Western Gas Sands Project Status Report

May 1, 1978

Prepared for
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Bartlesville Energy Research Center
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Compiled by CER Corporation
Las Vegas, Nevada

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1. SUMMARY

This report summarizes the progress of the major government sponsored projects undertaken to increase gas production from low permeability gas sands of the western United States during March 1978. Background information is given in the September 1977 Status Report, NVO/0655-100.

The Project Plan Document FY78 is being reviewed by the Department of Energy (DOE) in Washington, D.C. and will soon be finalized. The Project Status Report-Financial Supplement, April 1, 1978, the second Quarterly Basin Activity Report, and the Project Plan Document FY79 are being drafted. A bibliography of the Western Gas Sands Project (WGSP) information files will be initiated in April and published as part of this report.

The U.S. Geological Survey (USGS) sponsored a seminar on "Petroleum Research and Resources" on March 14 and 15, 1978, in Golden, Colorado. Results of recent investigations were presented at the two-day meeting. Resource assessment by the USGS is continuing.

The Bartlesville Energy Research Center (BERC) and participating National Laboratories, funded by DOE, are continuing their work in the area of research and development. The emphasis is on the development of new tools and instrumentation systems, rock mechanics, mathematical modeling and data analysis.

Field Tests and demonstrations active in the Uinta and Piceance Basins are:

Gas Producing Enterprises (GPE) Natural Buttes Unit Wells
No. 9, 14, 18, 19, 20, 21 and 22.

Mobil Research and Development Corporation, Well No. F-31-13G.

Rio Blanco Natural Gas Company, Well No. 498-4-1.

Gas Producing Enterprises Natural Buttes Unit Well No. 9 was fractured on March 27, 1978. The treatment consisted of 554,000 pounds of sand and 349,000 gallons of gel.

Mitchell Energy Corporation of Houston, Texas was awarded Department of Energy Contract EF-78-C-08-1547 on March 15, 1978. Field work under this contract is scheduled to begin on June 15, 1978, with the drilling of a new well.

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2. PROJECT MANAGEMENT

2.1 Technical Monitoring and Evaluation

A meeting was held on March 2, 1978, in Las Vegas between DOE, CER and Gas Producing Enterprises (GPE) regarding log interpretation of the Mesaverde and the zones to be tested in Natural Buttes Well No. 21. Mr. G. Kukal, CER, met with GPE in Denver, Colorado on March 14, 1978, to discuss log interpretation problems.

Messrs. G. Kukal and C. Appledorn, of CER, and C. Atkinson, DOE, attended the "Second U.S. Geological Survey (USGS) Petroleum Research and Resources Seminar," on March 14 and 15, in Golden, Colorado.

The "Fourth Semi-Annual Enhanced Gas Recovery Review Meeting" was held on March 21, 22, and 23 at the Marina Hotel in Las Vegas, Nevada. Copies of the agenda and meeting attendees are included in Appendices A and B.

Sandia hosted a tour of the Sandia Laboratories Mineback Stimulation Test Program, March 20, at the Nevada Test Site. About twenty people made the tour which featured detailed technical briefings in "G" Tunnel.

2.2 Activity Coordination

Messrs. G. Luetkehans and R. Mann, of CER, traveled to Texas A&M University to meet with Dr. Steve Holditch on testing and evaluation programs for tight gas sands.

CER personnel attended a coordination meeting at Sandia Laboratories regarding the mast truck and trailer being assembled at GO International, Ft. Worth, Texas.

2.3 Information Transfer

2.3.1 Documentation and Reports

The Project Plan Document FY78 is being reviewed in Washington, D.C. and will be finalized soon. The Project Status Report-Financial Supplement, April 1, 1978, the second Quarterly Basin Activity Report, and the Project Plan Document FY79 are being drafted.

2.3.2 Project Information Files

A bibliography of the Western Gas Sands Project (WGSP) information files will be initiated in April and published in a future edition of this report. These records are located at the CER Corporation offices in Las Vegas.

3. RESOURCE ASSESSMENT

Resource assessment includes geological, geophysical and reservoir evaluation studies to define and characterize the resource base. The USGS is performing the majority of the resource assessment work. Additional activity, however, primarily in the area of field tests and obtaining and analyzing cores, provides data to support its work.

3.1 U.S. Geological Survey Activities

On March 14-15, 1978, the USGS sponsored a seminar on "Petroleum Research and Resources" in Golden, Colorado. The results and progress of petroleum and natural gas research were presented at the meeting with Sessions IV and X specifically related to WGSP activities. The meeting agenda is shown in Appendix C.

3.1.1 Greater Green River Basin

C.W. Spencer presented an oral summary of the Western Gas Sands Project and T.F. Tyler discussed a preliminary evaluation of low permeability reservoirs in the Washakie Basin at the USGS Seminar.

The following activities are related to the Greater Green River Basin:

- a) Well penetration maps have been requested from the Petroleum Information Well History Control System (WHCS) file at 1:125,000 (1" is 2 miles) plus a new land grid plot at 1:250,000 (1" is 4 miles).
- b) The slabbing of 40,000 lbs of WASP (Wyoming Atomic Stimulation Project) core has been completed.
- c) Enhanced LANDSAT photos are being enlarged for lineament analysis.
- d) The results from 8 paleoanalyses have been tied to subsurface data.
- e) Work is continuing on regional cross sections.
- f) Approval has been received from Rainbow Resources to make a geochemical profile of their 26,000 ft test in T27N, R103W, Sublette Co., Wyoming.

3.1.2 Northern Great Plains Province

Results of recent investigations were presented in talks at the USGS Seminar and the Fourth Semi-Annual Enhanced Gas Recovery Review Meeting. The following items were worked on during the month of March:

- a) Coring sites in the Northern Great Plains study area were discussed with CER personnel.
- b) Core was sampled for petrologic and clay mineralogy studies.
- c) The Preliminary draft of two papers for the Williston Basin Symposium was finished.
- d) A manuscript was prepared for DOE Symposium on Enhanced Oil and Gas Recovery and Improved Drilling Methods.
- e) A manuscript was prepared on lineaments in South Dakota for the Symposium on New Basement Tectonics.

3.1.3 Piceance Basin — Uinta Basin

Two reports on investigations related to the USGS "Tight Gas Studies" were prepared and presented.

Fouch, T.D., 1978, Some mineralogical and depositional characteristics of "tight" sandstone reservoirs in the eastern Uinta Basin, Utah: Oral presentation at USGS Petroleum Research and Resource Seminar, March 14, 1978.

Fouch, T.D., Summary of results of geologic investigations of low permeability reservoirs in the Uinta Basin, Utah: Oral presentation at semi-annual EGR Meeting, March 22, 1978, Marina Hotel, Las Vegas, Nevada.

The following reports were released:

Johnson, R.C., 1978, Cross section showing depositional environments, and lithologies of some Upper Cretaceous and Tertiary rocks from DeBeque to the north central Piceance Creek Basin: U.S. Geological Survey Open-file Report No. 78-182.

The activities below are related to the Piceance-Uinta Basins:

- (a) Data is being collected to prepare isopachs of various reservoir units of the southern Piceance Basin.
- (b) Petrographic and Xray diffraction analysis of core samples from the Rio Blanco unit of Colorado is continuing.
- (c) Preparation of cross sections from the Wasatch Mountains to southcentral Uinta Basin is continuing.
- (d) Preparation of a chart showing detailed comparison among rock types, depositional environments, productive units, and engineering data between the Altamont oil field and the "tight gas" region of the southeast Uinta Basin is continuing. A report will be released open-file upon completion. This report will illustrate the details used to prepare the cross section shown in Figure 3-1.

Examination of core from two drillholes indicates that reservoirs in the Pariette Bench field are fractured, well-sorted, marginal-lacustrine channel-formed sandstone interbedded with calcareous and carbonaceous claystone and some grain-supported carbonate. Rocks formed in similar depositional environments produce oil and/or gas at Ute Trail, Natural Buttes, and Altamont-Bluebell fields. Petrographic and x-ray diffraction analyses of the core indicate that the primary mineral constituent is very fine to fine, sub-rounded to angular grains of quartz. Minerals present in small amounts include alkali and plagioclase feldspar, Ca-Mg-Fe carbonate, heavy minerals, and clays. Dominant framework grains are monocrystalline quartz exhibiting nonpenetrative grain contacts, some of which show a shard-like morphology. SEM analyses indicate that complex detrital and authigenic carbonate, clay, and zeolite minerals assemblages fill intergranular pore space cementing the framework grains. Little evidence for extensive compaction, pressure solution, and quartz overgrowth indicates that much of the cementation occurred during early diagenesis. Clay-mineral constituents are illite, chlorite, and interstratified mixed layer illite-smectite, which occur as randomly-oriented platelets distributed as aggregates coating framework grains.

Extensive carbonate and clay cementation has decreased reservoir potential causing reduction in porosity and matrix permeability; however, subsequent study of lateral variations in the mineralogy of these units may delineate areas favorable for better reservoir development.

FIGURE 3-1 STRATIGRAPHIC CROSS SECTION

Similar studies of additional core and outcrop exposures from Tertiary and Cretaceous rocks from throughout the Basin are a part of the U.S. Geological Survey investigations within the Western Gas Sands Project.

3.2 Coring Program

The WGSP Project Manager and CER geologists met with four Montana operators in Denver, Colorado, to discuss cost-sharing contracts to obtain cores from wells to be drilled in areas of interest to the WGSP.

3.3 Study of Basin Activities

Geologic studies have indicated that an immense resource of natural gas exists in reservoirs in a number of geologic basins scattered throughout the western states (Figure 3-2). Monitoring continues of drilling and testing activities in the four primary basins. Figures 3-3 through 3-6 indicate the four areas and recent wells of significance to the WGSP. The following paragraphs give a brief account of drilling activity.

3.3.1 Greater Green River Basin

Sweetwater County, Wyoming, has the majority of the basin drilling and testing operations. Surrounding Sweetwater County, there is important activity located in the Figure Four Canyon and Tip Top Fields of Sublette County, the western edge of Carbon County, the eastern portion of Lincoln County, and the northern area of Moffat County, Colorado, referred to as the Sand Wash sub-Basin.

Objectives in Sweetwater County are the Almond, Ericson, Rock Springs, and Blair formations of the Mesaverde Group. Operators with Mesaverde completions include Champlin Petroleum Company in the Wamsutter area, Amoco, with an apparent discovery in the Hansen Draw Field, and CIG with a wildcat flowing 789 MCFD northwest of the Stateline Field.

The Rock Springs Uplift located in the center of Sweetwater County has been the site of deeper tests in the Frontier and Dakota Formations. Kenneth Luff has two wells producing from the Dakota using a sand-emulsion fracture in Crooked Canyon Field. Davis Oil Company has staked a location south of the Luff wells to test the Dakota, and Jerry Chambers has three Frontier tests northwest of the Trail Ridge Field.

