July 1979
DOE/BG/01569-12
CER Corporation

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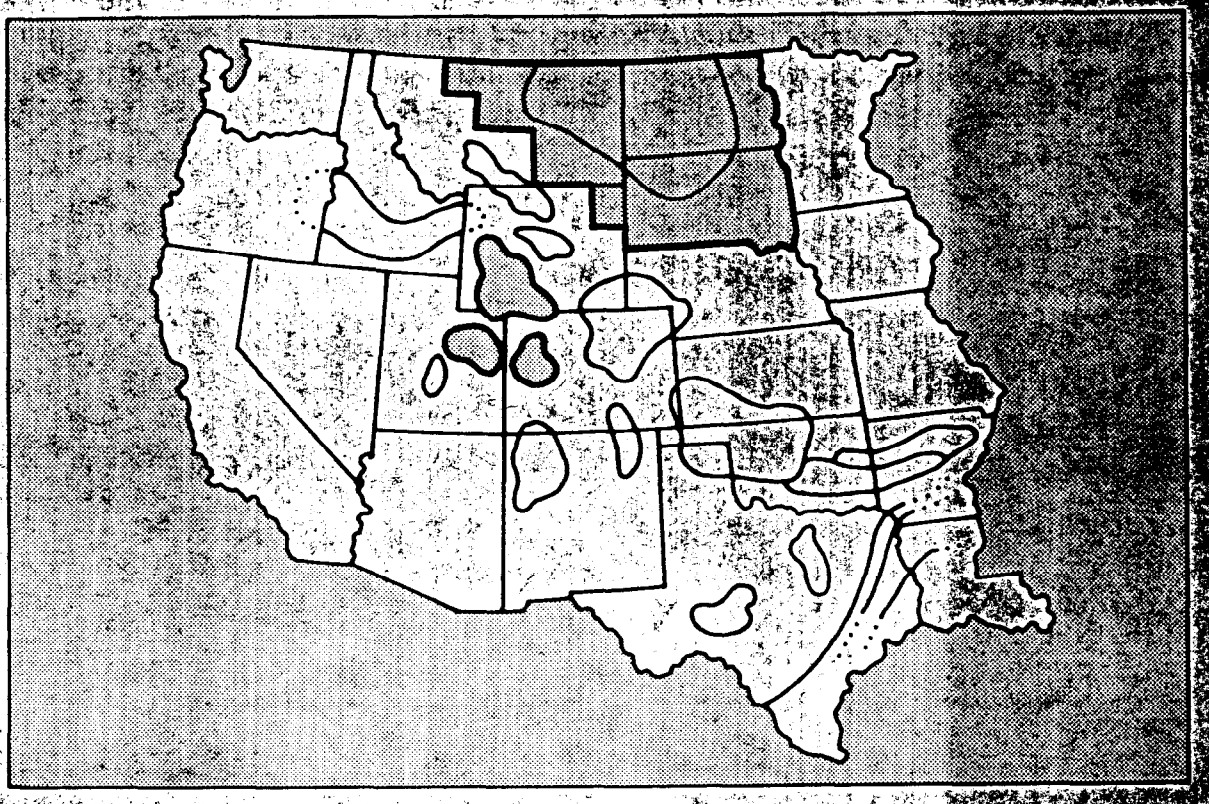
Western Gas Sands Project Status Report



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Prepared for
U.S. Department of Energy

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Las Vegas, Nevada

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1. SUMMARY

This edition of the WGSP Status Report summarizes July, 1979 progress of government-sponsored projects directed toward increasing gas production from the low-permeability gas sands of the western United States. Background information is provided in the *September, 1977, Status Report, NVO/0655-100.*

National Laboratories and Energy Technology Centers continued projects during July. Bartlesville Energy Technology Center continued work on core/fluid testing, fabrication of and improvements to confining pressure apparatus, advanced logging techniques and interpretation and reservoir simulation studies. At Lawrence Livermore Laboratory theoretical analysis and experimental programs continued for hydraulic fracturing. Testing of the borehole seismic and hydrophone systems for fracture mapping continued at Sandia Laboratories.

The CER Corporation RB-MHF 3 well has been transferred to Rio Blanco Natural Gas Company for further testing. Cyclic gas injection and production continued at CIG's Miller No. 1 and Sprague No. 1 wells. The DOE well test facility was transported to the Rio Blanco Natural Gas Company well No. 397-19-1 Government. The cumulative production of Mitchell Energy Muse-Duke No. 1 as of July 31, 1979 was just over one billion cubic ft of gas. A flow log was run on the Mobil PCU F31-13G well. Exploratory coring for the Sandia Hole No. 6 fracture experiment continued in July with the completion of two additional holes.

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2. PROJECT MANAGEMENT

2.1 TECHNICAL MONITORING AND EVALUATION

C. H. Atkinson (DOE), met with K. Krickenberger and J. Sassaman (Mitre Corporation) on July 11 in Las Vegas, Nevada, to discuss the WGSP and environmental considerations relating to the project.

C. H. Atkinson (DOE), and R. L. Mann and G. R. Luetkehans (CER Corporation) met with BETC and DOE/HQ personnel and the five-member industry advisory panel in Dallas, Texas, on July 19 to discuss the multi-well field test.

O. R. Coats (CER Corporation) made a trip to investigate the Rio Blanco Natural Gas well site (No. 397-19-1 Government), Rio Blanco County, Colorado, to set up the DOE well test facility.

H. E. Newman (CER Corporation) attended an H. K. VanPoollen Production Technology course in Denver, Colorado, July 16-20.

D. W. Hilchie visited CER Corporation in Las Vegas, Nevada, on July 23 to discuss the WGSP multi-well logging program. Mr. Hilchie will be working with G. C. Kukal as a consultant on this program.

S. Holditch (Sovereign Engineering International) visited CER Corporation in Las Vegas, Nevada, to discuss the multi-well computer programs with P. T. Branagan on July 30.

G. C. Kukal attended the Society of Petroleum Engineers Forum Series, "Frontiers of Technology" in Glenwood Springs, Colorado, July 30-August 3.

2.2 TECHNOLOGY TRANSFER

2.2.1 Documentation and Reports

The WGSP Financial Supplement for June, 1979, was distributed and data for the July supplement was compiled. Work on the WGSP Project Plan, FY 1980 continued. The DOE Well Test Facility Manual was updated in July. Work on a geologic review of the Northern Great Plains Province by CER Corporation personnel continued. Data for the WGSP Second Quarterly Basin Activities Report, 1979 was compiled. A report on the WGSP Logging Program was revised.

2.2.2 Project Data Bank

USGS professional papers Nos. 776 and 404: "Stratigraphic and Geologic History of the Montana Group" by Gill, and "Stratigraphy and Structure of the Flanks of the Black Hills Uplift, Wyoming, Montana and South Dakota" by Robinson, respectively, and a cross-section entitled Preliminary Stratigraphic Studies of the Upper Part of the Mesaverde Group, Wasatch Formation, Lower Part of the Green River Formation, Debeque Area, Colorado by Johnson and May were added to the project data bank. Work continued on the WGSP bibliography.

2.2.3 Articles and Publications

The following articles and publications relate to the WGSP and abstracts, when available, will be included.

On the Computation of the Three-Dimensional Geometry of Hydraulic Fractures
by R. J. Clifton, Brown Univ. and A. S. Abou-Sayed, Terra Tek Inc.

A computational method is outlined for modelling the three-dimensional development of hydraulic fractures due to the injection of a non-Newtonian fluid at the well bore. The rock formation is modelled as an infinite, homogeneous, isotropic, elastic solid with *in situ* stresses that vary with depth. The three-dimensional problem is made two-dimensional by assuming that the velocity profile through the thickness of the crack opening is the same as for flow between parallel plates, and by reducing the elasticity problem to an integral equation that relates pressure on the crack faces to crack openings. Crack openings for a given crack geometry and pressure distribution are obtained by using properties of two-dimensional Chebyshev polynomials to facilitate inversion of the integral equation. Two-dimensional fluid flow between the crack faces is analyzed using a finite element method.

Some Results from Continuum Mechanics Analyses of the Hydraulic Fracturing Process
by M. E. Hanson and R. J. Shaffer, Lawrence Livermore Laboratory

We are developing and applying theoretical, numerical models to analyze the hydraulic fracturing process. Applications include: fracturing near interfaces, effects of existing fractures near interfaces, pore-pressure effects, and stress-field changes due to embedded lenses. For a well-bonded interface, the calculations indicate that the stress-intensity factor of the leading crack tip decreases as the crack approaches a higher modulus material. As the tip crosses the interface into the higher modulus material, the stress-intensity factor abruptly increases to a higher value than it had in the lower modulus material. When the situation is reversed the intensity factor increases as the tip approaches the interface and then abruptly decreases when the tip crosses the interface.

Further calculations show that when existing cracks are present near the interface, the effects of the change in material properties across the bonded interface are reduced. In addition, our analysis shows that increases in pore pressure due to leakage of fluids from the fracture into the surrounding media causes the stress-intensity factor to drop; a decrease in the stress-intensity factor means a reduction in the tendency to break. In other calculations we analyzed the stress-field disturbance caused by lenses of one material that are embedded in another material. These calculations show that in regions that are not tectonically relaxed the stress field is modified by the lenses. We conclude that the *fracture geometry is modified by the presence of embedded lenses* under these conditions.

Particle Size Distributions Generated by Crushed Proppants and Their Effects on Fracture Conductivity
by H. B. Carroll, Jr., and B. A. Baker, U.S. Department of Energy

Department of Energy supported research conducted in the tight gas sands of the Piceance, Uinta, and Green River Basins of Colorado, Utah, and Wyoming, respectively, is directed toward evaluating massive hydraulic fracturing (MHF) for increasing natural gas production. Research at Bartlesville Energy Technology Center supporting the Western Gas Sands Project consists of examining potential areas of formation damage by MHF fluids and proppants.

Fractures produced by the MHF process are propped open by placement of particulate materials creating zones of high permeability and porosity. In this research, high permeability fractures were simulated by placing 40/60 mesh sand proppant between core halves, and subjecting the cores to increasing overburden pressure. As the proppant was crushed, the resultant particles were transported through the propped fracture by fracturing fluids. Mean, mode, and number per unit volume of the produced particle size distributions were measured and related to overburden pressure.

The effects of particle retention, when pumping similar particle distributions through the propped fracture, were detected by a pressure change across the core. Measured changes in the filtration efficiency, conductivity, and threshold plugging pressure of the propped fracture showed significant particle trapping within the porous media. Pressure versus time plots indicate successive pore plugging and particle breakthrough until the fracture is ultimately plugged.

Prefracturing Pressure Transient Testing: East Texas Cotton Valley Tight Gas Play
by J. N. Bostic and J. A. Graham, Amoco Production Company

Performance analysis of low permeability gas wells requires an accurate knowledge of formation flow capacity (kh) and initial static reservoir pressure (p_i). These parameters are used in calculating original gas-in-place, predicting well rates and reserves, and assessing economics. In addition, they are key parameters in massive hydraulic fracturing (MHF) design and evaluation work.

Formation flow capacity and initial reservoir pressure are best determined from prefracturing pressure transient tests; however, conventional testing techniques have proven inadequate in low-permeability formations.

Amoco's experience in prefracturing pressure transient testing of 0.001 to 0.01 md gas sands in the Cotton Valley Formation of east Texas has led to the establishment of the following three-step procedure to enhance accurate prefracturing pressure transient data collection:

- Preflow tests for static pressure determination (p_i),
- Pressure drawdown tests to determine producing characteristics, and
- Pressure buildup tests to determine the formation flow capacity (kh).

Severe wellbore storage effects, which are characteristic of low-permeability formations, have made it necessary to utilize some method of downhole shut-in in the Cotton Valley Formation to obtain the required pressure data within a reasonable amount of time. Although methods exist to analyze pressure transient data with storage effects, it has been found that an accurate analysis is possible when the storage effects have been minimized. Increased costs resulting from the use of downhole shut-in devices may be partially offset by careful planning of the test procedure.

Actual field results along with predicted results from a one-dimensional, radial, single phase gas reservoir simulator illustrate the effectiveness of the outlined technique and the need for accurate and reliable data.

3. RESOURCE ASSESSMENT

3.1 U.S. GEOLOGICAL SURVEY ACTIVITIES

3.1.1 Uinta-Piceance Basins

Results of analyses of Cretaceous and Paleocene rocks in the Price River Canyon by X-ray diffraction and petrographic methods were compiled.

Field work in the Piceance and Uinta Basins continued.

Preliminary mineralogical investigation of Natural Buttes CIGE No. 21 core samples of the Green River, Wasatch-Colton, Tuscher-Farrer, and Sego Formations, and the Mancos Shale continued. The purpose of this investigation is to describe the rocks and indicate diagenetic features and their effects on reservoir properties of the rocks. Preliminary observations are given below.

- Several samples are more porous than rocks from the same sequence which were reported in the Western Gas Sands Project Status Report, 1 January 1979 — 31 January 1979, p. 21.

- Some samples with very high apparent porosity values have extensive areas of kaolinite. These samples have the appearance of microcrystalline rock fragments under the petrographic microscope. However, SEM analysis of the apparent rock fragments indicates that the grains are felted kaolinite that is very porous but relatively impermeable. This type of occurrence of kaolinite affects the pore geometry of the potential reservoir and it may explain the log and core analysis that indicates high porosity but low permeability values for the rock. It is unlikely that this form of porosity will contribute significant volumes of gas or fluids to the borehole with or without stimulation even though log analysis indicates relatively high porosity values.

- Several generations of cementation (principally Fe-Mg carbonates and anhydrite) are present in some samples.

- Barium has also been detected in some rocks but its mineralogical form is uncertain.

Carbonate cements, kaolinite, and the element barium are all potentially significant rock constituents that may affect the productive capacity of a reservoir. The depositional, mineralogical, and stratigraphic controls on the occurrence of these constituents are uncertain, but regionally mappable. Although most of the core is thought to be fluvial rocks,

limited suitable samples preclude interpretation of the depositional processes responsible for the occurrence of these materials and their areal distribution. These rocks were formed in a variety of depositional settings and have undergone significant subsequent diagenesis. The regional significance of these individual mineralogical and physical features that relate to reservoir and borehole log properties cannot be accurately assessed from the limited and incomplete sample set.

The following reports have been approved for publication and will soon be available for sale under the following titles. All of these reports relate to the sedimentological and stratigraphic framework of rocks in the Piceance Basin which are being studied under the Western Gas Sands Project.

Johnson, R. C., 1979, Cross-section A-A′ of Upper Cretaceous and Lower Tertiary rocks, northern Piceance Creek Basin, Colorado: U.S. Geological Survey MF-1129-A.

Johnson, R. C., 1979, Cross-section B-B′ of Upper Cretaceous and Lower Tertiary rocks, northern Piceance Creek Basin, Colorado: U.S. Geological Survey MF-1129-B.

Johnson, R. C., 1979, Cross-section C-C′ of Upper Cretaceous and Lower Tertiary rocks, northern Piceance Creek Basin, Colorado: U.S. Geological Survey MF-1129-C.

Johnson, R. C., M. P. Granica, and N. C. Dessenberger, 1979, Cross-section A-A′ of Upper Cretaceous and Lower Tertiary rocks, southern Piceance Creek Basin, Colorado: U.S. Geological Survey MF-1130-A.

Johnson, R. C., M. P. Granica, and N. C. Dessenberger, 1979, Cross-section B-B′ of Upper Cretaceous and Lower Tertiary rocks, southern Piceance Creek Basin, Colorado: U.S. Geological Survey MF-1130-B.

Johnson, R. C., M. P. Granica, and N. C. Dessenberger, 1979, Cross-section C-C′ of Upper Cretaceous and Lower Tertiary rocks, southern Piceance Creek Basin, Colorado: U.S. Geological Survey MF-1130-C.

3.1.2 Greater Green River Basin

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

Work continued on the petrographic analysis of the Tierney wells in the Washakie Basin.

Sampling of the Inexco WASP well, Sec. 28, T. 36 N., R. 112 W., Sublette Cty, Wyoming, has begun.

