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Western Gas Sands Project Status Report

1 June - 30 June, 1980

Prepared for
U.S. Department of Energy
Bartlesville Energy Technology Center
Las Vegas Field Office
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SUMMARY

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

Northwest Exploration declined use of their site for the multi-well experiment; additional sites are being contemplated. Experiments began at Bartlesville Energy Technology Center designed to examine fracture closure and crushing strength of bauxite. At Lawrence Livermore Laboratory, work is progressing on the code to calculate fluid motion in an expanding propagating crack.

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SECTION 1

PROJECT MANAGEMENT

*Coastal and Deltaic Sedimentation
of Upper Cretaceous Eagle
Sandstone: Relation to Shallow
Gas Accumulations, North-Central
Montana*

by D. D. Rice
USGS

TECHNOLOGY TRANSFER

DOCUMENTATION REPORTS

The *WGSP Financial Supplement* for June, 1980, and the *April WGSP Status Report* have been distributed. Compilation of data has begun for the *Quarterly Basin Activities Report* for Second Quarter 1980. The Greater Green River Basin facies maps are being reviewed and revised where needed. Work continued on the production history of the Piceance Basin; later, maps will be drawn of each producing horizon and test. The Uinta Basin base map has been updated with production information.

PROJECT DATA BANK

The following maps were added to the WGSP data bank:

"Map Showing Appraisal of Mineral Resource Potential of Rare II Proposed Roadless Areas in National Forests, Montana (Exclusive of Coal, Oil, Gas and Construction Materials)," compiled by M. R. Mudge, R. L. Earhart and D. D. Rice, USGS, 1978.

"Landsat Lineaments in Western South Dakota," by G. W. Shurr, USGS, 1978.

ARTICLES AND PUBLICATIONS

The following paper relates to the WGSP and is included in the bibliography. The abstract is included here.

Depositional environments of the Upper Cretaceous Eagle Sandstone were studied at outcrops along the Missouri River and its southern tributaries from the town of Virgelle southeastward to the mouth of the Judith River in north-central Montana. In this area, the Eagle is divided into three members -- the Virgelle Sandstone Member, 80 to 130 ft (24 to 40 m) thick, and the middle and upper members, which together are as much as 220 ft (67 m) thick. The Eagle Sandstone is underlain by the Telegraph Creek Formation and overlain by the Claggett Shale, both of Late Cretaceous age. The Telegraph Creek accumulated in an offshore-shoreface transition environment and grades upward into the shoreface and foreshore sandstones of the Virgelle Sandstone Member. The basal Virgelle was deposited along an eastwardly prograding coastal-interdeltaic mainland shoreline. The middle member of the Eagle represents coastal-plain deposition. In the eastern part of the area, the upper part of this member comprises a sheetlike, delta-front sandstone capped by a thin coastal-plain unit. The delta-front sandstone was deposited along a wave-dominated shoreline that prograded over a coastal plain following an overall marine transgression. The upper member lies disconformably on the middle member and is represented by rock types which were deposited in two distinct depositional settings.

Interbedded sandstone, siltstone, and shale that exhibit variable bedding types in the northern outcrops probably accumulated in a tidal-flat environment. Progradational cycles of shoreface sandstones are characteristic of the upper member in the southern outcrop. Chert gravel in the upper member and in the basal part of the Claggett Shale forms a persistent time interval in the northern Rockies and probably represents a lag deposit laid down by the transgressing sea.

Natural gas from shallow accumulations in the Eagle Sandstone of the Bearpaw Mountains area is of biogenic origin and was probably

generated in the surrounding shales during Late Cretaceous time. Although gravity-induced faults formed after the gas generation provide the final trapping mechanism, the initial control for entrapment was stratigraphic. Most of the early generated gas has remigrated into separate, discrete structural traps where porous reservoirs are developed; some of the gas may have been selectively sealed in original stratigraphic traps. The outcropping depositional units, in particular the reservoir sandstones, can be traced into the subsurface and identified in nearby wells. Thus, an understanding of depositional environments is an important exploration tool for shallow gas accumulations.

SECTION 2

RESOURCE ASSESSMENT

U.S. GEOLOGICAL SURVEY ACTIVITIES

UINTA-PICEANCE BASINS

Stratigraphic and reservoir analysis continued of the Uinta and Piceance Basins.

Pressure data is being compiled in the Piceance Basin.

Contour maps of the top of the Cretaceous in the Piceance Basin are completed and in review.

Logs are being digitized of cored intervals from studied wells.

A Chinese delegation of petroleum scientists were taken on a field trip through the Uinta Basin.

A paper is in preparation for the study of Tertiary stratigraphy, sedimentology and mineralogy of cores from Southman Canyon area, Uinta Basin.

A paper was prepared on the relations between diagenesis and porosity in Mesaverde core from the Uinta Basin.

A paper for a study of Tertiary stratigraphy, sedimentology and diagenesis of cores from Pariette Basin Field, Uinta Basin is being prepared.

GREATER GREEN RIVER BASIN

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

A map was submitted for review: "Preliminary chart showing electric log correlation section J-J' of some Upper Cretaceous and Tertiary rocks, Washakie Basin, Wyoming," by T. F. Tyler, J. R. Peterson, and H. E. Bucurel.

A paper was presented entitled "Evaluation of organic matter and subsurface temperature and pressure with regard to gas generation in low-permeability Upper Cretaceous and lower Tertiary sandstones in Pacific Creek area, Sublette County, Wyoming," by B. E. Law, C. W. Spencer and N. H. Bostick at the National AAPG-SEPM-EMD Convention.

Exposed strata in the Hoback Basin are being analyzed.

Well and pressure data for Pinedale area wells are being compiled.

NORTHERN GREAT PLAINS PROVINCE

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

Core continues to be solicited from operators in the Bowdoin Dome area, Montana, and West Shore Pine Hills Field, South Dakota.

Cation-exchange and X-ray diffraction studies continued on clays from Gammon Shale in southwestern North Dakota.

Field and laboratory studies began of authigenic carbonates in the Gammon Shale from Montana and North and South Dakota.

Field work continued on Mosby and Eagle Sandstones-equivalent rocks in the northern Great Plains.

Papers were prepared on the following subjects:

- Diagenesis of Eagle Sandstone conventional and low-permeability reservoirs; and

- Bowdoin gas production from tight reservoirs.

Cross sections from western Canada to north central Montana are being drafted.

SCHEDULE STATUS

A milestone chart of USGS WGSP-related projects is shown in Figure 2-1.

CORE PROGRAM

Several operators were contacted during the month concerning possible core projects. Although there were some positive developments, no firm commitments were made by the end of June.

Cotton Petroleum was contacted during the first of June concerning potential coring locations in the Uinta Basin, south of the Natural Buttes Unit.

Cities Service Gas expressed interest in coring their well No. C397-8-4, Sec. 8, T3S, R97W, Rio Blanco County, Colorado (Piceance Basin). Core from the continental and/or marine Mesaverde section would be obtained. Also concerning the Piceance Basin, Dome Petroleum has a series of wells being drilled in the Baldy Creek Unit, Garfield County. They are considering coring the second well in this series, with a possible spud by the end of August.

