR MEASUREMENTS

NMR relaxation time (T_1) was measured for each sample. Inferred relaxation times for both sets showed the anticipated correlation with porosities inferred from calculated bulk densities. Preliminary values of spin-lattice relaxation times (T_1) ranged from 2 msec for the smallest porosity to 16 msec for the largest. Because of magnetic field drift during the measurements, the precision of these first measurements was low. Additionally, since values for measured porosity are not yet available, the functional form of the relationship between T_1 and porosity for the samples was not determined.

CORE PROPERTIES

Of importance are measurements of porosity, pore size distribution, permeability and relative permeability under different confining conditions. Also useful are the results of measurements of phenomena showing dependence on physical properties such as electrical conductivity, compressibility and sound velocity. This information is now being assembled. A review of available literature on the thermal properties of various sandstones gave insight on the nature of micropores anticipated for core as well as on fluid saturation methods. Some micropores are located in critical positions with respect to path for the flow of heat in sandstones. The thermal conductivity of sandstone is sensitive to the degree of fluid saturation as well as pore size and shape distribution.

NMR LOGGING TOOL DEVELOPMENT

A broad band receiver was ordered to replace the present older unit. The Faraday cage surrounding the magnet-coil system was completed, which will reduce pickup from radiating noise sources in the area. The magnetic field was found to be nonuniform over the faces of the permanent magnet. Therefore, magnetic field strength was mapped over the faces and an effective value was obtained for use in comparison with theoretical calculations.

Calculations are in progress on optimum magnet diameter and length for a prototype tool. Diameters of 4 in., 5 in., 5½ in. and 6 in., and lengths of 6 in., 9 in., 12 in. and 24 in. will be tested.

A 6 in. diameter permanent magnet in an 8 in. diameter hole will produce a field suitable for NMR at 500 kHz at 2 in. into the formation. Practical consideration may require alteration in magnet diameter and/or operating frequency.

SCHEDULE STATUS

Figure 3-9 is LASL's milestone chart.

SANDIA NATIONAL LABORATORY

HYDRAULIC FRACTURE CHARACTERIZATION

The surface electrical potential system (SEPS) is undergoing small electrical modifications so it will have the capability of measuring potential gradient around the fracture well. This will be in addition to the present capability of measuring the potential values around the fracture well. Some minor changes to the FORTRAN Software Program, HALFRC, will be required.

Preliminary codes for the desktop computer have been completed and are operational. Analysis of digitization and zero cross over-time measurement of pulse type signals can now be made. Although a sampling time interval of .5 milliseconds is the limit for the present desktop computer system, some analysis of hammer flow type signal is possible. Because of the extreme complications from multipath signals in the CW signal analysis, some effort has been shifted to the analysis of the hammer flow type signal. The analysis will be used for the fracture diagnostics case and will be considered for formation velocity information. A mathematical analysis has been initiated of the hydrophone system as to its time and frequency response.

SEISMIC FORMATION MAPPING PROGRAM

The full report of this program describing the modeling phase and the field experiment has been completed. The report will be issued after review and editing are completed. The possibility of further exploratory drilling at the Bryson Canyon site to confirm the seismic interpretation has been discussed. If such a program is approved, Sandia will aid in the location of these additional boreholes. The current thrust of the Seismic Formation Mapping Program has switched from the Bryson Canyon experiment to application at the upcoming multi-well experiment.

BOREHOLE RESISTIVITY SYSTEM

Increasing the number of elements along the two-dimensional borehole model in the finite element code brought calculations into closer agreement with the one-dimensional model, as shown in Figure 3-10. The remaining discrepancy may be due to the very large aspect ratio of elements near the borehole. These elements are a necessity if a rectangular mesh structure is maintained. Since the reverse problem will likely conform to this rectangular structure, the 2 to 3 percent error near ten meters will have to be tolerated. The ridge regression inversion algorithm (specifically Margvardt's method) is now being coded and will be used with both one and two-dimensional models.