Cores from the Lewis sands in the Washakie Basin were examined.

Cross-sections through the Green River, Washakie and Sand Wash Basins are being prepared.

Field work in the Sand Wash Basin has been completed.

3.1.3 Northern Great Plains Province

Field work in Montana and North and South Dakota continued.

3.1.4 Schedule Status

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

3.2 CORE PROGRAM

In the Green River Basin, seven companies were contacted concerning WGSP Coring Program participation. CIGE, Texas Oil and Gas, and PTS are considering the proposals. Cotton Petroleum turned down the proposal for wells in Sweetwater County because of possible high pressures, but will be interested for future wells. Yates Petroleum declined, but would like to discuss future wells. Davis Oil has taken the proposed well off the active drilling list and Kemmerer Coal will be recontacted in the future.

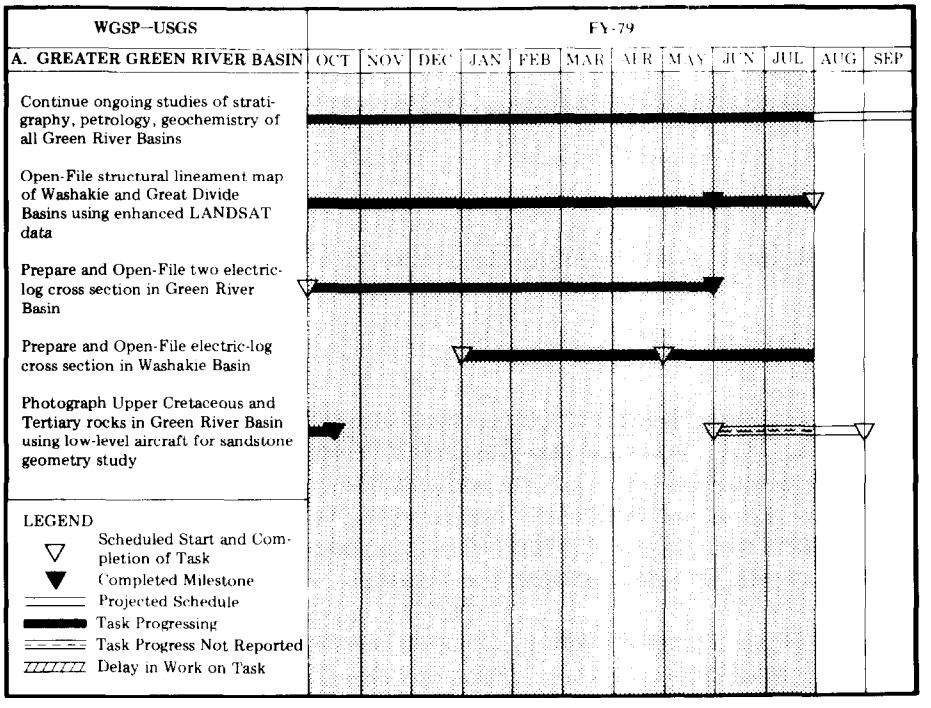
In the Northern Great Plains Province, Chevron declined proposed coring in southeast Montana, but will send any core that is taken to the USGS when studies have been completed. Kansas-Nebraska agreed to taking core from their north-central Montana well.

Burton & Hawks, and Chandler Resources declined core proposals for the Uinta Basin. Mapco, Inc. was also contacted and discussions are progressing on coring a Wasatch-Mesaverde interval.

In the Piceance Basin, discussions continued with David M. Munson about coring Mancos "B" and Mesaverde horizons in Rio Blanco Cty, Colorado. Also in Rio Blanco Cty, statements of work were drawn up for DOE and GRI funds to core and log portions of Mesaverde/Williams Fork and Mancos "B" in the Pacific Transmission Supply well 22-12 Federal Barcus Creek, se nw 12/1N/99W. In August, 240 ft of core is to be obtained from the Williams Fork Formation at 6,000 ft. About a month later, a 120 ft Mancos "B" core is planned at 10,500 ft. Logs are to be run over the Mancos "B" through Fort Union interval prior to setting intermediate casing.

3.3 LOGGING PROGRAM

Preparations were made for a logging operation on the Pacific Transmission Supply Company well No. 24-19 Federal, Sec. 19, T. 33 N., R. 114 W., Sublette County, Wyoming.



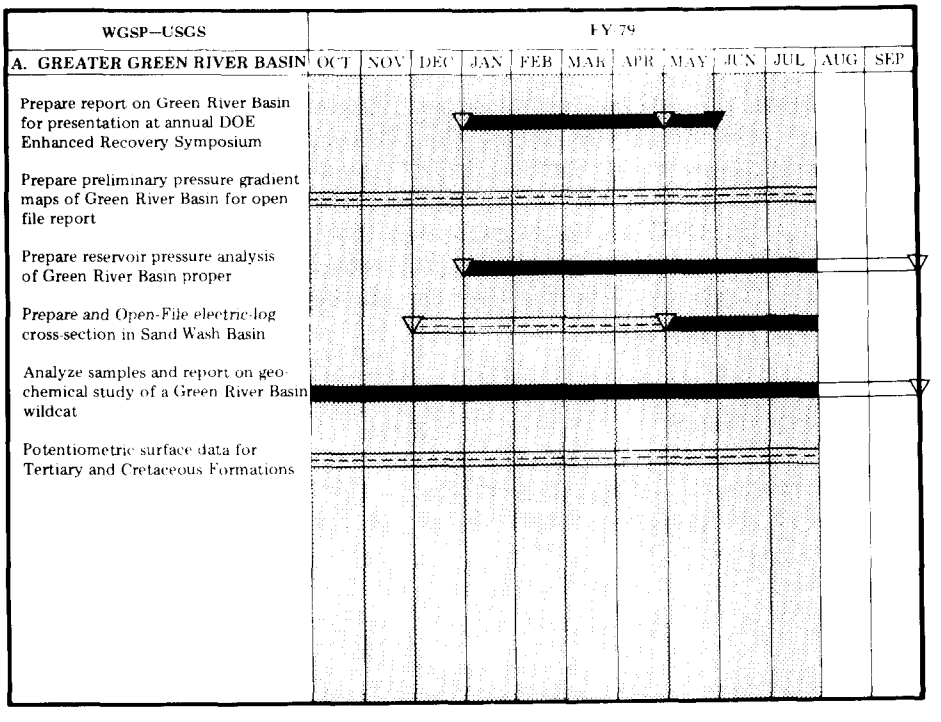
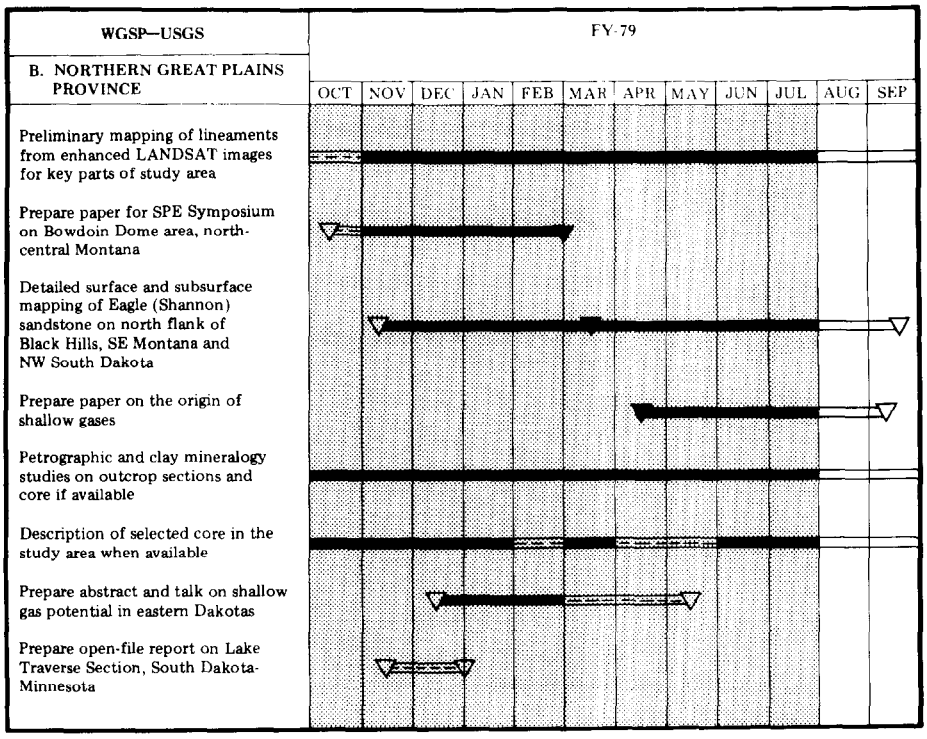


Figure 3-1 Milestone Chart — USGS



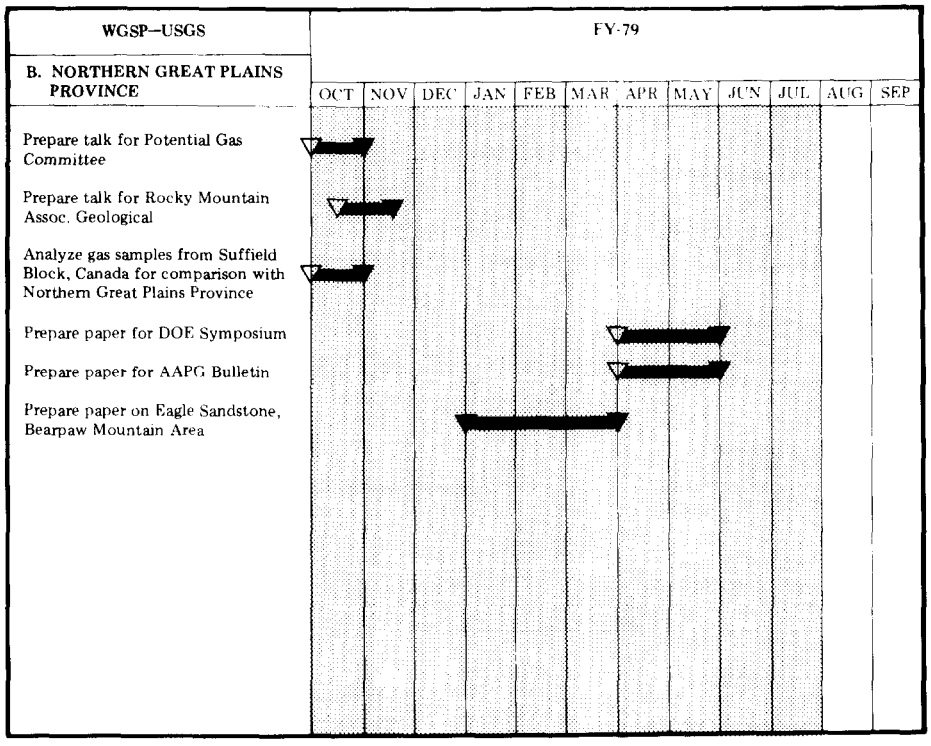
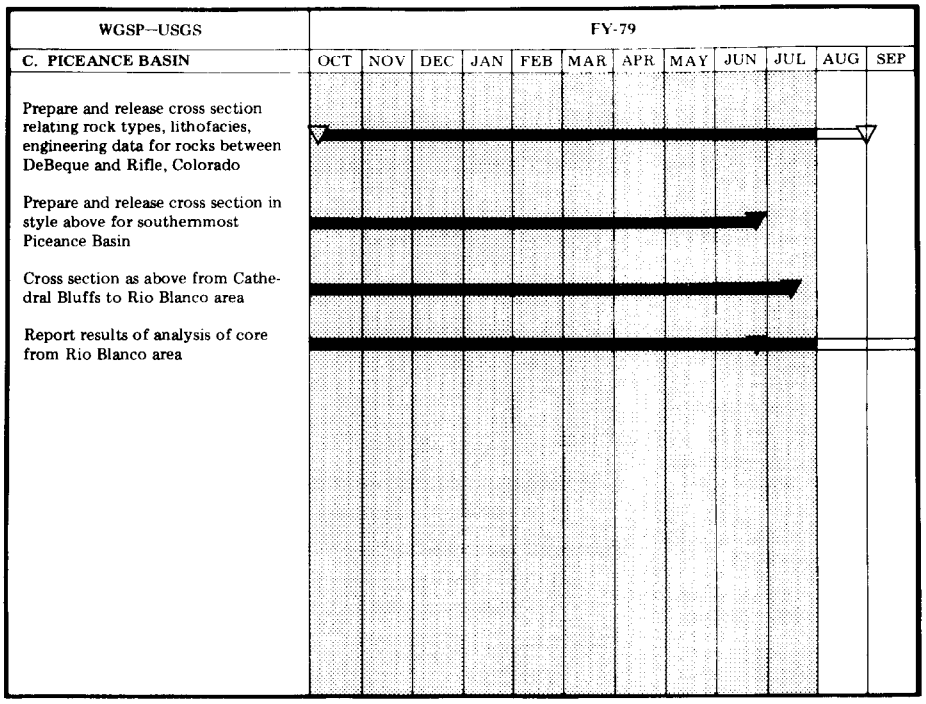


Figure 3-1 Continued



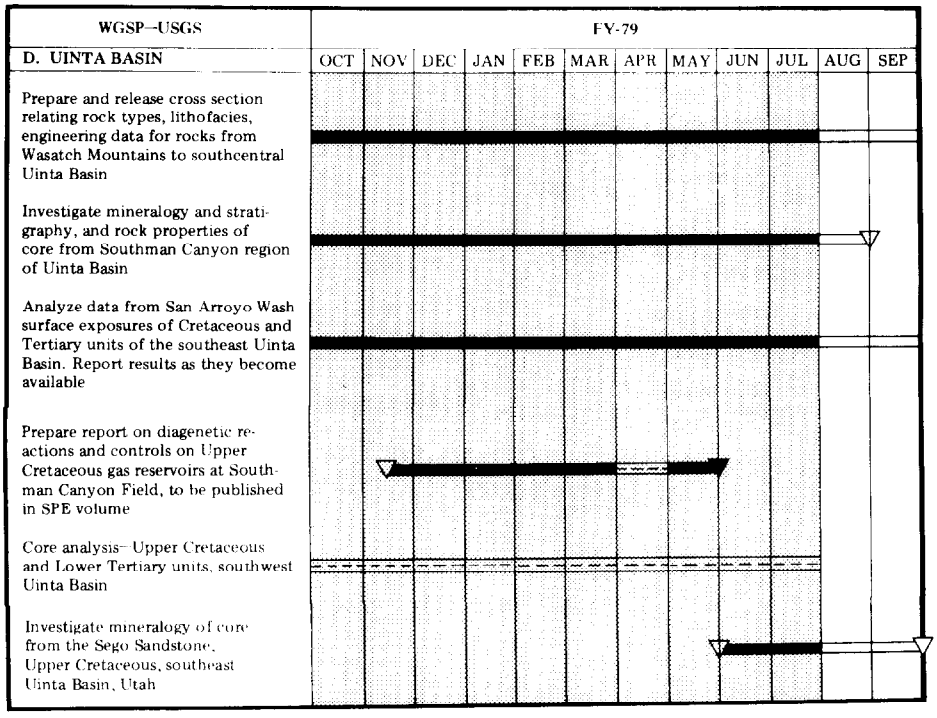


Figure 3-1 Continued

3.4 SURVEY OF BASIN ACTIVITIES

3.4.1 Greater Green River Basin

Ten wells of interest to the WGSP in the Greater Green River Basin added 16,104 MCFD of new gas in July. Two of eleven development and four of five wildcats were completed D&A. Producing horizons were the Frontier, Mesaverde, and Lewis.

Twenty new wells were staked during July: 17 development wells and 3 wildcats.

Wells of interest to the WGSP are summarized in Table 3-1 and located on Figure 3-2.

3.4.2 Northern Great Plains Province

Fifteen wells of interest to the WGSP were completed: nine development wells (4 D&A) and 6 D&A wildcats. Producing horizons (Blackleaf, Bow Island and Phillips) added 1,471 MCFD of new gas in July. One Bow Island IPF was not available.