Lario Oil & Gas was contacted concerning coring a well in Sec. 9, T14N, R3E, Butte County, South Dakota. Lario was interested in obtaining core from the Shannon horizon and even coring beyond the proposed 120 ft. Although the prospects were good, Lario decided against participating because they felt the contract was too complicated.

SURVEY OF BASIN ACTIVITIES

GREEN RIVER BASIN

During June, 23 wells were reported completed: 12 development wells were producers, 2 wildcats were discoveries, 4 of each type were D&A, and 1 development well was completed and shut in. Two development locations were abandoned. By month's end, 42 new locations were staked: 22 development and 20 wildcat.

Total initial potential flow (IPF) of new gas was 11,014 MCFD. The Frontier horizon was the largest contributor with 3,711 MCFD. Other horizons included the Lewis, Mesaverde undifferentiated, Transition Zone, Fox Hills, Almond, Fort Union and Frontier/Dakota commingled.

A summary of reported well activity is shown in Table 2-1, and Figure 2-2 shows the wells' locations.

NORTHERN GREAT PLAINS PROVINCE

By month's end, 30 newly-staked locations were reported: 16 development and 12 wildcat. There were also 30 wells reported as complete: 13 development wells were producers, 2 wildcats were discoveries, 1 development and 2 wildcat wells were D&A, and 10 development wells and 2 wildcats were completed and shut in. Four development locations were abandoned.

The largest contributing horizon was the Bow Island with an initial potential of 1,713 MCFD of new gas. Other contributors reported during the month included the Eagle, Phillips, Blackleaf, Blackleaf/Bow Island commingled and Vaughn/Bow Island commingled for a total gas initial potential flow of 4,138 MCFD. Twelve IPFs were not available.

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

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

PICEANCE BASIN

No wildcat completions were reported during June. Nine development wells were reported as producers, 1 was D&A and 1 was shut in for a total 11 completions. One development location was abandoned. Twenty-five new locations were staked by month's end: 20 development and 5 wildcat.

Total initial potential flow of new gas was 5,205 MCFD, with the Corcoran as the largest contributing horizon. Other horizons included the Mancos B, Rollins, and Ohio Creek/Mesa-verde commingled. One IPF was not available.

A sample of wells and new locations is listed in Table 2-3 and shown in Figure 2-4.

UINTA BASIN

Reported activity from this basin was limited during the month. Two development wells were reported as producers, with the total

initial potential flow of gas being 2,569 MCFD. Production was from the Wasatch Formation.

Twenty-two newly-staked locations were reported during June: 15 development and 7 wildcat.

Table 2-4 is a summary of wells and new locations from the basin, and Figure 2-5 shows their locations.

C K GEOENERGY CORPORATION

A draft copy of the final report for the Green River Basin/Wind River Basin Outcrop Study is being reviewed by DOE.

Except for the logging section, a draft of the final report of the Uinta Basin Core Hole Study has been submitted for review. The funds have been extended to complete the logging tasks.

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 Red Prong-Federal	1	swne 21/13N/92W Wildcat Field Carbon Cnty, WY	Mesaverde 8,500			Wildcat test, reported 5-27-80.	
Belco Petroleum	1-17 McGinnis	2	nws 17/26N/112W Green River Bend Field Lincoln Cnty, WY	Frontier 7,243-7,296 (gross)	7,622 PB: 7,583	27,750 gal water, 104,000 lb sand.	Develop. well, comp. 2-16-80.	105
Texas Oil & Gas	1 North Bitter Creek	3	e½nw 2/16N/99W Bitter Creek Field Sweetwater Cnty, WY	Fox Hills 7,436-7,883	8,124 PB: 7,979	Acidized w/ 2,000 gal; fractured w/103,000 gal gel, 150,000 lb sand.	Wildcat shallow pool discovery, comp. 8-29-78. No cores or tests.	540
Davis Oil (Well name changed from Sun Oil)	1 Sun Unit	4	sene 4/26N/97W Wildcat Field Sweetwater Cnty, WY	Lewis 14,200	14,271		Wildcat well, comp. 5-8-80 D&A. No cores; drill stem tested.

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
Sugar Creek Resources	1-5 BN-Pickard Brothers	1	sww 5/7N/60E Cedar Creek Field Fallon Cnty, MT	Eagle 1,560-1,696 (gross)	1,850 PB: 1,790	33,516 gal water, 80,000 lb sand, 319,200 scf CO ₂ .	Develop. well, comp. 10-22-79 as SIGW. No cores or tests.	N/A
Century Oil & Gas	23-1 Warwick	2	nwnw 23/28N/4W Wildcat Field Pondera Cnty, MT	Bow Island 2,000	1,944		Wildcat well, comp. 5-13-80 D&A. First report and completion,	
Brownlie, Wallace, Armstrong & Bander	9-22 Miles	3	senw 9/1N/53E Wildcat Field Custer Cnty, MT	Shannon 2,550			Wildcat test, reported 6-12-80. Operator has 1 additional Shannon test in locale.	
Lyttn Company; William Vaughney Jr.	3 lva Kolstad	4	senw 32/29N/4E Unnamed Field Liberty Cnty, MT	Bowdoin 1,500			Wildcat outpost, reported 6-10-80. Operator staked 1 additional Bowdoin test in locale on same day.

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
Teton Energy	29-2 Federal	1	swnw 29/8S/97W DeBeque Field Mesa Cnty, CO	Rollins 3,020-3,234 (gross)	3,683 PB: 3,260	Acidized w/ 1,000 gal; fractured w/52,000 gal gel, 80,000 lb sand.	Develop. well, comp. 1-2-80 as SIGW.	N/A
Chandler & Associates	14-4-2-1 Federal	2	sesw 4/2S/101W Trail Canyon Field Rio Blanco Cnty, CO	Mancos B 2,203-2,311	2,690	Acidized w/ 2,000 gal; fractured w/100,800 gal water, 265,000 lb sand.	Develop. well, comp. 11-12-79. No cores or tests.	340
Teton Energy	16-3 Yellow Creek-Federal	3	swsw 16/1S/99W Wildcat Field Rio Blanco Cnty, CO	Mancos 10,200			Wildcat test, reported 6-20-80.	
Northwest Exploration	44 USA	4	sesw 21/1S/101W Dragon Trail North Field Rio Blanco Cnty, CO	Mancos 2,688			Develop. test, reported 6-29-80. Operator staked 6 additional locations in locale on same day.

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	60-26B Natural Buttes Unit	1	swne 26/10S/22E Natural Buttes Field Uintah Cnty, UT	Wasatch 5,828-6,947 (gross)	7,031 PB: 7,002	87,000 gal water, 138,000 lb sand.	Develop. well, comp. 7-27-79. No cores or tests.	259
Pacific Transmission Supply Co.	31-26 Federal	2	nwne 26/12S/15E Unnamed Field Carbon Cnty, UT	Mesaverde 5,900			Develop. test, reported 6-20-80.	
Mapco Production	1-26A Federal	3	nene 26/9S/18E Natural Buttes Field Uintah Cnty, UT	Green River 5,500			Wildcat shallow pool test, reported 6-4-80. Operator staked 1 additional Green River location in locale on same day.	