ELECTROMAGNETIC IMPEDANCE SONDE

Dielectric Modeling

Work this past month was concentrated on digitizing optical pictures of rock samples and trying different approaches to define parameters which will suitably describe the observed pore structure. These pore structures will then be placed into the dielectric models. Figure 3-11 shows the

result of digitizing such a picture. The photograph is of sample No. 4403.8 from the CIGE NBU No. 21 core which was permeated with blue-dyed epoxy allowing the connected pores to be located and their outline traced. Figure 3-12 shows the same picture after computer analysis. The individual line segments represent constant spacing. Finding mean and standard deviation of the segment lengths might provide some indication of the pore shape. The line segments were drawn using the picture frame as the principal axis. If, however, each pore has its own axis system defined simply by the longest dimension, then a measure of the anisotropy of the system can be obtained. Figure 3-13 shows such an analysis. The angle between the pore principal axis and the picture horizontal axis is plotted for each pore. The figure shows that a weak anisotropy might exist but further work is necessary to determine the best method of defining the pore axis system and then the anisotropy.

Sonde Modeling

The modeling of coaxial coils was completed for homogeneous formation interrogations. The transfer impedances of coupling coils have served as the measurable responses to evaluate the refractive index of an undetermined formation. The refractive-index charts are now in use as a baseline for quantifying perturbations due to borehole conditions and invasion profiles.

Drilling muds with low conductivities were found to have negligible effects, which is consistent with published results of other investigators. On the other hand, muds with high conductivities have significant effects for operating frequencies higher than 30MHz. Inversion charts with borehole effects are being compiled for documentation.

The development of a generalized N-Zone code has been undertaken to assure that a formation can be evaluated when a general invasion profile is specified. Extremely slow convergence of the simpler problems in the

Figure 3-10 Comparison of 1-D and 2-D Model Calculations

Figure 3-11 Digitization of Sample No. 4403.8 from CIGE No. 21 Core

Figure 3-12 Computer Analysis of Digitized Sample No. 4403.8

Figure 3-13 Principal Pore Axis Angles

Figure 3-14 Milestone Chart — Sandia

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 3-14 Continued

past has ruled out the straightforward integration for the N-Zone case. Presently, the tedious analytical transformations for rapid convergence have been performed and coded for computations. Preliminary results for this generalized N-Zone code indicate an accuracy to the 12th digit when the physics and geometry were reduced to a homo-

geneous formation. Reductions to other configurations are in progress to check published results of other investigators.

SCHEDULE STATUS

The status of the Sandia WGSP progress is shown in Figure 3-14.

SECTION 4

FIELD TESTS & DEMONSTRATIONS

BACKGROUND

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

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

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

Table 4-1 MHF Contract Location and Frac Data

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

WATTENBERG FIELD

DE-AC08-77ET12046

Colorado Interstate Gas Company
Colorado Springs, Colorado
Status: Active

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

OBJECTIVE

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

COLORADO INTERSTATE GAS COMPANY

Production and injection of dehydrated gas for Miller No. 1 and Sprague No. 1 continued through July. Two weeks of production, amounting to 3,843.9 MCF from Sprague No. 1 during early July, was dehydrated and subsequently injected into Miller No. 1. During this portion of the cycle, 3,561.1 MCF of gas was injected with a water content

of 4 lbs of water per MCF.

During the latter two weeks of July, 463.8 MCF was produced from Miller No. 1, dehydrated and injected into Sprague No. 1. The injected gas amounted to 4,067.0 MCF. Five days of downtime were recorded during the 31 days of production and injection.

**DOE WELL
TEST FACILITY**

DE-AC08-79-BGO1569

CER Corporation
Las Vegas, Nevada

Status: Operational

Principal Investigator:
Technical Advisor for DOE:

R. L. Mann
C. H. Atkinson

OBJECTIVE

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

DOE WELL TEST FACILITY

The instrumentation trailer and 30 kw generator are undergoing modifications at the

EG&G facility in Las Vegas, Nevada.