FIGURE 3-2 LOW PERMEABILITY REGIONS

In Carbon County, Michigan Wisconsin Pipeline tested 1,043 MCFD from the Mesaverde; a well originally slated to test the Steele Formation (Figure 3-3).

Well No. 1

Michigan Wisconsin Pipeline
1-27 Creston-Nose
Section 27, T18N, R92W
Carbon County, Wyoming
Unnamed field
Mesaverde production (7,788-7,828 ft gross)
Frac: 20,000 gal. water, 22,000 lb sand
IPF: 1,043 MCFD
Completion date: 3/16/77

William Moss Properties has a well within the USGS recommended coring area that is an apparent Mesaverde producer; gas flowed at 501 MCFD during a drill stem test. Tom Brown and Sinclair Oil are also quite active in the area testing the Mesaverde.

Sublette and Lincoln Counties currently have many ongoing tests in the Frontier and Bear River formations. Apache Corporation recently completed a well with commingled Bear River/Frontier production in the Figure Four Canyon Field (Figure 3-3), and Mountain Fuel Supply has a well which is producing 2,674 MCFD from the Frontier, near Wilson Ranch Field, Lincoln County.

Well No. 2

Apache Corporation
2-23 Federal
Section 23, T27N, R112W
Sublette County, Wyoming
Figure Four Canyon Field
Frontier production (7,773-8,021 ft gross) and
Bear River production (8,475-8,628 ft gross)
Frac: 175,510 gal. emulsion, 95,200 lb sand
IPF: 2,830 MCFD
Development gas well
Completion date: 3/30/78

Moffat County, Colorado recently has had significant production from Lewis Sands. Anadarko Production has a well northeast of the Blue Gravel Field, producing 2,087 MCFD and has staked another well in the same township and range to test the Almond.

FIGURE 3-3 GREATER GREEN RIVER BASIN SHOWING WELLS OF INTEREST

Uinta County, Wyoming has a limited amount of activity; most tests are in the Frontier and deeper Nugget. Mountain Fuel Supply, however, has scheduled a well to test the Mowry/Aspen Formation, an upper Lower Cretaceous zone, in the northeast corner of the county.

3.3.2 Northern Great Plains Province

Drilling and testing activity in the Northern Great Plains Province is concentrated in the northern Montana counties of Toole, Hill, Chouteau, Blaine, Phillips and Valley.

New interest has been generated in testing the Bow Island and 2nd White Specks units in parts of Toole, Pondera and Liberty Counties. The major operators in the area are Antares Oil, Sun Oil, Montana Power, Fulton Producing, Webb Resources, Western Natural Gas and Milan R. Ayers. Thus far, the production has been from the untreated Bow Island, but the area is being monitored for the possibility of future fracture treatments and subsequent application to the WGSP.

The Tiger Ridge Field, which produces naturally from the Eagle Sands is located on the eastern border of Hill County. Tricentrol United States, Inc., is active in this area and has five tests scheduled to the Eagle. J. Burns Brown has three Eagle tests northeast of the Tricentrol wells in an unnamed field. Also of significance is the planning of a drilling program in the northeastern section of the county by Xeno, Inc. The company will be testing the 1st and 2nd White Specks and several Eagle zones during the summer.

In Blaine County, Xeno has announced plans for 25 to 30 Eagle tests in the Battle Creek Field. John J. Lyon recently completed a well north-east of the proposed Xeno exploratory area, producing 69 MCFD from the Eagle after fracturing (Figure 3-4).

Well No. 3

John J. Lyon
2 Battle Creek
Section 14, T36N, R20E
Blaine County, Montana
Unnamed field
Eagle production (1,903-1,945 ft gross)
Frac: 18,606 gal. water, 40,000 lb sand
IPF: 69 MCFD
Eagle discovery - new field
Completion date: 3/9/78

FIGURE 3-4 NORTHERN GREAT PLAINS PROVINCE SHOWING
WELLS OF INTEREST

Other operators in the county with numerous scheduled tests are Fuel Resources Development in Leroy Field, Tricentrol United States in Sherard and Tiger Ridge Fields and Kissinger Petroleum in Sawtooth Mountain Field.

An interesting development in South Dakota's Harding County, is the staking of a 2,000 ft Shannon test, 16 miles and a little west of the West Short Pine Hills Field by Koch Exploration. Jerry McCutchin has recently scheduled five new wells in the vicinity of his discovery which flowed 980 MCFD from the Shannon and opened this South Dakota Field. A lease sale will be held in early April, at which time 158 tracts comprising 57,133 acres are being offered. About half of these tracts are in the vicinity of the 1977 Shannon gas strike at West Short Pine Hills Field.

3.3.3 Piceance Basin

Drilling and testing activity in the Piceance Basin has been on a steady increase since the first of the year. Major objectives are the Mancos and Wasatch Formations in Rio Blanco County, the Mesaverde and Cozzette/Corcoran in Mesa County, and the Dakota/Morrison in the Douglas Creek Arch area, Garfield County.

Rio Blanco County is the most active area in the basin. The Lower Horse Draw, Trail Canyon, and Cathedral Fields all have active drilling. Production in these areas has been from Mancos zones.

New interest has been generated in the central area of Rio Blanco County, specifically in the Piceance Creek Field, due to the staking of five new locations by Indian Wells Oil Company. All five wells, along with eight Mobil Oil locations, are projected to the Wasatch.

In the Plateau Field, Mesa County, Mountain Fuel Supply has a well producing from the Corcoran Sand (Figure 3-5).

Well No. 4

Mountain Fuel Supply
1-35 Bull Basin
Section 35, T10S, R96W
Mesa County, Colorado
Plateau Field
Corcoran production (3,710-3,812 ft gross)
Frac: 115,654 gal. water, 237,938 lb sand
IPF: 140 MCFD, 2 BCD
Development gas well
Completion date: 3/30/78

Adolph Coors has staked two new wells west of this area, which increases the number of Coors locations to five.

FIGURE 3-5 PICEANCE BASIN SHOWING WELLS OF INTEREST

3.3.4 Uinta Basin

Drilling and testing activity in the Uinta Basin is concentrated in the Natural Buttes and Chapita Wells Units of Uintah County, Utah. The major objectives are the tight Tertiary Wasatch and Upper Cretaceous Mesaverde Formations. For example, Belco Petroleum has recently staked two Wasatch tests, which gives them a total of four tests in the Natural Buttes Field.

Gas Producing Enterprises (GPE) and Enserch Exploration are active in testing the Mesaverde. A recent GPE well, which is not part of the DOE contract work, utilized a large sand-emulsion fracture treatment in the Mesaverde (Figure 3-6).

Well No. 5

Gas Producing Enterprises
29 NBU
Section 11, T10S, R21E
Uintah County, Utah
Natural Buttes Field
Mesaverde production (5,576-9,626 ft gross)
Frac: 315,000 gal. emulsion, 760,000 lb sand
IPF: 750 MCFD
Development gas well
Completion date: 3/30/78

Directly east of the Natural Buttes Field, Pacific Transmission Supply is testing the Castlegate sand. This well is "tight" but future drilling in the area will be closely monitored for possible application to the WGSP coring program.

In Red Wash Field, most testing has been conducted by Chevron in the Green River Formation; Chevron currently has 20 such tests proceeding. Gulf Oil, however, has staked three new tests in the Tertiary Uinta Formation and Twin Arrow has a wildcat well scheduled for the Mancos.

The Island Field, southwest of the Chapita Wells Unit is the site of three Mapco Company Mesaverde tests. Belco Petroleum is also active in this area testing the Mesaverde.

FIGURE 3-6 UINTA BASIN SHOWING WELLS OF INTEREST

4. RESEARCH AND DEVELOPMENT BY ENERGY RESEARCH CENTERS AND NATIONAL LABORATORIES

4.1 Bartlesville Energy Research Center (BERC)

4.1.1 Improved Pressure Coring System

4.1.1.1 Core Retriever Design

Design work continued on the lower portion of the core barrel where the rotating ball valve is located with a design review meeting scheduled in May. A cost-sharing contractor will then be solicited since the design layouts will be adequate for cost estimates for manufacturing and testing.

4.1.1.2 Coring Fluid Selection

Testing and evaluation continued with the Dow-Corning DC-200 silicone fluid. Additional tests are planned with this fluid, with alternate fluids being considered.

4.1.1.3 Bit Design

The prototype core bit underwent laboratory testing in Berea Sandstone, but problems terminated the tests. The drill stem was prepacked with DC-200 fluid which was displaced by the entering core. This displacement caused a 200 psi pressure buildup in the core fluid chamber. Chip removal was poor and the cutting caused friction on the core hole walls. Testing will be resumed when the drilling machine problem is solved.

4.1.1.4 Measurement of Formation Core Characteristics

Two industrial laboratories are submitting proposals to perform core analysis. Proposal evaluation and contractor selection for the remainder of FY-78 will follow receipt of these proposals.

4.1.2 Interface Conductivity Effects on Electric Logs

A concentrated study of the literature relating to the surface conductivity of reservoir rock is in progress. The study shows that the Waxman-Smiths model is now widely accepted to describe the effects of

surface conductivity in clayey formations. A newer model proposed by Clavier, Coates and Dumanior is a refinement of the Waxman-Smiths model. Rink and Schopper and also Evers and Iyer have presented models which seem to apply more to clean sands. The basic concepts of these models are being carefully studied.

4.1.3 Mapping and Contouring Formation Water Resistivity

Topography maps of the Uinta Basin were received. Assimilation and listings of available formation water analyses have been completed. Locations of R_w information were plotted on section sheets. An internal report of extant data is being drafted.

4.1.4 Logging Techniques and Interpretations

A contract has been signed with Texas A&M University to study acoustic, density and neutron logs of western tight gas sands to improve interpretation techniques.

A proposal by Sandia Laboratories has been received to survey and critique various techniques for measuring water resistivity.

4.1.5 Rock-Fluid Interaction

The writing of the internal report on Fracture Fluid-Reservoir Rock Interactions, was continued this month. Several new references and pertinent laboratory data will be included.

The chemical components of a series of representative frac fluids were received from the Halliburton Company this month and Marvin Misak of Halliburton Services Company demonstrated the proper way to mix typical water-base gels.

4.2 Lawrence Livermore Laboratory (LLL)

4.2.1 Theoretical and Experimental Model Development and Application

A series of four calculations were completed to analyze the characteristics of a fracture symmetrically placed across and perpendicular to an interface. For these calculations, no relative motion was permitted across the interface, e.g., the interface was well cemented. The geometry of the system and ratios of the mechanical and flow characteristics for the two materials on both sides of the interface are shown below and in Figure 4-1.