GAS RESEARCH INSTITUTE SPONSORED PROJECTS

Work continued on resource evaluation and the development of a matrix or information model to identify the state-of-the-art in tight gas sands technology. A proposed matrix format has been developed and will be presented in July.

A subcontract has been proposed with M. D. Wood, Inc. to furnish FRAC-MAP services to obtain information on hydraulic fracture length at two sites in the Wattenberg Field, Colorado. The sites will be furnished by Amoco Production Company, which will also provide some well stimulation data.

EVALUATION OF SEISMIC DATA FOR DETAILED STRATIGRAPHIC STUDIES IN 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 on a geologic review of the tight gas potential in the Arkoma Basin and Ouachita Mountains Province of Oklahoma and Arkansas. Geologic review continued on the Raton Basin of New Mexico and Colorado, and preliminary background work has begun for the Anadarko Basin of Oklahoma and Texas.

TRW WESTERN GAS SANDS SUPPORT

COMPUTERIZED DATA BASE DEVELOPMENT

An assessment has been made of using existing computer data base systems to establish a WGSP computerized data base. Also, alternatives for developing that data base system

have been evaluated. Two types of systems have been considered. The first contains only abstracts of WGSP-related documents and other information sources; a user would access the system with a keyword and the system would print out sources of information relating to that keyword. The second, which includes the first, would also contain geological and technological data relevant to the WGSP. The systems will be designed so they can be accessible from remote locations by all project participants and other designated users.

WGSP FY 1981 PROJECT PLAN

Task and milestone inputs were obtained from all project participants, and a draft of the FY 1981 Project Plan Document was written according to project organization and format specifications provided by METC and WGSP management. The document has been submitted for project management review.

ECONOMIC ANALYSIS OF GAS PRODUCTION FROM TIGHT GAS SANDS

Work continues on the development and application of an economic analysis methodology. This report summarizes progress to date on this activity.

A data base for over 900 gas wells in the Uinta, Greater Green River, Piceance, and Denver (Wattenberg Field) Basins has been developed. Most of these data were acquired in a previous data acquisition task. Subsequently, the data base has been augmented by filling data gaps and updating gas production information. The well data have been evaluated and a subset of wells, which have adequate data available for analysis, has been defined.

For various reasons, including data availability, gas production data are being used to measure the effectiveness of well performance. Four independent production decline programs, using least-squares curve-fit, were

developed and coded to determine the best (in the least-squares sense) exponential, harmonic, hyperbolic and generalized hyperbolic fit. While all four programs provide good fits of the measured data, the generalized hyperbolic model provides the most reasonable extrapolation. However, an implementation disadvantage of this model is that it incorporates a two-dimensional iteration scheme; to obtain a converged solution requires trial and error selection of starting values for the iteration. Consideration was given to switching to exponential decline when the gas flow regime transforms from a linear to radial regime. However, calculations showed that in the tight reservoirs, linear or transitional flow exists through most or all of the expected lifetime of the well. The curve-fit programs can compute an extrapolated decline curve and cumulative production for any desired time. To implement a statistical analysis of the well data, generalized hyperbolic production decline curve-fits have been obtained for several hundred wells from the Denver Basin (Wattenberg Field), Washakie (Greater Green River) Basin, and Piceance Basin. A computer plot capability was developed which plots actual decline data and superimposes a plot of the computed curve fit. Such plots have been obtained for over a hundred wells.

A series of modifications, which address specific changes needed for analyses of the western basins, was incorporated into a previously-developed gas well economic model. Using the extrapolated curve-fits and cost data developed for the recent NPC evaluations, expected values of internal rates-of-return (DCF) are being calculated. In a given area, these calculations can be made as a function of economic factors, such as wellhead gas prices and/or engineering parameters, such as fracture size. Since the decline curves are based on existing wells, this reflects existing state-of-the-art technology. The results will show the effect of variations in stimulation and geologic parameters, and in gas price and well cost.

A more general approach is to compute a simultaneous regression on all technical parameters that have a significant effect on well production. A computerized procedure to accomplish this was developed by TRW for another study, and is currently being utilized on the Wattenberg and Washakie data sets.

MULTI-WELL EXPERIMENT

Northwest Exploration Company declined use of their site for the MWX in June. Site negotiations are presently underway with ARCO, Superior Oil Company and Exxon. All of these companies have holdings in the Colorado River Valley region near the Northwest Exploration Company site, which was desirable both from the technical and logistical aspects.

The Sandia-CER budget requirements were revised and were broken down by wells (MWX-1, -2, and -3) and by fiscal year. Preliminary schedules were made and it was demonstrated that sequential drilling of MWX-1, -2, and -3 by the same drill rig will result in significant dollar savings compared with separate mobilization of a drill rig for each well.

CORE PROGRAM

A meeting was held with Sandia organizations concerning pressure coring in the gas sands for MWX. Results of the meeting included:

- Pressure Core Inc. will be approached to see if they would make appropriate modifications so gas could be extracted directly from the inner core barrel; and
- a non-invasive gel would be provided for use in the pressure core barrel which would be compatible with oil-based mud used on the MWX.

Figure 2-6 Milestone Chart – MWX

The design of the steel skid for the core handling facility was completed.

Approval was received from the Petroleum Frequency Coordinating Committee to use the frequency 153.275 MHz at the site. This application will be resubmitted when the new

location is available.

SCHEDULE STATUS

Figure 2-6 is a milestone chart showing the MWX progress.

SECTION 3

RESEARCH & DEVELOPMENT BY ENERGY TECHNOLOGY CENTERS & NATIONAL LABORATORIES

BARTLESVILLE ENERGY TECHNOLOGY CENTER

IMPROVED PRESSURE CORING SYSTEM — SANDIA LABORATORIES

Core Retriever Design and Test

The layout for a longer (20 ft) pressure core barrel is being completed. Conceptual testing of a prototype inner barrel mechanism will begin in August.

Solid state pressure transducers have been installed in a laboratory test core barrel. Accuracy problems were encountered in testing, and several of the gauges have been returned to the manufacturer for calibration.

The simplified pressure regulator has been rebuilt and laboratory tested with water to 15 ksi and with air to 5 ksi. Twelve cores were recovered using this regulator and improved reliability and ease of servicing have been demonstrated. All stainless galling problems have been solved.

Providing an orientation feature for pressure cores is proceeding. Orientation sensors have been reviewed and design concepts are being generated which place a compass sensor in the gel-retaining plug, located above the bit.

The number of requests for pressure coring in low pressure (1,000 psi) reservoirs is

increasing and it is apparent that an effort is needed to develop coring capabilities using foam and air or air mist systems.

Core Fluid Tests

The Sandia-designed low invasion fluid continues to be used in field operations. The present recipe is 10 lbs/BBL of HEC polymer and 300 lb/BBL of CaCO_3 particles in a eutectic solution of CaCl_2 . Fluid mixing has been improved with the use of a large capacity mixer. A mixture that results in about 7 gal of fluid in the barrel appears to be optimum for minimizing air entrainment. In addition, five inner barrels of low invasion fluid were used for laboratory coring tests to evaluate bits. Fluid performance was excellent, with all cores being encapsulated in the fluid.