Forty-eight new wells were staked in the province: 43 development wells and 5 wildcats.

Wells of interest to the WGSP are summarized in Table 3-2 and located on Figures 3-3 and 3-4.

Table 3-1 Summary of Wells — Greater Green River Basin

OPERATOR	WELL NAME	MAP INDEX NO.[1]	LOCATION Sec/T/R	HORIZON[2] ft	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Marathon Oil	8-Unit-A	1	cnw 32/21N/94W Wamsutter Field Sweetwater Cty, WY	Lewis (8,566-95)	8,700	60,000 gal water 105,500 lb sand	Comp. development well, 6-29-79. No tests. Located in Core Area A.	3,304
Marathon Oil	2-26 Tierney II	2	csw 26/19N/94W Tierney Field Sweetwater Cty, WY	Mesaverde 9,516-9,766	10,243 PB: 10,188	142,194 gal water 253,270 lb sand	Comp. development well, 2-26-79. No tests. Located in Core Area A.	1,474
Davis Oil	1 Bright Trail Unit	3	swne 21/27N/108W Wildcat Field Sublette Cty, WY	Mesaverde (12,000)	18,000		Comp. Wildcat 6-4-79, D&A. Located in Core Area B2.	
Amoco Production	13 Unit	4	nesw 3/21N/112W Whiskey Buttes Field Lincoln Cty, WY	2nd Frontier (11,160-11,192)	11,320	222,768 gal emul. 561,170 lb sand	Comp. development well, 6-13-79.	2,349

[1] Refer to Figure 3-2
[2] Horizon - projected depth or producing interval

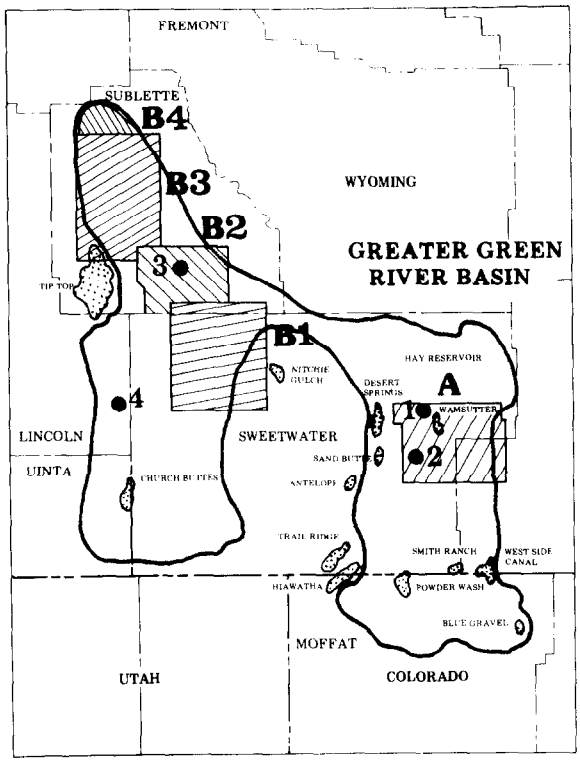


Figure 3-2

Greater Green River Basin Showing Wells of Interest and USGS Designated Core Areas (refer to Table 3-1)

Table 3-2 Summary of Wells — Northern Great Plains Province

OPERATOR	WELL NAME	MAP INDEX NO.[1]	LOCATION Sec/T/R	HORIZON[2] ft	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Joseph J. C. Paine & Associates	3 Ringstad	1	s½nw 3/129N/106W Little Missouri Field Bowman Cty, ND	Eagle 1,500			Development well Fr: 7-17-79. Operator has 28 additional Eagle tests in this locale.	
Montana Power	11-8-37-7 Federal	2	nesw 8/37N/7E Sage Creek Field Liberty Cty, MT	Blackleaf 1,980-1,985	2,540 PB: 2,430		Comp. development well, 5-25-79.	1,064
Midlands Gas	1-Federal -2812	3	sene 28/31N/32E Bowdoin Field Phillips Cty, MT	Phillips (1,046-1,119)	1,275 PB: 1,170	144,653 scf nitrogen 40,000 lb sand	Comp. development well, 5-10-79. No cores or tests. No log tops picked.	217
Amarala Pet	1-Downs	4	swse 32/1N/32E Wildcat Field Big Horn Cty, MT	Bow Island (2,700)	2,380		Completed Wildcat 6-22-79, D&A.	

[1] Refer to Figures 3-3 and 3-4
[2] Horizon - projected depth or producing interval

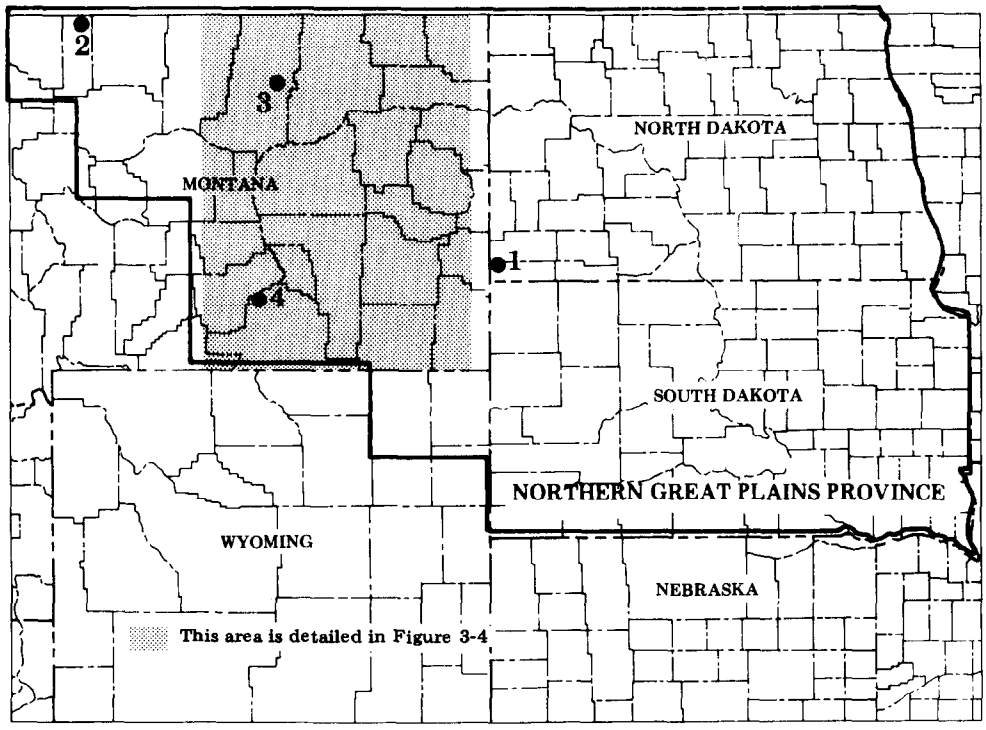


Figure 3-3

Northern Great Plains Province Showing Wells of Interest (refer to Table 3-2)

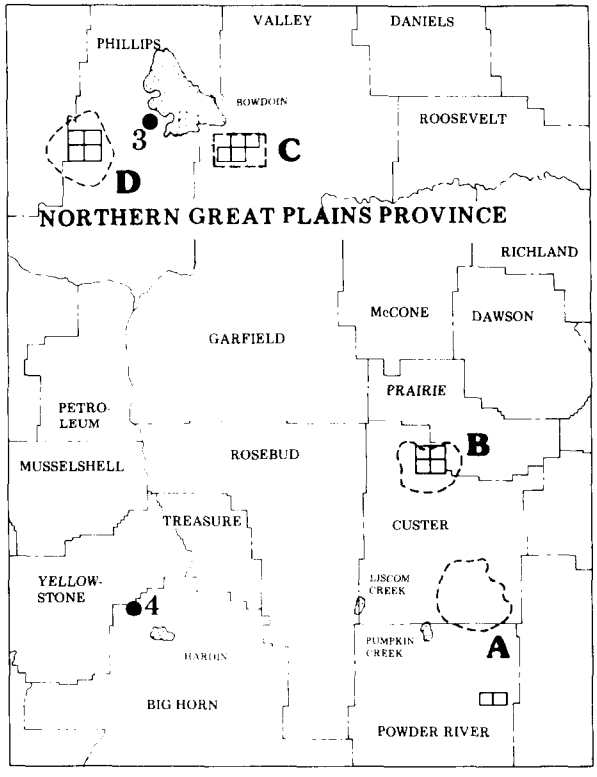


Figure 3-4

Detail of USGS Designated Core Areas (refer to Table 3-2)

3.4.3 Piceance Basin

Nine wells in the Piceance Basin were completed in horizons of interest to the WGSP. Six development wells produced 9,609 MCFD of new gas from the Mancos and Mesaverde.

Eleven development wells and 6 wildcats were staked during July.

Wells of interest are summarized in Table 3-3 and located on Figure 3-5.

Table 3-3 Summary of Wells — Piceance Basin

OPERATOR	WELL NAME	MAP INDEX NO.[1]	LOCATION Sec/T/R	HORIZON[2] ft	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Fuel Resource Development	6M Federal	1	sesw 20/2N/96W White River Field Rio Blanco Cty, CO	Mesaverde (6,170-6,852)	7,548 PB: 7,040	Acidized w/1,596 gal Fractured w/6,720 gal water, 25,000 lb sand.	Comp. development well, 4-23-79. No cores or tests.	3,681
Chandler & Associates	11-12-1-2 Fork Unit	2	nesw 12/1S/102W Douglas Creek Field Rio Blanco Cty, CO	Mancos (2,295-2,359)	2,598	Acidized w/2,000 gal Fractured w/2,000 BBL water, 55,000 lb sand.	Comp. development well, 6-5-79. No cores or tests.	662
Teton Energy	1 Getty et al	3	nwsw 21/8S/97W Debeque Field Mesa Cty, CO	Mesaverde (1,040-1,128)	1,800		Comp. development well, 11-3-78. No cores or tests. Operator has 3 other wells producing in this locale.	108

[1] Refer to Figure 3-5
[2] Horizon - projected depth or producing interval

3.4.4 Uinta Basin

Ten wells (9 development wells and 1 wildcat) were completed in horizons of interest and produced 13,875 MCFD of new gas from the Wasatch Formation.

Four new wells were staked in July (2 development wells and 2 wildcats).

Wells of interest to the WGSP are summarized in Table 3-4 and shown in Figure 3-6.

Table 3-4 Summary of Wells — Uinta Basin

OPERATOR	WELL NAME	MAP INDEX NO.[1]	LOCATION Sec/T/R	HORIZON[2] ft	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Belco Petroleum	51-13-13 Natural Buttes Unit	1	swse 31/9S/21E Natural Buttes Field Uintah Cty, UT	Wasatch (5,068-6,638)	6,956 PB: 6,873		Comp. development well, 6-6-79. No cores or tests.	734
Koch Exploration	10-1 Reiman	2	nesw 10/4S/6W Unnamed Field Duchesne Cty, UT	Wasatch (6,122-7,036)	7,146	Sand fract. w/25,000 gal emul.	Comp. Wildcat, 2-21-79. Wasatch Extension-Unnamed Field. Located in Core Area A.	611
CIG Exploration	59-21-10-21 CIGE	3	swsw 21/10S/21E Natural Buttes Field Uintah Cty, UT	Wasatch (5,230-6,576)	6,700 PB: 6,670	Acidized w/3,000 gal Fractured w/76,342 gal water, 150,000 lb sand.	Comp. development well, 6-3-79. No cores or tests.	3,000

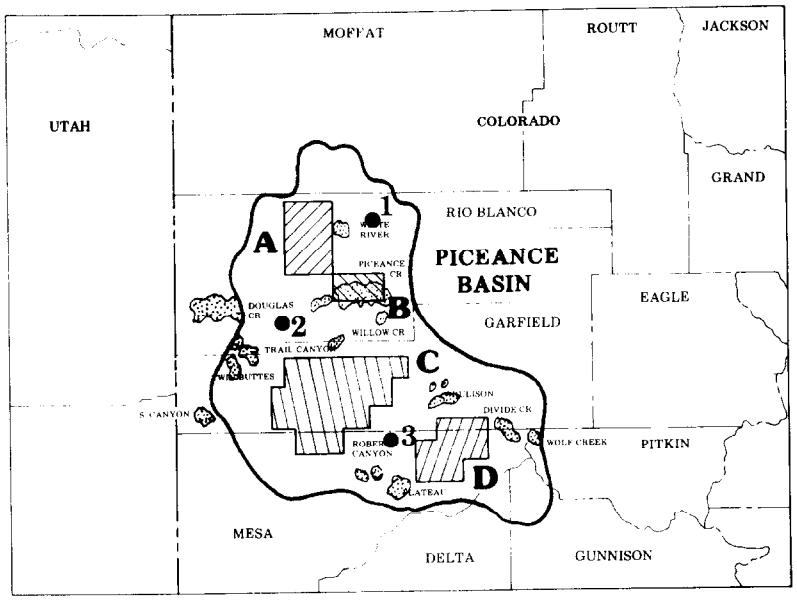
[1] Refer to Figure 3-6
[2] Horizon - projected depth or producing interval

3.5 C K GEOENERGY

Recording of wellhead pressure buildup was completed on Belco's Chapita Wells No. 6, No. 7 and No. 13 and was continued on the CIG No. 52X well. Water levels were determined in wells No. 7 and No. 13. Data will be analyzed to estimate kh values, total reservoir volumes, and reservoir geometries for these Wasatch sands.

Figure 3-5

Piceance Basin Showing Wells of Interest and USGS Designated Core Areas (refer to Table 3-3)



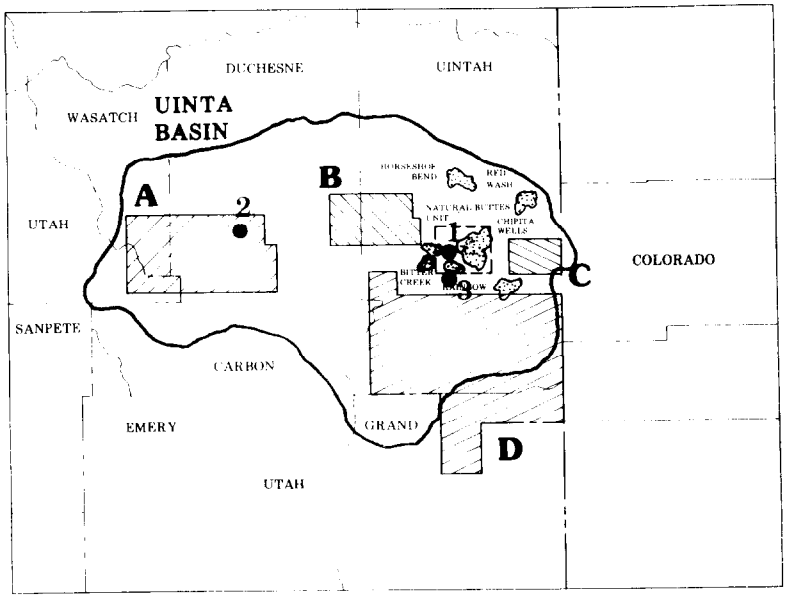


Figure 3-6

Uinta Basin Showing Wells of Interest and USGS Designated Core Areas (refer to Table 3-4)

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

4.1 BARTLESVILLE ENERGY TECHNOLOGY CENTER

4.1.1 Improved Pressure Coring System — Sandia Laboratories

4.1.1.1 Core Retriever Design and Test

Two DOWDCO pressure core barrels were modified for use in testing the Sandia low invasion coring fluid. The tests are scheduled August 7, 8, and 9 at the Terra Tek Drilling Laboratory in Salt Lake City, Utah.