Calculations

$$\begin{aligned} 1. \quad & k_b = 4 k_a \\ & E_b = E_a \\ & \nu_b = \nu_a \end{aligned}$$

$$\begin{aligned} 3. \quad & k_b = 4 k_a \\ & E_b = E_a \\ & \nu_b = 0.35, \nu_a = 0.20 \end{aligned}$$

$$\begin{aligned} 2. \quad & k_b = 4 k_a \\ & E_b = E_a \\ & \nu_b = 0.20, \nu_a = 0.35 \end{aligned}$$

$$\begin{aligned} 4. \quad & k_b = 4 k_a \\ & E_b = 2E_a \\ & \nu_b = \nu_a \end{aligned}$$

It can be seen that in all of the calculations, the permeability on side (b) was four times the permeability on side (a). For calculation 1, the mechanical characteristics on both sides of the interface were identical. In calculations 2 and 3, the Young's modulus was held constant on both sides, but Poisson's ratio was varied, first one way, then the other. In the fourth calculation, Poisson's ratio was held constant and Young's modulus on side (b) was twice Young's modulus on side (a). The cracks were stationary in these calculations.

Figure 4-2 shows the normalized stress intensity factor calculated for both tips of the fractures for the four cases outlined on Figure 4-1. These stress intensity factors are designated (a) or (b) relating to the side of the interface as on Figure 4-1, and are plotted as a function of the non-dimensional flow time-length parameter τ . The parameter $(P\sqrt{a})$ used to normalize the stress intensity factor, is the theoretical factor for an infinite continuum where (P) is the pressure in the crack and (a) is the semi-major axis of the crack ellipse. Sneddon¹ indicates that the static stress intensity factors define the conditions for the initiation of crack propagation but does not say anything about subsequent motion of the crack. In all cases, the effect of increases in pore pressure around the fracture due to fluid migrating from the fracture into the surrounding material is to reduce the stress intensity factors at the tip regions with increasing time.

¹ I.N. Sneddon and M. Lowengrub, "Crack Problems in the Classical Theory of Elasticity," John Wiley and Sons, New York (1969).

FIGURE 4-1 GEOMETRY AND RATIOS OF PARAMETERS USED FOR INTERFACE CALCULATIONS

FIGURE 4-2 STRESS INTENSITY FACTORS FOR INTERFACE CALCULATIONS FOR PARAMETERS SHOWN ON FIGURE 4-1

For calculation (1) with changes only in permeability, the intensity factors for both tips should plot on the same line with the normalizations used. Actually there is a slight spread between lines (1a) and (1b), but they are sufficiently close to verify the scaling. For cases (2) and (3), the differences in Poisson's ratio cause the stress intensity factors on the tip with the smaller Poisson's ratio to be initially greater than the factor at the tip in the material with the higher Poisson's ratio. The effect of changes in Young's modulus (case 4) is most pronounced. This is evidenced by the fact that the crack tip in the region having the larger Young's modulus is significantly increased or shifted upward while the stress intensity factor at the other tip is decreased or shifted down. The difference between the stress intensity factors between these two tips is 30 percent or more. If the breakage stress in both materials were the same, this would indicate that the tip in the higher Young's modulus material would have a greater tendency to extend than the other tip.

LLL found an analytic solution, Mayurama (1964)², for surface tilt due to a vertical hydrofracture. Unfortunately, the hydrofracture is represented as a constant width dislocation, a rather unrealistic assumption. However, one would expect this assumption to produce reasonable results for the tilt along the surface and poor results for displacements and strain near the hydrofracture. Consequently, the surface tilt predictions were used from the analytic model for reassurance on the accuracy of the finite element model. The finite model was confirmed to the specific problem the analytic model solves, an unlayered, isotropic, heterogeneous material with a Poisson's ratio of 0.25. The results are shown in Figure 4-3. Due to the dislocation nature of the hydrofracture in the analytic solution, the curves were scaled by equating the peak slopes. Hence, the slope units are arbitrary. The distance along the surface, x , is nondimensionalized by dividing by the distance from the surface to the top of the hydrofracture, d . The solid line is the finite element solution and the circles are from the analytic solution. The agreement between the two models is excellent.

4.2.2 Experimental Program

Experiments have been performed to observe crack growth across unbonded interfaces in layers of limestone and sandstone. As discussed earlier, two types of surface roughness have been used. In some experiments the crack was initiated in limestone between sandstone, and in others the crack was initiated in sandstone between limestone, Figure 4-4. The surfaces at one interface were roughened by sandblasting while the

² Mayurama, Takuo, 1964. Statistical elastic dislocation in an infinite and semi-infinite medium. Bulletin of the Earthquake Research Institute, Tokyo University, Vol. 42, 289-368.

FIGURE 4-3 SURFACE TILT DUE TO A VERTICAL HYDROFRACTURE

FIGURE 4-4 EXPERIMENTS ON HYDRAULIC FRACTURE ACROSS UNBOUNDED INTERFACES IN SANDSTONE AND LIMESTONE

surfaces at the other interface were ground smooth. The experiments performed show that a crack will pass from limestone to sandstone when the normal load across the interface is greater than about 800 psi. A crack will pass from sandstone to limestone when the normal stress across the interface is greater than about 600 psi. No definite effect of surface finish was observed. There is some indication that the breakdown fluid pressure at which crack initiation occurs partially determines whether or not the crack will cross the interface in certain load regimes. More experiments are planned to further investigate these effects.

4.2.3 Fracturing Experiments

The following report on "Fracturing Experiments" was originally published in the LLL Gas Stimulation Program Quarterly Progress Report, October through December 1977, Lawrence Livermore Laboratory, Report UCRL-50036-77-4 (1977).

Crack Propagation

During the last quarter of 1977, a new hydraulic system was constructed for generating hydraulic fractures. This system consists of a high-pressure pump, a fluid reservoir for refilling the pump, and a pressure transducer with a strip chart recorder for continuously monitoring the pressure of the fracturing fluid.

Using the new system, experiments on Indiana limestone were continued to study the growth of hydraulically driven cracks in the vicinity of unbonded interfaces across which a normal load is applied. It was found that a crack crossed an unbonded interface when the normal stress across the interface was 1,500 psi but not when the stress was reduced to 1,000 psi. More recent experiments indicated that, for a given normal stress across an unbonded interface in limestone, whether or not a crack will cross the interface depends on the pressure at which the crack initiates and grows.

In the experiments performed on Indiana limestone so far, a hydraulically driven crack is initiated generally when the fluid pressure reaches about $6,000 \pm 500$ psi. However, occasionally a sample will require as much as 7,000 or as little as 4,000 psi fluid pressure for crack initiation. In one experiment where initiation occurred at 7,000 psi, the normal stress across the interface was 950 psi but the crack failed to cross it. These experiments lead one to conjecture that whether or not the crack crosses the interface may depend on the fluid pressure at which the crack initiates as well as on the stress across the interface, although this is certainly not conclusive. In all of the experiments performed so far, the crack has propagated to, and in some cases across, the interface in the first burst of growth. This

situation might be expected to be different from the case in which the initial burst of the crack is completely contained within one of the blocks, and then the crack is grown slowly toward the interface, as was done in the PMMA-limestone experiment described earlier.³ This latter type of experiment has not yet been performed.

In the experiments on crack growth across unbonded interfaces in Indiana limestone that were performed during the last quarter, two types of finishes have been used on the surface. One type of surface was a smooth, machined finish and the other type was a roughened, sandblasted finish. The object was to see if the surface roughness, and hence the coefficient of friction or shear frictional force that could be transmitted across the interface, had an effect on whether or not the crack would cross that surface. No correlation has yet been observed.

Polyaxial Stress

An experimental program was pursued to 1) investigate the effect of the vertical stress on the direction and inclination of hydraulic fractures for a set condition of horizontal stresses and 2) determine the minimum difference between the two principal horizontal stresses for which hydraulic fractures cease to be randomly oriented and become aligned with the maximum horizontal stress direction. In order to limit the variables, only one hard rock type was selected for our tests, namely Montello granite. Montello granite is strong, isotropic rock. Its uniaxial compressive strength is 50,000 psi (3.45×10^8 Pa), and its uniaxial tensile strength is 2,100 psi (1.45×10^7 PA). The mechanical properties have been tested in detail by Erbstoesser.⁴

The rock specimens tested in this investigation were prismatic in shape. Large granite blocks were obtained from the Montello quarry, 50 miles north of Madison, Wisconsin. Specimens (generally 5 in. x 5 in. x 7 in.) were cut out of the blocks using a large diamond saw and were surface-ground so that opposite sides were parallel to within 0.003 in. and adjacent sides perpendicular to within 1° . The prepared specimens were oven-dried for 24 hours and then were allowed to cool at room temperature for another 24 hour period before testing.

³ M.E. Hanson, et. al., LLL Gas Stimulation Program Quarterly Progress Report, April through June 1977, Lawrence Livermore Laboratory, Rept. UCRL-50036-77-2 (1977).

⁴ E.R. Erbstoesser, Mechanical Behavior of Four Wisconsin Rocks, M.S. Thesis, University of Wisconsin, Madison (1976).

The apparatus used for the testing included a polyaxial load cell, a flow-control device, and flat jacks. The polyaxial cell was designed and made by Haimson.⁵ It can accommodate rock specimens of sizes up to 5-1/4 in. x 5-1/4 in. x 7 in. It has four independently actuated pistons for the application of two unequal horizontal loads to a prismatic specimen. The pistons are rounded inside the cell housing to facilitate proper fitting and O-ring sealing, but are rectangular outside. Pressure up to 3,000 psi can be applied in each of the four chambers inside the cell, which translates to horizontal loads on the specimen of up to 20,000 psi. The flow-control device consists of a high-pressure cylinder with a moving piston and a linear variable differential transducer (LVDT) to serve the piston movement (Figure 4-5). The LVDT output serves as a feedback signal to the control unit of a servo-control system which regulates the flow rate of the hydraulic fracturing fluid. During the initial stages of the investigation, specimens were directly loaded by the loading platens of the polyaxial cell (Figure 4-6 a). However, a lack of uniformity was observed in the load distribution of the faces of the rock specimen. In order to improve this condition, four fluid-filled copper flat jacks were made and installed between the loading platens and the faces of the rock specimens, as shown in Figure 4-6 b. The cushioning effect of the flat jacks considerably improved the load distribution. The flat jacks were connected to a hand-operated pump through 1/16 in. diameter high-pressure tubing. The pump provided the desired pressure in the flat jacks for the application of horizontal loads to the rock specimens.