The dynamic invasion test loop apparatus has been used to conduct over 40 laboratory fluid invasion tests. These tests will help select an efficient low invasion fluid for pressure coring. The testing generally supports the concept of using a polymer fluid with bridging particles to reduce invasion. The above recipe, as used in the field, is the best performer in these dynamic tests to date. It is superior to conventional drilling muds and polymer muds of lower viscosity. Studies are continuing on particle size optimization.

Analysis of field test invasion data using tracers confirms the value of using a low invasion fluid for pressure coring. In typical oil field formations, the level of core washing is reduced below the 5 to 10 percent level resulting in much higher average air saturation.

Bit Design and Fabrication

The Sandia-designed bits with improved hydraulics were laboratory tested in June. Two one-piece bits (incorporating a raised dam to reduce invasion) and two bits using a screw-in pilot were constructed. All bits used diffusion-bonded cutters mounted on

steel studs. All bits had a 6-½ in. diameter and cut a 2-½ in. core.

Polycrystalline Diamond Core Bit Tests

Laboratory testing of the second generation core bits was conducted. The Sandia single-piece bit demonstrated excellent coring capabilities in Berea Sandstone, Indiana Limestone and Nugget Sandstone. High penetration rates at low-bit weights resulted in well-defined cores. Field tests of this bit will begin in July at Denver City, Texas.

The two-piece pilot-style core bit jammed during testing. The jamming was most severe in the limestone but also occurred occasionally in the Berea Sandstone. This poor performance is believed to be associated with several factors inherent in atmospheric testing, such as dry test rocks and trapped air in the bit body preventing efficient flow of the low invasion fluid. As these conditions do not exist in fluid-filled bore holes, the bit is scheduled for further field testing.

IN SITU PERMEABILITY

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

Liquid and gas permeability measurements were conducted on Core No. 7427.5 from the CIGE NBU No. 21 well, Uinta Basin. As in the previously reported case of Core No. 6475.5, liquid permeabilities were consistently lower than Klinkenberg permeabilities. The results are shown in Figure 3-1. It was noted that at high net confining pressure, the ratio of the two permeabilities remained approximately constant. It appears that the initial drop in permeability (i.e. at low net confining pressures) may be attributed to the effects of brine-rock interaction. SEM and thin section studies indicate the absence of water-sensitive or swelling clays, and the discrepancy in permeability values may be due to the readsorption of water molecules

on clays which were dehydrated when the core plugs were dried. The difference in permeability may also be due to the effect of clay or fine movement and blockage of pores by the same as a result of the high differential pressure 0.058 MPa (85 psi) used to maintain flow. It is to be noted that the permeability of this core [initial gas permeability of 0.028 md at a net confining pressure of 0.827 MPa (120 psi), and mean pore pressure of 0.24 MPa (34.7 psi)] was significantly lower than the initial gas permeability of core No. 6475.5, which was 0.997 md under the same conditions of net confining pressure and mean pore pressure.

Pore volume compressibility for this core was determined to be 5.58×10^{-4} pV/pV/MPa. The sample had a porosity of 0.07.

Similar measurements were conducted on Core No. 900.6 (depth: 900.6 ft) from the DOE-GC-1 well, Sec. 16, T17N, R24E, Uinta Basin. This core had an initial gas permeability of 1.35 md (at the same conditions specified for the two core samples above). It was observed that the permeability of this sample (both the Klinkenberg permeability and the liquid permeability) did not decrease as drastically as for the other plugs as net confining pressure was increased. The results are shown in Figure 3-2. Liquid permeability values were lower than the Klinkenberg permeability values.

The porosity of this core was determined to be 0.163. Pore volume compressibility was 1.48×10^{-4} pV/pV/MPa.

Permeability of Interbedding Material of Tight Western Gas Sands – Lawrence Livermore Laboratory

Four samples were prepared and loaded into the pressure vessel. An external furnace for the pressure vessel was fabricated in June and will be installed in July. A parameter study was performed to evaluate the permeability measurement technique and a report of the results of this study is expected in July.

Figure 3-1 Comparison of Extrapolated Klinkenberg Permeability and Liquid Permeability

Figure 3-2 Comparison of Extrapolated Klinkenberg Permeability and Liquid Permeability

During July, permeability data at pressure (1 to 10 MPa) will be obtained for four samples. When installed, the vessel furnace will permit evaluation of permeability as a function of temperature (25 to 350°C).

LOGGING STUDIES

Interface Conductivity Effects on Electric Logging

Apparatus was set up to measure liquid permeability and electrical conductivity of tight core material as a function of overburden pressure. Several changes were made in the experimental procedure and samples from the Uinta Basin were tested. Increased overburden pressure resulted in decreased permeability and conductivity.

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

A search in the Vernal, Utah, area for Mesa-verde water samples was instigated and the companies contacted were: Enserch Exploration, Inc., Mapco (Mid America Pipeline Company), Gas Producing Enterprises, Dowell Inc., Halliburton, The Western Company, Gulf Oil Company, Conoco, Pacific Gas Transmission Co., and Schlumberger. All were agreeable to share formation water data. However, most of the information was rendered useless because of the practice of completing individual wells in all potentially productive zones.

One useful water analysis was obtained from the River Bend Unit No. 11-36B, Sec. 36, T9S, R19E, Uinta County, Utah, which has six perforated sections in the Mesaverde and four in the Wasatch. The bottom perforations in the Mesaverde were suspected of being water producers. This was verified during workover and 157 barrels of water were swabbed. Analysis of water recovered on the final swab run, from the Tuscher/Farrar Formation at 8,822 ft to 8,826 ft and 8,802

ft to 8,806 ft, was made with a calculated R_w of 0.27 ohm-meters at 75°F.

After being given access to twelve operators' files, it is concluded that there is insufficient information in company files to bring this project to a satisfactory end. Therefore, operators in the basin will be asked to cooperate in a data-generating system which will give a larger quantity of reliable water resistivity data.

ADVANCED LOGGING TECHNIQUES AND INTERPRETATIONS

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

A Gen Rad 1606B Impedance bridge was tested for dielectric constant measurements in the 500 KHz to 50 MHz range. A precision dial capacitor was attached to the terminals so the capacitance substitution method may be used. The unit performed well on dry samples.

Thirteen sandstone reservoir samples 2.25 in. in diameter and .25 in. thick were prepared for the study. A similar number of synthetic sandstone samples were prepared for equipment testing.

A laser apparatus, used to measure thermal properties of rock samples, was repaired and tested. Results from this stage of the project will be integrated with a dielectric heating process to estimate the dielectric properties of sandstone samples at high frequencies.

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

Tests on a 10-cm cube of Nugget sandstone verified theoretical predictions of the effects of the acoustic birefringence phenomenon. Several measurement approaches were tested, of which a continuous wave phase matching technique appears promising. In this method

the phase shift of an acoustic wave passing through the rock is measured. The phase shift is a property of acoustic birefringence and can be related to external stress. Analytical and experimental studies on same face geometry measurements, which would be required in a borehole, were begun.