4.1.1.2 Core Fluid Tests

Two freeze tests were completed to determine the low-temperature properties of the polymer coring fluid. These tests showed that highly viscous HEC polymer muds did not freeze until about -60°F and that they could easily be scraped off of a frozen core at -50°F. The 20 lb/BBL HEC mud was too viscous to be practical since it was difficult to remove the frozen core from the core barrel. The 15 lb/BBL HEC mud was clearly superior in mechanical properties and will be used for further low-invasion fluid testing. In addition to verifying the favorable low-temperature properties of the coring fluid, these tests demonstrate the flexibility of the HEC polymer system in readily maintaining the viscosity within desired limits by varying the concentration of the polymer.

Compressibility/air entrainment testing was completed with the same 15 lb/BBL HEC mud used in the freeze tests. These experiments showed that air entrainment can be a serious problem unless preventive measures are taken. The addition of a few drops of "BREAK" per liter of coring fluid increased the density of the mud from 11.4 ppg to 11.6 ppg, which reduced the air entrainment by about 20 ml per liter of fluid. This 11.6 ppg mud was then tested in an autoclave for compressibility at pressures up to 3,000 psi. The procedure was repeated for mud which was de-aerated in a vacuum chamber. The "as-mixed" mud exhibited a 2.73 percent shrinkage at 3,000 psi while the de-aerated mud was essentially the same as water (0.95 percent shrinkage at 3,000 psi). The mud column length reduction in the 10 ft-long core barrel would be 3.28 in. for "as-mixed" polymer mud and 1.14 in. for pure water. There should be no major plugging problems while coring if proper care is used to avoid air pockets when filling the inner core barrel with low-invasion fluid and if a 4 ± in. extension is used on the wiper plug.

Preparations have been completed for the drilling tests at Terra Tek in early August. This included mixing and de-aerating a large volume of coring fluid, obtaining high pressure grease injection equipment, and developing a proper procedure for filling the core barrel. The drilling tests will establish the feasibility of the two-fluid coring system.

4.1.1.3 Bit Design and Fabrication

Two pilot bits were assembled for the August 5 drilling tests at Terra Tek. The primary test pilot bit was fabricated by brazing diamond compax cutters to the steel stud using techniques available at Christensen, West Germany. The backup pilot used carbide cutters and a high temperature braze by the Sandia welding shop.

Two 6-1/2 in. main bit bodies were fabricated in a joint effort with DOWDCO completing the NC lathe work and Sandia providing the 5 axis mill work.

Only one of these bits will be used in the drilling test and it was equipped with the diamond compax attached to the Sandia steel studs by the diffusion bonding process.

4.1.1.4 Bit Test

Full core barrel and bit tests are scheduled at Terra Tek, August 7, and field tests are planned in the Denver City, Texas, area on August 18 or 19.

4.1.2 Interface Conductivity Effects on Electric Logging

Improvements of the confining pressure apparatus are being completed. After modifications, measurements on three core plug samples will be made simultaneously.

Resistance measurements on fifteen core plug samples were made using a Core Laboratories resistivity meter. Calculations of core resistivities and formation factors have shown significant variations in formation factors in these low permeability sands. Correlations between log derived factors and laboratory measured values are in progress.

4.1.3 In-Situ Permeability

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

A series of experiments were conducted on core No. 6475.5 from the Natural Buttes Unit well No. 21, Uinta Basin. Klinkenberg extrapolations were obtained at different net confining pressures. Figure 4-1 shows some of the results of these measurements. As seen from the figure, the slope of the line obtained by plotting permeability as a function of the reciprocal mean pressure decreases with increasing net confining pressure; i.e., at high net confinement, the effect of pore pressure on permeability is reduced, at least at low pore pressures. Measurements on core No. 9998A from the Mobil PCU F31-13G well, Piceance Basin, indicate the same behavior. Data for this core will be reported in August.

Figure 4-2 shows the effect of net confining pressure on Klinkenberg-extrapolated permeability for core No. 6475.5. Permeability values corresponding to a differential pressure of 40 psi (mean pore pressure of 20 psig) were obtained from Figure 4-1 and are plotted in the same figure. It appears that the permeability reduction is similar in both cases.

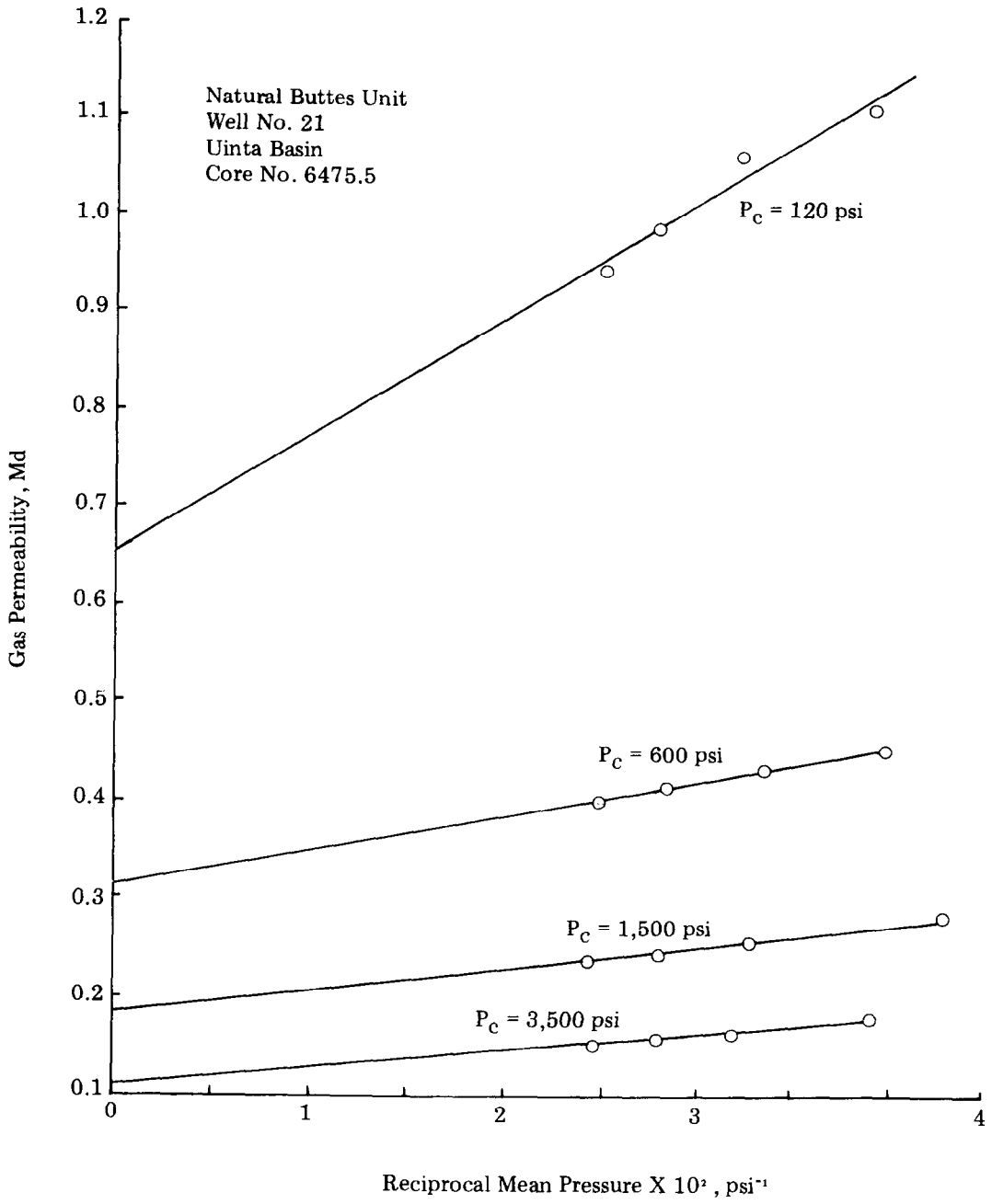


Figure 4-1 Effect of Confining Pressure on Klinkenberg Extrapolations

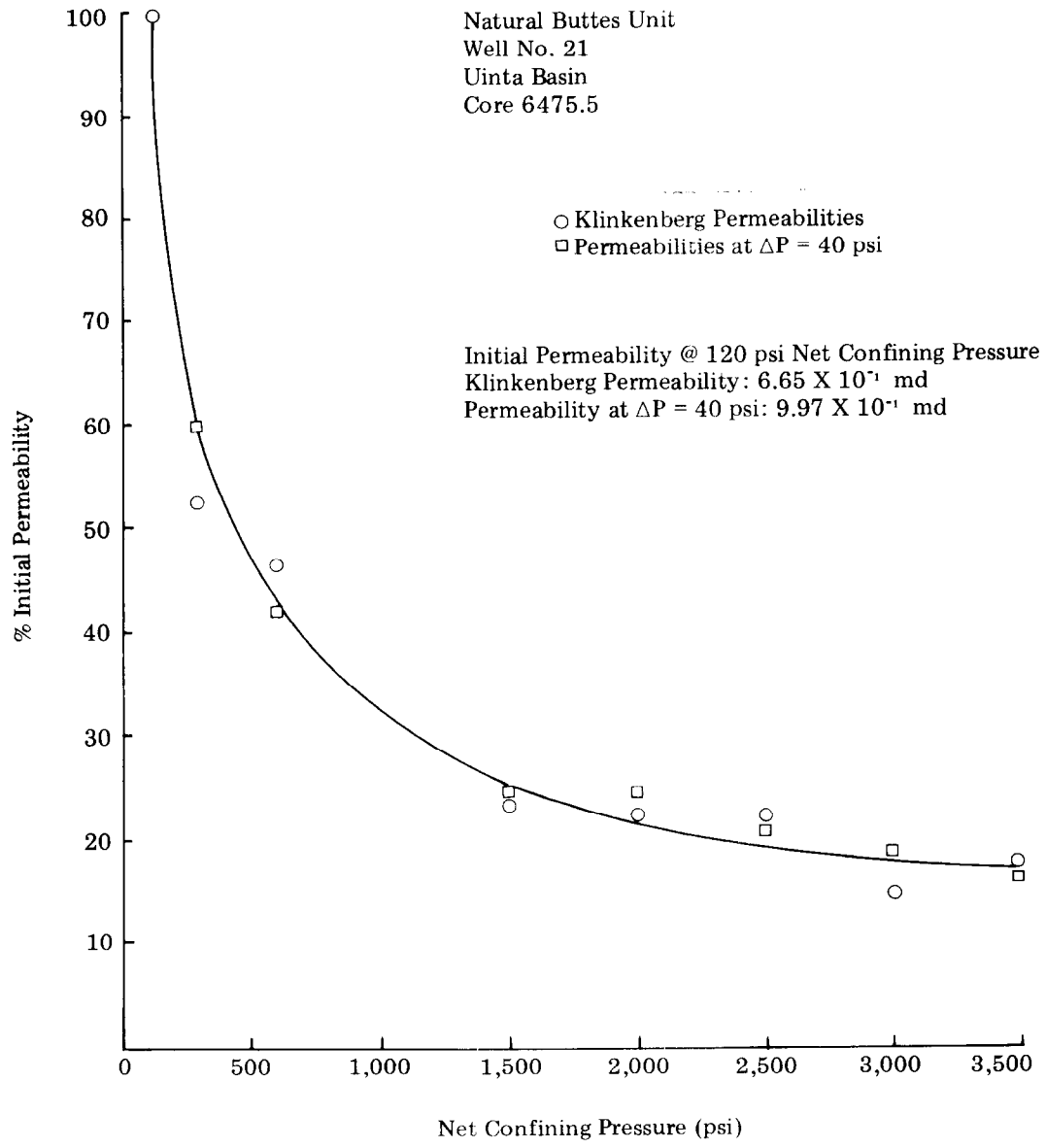


Figure 4-2 Effect of Net Confining Pressure on Klinkenberg - Extrapolated Permeability

The purpose of the measurements mentioned was to compare the pressure dependence of Klinkenberg permeabilities with that of liquid permeabilities. Liquid permeabilities were measured as a function of net confining pressure, using kerosene as the flowing liquid. As mentioned in the June Status Report, steady flow could not be attained. Results of measurements on cores Nos. 9957 and 8498A from the Mobil PCU F31-13G well are shown in Table 4-1.

For core No. 9957, the permeability values appear to be a function of confining pressure. However, there are two values of permeability which are rather high. The reason for this high permeability needs to be discerned before the liquid flow measurements can be compared with gas flow measurements. The measurements made on core No. 8498A were more erratic. High differential pressure (300 psi) and/or the movement of fines may account for the unsteady flow behavior. The same drop in pressure along the length of the core may result in release of dissolved gas within the core since a gas head was used to provide the kerosene pressure. This would account for the high permeability values measured, since the permeability measured would then be relative permeability to liquid rather than absolute liquid permeability. The measured gas permeability values for core No. 9957 at a pressure differential of 40 psi range from 1.1×10^{-1} at a net confining pressure of 120 psi to 1.07×10^{-2} at a net confining pressure of 5,000 psi, as previously reported. The liquid permeability varies from 1.67×10^{-4} md at 500 psi confining pressure (350 psi net confining pressure) to 1.61×10^{-3} to 1.09×10^{-2} md at a confining pressure of 5,000 psi. Klinkenberg permeabilities have not been estimated at different net confining pressures for either of these cores.

Results of measurements made on core No. 9957A at a single confining pressure (4,700 psi) are shown in Table 4-2. As in all liquid permeability measurements reported herein, there is a range of values. The permeability of core No. 9957A to kerosene varied from 3.74×10^{-4} to 2.26×10^{-3} md. In the June Status Report, the kerosene permeability for core No. 9957 (another plug from the same core) was reported to be between 1.35×10^{-5} and 1.51×10^{-3} md.

The liquid permeability apparatus was modified to enable reversal of flow direction. The cores used in this study were Nos. 9998 and 9957A. The flow direction was reversed approximately every 2 hrs. Volume flows varied from approximately 0.05 to 1.5 pore volumes. The results of these measurements are shown in Table 4-3. The two flow directions are denoted as X→Y and Y→X. Reversal of flow direction was sometimes accompanied by a rather marked alteration in the permeability value, but it is unclear whether this is due to fines movement or to the readjustment of the core to the new stress field imposed by reversal of the direction of differential pressure. The liquid permeability of core No. 9998 ranged from 7.72×10^{-4} to 8.67×10^{-2} md at a confining pressure of 5,000 psi. The gas permeability under similar confining pressure conditions (5,020 psi) was 2.9×10^{-3} (at 40 psig inlet pressure and 0 psig outlet pressure) as reported in the March Status Report. For core No. 9957A, the liquid permeability varied between 1.05×10^{-3} md and 1.86×10^{-2} md at a confining pressure of 5,100 psi in these experiments (compared with 3.74×10^{-4} to 2.26×10^{-3} md measured in earlier experiments).

Table 4-1 Liquid Permeability Measurements on Core from Mobil PCU F31-13G Well

Core Depth: 9,957 feet
Core No. 9957
Differential Pressure: 300 psi

Confining Pressure (psi)	Maximum Permeability (md)	Minimum Permeability (md)
500	6.19×10^{-2}	1.67×10^{-4}
1,000	1.62×10^{-2}	1.40×10^{-2}
1,500	7.36×10^{-3}	3.85×10^{-3}
2,000	9.95×10^{-3}	1.42×10^{-3}
2,500	6.78×10^{-3}	6.46×10^{-4}
3,000	2.83×10^{-2}	5.70×10^{-3}
3,500	5.91×10^{-3}	2.30×10^{-3}
4,000	6.28×10^{-2}	9.11×10^{-4}
4,500	1.13×10^{-3}	8.48×10^{-4}
5,000	1.09×10^{-2}	1.61×10^{-3}

Core Depth: 8,498 feet
Core No. 8498A
Differential Pressure: 300 psi

Confining Pressure (psi)	Maximum Permeability (md)	Minimum Permeability (md)
500	8.02×10^{-3}	2.49×10^{-3}
1,000	6.62×10^{-3}	3.89×10^{-3}
1,500	7.56×10^{-3}	3.85×10^{-3}
2,000	1.11×10^{-2}	5.17×10^{-3}
2,500	9.15×10^{-3}	4.88×10^{-3}
3,000	1.35×10^{-2}	7.98×10^{-3}
4,000	1.94×10^{-2}	4.59×10^{-3}

Table 4-2 Measurements Made at a Single Confining Pressure (4,700) psi on Core from Mobil PCU F31-13G Well

Core Depth: 9,957 feet
Core No. 9957A
Confining Pressure: 4,700 psi
Differential Pressure: 300 psi

Experiment No.	Time	K (md)
1	0 min	1.85×10^{-3}
	30 min	1.35×10^{-3}
	45 min	1.72×10^{-3}
	1 hr 15 min	1.81×10^{-3}
	1 hr 30 min	1.35×10^{-3}
	1 hr 45 min	1.22×10^{-3}
2	0 min	8.20×10^{-4}
	5 min	1.94×10^{-3}
	20 min	2.26×10^{-3}
	35 min	1.63×10^{-3}
	1 hr 05 min	3.74×10^{-4}
	1 hr 35 min	8.49×10^{-4}

4.1.4 Advanced Logging Techniques and Interpretation

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

Porosities of samples from the Natural Buttes No. 21 well were calculated from measurements of pore volumes using a helium porosimeter. These values were compared with the porosity obtained by direct measurement of the matrix volume as shown in Table 4-4. Exact agreement between the two methods was not obtained and the reason for the disagreement has not been determined. The permeability of representative samples will be measured. The samples will then be saturated with kerosene and the porosity will be measured by the saturation technique.