Testing Procedure

A prismatic specimen was placed in the center of the polyaxial cell, at equal distances from the loading platens in their retracted position. Vertical load was applied by a 500,000 lb servo-controlled loading machine. Horizontal loads were applied either directly through the polyaxial cell pistons (Figure 4-6 a) or by inserting the fluid-filled flat jacks between the polyaxial cell pistons and specimen sides (Figure 4-6 b). Opposite pairs of pistons or flat jacks were simultaneously pressurized by means of a 30,000 psi pressure generator. Two types of tests were performed: pressure control and flow control.

In the pressure control test, the vertical and horizontal loads were held constant and the borehole pressure was raised either by hand or by a programmable servo-controlled pressure intensifier. When breakdown

⁵ B.C. Haimson, "Determination of In-Situ Stresses Around Underground Excavations by Means of Hydraulic Fracturing," Final Technical Report to U.S. Bureau of Mines (HO220080), University of Wisconsin, Madison (1974).

FIGURE 4-5 FLOW CONTROL DEVICE

FIGURE 4-6 (A) DIRECT PISTON LOADING (B) LOADING THROUGH PRESSURIZED FLAT JACKS

pressure was reached, fracture occurred, borehole pressure dropped immediately, and the pressurization was discontinued. In the flow-control test, the borehole pressure was supplied by a pressure intensifier through the flow-control device described earlier.

When the test was completed, the outside loads were removed gradually and simultaneously so as not to induce any additional failure in the rock. The specimen was subsequently removed, and observations regarding the hydraulic fracture and its orientation were recorded.

Experimental Results

Effect of Vertical Stress on Hydrofracture Direction

Twenty-three specimens of Montello granite were tested to verify the effect of the vertical stress (σ_v) on the direction and inclination of hydrofractures. Table 4-1 gives the experimental details and results. The magnitudes of the least and largest horizontal stresses were kept at ($\sigma_{Hmin} = 2,500$)psi and ($\sigma_{Hmax} = 5,000$) psi in the initial tests. However, when flat jacks were introduced, the least and largest horizontal stress magnitudes were lowered to 2,000 and 4,000 psi, respectively, to prevent premature leakage in the jacks. The vertical stress was varied between 500 and 4,000 psi. After some initial experimentation, the specimen size was kept at 5 in. x 5 in. x 7 in. and the borehole at 0.5 in. Similarly, after some tests in which borehole pressurization was conducted manually or by pressure control, flow control was used exclusively in the remainder of tests.

In all tests but one, fractures were initiated vertically at the borehole in a direction parallel to that of (σ_{Hmax}). For ratios of (σ_{Hmin}/σ_v) larger than 1, the evidence from most tests is that, away from the borehole, the initially vertical fractures turned, to become horizontal before emerging to the face of the specimen. For ratios smaller than 1, the fracture remained vertical throughout.

Figures 4-7 and 4-8 are photographs of vertical sections through hydrofractured boreholes of specimens 4 and 7. In both tests the ratio of (σ_{Hmin}/σ_v) was greater than 1 (5/3 and 4, respectively), and in each case hydrofracturing produced an initial vertical fracture which apparently turned horizontal away from the borehole.

The relationship between the magnitude of the breakdown pressure (P_c) and that of σ_v was also studied (Figure 4-9). It appears that P_c increases with an increase in σ_v at the same horizontal stress conditions. This conflicts with theory, which precludes σ_v from having an effect on P_c . Results may be affected by the limited height of the specimens as compared with field situations.

TABLE 4-1 EFFECT OF VERTICAL STRESS ON HYDROFRACTURE ORIENTATION AND BREAKDOWN PRESSURE IN MONTELLO GRANITE

Test No.	Vertical stress, σ_v (psi)	Horizontal stress			Breakdown pressure, P_c (psi)	Hydrofracture orientation ^a
		σ_{Hmin} (psi)	σ_{Hmax} (psi)	σ_{Hmin}/σ_v		
1	500	2500	5000	5	3550	A
2	500	2500	5000	5	3100	A
7	500	2000	4000	4	2850	A
12	500	2000	4000	4	4000	B
21	500	2000	4000	4	3200	B
22	500	2000	4000	4	3100	A
3	1000	2000	4000	2	4300	C
8	1000	2000	4000	2	3200	B
11	1000	2000	4000	2	3550	A
15	1000	2000	4000	2	3300	B
23	1000	2000	4000	2	3600	A
4	1500	2500	5000	5/3	3450	A
10	1500	2000	4000	4/3	3550	A
13	1500	2000	4000	4/3	3700	B
24	1500	2000	4000	4/3	3650	B
5	2000	2500	5000	5/4	3450	A
6	2500	2500	5000	1	3750	A
9	2000	2000	4000	1	2900	B
25	2000	2000	4000	1	3550	B
26	2500	2000	4000	4/5	4500	B
18	3000	2000	4000	2/3	4050	B
16	4000	2000	4000	1/2	3850	B
17	4000	2000	4000	1/2	3800	B

^aTypes of hydrofracture orientation:

A—vertical fracture at borehole in σ_{Hmax} direction, becoming horizontal away from the hole.

B—vertical fracture throughout the σ_{Hmax} direction.

C—horizontal fracture.

Notes

Specimen size. Specimens 1 to 6: 5-1/4 in. × 5-1/4 in. × 7 in.; specimens 7 to 10: 5-1/4 in. × 5-1/4 in.; specimens 11 to 26: 5 in. × 5 in. × 7 in.

Horizontal loading. Specimens 1 to 10: Direct piston; specimens 11 to 26: Flat jacks.

Borehole size. Specimens 1, 17, and 16: 0.3 in. diameter, specimens 3 and 12: 0.8 in. diameter (miniature straddle packer used in the borehole); all other specimens 0.5 in. diameter.

Borehole pressurization. Specimens 1 to 13: pressure control (20-30)

FIGURE 4-7 VERTICAL SECTION
THROUGH
SPECIMEN NO. 4

FIGURE 4-8 VERTICAL SECTION
THROUGH
SPECIMEN NO. 7

FIGURE 4-9 BREAKDOWN PRESSURE RESULTS (FLOW-CONTROL
TESTS ONLY) AS A FUNCTION OF σ_{Hmin} / σ_v

Effect of Horizontal Stresses on Hydrofracture Orientation

Thirty-one specimens of Montello granite were tested to verify the effect of horizontal stresses on the direction of hydrofractures. The specimen and borehole sizes were 5 in. x 5 in. x 7 in., and 0.5 in. The magnitudes of the largest horizontal stress and the vertical stress were kept at 2,000 and 4,000 psi, respectively. The least horizontal stress was varied between zero and 2,000 psi. Table 4-2 gives the experimental details and results.

In all tests, fractures were initiated vertically at the borehole. When the least horizontal stress (σ_{Hmin}) was between zero and 1,900 psi, fractures propagated in the direction of the largest horizontal stress (σ_{Hmax}). Fourteen tests were run with (σ_{Hmin}) between 1,925 and 2,000 psi; in nine of these, fracture orientations were found to be other than subparallel (within 8° or less) to (σ_{Hmax}) direction. The angle of variation is shown in degrees in Table 4-2. The angles vary from 10° to 70° .

Figures 4-10 to 4-15 are photographs of horizontal sections through the middle of typical tested specimens. Hydrofracturing horizontal stress conditions shown are ($\sigma_{Hmax} - \sigma_{Hmin}$) = 1,000, 200, 100, 75, 50 and 0 psi. The only three stress conditions for which the vertical hydrofracture was not perfectly aligned with (σ_{Hmax}) were those in which the horizontal stress differences were 0, 50 and 75 psi. It should also be noted that some of the tests in which the difference was 25-75 psi actually yielded fractures in the proper (σ_{Hmax}) direction. The randomness of the orientation when the state of stress around the borehole is practically hydrostatic, can be explained by fracture initiation at the weakest point on the circumference of the hole. The position of such weak points will vary from specimen to specimen.

Since most field conditions indicate that the principal horizontal stresses are not hydrostatic to within 75 psi, it may be concluded that in massive isotropic rocks, vertical hydrofractures will practically always extend in a direction parallel to that of (σ_{Hmax}).

The experimental breakdown pressures were plotted in Figure 4-16 as a function of the tangential stress at the borehole wall. The scatter of results is rather surprising, since identical loading conditions were maintained for all specimens. A closer look at the rock used, revealed that it came in several large blocks, not all of the same color or texture. It is suspected that the scatter of breakdown pressure results may have resulted from nonuniform mechanical properties of the different blocks tested.

TABLE 4-2 EFFECT OF HORIZONTAL STRESSES ON HYDRO-FRACTURE ORIENTATION AND BREAKDOWN PRESSURE IN MONTELLO GRANITE

Test No.	Horizontal stress			Breakdown pressure, P_c (psi)	Hydrofracture orientation ^a
	σ_{Hmin} (psi)	σ_{Hmax} (psi)	$\sigma_{Hmax} - \sigma_{Hmin}$ (psi)		
20	0	0	0	2100	A
30	0	2000	2000	1800	A
58	667	2000	1333	2750	A
57	850	2000	1150	2950	A
54	1000	2000	1000	3300	A
56	1000	2000	1000	3050	A
59	1000	2000	1000	3250	A
55	1300	2000	700	3550	A
33	1500	2000	500	3500	A
35	1600	2000	400	3500	A
62	1600	2000	400	3850	A
36	1700	2000	300	3300	A
37	1700	2000	300	3500	A
32	1800	2000	200	3100	A
42	1800	2000	200	4450	A
38	1900	2000	100	3800	A
40	1900	2000	100	2850	A
53	1925	2000	75	4450	B (35°)
52	1925	2000	75	4000	B (60°)
44	1950	2000	50	4400	B (10°)
48	1950	2000	50	4350	B (25°)
51	1950	2000	50	4350	B (50°)
46	1975	2000	25	4450	B (8°)
49	1975	2000	25	4300	B (30°)
27	2000	2000	0	3000	B (50°)
29	2000	2000	0	3700	C
43	2000	2000	0	4450	B (8°)
45	2000	2000	0	4300	B (30°)
47	2000	2000	0	4375	B (35°)
50	2000	2000	0	4200	C
41	2000	2100	100	4400	A

^aTypes of hydrofracture orientation:
A—vertical hydrofracture in the direction of σ_{Hmax}
B—vertical hydrofracture at some angle to σ_{Hmax} (angle given in parentheses).
C—hydrofracture not visible.