HYDRAULIC FRACTURING AND FRACTURE CONDUCTIVITY

Proppant Embedment In Hydraulically Fractured Reservoirs

One of the problems associated with hydraulic fracturing is fracture closure due to crushed proppant in deep reservoirs. A proppant of sintered bauxite was developed to alleviate this problem. However, in deep reservoirs, closure pressures can cause proppant embedment and result in loss of fracture conductivity.

Work has begun on the embedment of sintered bauxite into Berea as a standard. Replicate experiments with 12/20 mesh proppant have shown that the initial 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.

Gray Berea Sandstone was used in a series of experiments designed to examine fracture closure and crushing strength of bauxite. Fracture closure or proppant embedment was examined as a function of proppant coverage and fracture closure pressure. Bauxite proppant (12/20 mesh) was placed between two 4-in. square Berea Sandstone blocks (2 in. thick). The propped area was a 2-in. square area. Dial micrometers were used to measure fracture closure.

Figure 3-3 shows fracture closure as a function of proppant coverage at four closure pressures. Except for the 25 percent coverage data, the values shown in the figure are averages of multiple tests. When coverage is

reduced to 25 percent, the sandstone blocks tend to fracture with increased embedment. When rock fracturing occurred, the results were discarded because the data is not representative of reservoir conditions.

Formation depths were calculated using a gradient of 0.6 psi/ft. These plots represent fracture closure pressures at depths of 1,700 ft to 15,400 ft. Although the slopes at each pressure are linear, the slope increases indicate deeper proppant penetration at higher pressures. For fractures at greater depths, decreased proppant coverage will result in a corresponding greater loss of fracture conductivity. For a 25 percent proppant coverage, fracture closure was found to be approximately one-half at 15,400 ft. Although Berea Sandstone is softer and more porous than typical tight gas sand formations, initial results indicate that proppant embedment is greater into tight gas sand rocks than into the Berea. However, large quantities of homogeneous tight gas sand core were not available for repetitive embedment tests. Further tests are planned to correlate this work with typical tight sands.

Microscopic examinations of the stressed bauxite showed that part of the proppant cleaved or cracked, but did not shatter like sand proppants. Ongoing tests will determine the relative crushing strength of these two materials.

Feasibility of Fabricating Light Weight Proppants for Application in Gas and Oil Well Stimulation — Terra Tek, Inc.

The primary object of this contract is to determine the feasibility of fabricating light weight proppants for application in deep gas and oil well stimulations. This work includes the selection of viable materials and manufacturing techniques.

A theoretical comparison of solid, hollow and porous spheres is shown in Figure 3-4. Also shown are values for glass, sintered bauxite (using estimated properties), and a "design goal" of specific gravity of 2.0 with a fracture

Figure 3-3 Fracture Closure Vs. Proppant Coverage Using 12/20 Mesh Sintered Bauxite and Grey Berea

Figure 3-4 Theoretical Comparison of Porous with Hollow Spheres, 20/40 Mesh

pressure of 20,000 psi. Several trends are apparent, the most obvious being the strength versus specific gravity tradeoff. However, the differences between materials is also striking. The advantages of using a high strength material such as the AD999 (99.9 percent pure) alumina is apparent. In general, the results appear to indicate that significant advances in proppant strength-density properties are possible.

With the exception of the AD999 alumina, the hollow spheres are predicted to have an advantage over the porous spheres. However as shown by the AD999 alumina, this is not a universal rule but depends on the modulus and bend strength of material.

Proppant Transport in Massive Hydraulic Fracturing – University of Tulsa

The object of this contract is to study proppant transport during massive hydraulic fracturing, particularly, the settling of proppant particles in fracture fluids where the fluid viscosity has been enhanced by gelling agents. Primary considerations have been in developing a computational model and identifying the requirements for an economically feasible fracture treatment.

RESERVOIR SIMULATION STUDIES

Reservoir Simulation for Hydraulically Fractured Gas Wells in Lenticular Formations – University of Oklahoma

Work continued toward developing reservoir simulation techniques for analysis and evaluation of hydraulically fractured gas wells completed in noncontinuous lenticular formations. To run the multi-dimensional gas well simulator, computer services were re-established with the University of Tulsa Computer Center. The capability of the existing two-dimensional gas well simulators is being extended to include important effects such as non-Darcy flow in the reser-

voir and fracture, wellbore and fracture storage effects, and frictional pressure drop within the production string.

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

Further study of the uniqueness of reservoir and fracture parameters continued as well as the effect of fracture geometry on the pressure transient response of a well. In addition, work was begun using the Two-Phase Fracture Propagation Model.

The first uniqueness study consisted of a base case model having two 10-ft producing zones with 5 percent hydrocarbon porosity and .10 md permeability. The upper zone had a fracture with a 100-ft half-length and fracture conductivity of 2.6 md-ft. The lower zone had a fracture with a 40-ft half-length and fracture conductivity of 1.1 md-ft. A match of the pressure transient response of the two layer model was obtained with a single 20-ft producing zone and a single fracture with 76-ft half-length and 2.0 md-ft fracture conductivity. Drawdown and buildup curves from the two cases showed agreement between the curves. Figure 3-5 is a comparison between the production forecasts obtained from the two models. It is noted that the single-layer model has a slightly higher initial production rate and declines at a slightly faster rate than the two-layer model. Despite the difference in rates, the two wells had nearly identical cumulative productions at the end of the 10 years.

The second uniqueness study consisted of a two-layer base case model having two 10-ft producing zones with .10 md permeability and 5 percent hydrocarbon porosity. The upper zone had a fracture with 624-ft half-length and fracture conductivity of 9.8×10^3 md-ft. The lower zone had a fracture with 40-ft half-length and fracture conductivity of 6.3×10^2 md-ft. A match of the two layer model was obtained with a single 20-ft producing zone and a fracture with 344-ft

Figure 3-5 Comparison of Production Forecasts

Figure 3-6 Comparison of Production Forecasts

half-length and fracture conductivity of 5.4×10^3 md-ft. Drawdown and buildup curves of the two models showed very close agreement in their pressure responses. Figure 3-6 shows a comparison between the production forecasts obtained from the two models. There is quite a bit of discrepancy in the curves during the later production years. This could be explained by the fact that the lower zone in the two-layer model produces at a much lower initial rate because it is not fractured as extensively. The lower zone then will not deplete as fast and therefore, sustains production for a longer period than the single-layer model, which has a fairly large fracture.

The third uniqueness study was performed using two models that did not contain fractures but had producing zones with different permeabilities. The two-layer model consisted of two 10-ft producing zones with 5 percent hydrocarbon porosity. The upper and lower zones had permeabilities of 1.0 and .10 md, respectively. A match of the two-layer model was obtained with a single layer model having a 20-ft producing zone with .535 md permeability. Drawdown and buildup curves from the two models were in close agreement. Figure 3-7 is a comparison of the production forecasts for the two models. It can be seen that there is quite a difference between the two production forecasts despite the fact that the pressure transient responses are nearly identical.