Table 4-3 Liquid Permeability Measurements (With Periodic Reversal of Flow Direction) on Core from Mobil PCU F31-13G Well

Core Depth: 9,998 feet
Core No. 9998
Confining Pressure: 5,000 psi
Differential Pressure: 300 psi

Flow Direction	Time	Permeability (md)
X→Y	15 min	8.67×10^{-2}
	30 min	4.66×10^{-3}
	45 min	1.38×10^{-3}
	1 hr 15 min	3.12×10^{-3}
Y→X	10 min	2.72×10^{-3}
	30 min	2.45×10^{-3}
	1 hr 00 min	2.09×10^{-3}
	1 hr 20 min	1.32×10^{-2}
	1 hr 25 min	1.82×10^{-2}
	1 hr 55 min	2.97×10^{-3}
X→Y	10 min	1.67×10^{-2}
	15 min	2.75×10^{-2}
	30 min	1.55×10^{-2}
	50 min	4.79×10^{-2}
	1 hr 10 min	5.62×10^{-3}
Y→X	15 min	1.42×10^{-3}
	40 min	1.29×10^{-3}
	1 hr 20 min	1.84×10^{-3}
	1 hr 45 min	7.72×10^{-4}

Core Depth: 9,957
Core No. 9957A
Confining Pressure: 5,100 psi
Differential Pressure: 300 psi

X→Y	5 min	5.40×10^{-3}
	30 min	1.90×10^{-3}
	1 hr 00 min	1.35×10^{-3}
	1 hr 30 min	1.05×10^{-3}
Y→X	10 min	2.88×10^{-3}
	35 min	1.79×10^{-3}
	1 hr 05 min	3.46×10^{-3}
	1 hr 35 min	2.05×10^{-3}
X→Y	10 min	4.47×10^{-3}
	40 min	3.69×10^{-3}
	1 hr 10 min	5.55×10^{-3}
	1 hr 40 min	1.42×10^{-3}
Y→X	15 min	4.15×10^{-3}
	35 min	1.92×10^{-3}
	1 hr 25 min	1.64×10^{-3}
	1 hr 50 min	1.58×10^{-3}
X→Y	5 min	1.86×10^{-2}
	1 hr 15 min	1.89×10^{-3}
	1 hr 45 min	1.35×10^{-3}
	2 hr 30 min	1.03×10^{-3}

Table 4-4 Cores from Natural Buttes No. 21

Plug No.	(Matrix Cup) Porosity %	(Porosimeter) Porosity %	Plug No.	(Matrix Cup) Porosity %	(Porosimeter) Porosity %
1	4.75	4.83	25	3.20	3.23
2	5.16	4.59	26	3.17	2.84
3	3.02	3.31	27	3.24	3.11
4	2.62	2.96	28	5.19	6.07
5	2.82	3.11	29	6.33	6.44
6	4.97	5.45	30	6.47	7.12
7	5.15	5.22	31	2.98	2.94
8	4.41	5.29	32	5.61	5.51
9	3.93	4.53	33	6.17	5.97
10	3.61	3.30	34	5.76	6.01
11	3.27	3.92	35	4.07	4.51
12	8.48	8.13	36	3.78	3.90
13	5.52	5.60	37	8.68	8.74
14	7.20	7.05	38	8.68	9.08
15	10.78	10.10	39	8.99	8.84
16	4.17	5.02	40	9.53	9.14
17	1.52	4.82	41	9.28	9.36
18	6.37	7.17	42	7.23	6.43
19	6.18	5.62	43	2.64	2.29
20	5.09	5.53	44	4.06	3.66
21	6.63	7.14	45	4.34	5.03
22	7.45	7.79	46	3.77	3.40
23	8.71	8.40	47	6.38	6.28
24	9.03	8.44	48	10.01	9.59

4.1.4.2 Instrumentation for Formation Evaluation and Advanced Logging Techniques — Sandia Laboratories

In the past, models used to predict the response of induction logging tools have all assumed a point-source magnetic dipole for the simulation of the transmitting and receiving coils. A higher order series expansion of a single turn coil has been made. The convergence of this series for a coil of finite size has been established and the series has been incorporated into codes required for the evaluation of induction logging techniques in homogeneous media. One significant point of the Sandia solution is that the receiving coils can now be placed as close as one coil diameter to the transmitting coil. Thus, accurate predictions, which were previously unavailable, can now be obtained.

In addition, inhomogeneous models associated with invasion/depletion zones of wells have been solved analytically. Review and coding of these solutions will begin in August. Extensive use of integration subroutines will be expected, but slow convergence of numerical integrations may necessitate certain mathematical transformations not treated presently.

4.1.4.3 Remote Characterization of Fluid Saturation in Western Sands — Los Alamos Scientific Laboratory

A study of the microstructure and dynamic behavior of various Western Gas Sands core samples has recently been initiated. It is hoped that by elucidating the physical structure of these particular reservoir rocks, as well as their response to varying conditions of temperature and pressure, the macroscale behavior of fluids present in these formations can be more completely understood and predicted. The principal analytical methods to be employed in this effort will include scanning electron and optical microscopy.

The determination of the relationship (if in fact one exists) between microstructure and the bulk permeability and porosity of a given formation will prove to be a key element in any plan to stimulate production from a tight reservoir. An experimental program that has been designed to clarify this relationship, at least in part, is visualized as consisting of several areas of inquiry:

- Microstructure Analysis
- Compression/Extension Dynamics
- Thermal Behavior

Core samples from the Twin Arrow well C&K No. 4-14 (Piceance Basin) were crushed, pulverized, and analyzed for nitrogen, carbon, hydrogen, and total ash content after combustion on the CHN analyzer. Three of the pulverized samples were dried at 100° C for 20 hrs and compared with samples which were analyzed directly after pulverization. The CHN results showed no statistical differences due to drying.

Each sample was analyzed at least three times. The reported values in Table 4-5 represent the averages of all the runs plus the standard deviation.

Table 4-5 — CHN Analysis of Core Samples from Well C&K 4-14

Depth (ft)	% N	% C	% H	% Ash
(1,009.45 — 1,009.65)	0.155 ± 0.013	3.29 ± 0.16	0.625 ± 0.053	88.9 ± 0.5
(1,010.35 — 1,010.50)	0.169 ± 0.023	3.81 ± 0.40	0.651 ± 0.081	89.0 ± 0.3
(1,012.34 — 1,012.60)	0.226 ± 0.044	1.95 ± 0.27	0.362 ± 0.034	91.0 ± 0.1
(1,013.75 — 1,013.95)	0.155 ± 0.017	1.03 ± 0.06	0.349 ± 0.931	94.4 ± 0.1
(1,015.60 — 1,015.80)	0.061 ± 0.094	1.73 ± 0.13	0.530 ± 0.023	85.5 ± 3.4
(1,016.90 — 1,017.10)	0.054 ± 0.020	1.58 ± 0.15	0.517 ± 0.058	91.4 ± 1.0

Experiments have been initiated to measure the sensitivity of the NMR system to samples external to the radio frequency coil. A 4 in. laboratory electromagnet is being modified and reconfigured to provide a remotely-produced region of homogeneous magnetic field in simulated downhole geometry.

4.1.5 Reservoir Simulation Studies — Intercomp

The analytical development of a two-dimensional reservoir simulator has been performed for a vertically fractured dry gas reservoir. The model considers two-dimensional rectangular flow in the reservoir and one-dimensional flow in the fracture. The model includes the effect of non-Darcy flow in the reservoir and fracture, fracture face formation damage, wellbore and fracture storage effects, and frictional pressure drop effects in the production string. The derived equations are general enough to consider variable rock property data and extension to a three-dimensional case. However, the general equations have been reduced to the case of flow in a homogeneous slab penetrated by a vertical fracture. In addition, a statistical model of discontinuous sand lenses contained in the producing zones of the western tight sands area is also under development. It is believed that by incorporating the geologic characteristics of these formations into the reservoir simulator, a more representative model of the actual flow processes will be obtained. Such an approach should result in a reservoir simulator which can be used as an exploration tool as well as in pressure transient analysis of a given well.

The pressure transient analyses for Federal No. 498-4-1 and all zones of the Mobil PCU F31-13G well are nearly complete. The parametric analysis portion of the MHF Test Data and Engineering Studies of the WGSP have been initiated and should be finished by September 1, 1979. At that time, a final report summarizing the results of the first year's work will be written.

4.1.6 Rock — Fluid Interaction

The embedment of a second sintered bauxite proppant (12-20 mesh) was measured as a function of applied pressure using sandstone cores from the intervals previously tested (Report on Proppant Embedment, June Status Report). As before, the core slabs were saturated with 2 percent KCl. The size distribution for the proppant used is given in Table 4-6.

Table 4-6 — Size Distribution of 12-20 Mesh Bauxite

Sieve	Size (mm)	Weight %	Estimated Number %
10-14	2.00 — 1.41	4.2	1.3
14-16	1.41 — 1.19	15.6	7.2
16-18	1.19 — 1.00	28.5	22.0
18-20	1.00 — 0.841	49.9	65.1
20-25	0.841 — 0.710	1.9	4.1
> 25	less than 0.710	0.1	0.2

The width of the propped fracture for no embedment was taken to be 1.59 mm as in the preceding study. Data on embedment was obtained in a manner similar to that previously described (i.e., between a steel plate and the core slab), and between two core slabs using 50 percent proppant coverage. Unlike the data previously reported, the compressibility of the core slab was taken into account. This resulted in somewhat more scatter in the data. Another difference between the results is the use of 180 psi as a zero reference pressure. This was done to allow for availability in proppant repositioning and movement with the initially applied closing pressure. A few of the features apparent upon examination of the data were:

- Embedment into the 6,903-ft depth core was greater.
- The order of embedment was the reverse of what was expected, i.e., more embedment for higher proppant coverages.
- Proppant embedment tended to level off more rapidly with increasing applied pressure for the 6,903-ft core.

The first observation can be explained by the greater hardness of the 7,698.4-ft depth core slab. The data was not clearly shown until the refined techniques were used.

It is not clear why lower proppant coverage should give less embedment. Although there is relatively high variability in the apparent embedment on going from zero applied force to 180 psi, it cannot begin to reorder the embedment plots to the expected order.

The greater hardness of the 7,698.4-ft core, and therefore the lower embedment rate, coupled with the non-uniform size distribution of the proppant, probably explains why the embedment measurements for the 6,903-ft core tend to level off more rapidly than those of the 7,698.4-ft core.

The ordering of the embedment plots for the 50 percent coverage using two core slabs could be due in part to over-correcting for the core compressibility since the proppant does not support the core completely. Because the 6,903-ft core had a compressibility of roughly 1.7 times that of the 7,698.4-ft core, the proppant embedment data for the 6,903-ft core would be more seriously over-corrected. The hardness of the steel plate relative to the core slabs could also be a significant factor.

4.1.7 Schedule Status

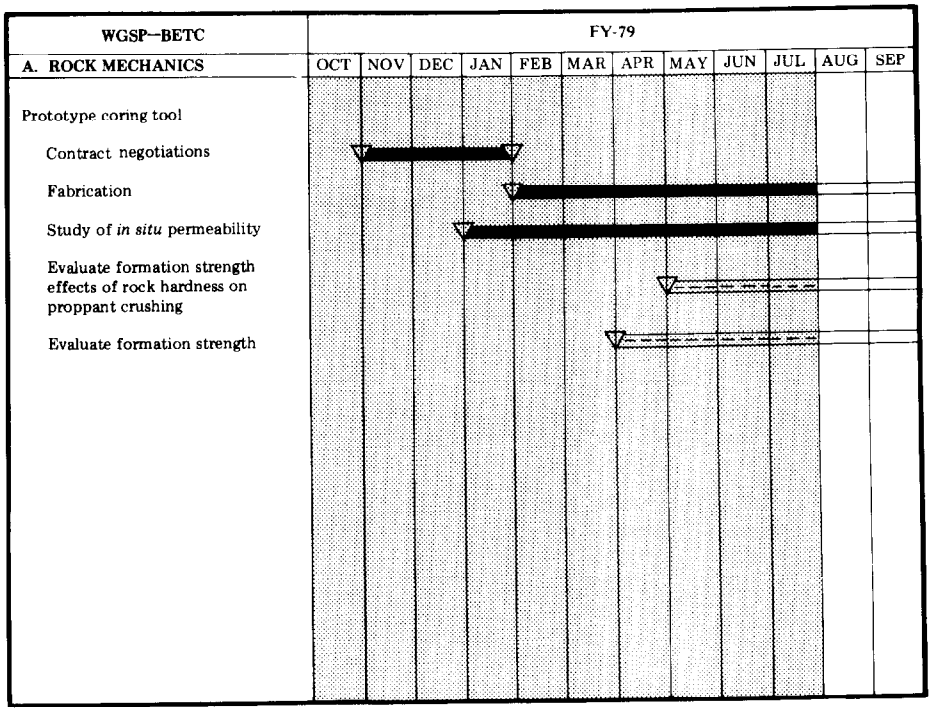
Figure 4-3 is a milestone chart depicting July progress of BETC projects.

4.2 LAWRENCE LIVERMORE LABORATORY

4.2.1 Theoretical Analysis

Analyses of crack propagation near an interface were completed using quarter-plane symmetry in an finite element model. A material was sandwiched between pieces of another material which was characterized by a different elastic constant. A crack, initiated at the midpoint between the interfaces formed by the two materials, propagated bilaterally to the interfaces.