FIGURE 4-10 HORIZONTAL SECTION OF SPECIMEN NO. 54

FIGURE 4-11 HORIZONTAL SECTION OF SPECIMEN NO. 42

FIGURE 4-12 HORIZONTAL SECTION OF SPECIMEN NO. 38

FIGURE 4-13 HORIZONTAL SECTION OF SPECIMEN NO. 52

FIGURE 4-14 HORIZONTAL SECTION OF SPECIMEN NO. 48

FIGURE 4-15 HORIZONTAL SECTION OF SPECIMEN NO. 27

FIGURE 4-16 BREAKDOWN PRESSURE RESULTS AS A FUNCTION OF TANGENTIAL STRESS

Conclusion

LLL conducted 23 tests in Montello granite to verify the effect of the vertical stress magnitude on hydrofracture orientation. Test results determined that so long as the vertical stress is smaller than the least horizontal compressive stress, there is a good probability that the hydrofracture, which initiates vertically at the borehole, will rotate and become horizontal as it extends away from the borehole.

LLL also conducted 31 tests to investigate the effect of the difference ($\sigma_{Hmax} - \sigma_{Hmin}$) on the orientation of the hydrofracture. In these tests, the vertical stress was kept higher than (σ_{Hmin}). The results show that hydrofractures are vertical and parallel to (σ_{Hmin}) so long as ($\sigma_{Hmax} - \sigma_{Hmin}$) is greater than 75 psi, which attests to the sensitivity of the hydrofracture direction to the principle of the path of least resistance.

4.2.4 Logging

It has been said that a major reason for the less than spectacular results of the Rio Blanco and Rulison gas stimulation experiments was a lack of gas to stimulate. It has also been said that the preshot well log interpretation was unable to show this lack.

The preshot analyses based on the logs of Rio Blanco, were in fact fairly optimistic. This may have been, in large part, caused by overestimation of preshot permeability. This, in turn, could well have been caused by overestimation of porosity, and since calculated permeability is proportional to porosity to the sixth power⁶, it does not take a large overestimate of porosity to get a large overestimate of permeability.

The porosity was estimated to be between about 9 percent and 14 percent in the pay zones which gives rise to a calculated permeability range of 0.01 md at the low end to 0.1 md at the high, i.e., an order of magnitude.

The log-derived porosity is in turn a fairly strong function of "shaliness," and this is quite possibly the crux of the problem. It is thought that the normal derivation of shaliness from gamma-ray or self-potential logs is unsatisfactory in the tight western gas sands. These normal methods of determining shaliness are based on normal properties of most shales. Gamma-ray logs depend on the fact that shale normally contains more gamma-activity than other materials. Self-potential logging depends on the electrochemical properties of the shale. If these properties in the shales in question are abnormal, another method based on the aluminum content of the clay minerals in the shale, could be tried.

Neutron-induced gamma-ray activation has been used to determine shaliness on an experimental basis⁷. Neutrons are used to activate aluminum in the shale and thus, obtain, via gamma-ray spectroscopy, a quantitative estimate of the shale. It might be advisable to experiment with this technique in the tight western gas sands, since development of this technique might be a major improvement in logging technology.

4.3 Sandia Laboratories

4.3.1 Hydraulic Fracture Mapping

4.3.1.1 Wattenberg Fracturing Experiment

Sandia Laboratories, USGS, and Texas A&M University are participating with Amoco in a series of fracturing experiments in the Wattenberg Field northeast of Denver, Colorado. The third and final Wattenberg

⁶ Schlumberger Log Interpretation, Vol. I, Principles (1972) p 102.

⁷ H.D. Scott and M.P. Smith, "The Aluminum Activation Log," SPWLA 14th Annual Logging Symposium, Lafayette, LA, (1973).

experiment was conducted on March 6 and 7. The well, Carlson No. 1, is located 1.7 miles west of Ft. Lupton, Colorado, just north of State Road 52. The Amoco TV camera was placed downhole during the breakdown, which consisted of 20,000 gallons of 3 percent KCL gelled water. After approximately 6,000 gallons were pumped, the TV camera failed and was removed.

A Hewlett-Packard pressure gauge was inserted in a packoff pup at the surface for both the breakdown and main fracture treatment. Good pressure records were obtained for both.

The surface electrical potential instrumentation utilized the fracture well casing for pulsing. Design changes to permit pulsing of the downhole current probe are presently underway. This instrumentation system includes the capability to record fracture fluid flow rates (included in Figure 4-17).

For the main fracture, the borehole seismic package was located in the lubricator above the fluid injection point. Immediately following shut-in, the seismic package was landed 50 feet above the casing shoe and clamped in place. Data, recorded for approximately 6 hours, is still being analyzed.

4.3.2 Mineback Stimulation Test Program

The results of three exploratory coreholes that were drilled to locate the fractures of the Hole #6 "Interface Experiment" have been analyzed and a new mineback plan has been formulated. The mineback will restart at the beginning of April using conventional blast and muck techniques to proceed off the syncline in a southerly direction back into the ash fall tuff where the Alpine miner can again be efficiently utilized. The path toward the wellbore of Hole #6 will follow along the projection of the fracture found in EV6#1. Small hydraulic fracture breakdown tests were conducted in each of the coreholes (11, 7 and 5 zones in EV6#1, #2, and #3, respectively), in order to obtain the in situ stresses in the vicinity of Hole #6 (see Figure 4-18). The pumping records have not yet been analyzed; several of the zones will be revealed in conjunction with the mineback.

FIGURE 4-17 FLOW RATE SIGNATURES

FIGURE 4-18 CURRENT MINEBACK ACTIVITIES, G TUNNEL, NEVADA TEST SITE

TABLE 4-3 TENSILE STRENGTH, ELASTIC MODULI AND P AND S WAVE VELOCITIES OF UE 12g. 10# CORE SAMPLES

Depth	Type	Tensile Strength (psi)	Modulus of Elasticity x 10 ⁶ psi	Poisson's Ratio	Bulk Modulus x 10 ⁶ psi	Shear Modulus x 10 ⁶ psi	P Wave Velocity ft/sec	S Wave Velocity ft/sec
1297	Ash Fall	35	1.22	0.213	0.71	0.50	9450	4870
1305	Transition	126	2.12	0.218	1.25	0.87	10100	5510
1313	Transition	108	0.80	—	—	—	7900	4430
1323	Densely Welded	820	5.07	0.213	2.94	2.09	14670	7080
1338	Lower Transition	—	2.35	0.194	1.28	0.98	10800	5880
1343	Lower Transition	—	2.20	0.265	1.56	0.87	11540	6280
1354	Ash Fall	—	0.81	0.332	0.8	0.30	6190	3450
1363	Ash Fall	—	0.30	0.206	0.17	0.12	5160	3130

Further material property data from the Hole #6 core samples have been received. Table 4-3 shows the tensile strengths, elastic moduli, and p and s wave velocities for samples in the ash fall tuff, welded tuff, and the transition regions. The sample at 1,323 ft is representative of the densest section of the welded tuff and the sample at 1,363 ft is typical of the ash fall tuff units underlying the welded tuff. Welded tuffs are often categorized as having densities greater than 2.1 gm/cc, compressional strengths greater than 5,000 psi and p wave velocities greater than 9,000 ft/sec.

The mineback through the EV5#2 minifrac is complete. These small hydraulic fractures were initiated in nine zones and the pressure records and subsequent mineback were used to determine the in situ stresses and their orientations. The tests were conducted to analyze the effect that observed faults in the region of the Hole #5 "Staged Proppant Experiment" had on the stresses and consequently on the induced fractures. As before, complicated fracture systems were revealed in this mineback; maps, photos and descriptions are being compiled and correlated.

These additional fracture tests and minebacks along HFS#23 and EV5#2 complete the experimental work on the Hole #5 experiment. A complex geology was encountered in this region which had a significant effect on fracture behavior. All data are being analyzed in an attempt to quantify the observed behavior. A final report will be completed for this experiment during the next quarter.

4.3.3 Mobile Well Test Facility

4.3.3.1 Mast Truck

The mast truck is complete except for a few accessories such as the spare tire, hydraulic jack and tire chains. The grease injection system with electrical supply has been installed, floodlights mounted on the mast, and tool storage boxes mounted on the bed of the truck.

4.3.3.2 Instrument Trailer

The instrument trailer was transported to Sandia Laboratories after the logging cable was spooled on the draw works and the voltage regulator installed. This completed the contract with the trailer manufacturer in Fort Worth, Texas. Sandia Laboratories is now adding the operating equipment (desk, chairs, storage cabinets, tools, instrument racks, etc.) and providing minor modifications...

Logging tools and appropriate recorders have been ordered by Sandia Laboratories. The combined pressure and temperature tool with signal processor has been ordered with an expected delivery date of mid-June 1978.

The PDP11/10 computer was shipped to CER Corporation, Las Vegas, and is presently being used to train field personnel in its use and in the preparation of additional programs for use by the Western Gas Sands Project.

4.3.4 Other Program Related Activities

Sandia participated in the Fourth Semi-Annual Enhanced Gas Recovery Review meeting in Las Vegas, Nevada on March 21-23, 1978. Presentations were made by H.M. Stoller, Sandia's Role in the EGR Program, C.L. Schuster, Fracture Diagnostics Activities, N.R. Warpinski, Mineback Stimulation Test Program, and A.L. McFall, Improved Pressure Core Barrel Development.

In conjunction with the Las Vegas meeting, Sandia hosted a one-day trip on March 20 to the Nevada Test Site (NTS) to review the mineback program activities at G tunnel. About 20 people made the tour which featured detailed technical briefings in the tunnel, a visit to Sedan crater, and a tour of the NTS drill yard.

4.4 Tiltmeter

The tiltmeter activity has been under the direction of the U.S. Geological Survey/Menlo Park, but effective March 13, 1978, this effort is now performed by M.D. Wood, Incorporated.

A tiltmeter array was fielded in March at the Talley Energy Systems, Incorporated (TESI) well located approximately ten miles due west from Rock Springs, Wyoming. This first phase of TESI's oil shale in situ retorting experiment is scheduled in mid-May and involves treating the well by MHF at a depth of 400 ft. Phase Two in July involves the use of explosives and Phase Three will cover the oxygen retorting activity slated for the Fall. Although this field experiment is not a part of the WGSP, the tiltmeter instrumentation responses that may be obtained during the Phase One portion are of interest to the Project. Monitoring of the tiltmeter array commenced March 27, 1978, to characterize the background noise.

4.5 U.S. Geological Survey Borehole Gravity Meter

The Borehole Gravity Meter is experiencing a schedule slide caused by an electronics problem.

5. FIELD TESTS AND DEMONSTRATIONS

5.1 Background

Active projects are: MHF demonstrations in the Uinta Basin, Utah by Gas Producing Enterprises, Incorporated; a dry gas injection experiment in the Wattenberg Field, Colorado by Colorado Interstate Gas Company; and two MHF tests in Colorado's Piceance Basin by Mobil Research and Development Corporation and Rio Blanco Natural Gas Company.

A new DOE/Industry contract was executed with Mitchell Energy Corporation for an MHF test in the Fallon-North Personville Field in Texas.