The fracture geometry study used a single 20-ft producing zone having 5 percent hydrocarbon porosity and permeability of .10 md. Three different fracture geometries were studied. The first was a single-wing fracture having a length of 100 ft. The second was a complex fracture having three fractures at 120° angles, each having a length of 66.67 ft (for a total fracture length of 200 ft). The third was two double-winged, perpendicular fractures having half-lengths of 50 ft (for a total of 200 ft). All of the fractures had conductivities of 10^3 md-ft. Figures 3-8 and 3-9 show the drawdown and buildup curves for the three different fracture geometries. Figure 3-10 is a plot of the production

forecasts for the three fracture geometries. It can be seen that by increasing the number of fractures around the wellbore but still maintaining the same total fracture length, the long-term production characteristics of the well will be enhanced.

The Two-Phase Fracture Propagation Model is now operational and is close to its final form. The two-phase water, oil model can be used to simulate initiation, propagation and closure of a fracture along with flow and shut-in periods before and after fracture treatment. A stand-alone or simultaneous proppant program is also included to simulate the propping of the fracture created in the fracture model. An example model will be used to study the effect of after-fracture flowback time on the buildup tests commonly run after fracture treatment of a well. The radial gas model used in the previous studies will be used to determine if a well was tested too soon. If the fracturing fluid still fills some of the fracture as well as the ones a few inches into the fracture face or reservoir rock, this will indicate that a short ineffective fracture was formed, when in reality, a longer fracture was created.

SCHEDULE STATUS

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

LAWRENCE LIVERMORE LABORATORY

THEORETICAL ANALYSIS

Crack Growth Near a Frictional Interface

Calculations have continued to analyze the penetration of a pressure-driven fracture across a frictional interface. It was previously reported how frictional slip tends to draw a fracture towards an interface and the results were presented in terms of the Mode I stress intensity factor. Stress intensity factors cannot be used to study penetration of a fric-

Figure 3-7 Comparison of Production Forecasts

Figure 3-8 Drawdown Curves for Three Fracture Geometries

Figure 3-9 Buildup Curves for Three Fracture Geometries

Figure 3-10 Production Forecast for Three Fracture Geometries

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

Figure 3-12 Fracture Geometry

tional interface because that factor does not correctly depict the state of stress across the interface. The strain energy density has been calculated in the vicinity of the fracture tip and just across the interface as the pressurized fracture approaches the interface. Strain energy behaves like the square of the Model I stress intensity factor in the vicinity of the fracture tip.

Figure 3-12 shows the geometry of the problem. The materials on either side of the interface have the same mechanical properties with Young's modulus, $E = 20$ GPa and Poisson's ratio, $\nu = 0.25$. Several calculations were performed to determine the strain energy density for a series of frictional stresses that the interface could support. Results of these calculations, shown in Figure 3-13, show a normalized strain energy density, R_e , as a function of normalized frictional shear stress, I_e , that the interface can support. Normalized strain energy density is defined as

$$R_e = \frac{e_T E}{P_c} \frac{\eta}{\ell}$$

where e_T is the strain energy density, P_c is the pressure in the crack (constant over the length of the crack), ℓ is the length of the pressurized crack and η is the characteristic dimension of the crack tip region over which the energy density, e_T , is averaged. The normalized shear stress which the interface can support is defined as

$$I_e = \tau_f^0 / P_c, \quad \text{where } \tau_f^0 \text{ is the frictional}$$

shear stress the interface can support when the pressurized fracture is not present. (The normal load across the interface is modified and varies as the pressurized crack approaches the interface.) Except for the lower end, the curve is linear over the range analyzed.

Figure 3-13 Normalized Strain Energy Density, R_e , as a Function of Frictional Shear Stress, I_e

Fluid Motion in an Expanding Crack

Work is progressing on the code to calculate the fluid motion in an expanding propagating crack. Presently the code calculates a moving fluid front down a channel, which can be done using two separate methods. The results of the two compare fairly well.

One code can calculate flow when the problem boundary does not align with zone boundaries, which is needed when the crack is allowed to expand in width. Presently, the crack face is not moved in time.

EXPERIMENTAL PROGRAM

During June a new set of PMMA blocks was designed and constructed for studies of fluid flow in cracks. Rock samples consisting of layers of limestone, sandstone and dolomite were also designed and constructed for studies of crack growth in heterogeneous rock materials.

Work continued on measurement of the failure envelope and hydrostatic pressure-volume curves up to 0.7 GPa of Mesaverde shale from Wyoming.

GEOLOGY/GEOPHYSICS

"Evolution and Stress History of Low-Permeability Upper Cretaceous Gas Reservoirs in the Rocky Mountains," (UCRL-83514), was presented at the AAPG Annual Meeting in Denver. As a result, an invitation was received from the USGS in Denver to assist in interpretation of fracturing in cores from a deep, over-pressured well in the Green River Basin.

Work is continuing on compilation and interpretation of Uinta Basin and Rock Springs uplift structural data.

SCHEDULE STATUS

The milestone chart of LLL's progress is in Figure 3-14.

LOS ALAMOS SCIENTIFIC LABORATORY

A new NMR spectrometer permits 180° pulsing measures at shorter times with greatly improved signal-to-noise ratios. This instrument will allow more accurate NMR characterization of rock samples and ultimately result in better calibration of the downhole tool.

Preliminary data from the permanent magnet downhole tool indicates that a slight misalignment can be readily detected in the NMR signal. Also, enclosing the magnet and coil assembly in a Faraday cage reduced the electronic noise, and the dead time following the RF pulse was reduced by using a diode array to isolate the transmitter.

Figure 3-15 shows the milestone chart of LASL.

SANDIA LABORATORIES

HYDRAULIC FRACTURE CHARACTERIZATION

Software changes have been completed in the seismic data analysis program to investigate vertical angles to the seismic source. Applying this program to the Shell Big Mineral Creek experiment indicates only a small rotation from the data previously reported. Examination of the vertical heights of signals received by the seismic system in Unit Well No. 343 during breakdown is in process and will be reported in July.

The downhole tool, which has four hydrophone transducers, has undergone preliminary testing in the Sandia borehole in area Y. The 6-in. diameter hole is approximately 245 ft deep and the water level was detected at about 140 ft. The hydrophone test tool was placed so the top of the tool was at 150 ft. The test included a small vibrator that was placed approximately 5 ft, 20 ft, and 45 ft from the borehole and was driven at CW frequencies over a range of 40 Hz to 300 Hz. Hammer blows were included on the surface at various distances from the borehole. One

Figure 3-14 Milestone Chart - LLL

to two minutes for each CW frequency were selected and the output of the transducers was recorded on magnetic tape.

Codes were developed for the desktop computer to digitize the CW frequency data and the hammer-blow data. Codes are also being developed for the desktop computer that will analyze the first several cycles of the hammer blows.