The motion of a point near one interface was followed as the crack propagated to the interfaces and stopped. Calculations continued until the reflected elastic waves from the opposite interface arrived. Even when the crack speed was half the dilatational wave speed, these reflected waves arrived shortly after the crack stopped so that particle motion near the crack



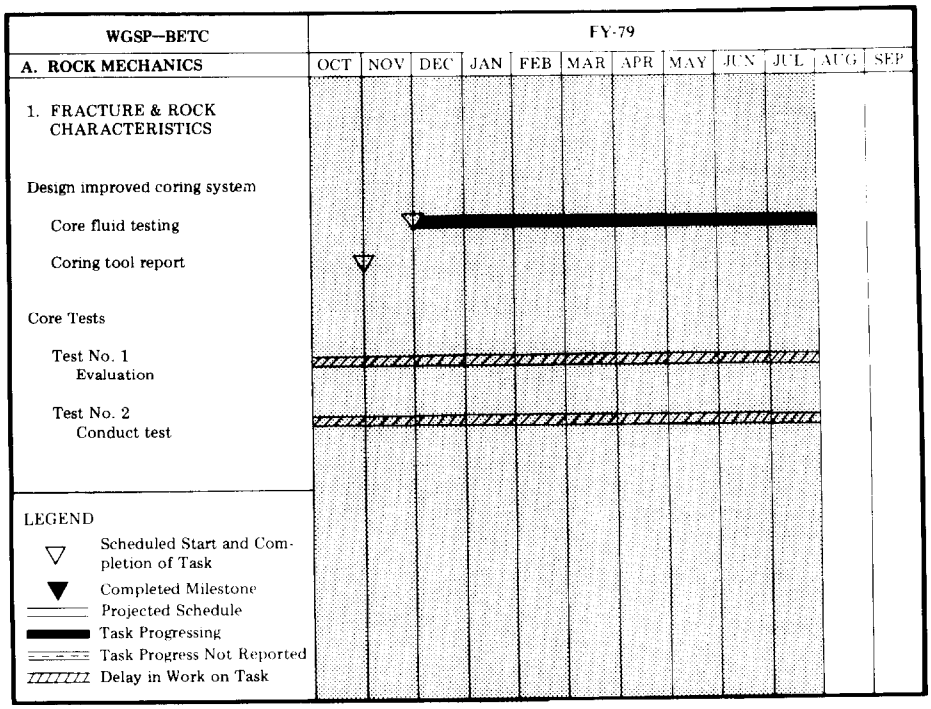
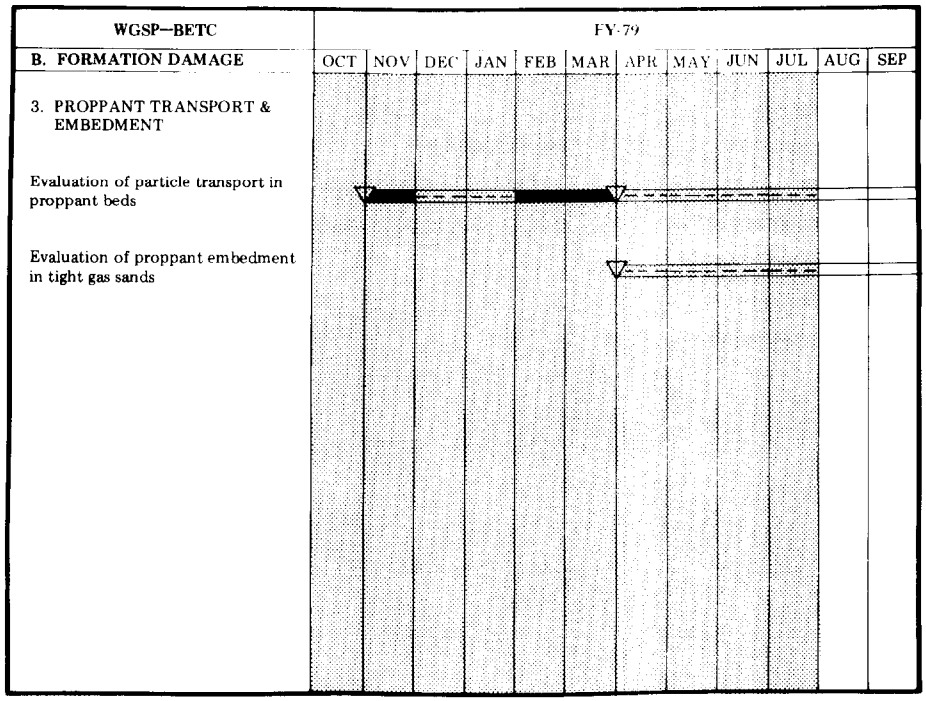
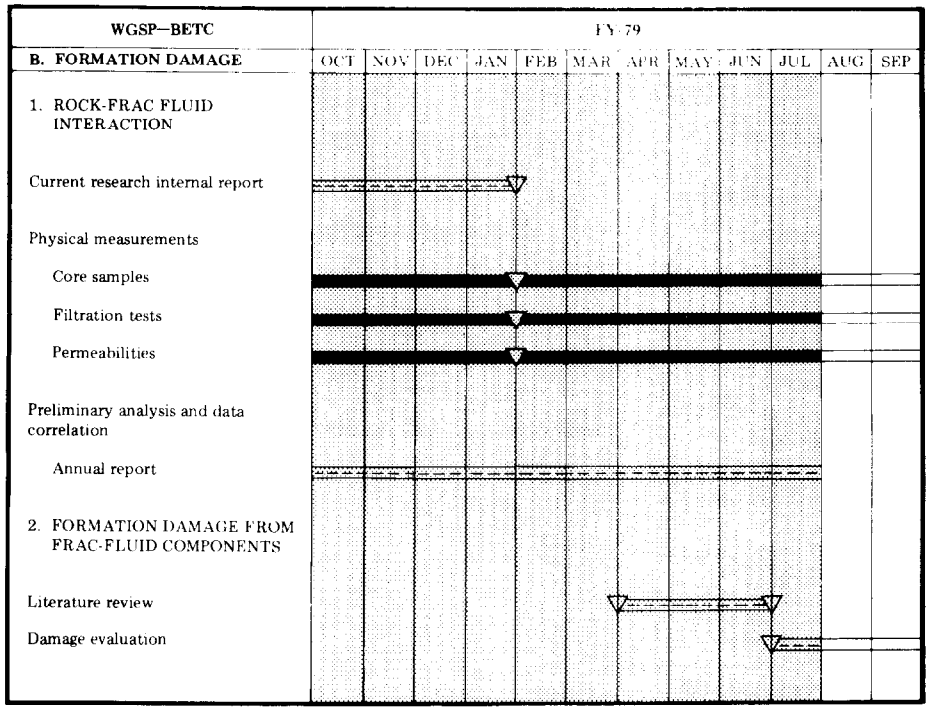


Figure 4-3 Milestone Chart — BETC





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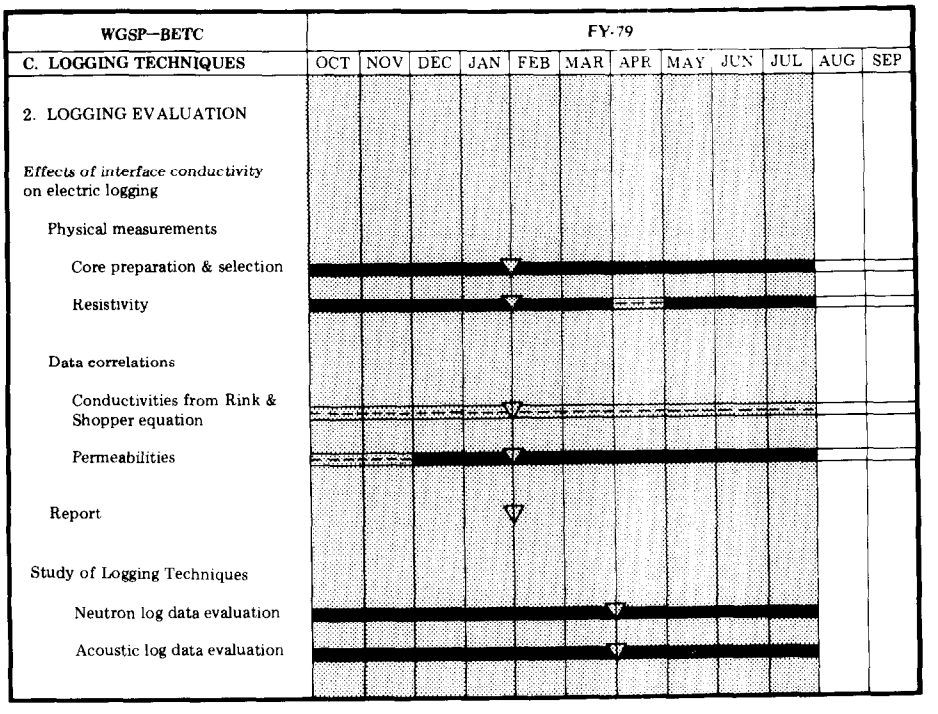

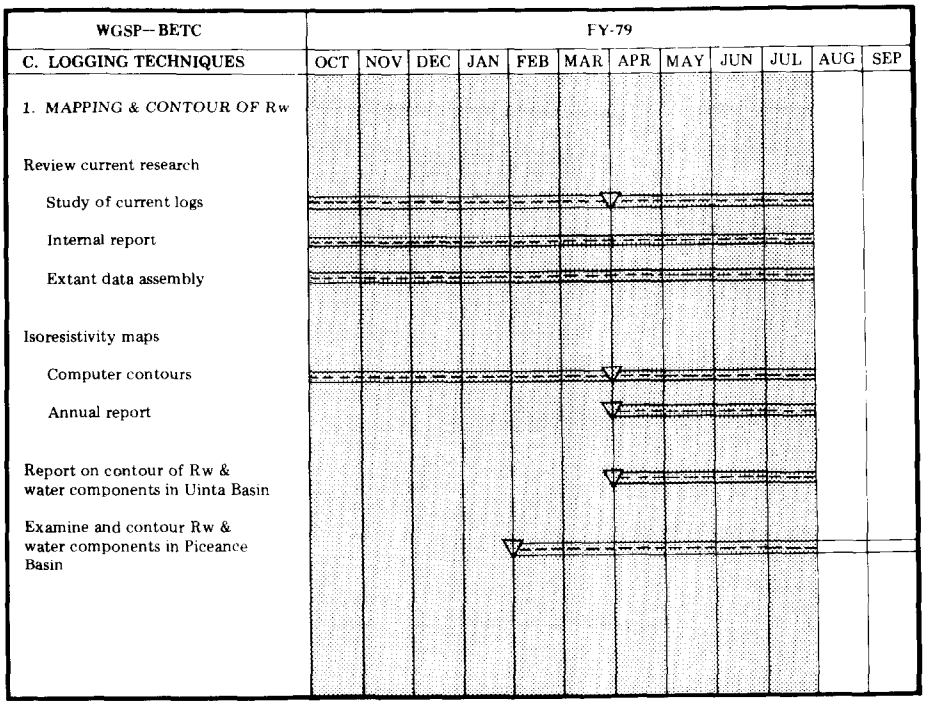

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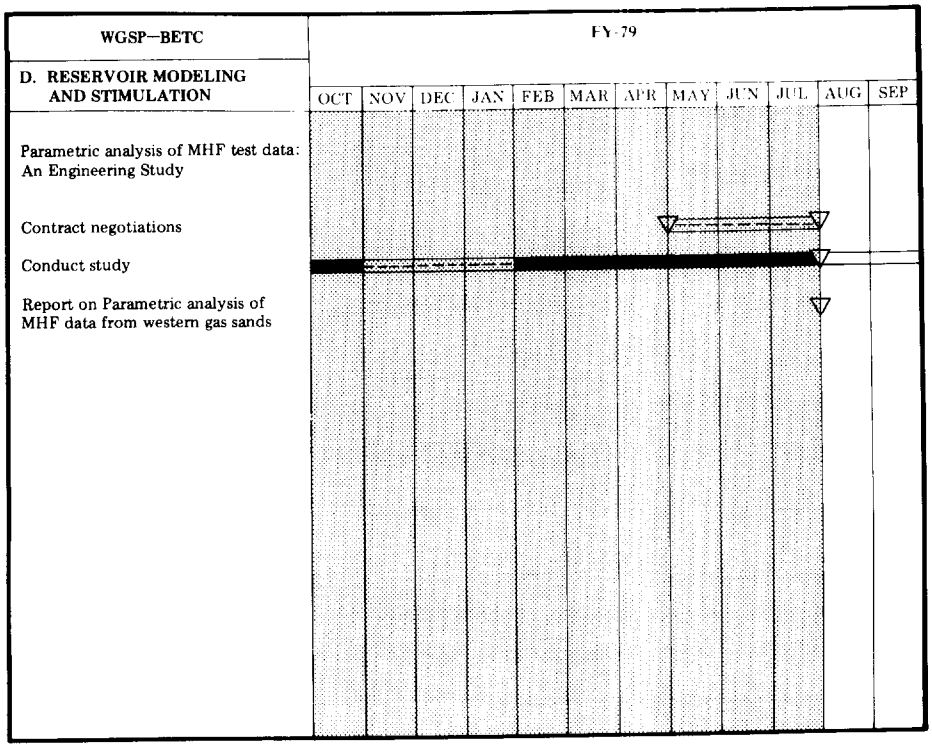


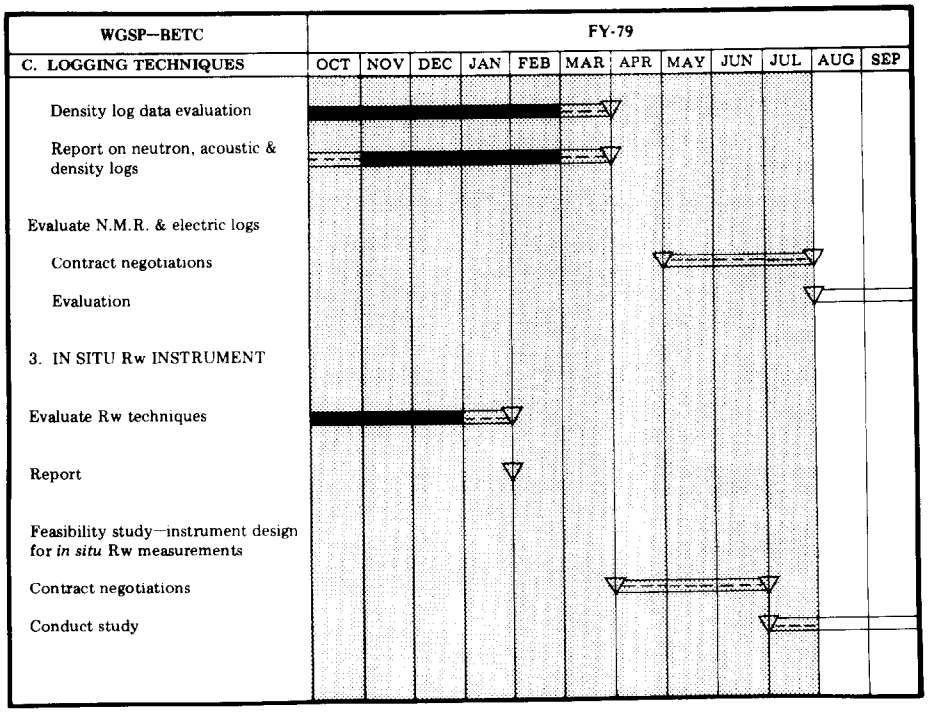


Figure 4-3 Continued

tip could not be followed for a sufficient time to determine the material rebound characteristics. Reflected waves were not allowed to affect the particle motion because this geometry represented the fracture processes in the earth. The crack should approach one interface unaffected by the presence of another symmetrically located interface. In order to solve this geometry, the model is being enlarged so that analysis can be performed using half-plane symmetry.

Debugging the code, which will permit the calculation of fictional interfaces, was completed; however, further code development may be required. A series of runs has been initiated to determine the effects of a fictional interface on the stress intensity factor as a pressure driven fracture approaches the interface.

4.2.2 Experimental Program

Fabrication was completed on a set of limestone blocks which will be used in experiments to study the behavior of a hydraulic fracture in the vicinity of the line where two perpendicular unbonded interfaces, one of which supports a normal load, intersect. The purpose of these experiments is to simulate the case in which the hydraulic fracture approaches an interface near the region in which the interface is intersected by a pre-existing crack. This case has been modeled theoretically and the results of the calculations suggest that the presence of pre-existing cracks alters the effective moduli of the material.

Brazil tensile tests have been completed parallel and perpendicular to the bedding on the Mesaverde sandstone samples from Sublette Cty, Wyoming. Other specimens of this material have been prepared for further equation-of-state studies. Pressure-volume studies have begun on Colorado Mesaverde sandstone and shale.

4.2.3 Geology/Geophysics/Logging

Logs and core analysis data from the Bowdoin area in Montana have been studied. The results of these studies have been documented and will be released soon.