The CER Corporation RB-MHF 3 is on inactive status pending satisfactory contractual arrangements to perform additional tests, and for final disposition of the well.

Table 5-1 summarizes both completed and active Western Gas Sands Project MHF treatments. Progress of ongoing projects is described in the following sections.

TABLE 5-1 MHF CONTRACT LOCATIONS AND FRAC DATA

COMPANY, BASIN AND FORMATION	LOCATION	WELL	INTERVAL FRACTURED	FRAC. DATE	FRAC TREATMENT	FLUID INJECTED
	T / R / Sec		Feet		Lbs. of Sand	10 ³ Gal.
AUSTRAL Piceance, Mesaverde	7S, 94W, S3 Garfield Co. Colorado	Federal 3-94	5,170-6,333	8-25-76	1,140,000	542 gel H ₂ O
CONSORTIUM MANAGED BY CER CORPORATION Piceance, Mesaverde	3S, 98W, S11 Rio Blanco Co. Colorado	RB-MHF-3	8,048-8,078	10-23-74	400,000	117 Gel
			7,760-7,864	5- 2-75	880,000	285 Gel
			5,925-6,016	5- 4-76	815,000	400 Gel
			5,851-5,869	11- 3-76	448,000	228 Gel
GAS PRODUCING ENTERPRISES, INC. Uinta, Wasatch and Mesaverde	10S, 22E, S10 Uintah County Utah	Natural Buttes No. 18	6,490-8,952	9-22-76	1,480,000	745 Gel
	10S, 21E, S21 Uintah County Utah	Natural Buttes No. 19	7,224-9,664	9-21-76 9-28-76	1,053,000	655 Gel
	9S, 21E, S22 Uintah County Utah	Natural Buttes No. 14	6,646-8,004	3-15-77	1,093,000	544 Gel
	9S, 21E, S28 Uintah County Utah	Natural Buttes No. 20	8,498-9,476	6-22-77	826,000	322 Gel
	10S, 22E, S18 Uintah County Utah	Natural Buttes No. 22	6,858-8,550	11-21-77	1,091,000	479 Gel
	9S, 21E, S19 Uintah County Utah	Natural Buttes No. 9	5,661-8,934	3-27-78	554,000	349 Gel

TABLE 5-1 CONTINUED

COMPANY, BASIN AND FORMATION	LOCATION	WELL	INTERVAL FRACTURED	FRAC. DATE	FRAC TREATMENT	FLUID INJECTED
	T / R / Sec		Feet		Lbs. of Sand	10 ³ Gal.
DALLAS PRODUCTION Forth Worth, Bend Cong.	Ben D. Smith Survey A-779 Wise County, Texas	Ferguson A-1	5,957-6,794	9-10-76	506,000	139 Foam 198 Emul.
EL PASO NATL. GAS Northern Green River, Fort Union	30N, 108W, S5 Sublette Co. Wyoming	Pinedale Unit No. 5	10,950-11,180 10,120-10,790	7- 2-75 10-20-75	518,000 1,422,000	183 Emul. 8 Gel 459 Gel
MOBIL Piceance Mesaverde	2S, 97W, S13 Rio Blanco Co. Colorado	F-31-13G	10,549-10,680 9,392- 9,534	6-22-77 8-24-77	580,000 600,000	316 Gel 260 Gel
PACIFIC TRANSMISSION Uinta, Mesaverde	8S, 23E, S25 Uintah County Utah	Fed 23-25	NO FRACS PERFORMED			
RIO BLANCO Piceance, Mesaverde	4S, 98W, S4 Rio Blanco Co. Colorado	Fed 498-4-1	6,150-6,312	10-22-76	776,000	276 Gel
WESTCO Uinta, Mesaverde	10S, 19E, S34 Uintah County Utah	Home Fed. No. 1	7,826- 9,437 10,014-10,202	12-21-76 10- 1-76	500,000 600,000	412 Gel 248 Gel

RIO BLANCO MASSIVE HYDRAULIC FRACTURING EXPERIMENT

EY-76-C-08-0623

CER Corp.
Las Vegas, Nevada

Status: Awaiting Advisory
Committee Decision

Interagency Agreement Date: June 19, 1974

Anticipated Completion: September 30, 1978

Project Cost	DOE	\$1,990,000
	Industry	<u>1,630,000</u>
	Total	\$3,620,000

Principal Investigator:	G. R. Luetkehans
Technical Advisor for DOE:	Charles H. Atkinson, Bartlesville Energy Research Center

OBJECTIVE

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

5.2 CER Corporation

5.2.1 Summary of Past Activities

DOE contract EY-76-C-08-0623 was awarded to CER Corporation in March 1974. The original contract provided for the drilling of a new well and two MHF treatments. Contract modifications have added two additional MHF treatments and extended the term of the contract until September 30, 1978.

5.2.2 Current Status

Field activities on the RB-MHF 3 well have been suspended because of lack of funds. Further action is dependent upon the completion of satisfactory contractual arrangements with an outside party to complete the commingling of the fractured gas zones and to perform additional testing in return for the well and subsequent gas production.

WATTENBERG FIELD

EY-77-C-08-1514

Colorado Interstate Gas Company
Colorado Springs, Colorado

Status: Active

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

Total Project Cost: (Estimated)	DOE	\$ 75,000
	CIG	99,000
	Total	\$174,000

Principal Investigator: Howard Fredrickson
Technical Project Officer for DOE: C. H. Atkinson, Bartlesville Energy
Research Center

OBJECTIVE

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

5.3 Colorado Interstate Gas Company

5.3.1 Scope of Work

DOE and Colorado Interstate Gas Company (CIG) entered into Contract No. EY-77-C-08-1514 on September 1, 1977. The experiment will determine if productivity of wells completed in low permeability natural gas reservoirs can be improved by reducing the interstitial water saturation by cyclic injection of dry natural gas. In addition, cyclic injection of dry natural gas may improve productivity by dehydrating matrix clays and by removal of formation damage adjacent to the surfaces of induced fractures.

5.3.2 Current Status

The compressor manufacturers have indicated that standard engine and compressor sets will not match the required design conditions. Based upon this information, a compressor has been ordered to meet the design criteria with delivery expected in January 1979. One additional month will be required for completion of site preparation and BHP buildup after receipt of the new compressor. The first cyclic injection-withdrawal will commence approximately March 1, 1979.

NATURAL BUTTES UNIT, UINTAH COUNTY, EY-76-C-08-0681 UTAH MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

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

Status: Active

Contract Date:	July 1, 1976	
Anticipated Completion:	Sept. 30, 1978	
Total Project Cost: (Estimated)	DOE	\$2,827,000
	Industry (prior costs)	1,881,000
	Industry (new costs)	<u>3,051,000</u>
	Total	\$7,759,000
Principal Investigator:	W. E. Spencer	
Technical Project Officer:	C. H. Atkinson, Bartlesville Energy Research Center	

OBJECTIVE

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

5.4 Gas Producing Enterprises, Inc.

5.4.1 Summary of Past Activities

Gas Producing Enterprises was awarded DOE Contract EY-76-C-08-0681 in July 1976. Originally, two old wells, Natural Buttes Unit Wells 14 and 18, and four new wells, 19, 20, 21, and 22 were to receive MHF treatments. Three contract modifications have been entered into, adding one old well, Natural Buttes Unit No. 9, two new wells, 23 and CIGE 2-29-10-21, and increasing the scope of work for Natural Buttes Unit Well No. 21.

5.4.2 Current Status

Natural Buttes Unit Well No. 9 was fractured on March 27, 1978. The treatment consisted of 7,000 gallons of 7-1/2 percent HCL, 35,000 gallons 2 percent KCL pads with 10 pounds/1,000 gallons guar gum, 56,000 gallons 2 percent KCL with 60 pounds/1,000 gallons guar gum gel, 258,000 gallons 2 percent KCL water with 40 pounds/1,000 gallons guar gum gel, 28,000 pounds 100-mesh Ottawa Sand, 525,000 pounds 40/60 mesh Ottawa Sand, 2,200 pounds 50/50 Unibeads, 174-7/8 in. RCN balls of 1.4+ specific gravity, and 110 tons of CO₂. Figure 5-1 shows the equipment set-up for the frac.

Natural Buttes Unit Wells No. 14, 18, 19 and 20 were flowing to sales during the month. Specific Production data for these four wells appears in Figures 5-2, 5-4, 5-6, and 5-8. Unit No. 22 was placed on initial production February 1, 1978, and continued throughout February and March, see Figure 5-10 for specific production data. Figures 5-3, 5-5, 5-7, 5-9 and 5-11 show the sands fractured in these wells. Natural Buttes Unit Wells No. 21 and 23 are awaiting completion.

FIGURE 5-1 NATURAL BUTTES NO. 9 FRACTURE SET-UP

FIGURE 5-2 NATURAL BUTTES NO. 9 WELL SHOWING SANDS FRACTURED

FIGURE 5-2 CONTINUED

FIGURE 5-2 CONTINUED

FIGURE 5-3 FLOW RATE PERFORMANCE OF NATURAL BUTTES NO. 14

FIGURE 5-4 NATURAL BUTTES NO. 14 WELL SHOWING SANDS FRACTURED

FIGURE 5-4 CONTINUED

FIGURE 5-4 CONTINUED

FIGURE 5-4 CONTINUED

FIGURE 5-4 CONTINUED

FIGURE 5-5 FLOW RATE PERFORMANCE OF NATURAL BUTTES NO. 18

FIGURE 5-6 NATURAL BUTTES NO. 18 WELL SHOWING SANDS FRACTURED

FIGURE 5-6 CONTINUED

FIGURE 5-6 CONTINUED

FIGURE 5-6 CONTINUED

FIGURE 5-6 CONTINUED

FIGURE 5-7 FLOW RATE PERFORMANCE OF NATURAL BUTTES NO. 19

FIGURE 5-8 NATURAL BUTTES NO. 19 WELL SHOWING SANDS FRACTURED

FIGURE 5-8 CONTINUED

FIGURE 5-8 CONTINUED

FIGURE 5-8 CONTINUED

FIGURE 5-8 CONTINUED

FIGURE 5-8 CONTINUED

FIGURE 5-9 FLOW RATE PERFORMANCE OF NATURAL BUTTES NO. 20

FIGURE 5-10 NATURAL BUTTES NO. 20 WELL SHOWING SANDS FRACTURED

FIGURE 5-10 CONTINUED

FIGURE 5.11 FLOW RATE PERFORMANCE OF NATURAL BUTTES
NO. 22

FIGURE 5-12 NATURAL BUTTES NO. 22 WELL SHOWING SANDS FRACTURED

FIGURE 5-12 CONTINUED

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

EF-78-C-08-1547

Mitchell Energy Corporation
Houston, Texas

Status: Drilling to
Commence approx.
June 15, 1978

Contract Date:	March 15, 1978
Anticipated Completion:	April 30, 1979
Total Project Cost: (Estimated)	DOE \$ 553,771
	Industry <u>1,074,550</u>
	Total \$1,628,321
Principal Investigator:	F. D. Covey
Technical Project Officer for DOE:	C. H. Atkinson, Bartlesville Energy Research Center

OBJECTIVE

To investigate the reservoir, fluid characteristics and results of massive hydraulic fracturing in the Cotton Valley Limestone Formation

5.5 Mitchell Energy Corporation

5.5.1 Scope of Work

DOE Contract EF-78-C-08-1547 was signed with Mitchell Energy Corporation in March 1978. The scope of work includes drilling, coring, logging and testing a new well, McGillivray Muse No. 2, treating with MHF and evaluating results.