BOREHOLE RESISTIVITY SYSTEM

The two-dimensional finite element solution to the borehole resistivity problem was made operational. The code was tested on a radially stratified resistivity profile which could then be compared with the previously developed one-dimensional model. The physical model represents a 0.0381-m radius probe inside a 0.0762-m radius wellbore fluid. The wellbore fluid conductivity was taken to be 1 ohm/m, the invaded zone conductivity 0.05 ohm/m, and the virgin formation conductivity 0.01 ohm/m. The invaded zone extended out to a radius of 2 m. A comparison of the resulting potentials and apparent resistivities from the one- and two-dimensional models is given in Figure 3-16. The discrepancy in apparent resistivity at larger distances from the current source apparently results from having too few elements in the vicinity of the wellbore. This comparison will be made again with an improved mesh design. The finite element model will also be used to solve some two-dimensional resistivity distributions before the inversion program is incorporated.

HIGH RESOLUTION SEISMIC FORMATION MAPPING

The results of the seismic survey led to an interpretation of at least three sand channels trending across the survey area. These chan-

nels are referred to as "A," "B" and "C." C is intersected by CK GeoEnergy well DOE-GC-1 as determined by logs from the well and a tie to the seismic data using a synthetic seismogram. The average trend of each channel is roughly N 60° E, although each meanders in the nature of river channels. To determine where these channels should crop out on the eastern cliff face of the site, the N 60° E bearing is projected up the measured dip from the known depth (C) or estimated depth (A and B) at the survey area. Figure 3-17 shows the survey area, projected trends, and estimated outcrop positions of channels A, B, and C. Also shown are existing channels measured in outcrop by CK GeoEnergy geologists; the numbering is CK identification. Comparison of seismic projections with measured estimates of candidate channels is given in Table 3-1. Although not identical, the agreement between seismic and outcrop (excluding the bearings of C and number 8) are quite good regarding position and bearing, especially when considering the seismic is extrapolated over 1,000 ft and the outcrop determinations are statistical in nature.

The overall result of the seismic model study and the field experiment are being prepared.

Table 3-1 Comparison of Seismic and Outcrop Descriptions of Channel Sandstones

Channel	Elevation (top), ft	Thickness, ft	Bearing
A	6,240	40 (?)	N 60 E ¹ , N 60 E ²
7	6,240	8	N 25 E ³
B	6,340	40 (?)	N 60 E ¹ , N 80 E ²
10	6,400	20	N 100 E ³
5	6,280	10	N 25 E
C	6,370	40 (?)	N 60 E ¹ , N 110 E ²
8	6,410 - 6,420	26	N
4	6,310 - 6,320	25	N 20 E ³

1 - average channel trend

2 - projected meander trend at outcrop

3 - statistical fit of meander trend at outcrop

Figure 3-16 Comparison of Potentials and Apparent Resistivities from One- and Two-Dimensional Models

Figure 3-17 Map Showing Projected Trends of Channels A, B and C (dashed lines), Projected Outcrop (end of dashed lines) and Positions of Mapped, Outcropping Channels in Area

ELECTROMAGNETIC IMPEDANCE SOURCE FOR THE EVALUATION OF TIGHT GAS RESERVOIRS

Dielectric Modeling

The bulk dielectric properties of an inhomogeneous material are frequency dependent. This frequency dependence, or dispersion, has been observed by several investigators for systems comprised of sandstones saturated

or partially saturated with saline waters. In past work, such a system has been modeled as a nonconducting material with imbedded inclusions of conducting fluid. The shape of the inclusions is very important: long and thin inclusions cause more dispersion than spherically-shaped ones. In this model, distribution functions for the aspect ratios of pore structures are generated from the dielectric data. It is hoped that these distribution functions can be related to fluid and gas flow parameters.

During June, partial water saturation was investigated. It was concluded that if a specimen is water wet, the water will seek out the pores with large surface-to-volume ratios (large aspect ratios). Conversely, in oil-wet specimens, the water will bead and be found in the more spherically-shaped pores.

Figures 3-18 and 3-19 illustrate representative dielectric responses for several values of water saturation. Figure 3-18 is in qualitative agreement with data obtained from Soviet researchers. Comparable data for oil-wet specimens are unavailable.

Laboratory Investigations

Since the dielectric measurements are related to the pore geometry, it is necessary to quantify the pore structure of a given rock sample. Work is progressing on the digitization of the pore geometry observed in SEM or optical microscopy photographs. Since these pictures are cross sections of the rock, it must be determined if this information is sufficient to infer a three-dimensional model of the pore structure. Work done by past researchers

(e.g., K. Hadley, J. Geophys. Res. 81, 3484, 1976) indicated that the total porosity can be determined from knowledge of the total pore area in a two-dimensional cross section. However, it is unknown whether such knowledge is enough to provide an estimate of the rock permeability. Since the digitized structures are being put into the computer, some method of quantifying their shape is required. Aspect ratios (the numbers commonly employed to define pores) do not give a complete representation of the complex structure of the observed pores. An alternative scheme is to divide the pore into many segments in two-dimensions rather than just a major and minor axis, as is done to define an aspect ratio. This yields a size distribution which more accurately represents the pore shape. With this information, other approaches will be tried to find some quantitative description of the pore geometry, which can be used in the theoretical modeling of the rock properties.

SCHEDULE STATUS

Figure 3-20 shows Sandia's WGSP progress.

Figure 3-18 Real Part of Complex Dielectric "Constant" as a Function of Frequency for Water-Wet Sandstone

Figure 3-19 Real Part of Complex Dielectric "Constant" as a Function of Frequency for Oil-Wet Sandstone

Figure 3-20 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 IMPEDANCE SONDE												
Feasibility Study												
Electrical Description												
Geological Description												
Prototype Development												
ELECTROPOTENTIAL SONDE												
Feasibility Study												
Parametric Description												
Prototype Development												

Figure 3-20 Continued

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SECTION 4

FIELD TESTS & DEMONSTRATIONS

BACKGROUND

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

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

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

Table 4-1 MHF Contract Location and Frac Data

Company Basin & Formation	Location T/R/Sec	Well	Interval Fractured ft	Fracture Date	Fracture Treatment Lb of Sand	Injected Fluid 10 ³ Gal	Production Rates MCFD		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	09-21-76	424,000	280 Gel	—	166	—
			7,224-8,676	09-28-76	784,000	364 Gel			
	9S/21E/Sec 22 Uintah Cty, Utah	Natural Buttes No. 14	6,646-8,004	03-15-77	1,093,000	544 Gel	38	800	21.0
	9S/21E/Sec 28 Uintah Cty, Utah	Natural Buttes No. 20	8,498-9,476	06-22-77	826,000	322 Gel	75	1,200	16.0
	10S/22E/Sec 18 Uintah Cty, Utah	Natural Buttes No. 22	6,838-8,550	11-21-77	1,151,000	499 Gel	—	700	—
	9S/22E/Sec 19 Uintah Cty, Utah	Natural Buttes No. 9	5,661-8,934	03-27-78	554,000	349 Gel	140	540	3.9
	10S/21E/Sec 29 Uintah Cty, Utah	CIGE No. 2	9,237-9,653	06-22-78	170,500	203 Gel	—	Water	—
			7,251-8,774	08-08-78	1,965,000	722 Gel	—	Water	—
MITCHELL ENERGY Cotton Valley, Limestone Trend	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 from the Miller No. 1 well and injection of dehydrated gas into the Sprague No. 1 well began May 15 and continued until June 5. This cycle was longer than normal in an attempt to inject as much gas as possible into the Sprague. However, Miller No. 1 did not have sufficient deliverability to supply the injection at Sprague No. 1 for three weeks. Therefore, additional gas was taken from the pipeline. Due to the increased cost, it was then decided to return to the two-

week production/injection schedule.