**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 July, GPE Natural Buttes Nos. 9, 14, 18 and 20 flowed to sales. NBU No. 19 was shut in due to repairs and NBU No. 22 was shut in because it was making water. NBU No. 21 is still temporarily abandoned in the Mesa-

verde horizon.

Figures 4-1 through 4-6 show the production histories of these wells since they were fractured.

Figure 4-3 Flow Rate of Natural Buttes No. 18 Well

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

Figure 4-5 Flow Rate of Natural Buttes No. 20 Well

Figure 4-6 Flow Rate 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

Equipment modifications are being made so two of the exploratory coreholes can be used for in situ stress measurements.

Fluid Mechanics/Proppant Transport Experiments

In situ stress measurements were made in the region where tests will be conducted to determine site suitability. It was found that the minimum in situ stress is quite uniform with a magnitude of about 525 psi. Mineback of the created fractures is now underway to determine the orientation of the stress field and to provide an experiment access drift.

In Situ Stress Measurement by Hydraulic Fracturing Through Perforations

Five zones in a second cased hole have been perforated with four perforations in the farthest zone and two perforations in each of the other four zones. Orientations of the perforations are staggered horizontally and vertically. These zones will be fractured in August.

Feasibility Study for the Prediction of In Situ Stress and Hydraulic Fracture Orientation by Strain Relaxation Measurements

Knowledge of the state-of-stress is particularly important for accurate prediction of the shape and orientation of massive hydraulic fractures that stimulate gas production in low permeability reservoirs. Accordingly, a feasibility study has been conducted in tuff at

the G tunnel (NTS) to determine the state-of-stress from time-dependent strain relaxation of over-cored specimens. This was done using two techniques: a strain gauge rosette on the surface of the core and disc gauges attached to the circumference of the core. The strain-gauge rosette was mounted prior to over-coring and measured both the elastic and time-dependent strain relaxation of the core. After overcoring and the removal of core from the tunnel wall, the disc gauge was attached and measured only the time-dependent relaxation.

Preliminary analysis of the data indicated that the tuff behaved linear viscoelastic with the cores relaxing asymptotically to a final permanent strain within 36 hours. Both techniques produced similar results, which suggests that the orientation of the principal strain is identical for the instantaneous elastic strain and the time-dependent relaxation strain. The principal stresses and their directions can be estimated from these strain determinations using the appropriate elastic constants. These calculations are nearly complete.

This study suggests that both techniques for strain-relaxation measurements of oriented core at depth may indicate the orientation of the principal strains and stresses and thus, accurately predict the orientation of subsequent hydraulic fractures. Additional studies in the Piceance and Uinta Basins are planned.

Petrological and Geochemical Effects on Hydraulic Fracture Behavior

A comprehensive investigation is being conducted of the "hard bands" observed in the NTS Tunnel Bed No. 5 formation. These bands have been associated with measured high minimum stresses and thus have affected hydraulic fracture behavior. The objectives of this study are:

- a detailed mineralogical analysis of these layers, using optical microscopy, SEM and x-ray diffraction;
- an interpretation of their origin; and
- to determine what relationship exists between the distribution of the hard bands, elastic moduli changes and in situ stress.

To date, the petrographic information shows the bands to be composed of intensely zeolitized tuff, whereas the adjacent material is not zeolite-cemented. The most abundant zeolite phase is calcium-rich clinoptilolite; in addition, low-cristobalite appears frequently in both the hard bands and unaltered tuff. A diagenetic origin for these features

has been proposed which involves zeolite precipitation from silica-rich groundwater where the bands possibly mark former positions of the water table.

Petrographic data collection has not yet been completed; the series of strain-relief stress measurements reported in the previous section will also provide samples for study. When this work is completed, it may be possible to relate the hard bands to changes in moduli and/or in situ stress. A possible analog in the tight gas sands may be silica diagenesis occurring where upward-diffusing groundwater meets an impermeable barrier.

SCHEDULE STATUS

Figure 4-7 is a milestone chart, depicting the Sandia-Mineback progress.

Figure 4-7 Milestone Chart — Sandia Mineback