5.5.2 Current Status

Drilling is scheduled to start June 15, 1978.

**PICEANCE CREEK FIELD, COLORADO,
MASSIVE HYDRAULIC FRACTURING
DEMONSTRATION**

EY-76-C-08-0678

Mobil Research and Development Corporation
Dallas, Texas

Status: Active

Contract Date:	July 1, 1976
Anticipated Completion:	December 31, 1978
Total Project Cost: (Estimated)	DOE \$2,510,000
	Contractor (prior costs) 2,376,485
	Contractor (new costs) 1,590,515
	Total \$6,477,000
Principal Investigator:	John L. Fitch
Technical Project Officer:	C. H. Atkinson, Bartlesville Energy Research Center

OBJECTIVE

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

5.6 Mobil Research and Development Corporation

5.6.1 Summary of Past Activities

Mobil was awarded DOE Contract EY-76-C-08-0678 in July 1976, to perform up to six MHF treatments in a new well in Rio Blanco County, Colorado. The well was drilled by Signal Drilling Company under separate DOE Contract EY-77-C-08-1504. Two treatments were performed in June and August 1977, and the two zones were commingled and produced to sales during the winter. Preparation for the third MHF treatment will commence in April, 1978.

5.6.2 Current Status

The well produced to the pipeline throughout the month of March. Production data is given in Figure 5-12. Figure 5-13 shows the sands fractured in this well.

5.6.3 Future Activities

Noise/temperature logging of the producing intervals is scheduled to begin on April 8. The completion unit should rig up on April 10 and pull the tubing, which is now landed below most of the perforations, to above the top of the perforations so that production logs can be obtained below the tubing. Use of a stripper head should permit this operation without killing the well.

Following production logging, a retrievable bridge plug will be set at $\pm 9,040$ ft. The interval 8,765-8,972 ft, overall, (Zone 5) will be perforated and tested. If this zone is suitable, the third frac job can be done about May 3.

FIGURE 5-13 FLOW RATE PERFORMANCE OF MOBIL F-31-13G WELL (AVERAGE DAILY RATE)

FIGURE 5-14 MOBIL F-31-13G WELL SHOWING SANDS FRACTURED

FIGURE 5-14 CONTINUED

RIO BLANCO COUNTY, COLORADO MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

EY-76-C-08-0677

Rio Blanco Natural Gas Company
Denver, Colorado

Status: Active

Contract Date:	August 1, 1976
Anticipated Completion:	March 31, 1978
Total Project Cost:	DOE \$ 410,000
	Contractor 593,000
	<u>Total \$1,003,000</u>

Principal Investigator:	Robert E. Chancellor
Technical Project Officer:	C. H. Atkinson, Bartlesville Energy Research Center

OBJECTIVE

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

5.7 Rio Blanco Gas Company

5.7.1 Summary of Past Activities

DOE Contract EY-76-C-08-0677 was signed with Rio Blanco Natural Gas Company in June 1976. The first MHF treatment was performed on October 22, 1976. A supplemental agreement, effective October 1, 1977, provided for a second MHF treatment, which was performed on November 30, 1977.

5.7.2 Current Status

The well is being cleaned up in preparation for testing.

**FIGURE 5-15 RIO BLANCO NATURAL GAS FEDERAL 498-4-1 WELL
SHOWING SANDS FRACTURED**

FIGURE 5-15 CONTINUED

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APPENDIX

**FOURTH SEMI-ANNUAL ENHANCED GAS RECOVERY
REVIEW MEETING**

**Marina Hotel, Las Vegas, Nevada
March 21, 22 and 23, 1978
Pier 4 Meeting Room**

**March 21, 1978
Tuesday**

SESSION CHAIRMAN: Don Ward

9:00 a.m. Don Ward, Department of Energy
Introduction

9:10 a.m. Augustine Pitrolo, Morgantown Energy Research Center
Overview of Fossil Energy

9:30 a.m. Hugh Guthrie, Department of Energy
Status of Fossil Energy Program

10:00 a.m. Coffee Break

10:15 a.m. Jerry Ham, Department of Energy
Overview of EGR Strategy Planning

10:45 a.m. Bill Hochheiser, Department of Energy
Strategy Plan Status and Schedule

11:15 a.m. Vello Kuuskraa, Lewin and Associates, Inc.
Data Gathering for Reservoir and Economic Modeling

11:45 a.m. Walt Holman, Booz, Allen and Hamilton
Industry Survey

12:15 p.m. LUNCH

SESSION CHAIRMAN: Jerry Luetkehans

1:30 p.m. Charles Atkinson, Department of Energy
General Description of Western Gas Sands
Project Activities; Review of Field Tests

2:10 p.m. Merle Hanson, Lawrence Livermore Laboratory
LLL's Role in the EGR Program

2:40 p.m. Coffee Break

3:00 p.m. Hap Stoller, Sandia Laboratories
Sandia's Role in the EGR Program

3:30 p.m. William Overbey, Morgantown Energy Research Center
Status Report on Eastern Gas Shales Project

4:30 p.m. ADJOURNMENT FOR DAY

March 22, 1978
Wednesday

SESSION CHAIRMAN: Charles Atkinson

9:00 a.m. Leo Schrider, Morgantown Energy Research Center
MERC In-House Research and Development

9:20 a.m. Robert Wise, Morgantown Energy Research Center
Methane Drainage Program

9:40 a.m. C. Ray Williams, Bartlesville Energy Research Center
Improved Pressure Core Barrel; In Situ Stress Measurements

10:00 a.m. Herb Carroll, Bartlesville Energy Research Center
Frac Fluid/Formation Interaction; Surface Conductivity Measurements

10:15 a.m. Coffee Break

10:30 a.m. Gordon Anderson, Lawrence Livermore Laboratory
Lab Results of Hydrofrac Work

10:50 a.m. R.M. Potter, Los Alamos Scientific Laboratory
Hydraulic Fracture Initiation Sites Identified by Geophysical Logs

11:05 a.m. William J. Carter, Los Alamos Scientific Laboratory
Explosive Stimulation of Tight Formations

11:20 a.m. Nick Vanderborgh, Los Alamos Scientific Laboratory
Rapid Analysis of Gas Yields from Tight Formations

11:35 a.m. Darrell Wood, U.S. Geological Survey
Fracture Orientation by Tilt Meter Methods

12:00 NOON

LUNCH

SESSION CHAIRMAN: Bob Mann

1:30 p.m. Carl Schuster, Sandia Laboratories
Frac Orientation Work

2:00 p.m. Norm Warpinski, Sandia Laboratories
NTS Mineback

2:30 p.m. Gerald C. Kukal, CER Corporation
New Logging Concepts

2:45 p.m. Paul Branagan, CER Corporation
Western Gas Sands Project Mobile Test Trailer

3:00 p.m. Coffee Break

3:15 p.m. Tom Fouch, U.S. Geological Survey
Mineralogy and Stratigraphy of the Piceance Basin

3:45 p.m. Dudley Rice, U.S. Geological Survey
Occurrence of Gas in Shallow Low Permeability
Reservoirs of the Northern Great Plains

4:15 p.m. Carroll F. Knutson, C K GeoEnergy
Calculated Uinta Basin Permeabilities Based on
Linear Modeling

4:30 p.m. Jeff Mann, Booz, Allen and Hamilton
Socio-Economic Studies Associated with the EGR
Strategic Planning

5:00 p.m. ADJOURNMENT FOR DAY

March 23, 1978
Thursday

SESSION CHAIRMAN: Charles Atkinson

9:00 a.m. Arfon Jones, Terra Tek
Rock Mechanics Aspects of Tight Gas Reservoirs

9:20 a.m. Harvey Price, Intercomp
Application of Reservoir Engineering to Gas Well
Performance

9:50 a.m.

Coffee Break

10:00 a.m.

Forum

1. Fracturing and Production Models
Harvey Price, Chairman
2. Fracturing Techniques, Testing and Evaluation
Lloyd Elkins, Chairman
3. Methane From Coal
Todd Doscher, Chairman
4. Coring and Testing Program to Evaluate
Speculative Resource Areas
Charles H. Atkinson, Chairman
5. Program Implementation - A Need
For Working Groups?
Don Ward, Chairman

SEMI-ANNUAL EGR MEETING

March 21, 22 and 23, 1978
Marina Hotel, Las Vegas, Nevada

Charles Atkinson	DOE/BERC-NV	Las Vegas, NV
John S. Ball	DOE/BERC	Bartlesville, OK
Herb Carroll	DOE/BERC	Bartlesville, OK
Robert Clarke	DOE/E&EAD	Las Vegas, NV
James Cotter	DOE/NV	Las Vegas, NV
Hugh Guthrie	DOE/OGSIST	Washington, D.C.
Jerry Ham	DOE/FE	Washington, D.C.
Bill Hochheiser	DOE/OGSIST	Washington, D.C.
William Overbey, Jr.	DOE/MERC	Morgantown, WV
Augustine Pitrolo	DOE/FE	Washington, D.C.
Leo A. Schrider	DOE/MERC	Morgantown, WV
Jeff Smith	DOE/FE	Washington, D.C.
Don Ward	DOE/FE	Washington, D.C.
C. Ray Williams	DOE/BERC	Bartlesville, OK
Bob Wise	DOE/MERC	Morgantown, WV
Walt Holman	Booz, Allen, Hamilton	Washington, D.C.
Jeff Mahan	Booz, Allen, Hamilton	Washington, D.C.
Chris Rust	Booz, Allen, Hamilton	Washington, D.C.
Conrad Appledorn	CER Corporation	Las Vegas, NV
Paul Branagan	CER Corporation	Las Vegas, NV
Dick Hammond	CER Corporation	Las Vegas, NV
Gerald Kukal	CER Corporation	Las Vegas, NV
Jerry Luetkehans	CER Corporation	Las Vegas, NV
Bob Mann	CER Corporation	Las Vegas, NV
Nick Newman	CER Corporation	Las Vegas, NV
Charles Boardman	CK GeoEnergy	Las Vegas, NV
Hank Coffey	CK GeoEnergy	Las Vegas, NV
Carroll Knutson	CK GeoEnergy	Las Vegas, NV
Bill Carter	LASL	Los Alamos, NM
Nick Vanderborgh	LASL	Los Alamos, NM
Jerry Brashear	Lewin & Assoc.	Washington, D.C.
Todd Doscher	Lewin & Assoc.	Los Angeles, CA
Lloyd Elkins	Lewin & Assoc.	Tulsa, OK
Vello Kuuskraa	Lewin & Assoc.	Washington, D.C.