Operations continued normally except for a three-day halt at the end of June to replace the glycol pump on the dehydrator. The water content of the gas being injected averaged 3.5 to 4 pounds of water per million cubic feet.

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

The well test facility is still at EG&G's facility in Las Vegas undergoing modifications.

To enhance the ability to analyze well test data from the trailer, the development began of a three-dimensional, single-phase reservoir simulator. This model will have fracture

analysis capabilities.

The analysis of the Miller No. 1 data was completed. A comparative analysis of the Sprague No. 1 data from this year with data obtained last year has been started to determine improvements as a result of cyclic injection.

**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 June, GPE Natural Buttes Unit Nos. 9, 14, 18 and 20 flowed to sales a total of 47,800 MCF. NBU No. 9 and 18 flowed 30 days; No. 20 flowed for 27 days, No. 14 flowed for 15 days; and No. 19 flowed for

15 days. Natural Buttes Unit No. 21 is temporarily abandoned and No. 22 is shut in.

The production histories of these wells are shown in Figures 4-2 through 4-7.

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

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

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

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

**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

No further work was performed in June. G-tunnel operations were curtailed due to a strike by miner and support unions.

Fluid Mechanics/Proppant Transport Experiments

Instrumentation packages for measuring crack width and pressure at various locations, and a crack detector for determining the length of the fracture vs. time, have been fabricated. Several of these packages will be built and fielded in a preliminary experiment to test techniques and to determine the quality of the data.

In Situ Stress Measurement by Hydraulic Fracturing Through Perforations

No further work was performed in June due also to the strike by the miner and support unions.

Rock Mechanics and Fluid Mechanics

Experiments are being conducted in the laboratory to show and quantify the importance of in situ stress differences on the direction of fracture propagation. These tests are being conducted on 8-in. diameter samples. The specimens are subjected to overburden stresses, and confining stresses are applied to one-half of the sample.

Fractures are then initiated in the samples and the effect of the confining stresses are observed. Presently, these tests are being

conducted with Nevada tuff samples; however, Tennessee and Nugget sandstone, Westerly Granite and Indiana Limestone may also be used. Preliminary experiments show that a 300 psi difference in pressure is sufficient to keep a fracture from propagating into the stressed area.

To determine the influence of in situ and residual stresses on containment of hydraulic fractures, in situ strain measurements in ashfall tuff had previously been made in the G-tunnel at NTS. Three horizons were instrumented with separate gauges. The lowest instrumented bedding horizon corresponded to the horizon in which a mined-back hydraulic fracture terminated abruptly and where a peak in the minimum principal in situ stress, σ_3 , was measured by small hydraulic fractures.

Recently, unconfined compression tests on specimens parallel and perpendicular to bedding were completed. This was to calculate stresses from the measured strains using elastic properties of the ashfall tuff from the three horizons. Significant differences in the elastic modulus were found. In the upper horizon, the tuff was highly anisotropic with a modulus of about 3.52 GPa perpendicular to bedding and about 6.54 GPa parallel to bedding. In the middle layer, the tuff was less anisotropic with a modulus of about 2.45 GPa and 3.15 GPa parallel and perpendicular to bedding, respectively. In the lowest horizon, the tuff was isotropic with a modulus of about 1.76 GPa. The elastic anisotropy in the upper horizon can be correlated to a strong dimensional grain fabric in the tuff. This fabric was not found in the lowest horizon.

Calculations of the minimum principal stress, σ_3 , using elastic properties and measured strains, showed a consistent increase in σ_3 . It ranged from 0.56 MPa in the upper horizon, to 0.64 MPa in the middle horizon, to 1.66 MPa in the lower horizons. All stresses were compressive. The large abrupt increase in σ_3 in the lower horizon provided an independent measure of the stress peak. This result confirms that an increase in σ_3

can control the vertical growth of hydraulic fractures. Thus, while the in situ stress state directly affects the growth of hydraulic fractures, elastic moduli (variations due to fabric within the rock) can affect the stress state.

The mechanism of crack growth determines the extent of the near crack surface damage produced as the crack propagates. The extent of this process' zone damage is one of the factors that determines the permeability of the fracture surface. Thus, it has a direct bearing on the sizing of a hydrofracture to achieve the desired production rate. In addition, the damaged zone near the crack surface affects the closure rate of the fracture and may reduce the effectiveness of the proppant.

In a joint study with the University of Maryland, the process zone is being examined to determine its size and shape under simple loading conditions. In this study, the crack-tip region is examined under load, using a surface replicating technique. At various stages of the loading history, an acetate film replica is made of the polished surface of the fracture specimen in the region where the crack intersects the surface. The replicas are then examined by the SEM to determine the size and shape of the cracktip process zone. Three experiments have been run. In two of these, the cracked specimen was monotonically loaded until the crack advanced. In the third, a crack was propagated under cyclic loading. The replicas from these experiments are now being prepared for SEM study.

The stress field has been numerically calculated for an internally pressurized and finite crack near a material interface. The solution process requires two steps. The first involves the numerical solution of a singular integral equation which equates the stress field on the crack boundary to the arbitrary, but specified, internal pressure distribution of the crack. The second step convolves this solution with an appropriate Green's function to obtain the stress field beyond the crack tip. The stress intensity factor, K_I ,

is also determined. This calculation is more accurate and much less cumbersome and time-consuming than standard finite element crack codes. Unlike finite element calculations, solutions can be found when the crack tip is extremely close to the interface.

For the crack/interface geometry illustrated in Figure 4-8, the change in stress intensity factor, K_I , as the crack approaches the interface, is given in Figure 4-9. It is commonly believed that K_I approaches zero as the crack tip draws closer to the interface, but Figure 4-9 indicates that the zero value is probably never attained. The decrease in K_I as the crack approaches the interface suggests that fracture propagation might terminate near the interface. However, Figure 4-10 indicates that as the tensile stresses near the crack tip decrease with decreasing K_I , the load is transferred across the interface into the higher modulus material. Because of these large discontinuous stress variations, it is likely that use of K_I alone as a fracture propagation criterion is inappropriate. Fracturing may therefore occur in the high modulus material if this stress load becomes sufficiently large, but a suitable criterion for fracture growth at an interface remains unknown.

SCHEDULE STATUS

The progress of the Sandia Mineback program is shown in Figure 4-11.

Figure 4-8 Geometrical Relationships Between Crack and Interface

Figure 4-9 Variation in Stress Intensity Factor as a Crack Approaches An Interface

Figure 4-10 Tensile Stress as a Function of Distance from Crack Tip

Figure 4-11 Milestone Chart - Sandia Mineback