Harvey S. Price	Intercomp	Houston, TX
Gordon Anderson	LLL	Livermore, CA
Merle Hanson	LLL	Livermore, CA
Fred Holzer	LLL	Livermore, CA
Ron Shaffer	LLL	Livermore, CA
Ron Zielinski	Monsanto/Mound	Miamisburg, OH
Alan McFall	Sandia Labs	Albuquerque, NM
David A. Northrop	Sandia Labs	Albuquerque, NM
Carl L. Schuster	Sandia Labs	Albuquerque, NM
Hap Stoller	Sandia Labs	Albuquerque, NM
Norm Warpinski	Sandia Labs	Albuquerque, NM
W.G. McGlade	SAI	Morgantown, WV
Arfon Jones	Terra Tek	Salt Lake City, UT
K.R. Lewis	TRW	McLean, VA
R.L. Robertson	TRW	McLean, VA
D.R. Watkins	TRW	McLean, VA
Tom Fouch	USGS	Lakewood, CO
Dick Mast	USGS	Lakewood, CO
Dudley Rice	USGS	Denver, CO
Frank Stead	USGS	Denver, CO
Sunder H. Advani	West Virginia Univ.	Morgantown, WV
M.D. Wood	Wood, Inc.	Portola Valley, CA

PROGRAM AND SPEAKERS

UNITED STATES GEOLOGICAL SURVEY SEMINAR ON
PETROLEUM RESEARCH AND RESOURCES

Green Center Auditorium
Colorado School of Mines
Golden, Colorado
March 14, 15, 1978

March 14

8:00 Welcome and Introduction to the Seminar R.F. Mast

SESSION I

Framework and petroleum resource studies Atlantic continental margin
Co-chairmen: D.W. Folger, R.E. Mattick

8:15 Introduction. D.W. Folger
8:20 Acoustic stratigraphy of the Georges Bank Basin . J.S. Schlee
8:35 Development of the U.S. continental margin from
Cape Fear to Cape Canaveral W.P. Dillon
8:50 The ocean-continent transition zone in the vicinity
of Baltimore Canyon trough J.A. Grow
9:05 High sensitivity aeromagnetic survey of the U.S.
Atlantic continental margin as applied to studies
of geologic framework J.C. Behrendt
9:20 Basin structure of the U.S. Atlantic continental
margin: magnetic studies K.D. Klitgord
9:35 The petroleum potential of the Atlantic Margin. . R.E. Mattick

SESSION II

Framework and petroleum resource studies offshore West Coast and Alaska
Co-chairmen: D.W. Scholl, H.E. Cook

9:50 Introduction. D.W. Scholl
9:55 Eastern Gulf of Alaska, offshore bedrock sampling
and crustal structure G.R. Winkler
10:10 Eastern Gulf of Alaska, interpretations of offshore
reflection data T.R. Bruns
10:25 Geological implications of Lower Cook Inlet
COST well L.B. Magoon
10:40 Preliminary thoughts on the structure of Kodiak
Shelf M.A. Fisher
10:55 The Aleutian Basin of the Bering Sea; a super large
frontier area for hydrocarbon exploration . . . A.K. Cooper
11:10 Navarin Basin, where a little bit of southern Bering
Sea ice overlies a lot of petroleum potential . Mike Marlow
11:25 Submarine acoustic anomalies, escaping gas, peat
and more; Norton Basin, Northern Bering Sea . . Mark Holmes

- 11:40 Structural framework of Beaufort Shelf
(Petroleum Hall). Arthur Grantz
- 12:00 LUNCH
- 1:00 Geochemical analyses of a possible petroleum gas
seep in Norton Basin. Keith Kvenvolden
- 1:15 Structure and stratigraphy of Hope Basin, southern
Chukchi Sea Stephen Eittreim
- 1:30 Geo-environmental hazards in offshore Pacific-Arctic
areas; what are they and what is SLURP? Monty Hampton
- 1:45 Laumontite diagenesis of mineralogically immature sand-
stone; conditions governing crystallization . . Thane McCulloh

SESSION III

Northern Alaska petroleum studies
Co-chairmen: K.T. Bird, A.T. Ovenshine

- 2:00 Introduction. K.J. Bird
- 2:05 Program to assess petroleum resources in National
Petroleum Reserve-Alaska (NPR-A) George Gryc
- 2:25 New subsurface information on the Lisburne Group
in NPR-A. K.J. Bird
- 2:40 Geology and geochemistry of the Oumalik, Topagoruk,
and Barrow 13 wells NPE-A L.B. Magoon
- 2:55 Geologic studies of the Lower Cretaceous Nanushuk
Group, North Slope, Alaska. T.S. Ahlbrandt
- 3:10 Hydrocarbon potential of the Arctic National
Wildlife Range-Alaska C.G. Mull

SESSION IV

Onshore basin studies, western tight gas sands and
USGS core libraries programs
Co-chairmen: C.W. Spencer, B.E. Law

- 3:25 Introduction. C.W. Spencer
- 3:40 Mineralogical and depositional characteristics of some
"tight" sandstone reservoirs in the eastern
Uinta Basin, Utah T.D. Fouch
- 3:55 Preliminary evaluation of low-permeability reservoirs
in the Washakie Basin, Wyoming. T.F. Tyler
- 4:10 Potential for major gas resources in shallow low-
permeability reservoirs in the northern
Great Plains. D.D. Rice
- 4:25 Hydrocarbon evaluation of the northern disturbed
belt, Montana M.R. Mudge
- 4:40 Evaluation of Phosphoria Formation petroleum source
rocks in the overthrust belt and northeastern
Great Basin E.K. Maughan
- 4:55 New ideas on the Pilot and Deseret Basins-- oil sources
for Paleozoic and younger reservoirs in the Cordilleran
miogeosyncline and overthrust belt, Utah. . . . C.A. Sandberg

March 15

SESSION V

Eastern black shales characterization studies

Co-chairmen: W.W. deWitt, R.C. Kepferle

- 8:00 Introduction W.W. deWitt
8:10 Regional correlation of selected Devonian black shales
in the west half of the Appalachian Basin. . . J.B. Roen
8:25 A Cambrian aulacogen and its influence on Paleozoic
sedimentation in the eastern United States
interior platform. L.D. Harris
8:40 Lithology-dependent joint patterns in the Appalachian
plateau G.W. Colton
8:55 Conodont-documented reinterpretation of the Bane dome,
Giles County, Va.--a structural reevaluation of the
Allegheny frontal zone W.J. Perry, Jr.
9:10 Cretaceous basin analysis and petroleum potential
of California. D.G. Howell

SESSION VI

Reservoir rocks and sedimentary process studies

Co-chairmen: P.A. Scholle, T.A. Ahlbrandt

- 9:25 Introduction P.A. Scholle
9:30 Petroleum potential of chalks. P.A. Scholle
9:45 Interpretation of eolian environments from
minor structures E.D. McKee
10:00 Reservoir quality aspects of eolian deposits . . T.S. Ahlbrandt
10:15 Ancient continental slope sequences and their usefulness
in understanding modern slope development. . . H.E. Cook
10:30 Compaction of limestone sediments--implications for
petroleum origin and migration E.A. Shinn
10:45 Diagenesis of Sunniland limestones and its effects
on reservoir properties. R.B. Halley

SESSION VII

Stratigraphic-seismic studies

Co-chairmen: A.H. Balch, D.J. Taylor

- 11:00 Introduction A.H. Balch
11:05 Use of vertical seismic profiles in stratigraphic
exploration A.H. Balch
11:20 Seismic model study of Patrick Draw field, Wyoming -
a stratigraphic trap in the Upper Cretaceous
Almond Formation R.C. Anderson
11:35 Seismic expression of stratigraphic traps in the
Minnelusa Formation, Powder River Basin, Wyoming. R.T. Ryder
12:00 LUNCH

SESSION VIII

Organic geochemistry program
Co-chairmen: G.E. Claypool, A.H. Love

- 1:00 Introduction G.E. Claypool
1:05 Geochemistry of organic matter and petroleum
exploration. G.E. Claypool
1:20 Depth gradients of vitrinite reflectance in southern
California oil basins--importance for exploration
in young sedimentary basins. N.H. Bostick
1:35 Geochemical correlation of crude oils and source rocks
in the Western U.S.. J.N. Clayton
1:50 South Florida Basin and carbonates as petroleum
source rocks J.G. Palacas
2:05 Evidence for deep origin of petroleum. L.C. Price
2:20 Variations of carbon isotopes through time as an indicator
of basinal hydrocarbon source rock potential . P.A. Scholle

SESSION IX

Geochemical detection of oil and gas accumulations
Co-chairmen: T.J. Donovan, M.E. Henry

- 2:35 Introduction T.J. Donovan
2:40 Geochemical prospecting for oil and gas from orbital
and suborbital altitudes T.J. Donovan
2:55 Helium surveying as a geochemical exploration
technique. A.A. Roberts

SESSION X

Borehole gravity studies
Co-chairmen: J.W. Schmoker, S.L. Robbins

- 3:10 Introduction J.W. Schmoker
3:15 Borehole gravity accuracy studies J.W. Schmoker
3:30 Borehole gravity--advanced interpretation and
applications L.A. Beyer

SESSION XI

Oil and gas data systems
Co-chairmen: W.W. Mallory, T.S. Dyman

- 3:45 Introduction W.W. Mallory
3:50 Oil and gas field map of North America and the
Petroleum Data System W.W. Mallory
4:00 Application of computer techniques to oil and gas
resource problems. T.S. Dyman

SESSION XII

Research program for oil and gas resource appraisal

Co-chairmen: B.M. Miller, E.W. Scott

- 4:15 Introduction B.M. Miller
- 4:20 Developments in methodology of predicting resource
estimates, and the distributions of undiscovered
oil and gas fields by size and number for the Permian
Basin and Gulf of Mexico B.M. Miller
- 4:35 An appraisal of oil and gas resources in the Gulf
of Mexico R.B. Powers
& Robert Pike
- 5:00 An appraisal of oil and gas resources in the
Permian Basin. G.L. Dolton
& A.B. Coury