4.2.4 Schedule Status

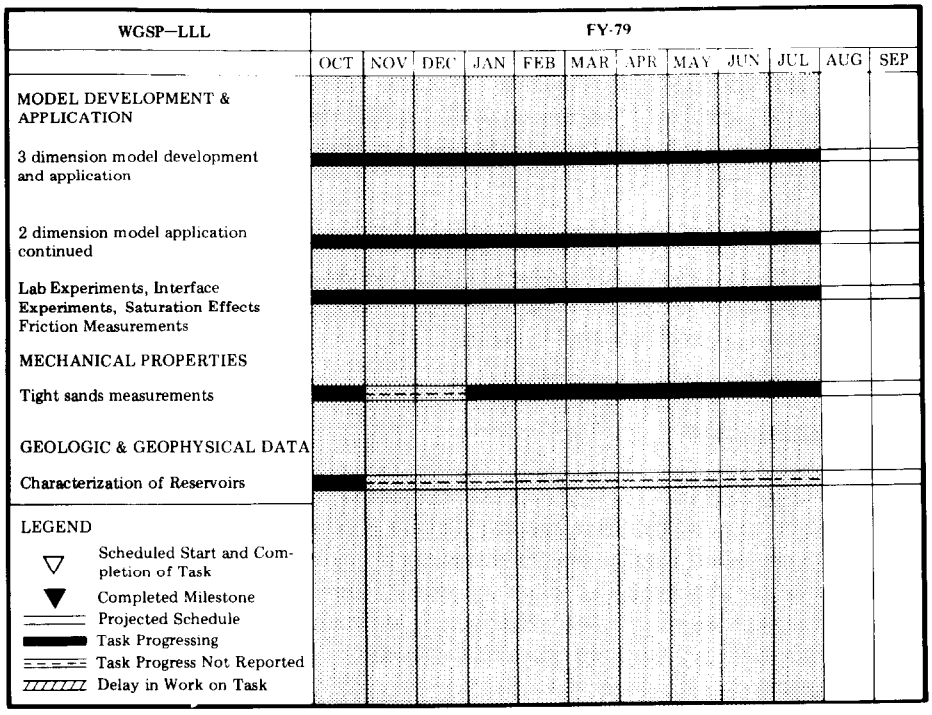
Figure 4-4 is a milestone chart showing LLL progress in WGSP projects for FY 1979.

4.3 SANDIA LABORATORIES

4.3.1 EGR Instrumentation and Diagnostic Program

4.3.1.1 Hydraulic Fracture Characterization

A DEC PDP 11/34A computer system is being purchased to support the borehole seismic system and the stacked hydrophone array system instrumentation development efforts. In addition, the plotting capability of the Versatec 1200A will be used for post-test analysis of Surface Electrical Potential System (SEPS) data.



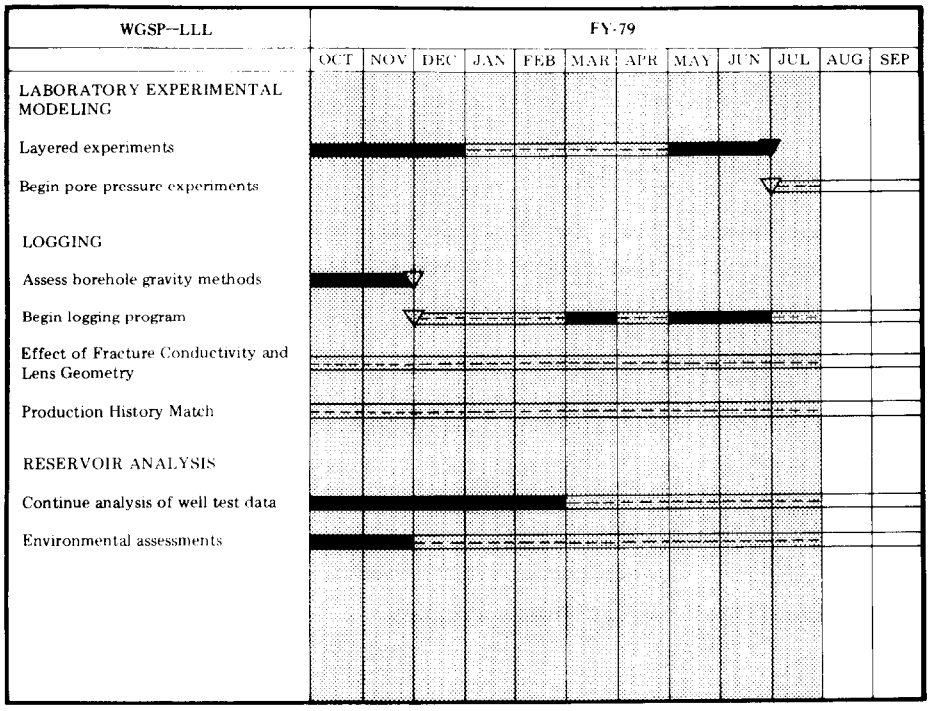


Figure 4-4 Milestone Chart — LLL

4.3.1.2 Borehole Seismic System

The borehole seismic system will be fielded on the Shell Oil Company well No. 343 near the Texas-Oklahoma border in September. The exact date has not been set at this time. Surface explosive charges will be used in order to determine package orientation. Successful detection package orientation could eliminate the requirement of the cumbersome and unreliable gyro system now being used. The seismic signals from this test will be digitized and stored in B-59's PDP-11 by using threshold detectors, thus storing larger seismic signals in near real time. The signals obtained can then be plotted and fracture orientation can be determined even before the fracture is complete if the explosive charges produce the desired results in fixing the seismic system position.

4.3.1.3 Borehole Hydrophone System

The 30-ft hydrophone system has been tested in order to determine the source of excess noise previously found in the system. The source of the noise was found, corrections were made and the output signal-to-noise ratio of the system has been improved. The high gain amplifiers have been reworked to obtain a faster increase in attenuation vs. frequency and to obtain a gain which is more consistent from one amplifier to the next. The gains are fairly consistent at 70 db and the frequency roll-off has been increased to approximately 18 db per octave. This system is scheduled for further testing in the Sandia borehole. Testing has continued on the six hydrophone units from International Transducer Corporation. Pressure tests were made to 10,000 psi. The high pressure seal system of the hydrophones functioned satisfactorily on all the units; however, several units failed to operate electrically above 9,000 psi. Further tests will be required to determine if electrical operational problems exist at high pressure.

4.3.1.4 Formation Mapping

T. L. Dobecki (Sandia), C. Knutson (C K GeoEnergy), and S. Brasel (Seismic International Research Corporation) visited sites No. 1 and No. 2 in the Bryson Canyon and Horse Point gas fields in the southern Uinta Basin to lay out patterns of areal seismic coverage for each. In addition, specific "target" sand lenses out cropping in the cliff faces at site No. 1 were noted for use in the preliminary transmission/reflection tests to determine the frequency content of wavelets transmitted from the top of the cliff (survey location) as well as travel times to these specific units.

At present, SIRC is in the process of securing Bureau of Land Management approval for survey operations. Survey activity should commence in August.

4.3.1.5 Advanced Electromagnetic (EM) Logging Techniques

Inhomogeneous models associated with invasion/depletion zones of wells have been solved analytically. Review and codings of these solutions will begin in August. Extensive use of integration subroutines is expected.

4.3.2 Schedule Status

Figure 4-5 is a milestone chart depicting Sandia's WGSP activities.

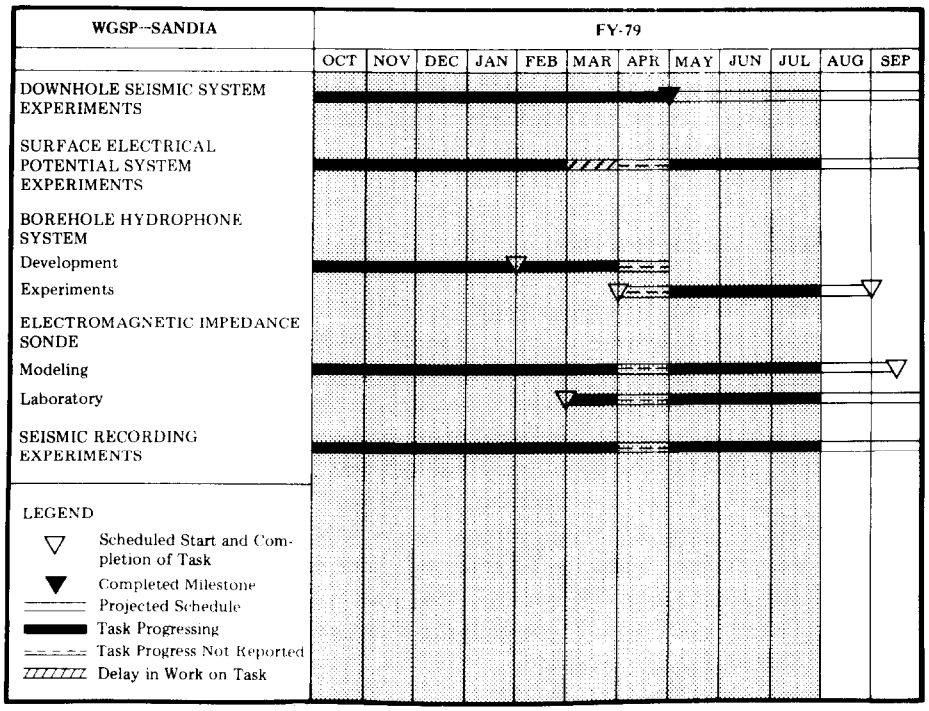


Figure 4-5 Milestone Chart — Sandia

4.4 GAS RESEARCH INSTITUTE

The Gas Research Institute (GRI) has initiated their project for field evaluations of reservoir fracturing to increase producibility of tight gas reservoirs by providing essential field data. GRI will coordinate their proposed work with DOE-funded projects to increase the efficiency, cost-effectiveness and scope of research in critical WGSP-related areas of resource characterization and stimulation technology. Three projects were funded in July and work has commenced.

4.4.1 Hydraulic Fracture and Testing of Rio Blanco Natural Gas Co. Government 397-1

Fracturing and testing of the 397-1 well in the Piceance Basin of northwest Colorado was proposed to DOE as an extension of current fracturing experiments in the area. The industrial partner estimated that $150,000 was needed for the fracture treatment and associated activities, not including the extensive test program. The project required pre-frac testing of gas-bearing intervals in the upper Mesaverde, massive hydraulic fracturing, followed by post-frac testing. Extensive data are available from several DOE-and Industry-sponsored wells within a six mile radius for correlation and comparison. DOE supports this project, but cannot fund the entire work plan, particularly in the CY 79 summer season. As their contribution, DOE provided a fully instrumented logging-testing trailer to support the testing work, a significant part of the overall cost.

As shown by Figure 4-6, the well is three miles from the RB-MHF 3, the DOE/Industry well which has been fractured four times in the Mesaverde and Fort Union horizons, and an equal distance from the RB-E-01 nuclear well. It is five miles from the RBNGC-498-1 which was fractured twice conventionally by the company, and by two additional massive fracs with DOE support. Although these fracs were initially considered successful, there is evidence of frac closure in one zone, presumably from proppant crushing, which caused flow rates to decrease abnormally.

The No. 397-1 well is to be fractured in zones correlatable to a commercial zone in the No. 498-1 and to the second frac interval in the RB-MHF 3. The proposed frac incorporates high strength proppants.

As shown by Figure 4-7, the frac included four sands between 8,500 and 8,600 ft. This zone showed considerable gas when the upper sand was drilled, saturating the detector. The well kicked shortly afterward, requiring kill procedures to bring the well under control. A drill stem test of the zone flowed gas and CER's evaluation of the raw logs from the well indicated that the zone was favorable for commercial gas production providing a successful treatment technique could be found.

Work began on this project on July 13, 1979, with the DOE mobile well test facility on site. Preliminary testing and well work was cooperatively financed by GRI, DOE and the operator. Tubing was run in the well, the well swabbed dry, and the first zone was perforated. After a short buildup test, the perforations were broken down with 3,000 gal 15 percent MSR acid and ball sealers. Pre-frac flow testing was performed, followed by a BHP buildup and a pre-frac analysis. The fracture treatment is tentatively scheduled for August 20, 1979.

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

A project has been funded to perform seismic research using recently developed techniques to determine if the geometry of lenticular sands at depth can be determined. Sandia Laboratories has proposed to obtain data in the Uinta Basin that will complement and extend outcrop and core hole studies being made by C K GeoEnergy Corporation under contract to DOE. The program proposed by Sandia Laboratories is:

- Locate an optimum site having the following characteristics:

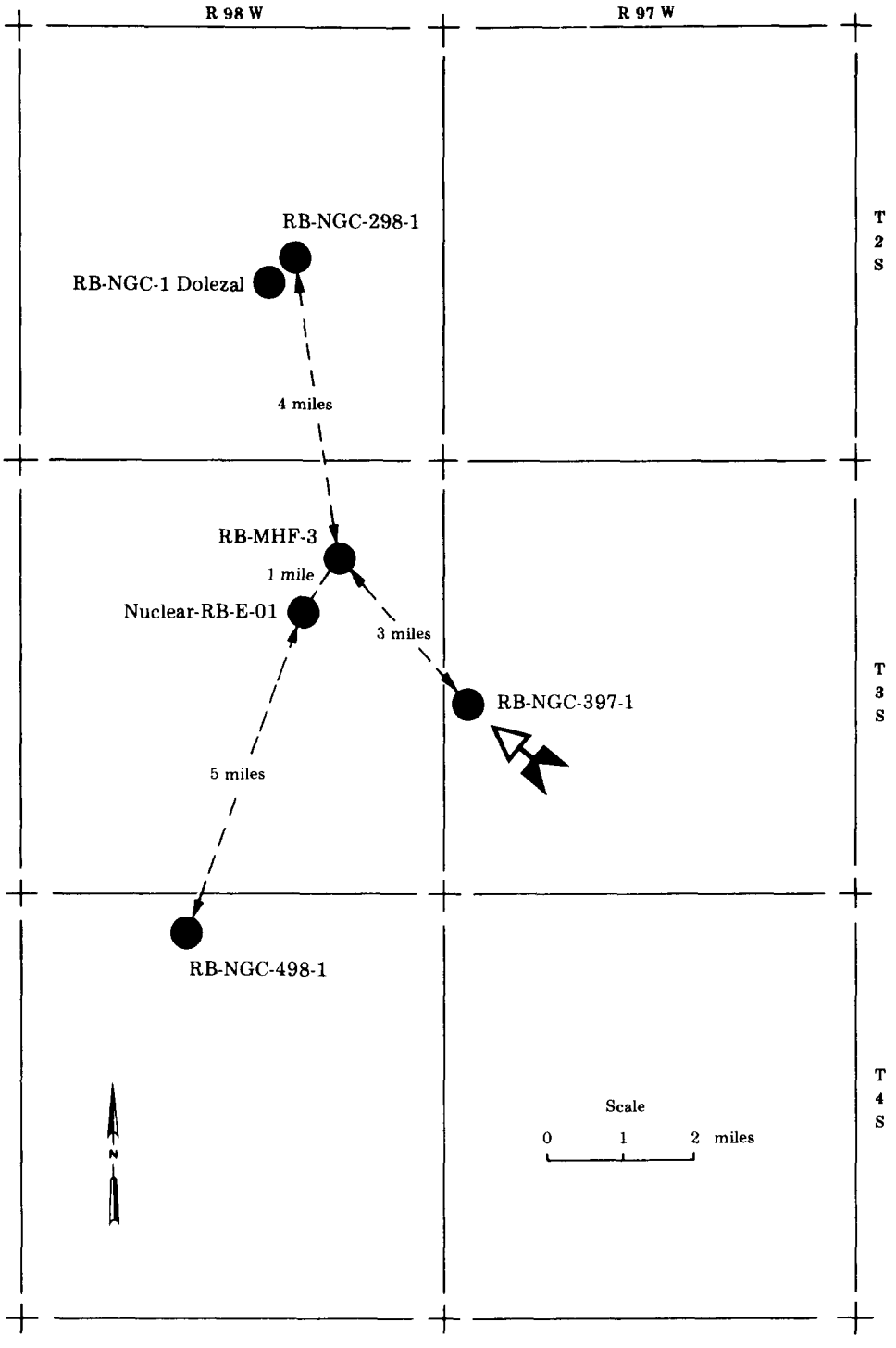


Figure 4-6 Location Map for Massive Frac Wells

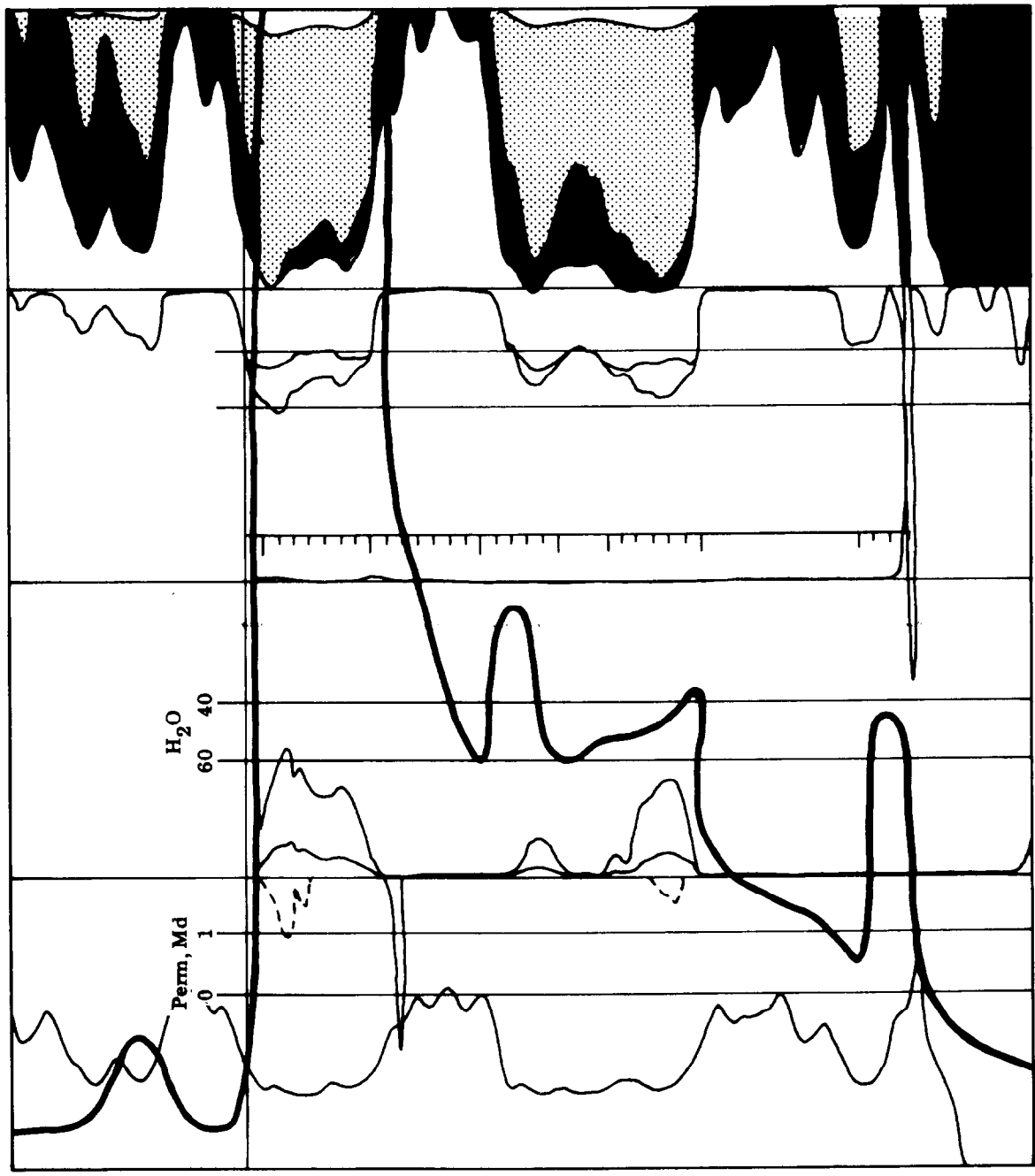


Figure 4-7 RBNGC-397-1 Well, Rio Blanco County, Colorado

Mesaverde depth range-surface outcrop to 5,000 ft
Known channel (lenticular sand) existence
Adequate well log control
Production history preferred (i.e. known gas resources).

- Construct a preliminary model using known geologic controls.
- Perform seismic modeling based on the geologic model and log control; perform sensitivity analysis.
- Perform a seismic reflection survey: map sand lenses, define geologic section and trends of lenses, explain production irregularities where production data are available, and modify geologic model.

A contract has been negotiated with Seismic International Research Corp. to perform a twelve-fold survey in the Eastern Uinta Basin, Utah. This survey will use an existing core hole and existing outcrop control to delineate sand lenses to a depth of 500 ft.

A follow-up survey, Phase II of the project, funded by DOE, will extend the seismic work downdip into the basin. Logs of existing wells and the first GRI-funded work will control this survey.

Extensions of this research may be performed in the future at the site of the proposed multi-well fracturing experiment.

4.4.3 Core and Log the Pacific Transmission Supply Company 22-12 Federal, Piceance Basin, Colorado

A contract has been negotiated with the Pacific Transmission Supply Company to core sections of the Upper Mesaverde and Mancos B formations in their Federal 22-12 well in the Piceance Basin as a cooperative project between GRI, DOE, and the operator.

5. FIELD TESTS AND DEMONSTRATIONS

5.1 BACKGROUND

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

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

The CER Corporation RB-MHF 3 is on an inactive status as the well is being transferred to the Rio Blanco Natural Gas Company to perform additional tests. The RB-MHF 3 Final Report has been issued in a three-volume set. A set may be ordered from NTIS, U.S. Department of Commerce, Springfield, Virginia, 22161.

Table 5-1 summarizes completed and active WGSP MHF treatments. Progress of these projects is presented in the following sections.

Table 5-1 MHF Contract Locations and Frac Data

COMPANY, BASIN & FORMATION	LOCATION T/R/Sec	WELL	INTERVAL FRACTURED ft	FRAC DATE	FRAC TREATMENT Lb of Sand	INJECTED FLUID 10^3 Gal
AUSTRAL Piceance, Mesaverde	7S/94W, Sec 3 Garfield Cty Colorado	Federal 3-94	5,170- 6,333	8-25-76	1,140,000	542 Gel Gel H O
CONSORTIUM MANAGED BY CER CORPORATION Piceance, Mesaverde	3S/98W, Sec 11 Rio Blanco Cty Colorado	RB-MHF-3	8,048- 8,078 7,760- 7,864 5,925- 6,016 5,851- 5,869	10-23-74 5- 2-75 5- 4-76 11- 3-76	400,000 880,080 815,000 448,000	117 Gel 285 Gel 400 Gel 228 Gel
GAS PRODUCING ENTERPRISES, INC. Uinta, Wasatch and Mesaverde	10S/22E/Sec 10 Uintah Cty Utah	Natural Buttes No. 18	6,490- 8,952	9-22-76	1,480,000	745 Gel
	10S/21E/Sec 21 Uintah Cty Utah	Natural Buttes No. 19	8,909- 9,664 7,224- 8,676	9-21-76 9-28-76	424,000 784,000	260 Gel 364 Gel
	9S/21E/Sec 22 Uintah Cty Utah	Natural Buttes No. 14	6,646- 8,004	3-15-77	1,093,000	544 Gel
	9S/21E/Sec 28 Uintah Cty Utah	Natural Buttes No. 20	8,498- 9,476	6-22-77	826,000	322 Gel
	10S/22E/Sec 18 Uintah Cty Utah	Natural Buttes No. 22	6,858- 8,550	11-21-77	1,091,000	479 Gel
	9S/22E/Sec 19 Uintah Cty Utah	Natural Buttes No. 9	5,661- 8,934	3-27-78	554,000	349 Gel
	10S/21E/Sec 29 Uintah Cty Utah	Natural Buttes No. 2	7,251- 8,774	8- 8-78	1,965,000	722 Gel
	10S/22E/Sec 7 Uintah Cty Utah	Natural Buttes No. 23	5,080- 6,294	10- 4-78	440,000	240 Gel
DALLAS PRODUCTION Fort Worth, Bend Cong.	Ben D. Smith Survey A-779 Wise Cty 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/Sec 5 Sublette Cty 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
MITCHELL ENERGY Cotton Valley, Limestone Trend	Limestone Cty Texas	Muse-Duke No. 1	11,220-11,430	11-15-78	2,800,000	891 Gel
MOBIL Piceance, Mesaverde	2S/97W/Sec 13 Rio Blanco Cty Colorado	F-31-13G	10,549-10,680 9,392- 9,538 8,765- 8,972 8,163- 8,650 7,704- 7,794 7,324- 7,476	6-22-77 8-24-77 5-10-78 7- 6-78 9- 7-78 11-15-78	580,000 600,000 388,000 660,000 218,000 700,000	316 Gel 260 Gel 150 Gel 288 Gel 120 Gel 365 Gel
PACIFIC TRANSMISSION Uinta, Mesaverde	8S/23E/Sec 25 Uintah Cty Utah	Federal 23-25	NO FRACS PERFORMED			
RIO BLANCO NATL. GAS Piceance, Mesaverde	4S/98W/Sec 4 Rio Blanco Cty Colorado	Federal 498-4-1	6,150- 6,312 5,376- 5,960	10-22-76 11-30-77	766,000 243,000+ 22,500 Reads	276 Gel 164 Gel
WESTCO Uinta, Mesaverde	10S/19E/Sec 34 Uintah Cty 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

UGR File #2..6
July 1979
DOE/BG/01569-12
CER Corporation

RIO BLANCO MASSIVE HYDRAULIC FRACTURING EXPERIMENT

EY-76-C-08-0623

CER Corporation
Las Vegas, Nevada

Status: Well transferred to another operator.

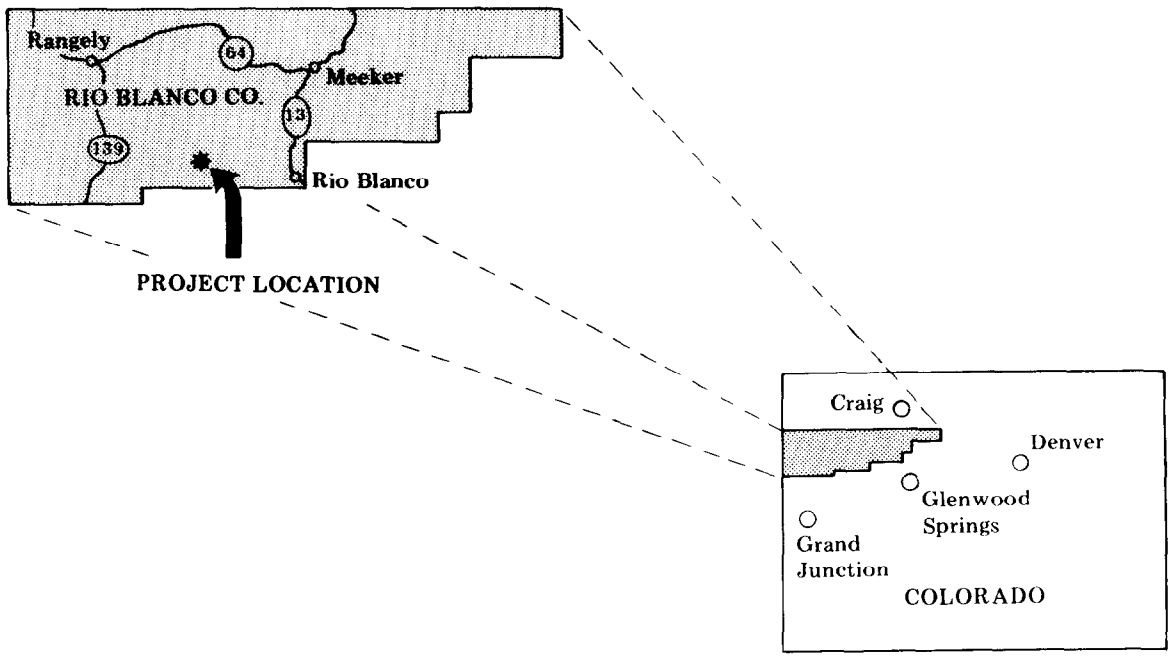
Interagency Agreement Date: June 19, 1974
Anticipated Completion Date: July 1, 1979

Project Cost (estimated):	DOE	$1,990,000
	Industry	1,630,000
	Total	$3,620,000

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

OBJECTIVE

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



5.2 CER CORPORATION

DOE contract 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 added two additional MHF treatments and extended the term of the contract.

Field activities on RB-MHF 3 well have been suspended. CER Corporation is transferring (or selling) the MHF well to Rio Blanco Natural Gas Company and in return Rio Blanco agrees to attempt to complete the well, commingle the previously fractured zones, test the well and provide the data to the industrial participants and DOE. Legal documents have been distributed to the project participants for their concurrence.

Three documents were developed in order to clean up the remaining matters associated with CER's involvement in the MHF experiment and in Contract AT(26-1)-623. These documents are:

- Assignment of MHF Experiment Rights and Obligations between CER Corporation and Rio Blanco Natural Gas Company;
- Agreement and Consent to Assignment among the DOE, CER Corporation and Rio Blanco Natural Gas Company;
- Agreement and Assignment of Rights of Recoupment among Rio Blanco Natural Gas, Equity and the fifteen industrial participants.

This is the final report for Contract EY-76-C-08-0623.

WATTENBERG FIELD

EY-77-C-08-1514

Colorado Interstate Gas Company
Colorado Springs, Colorado

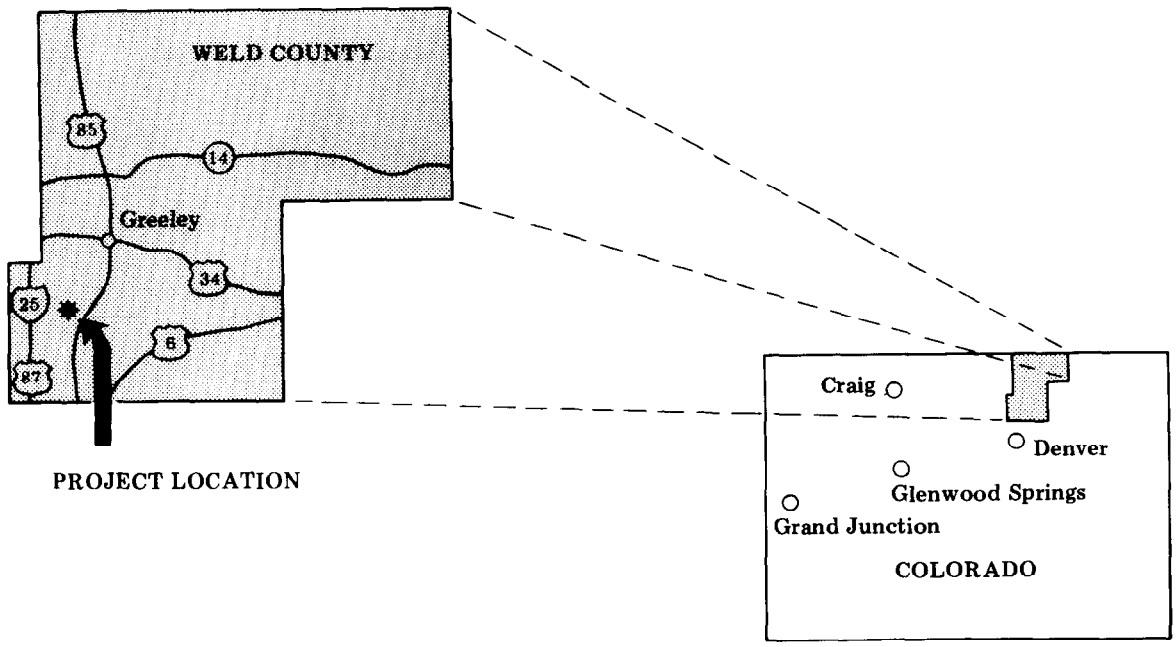
Status: Active

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

OBJECTIVE

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



5.3 COLORADO INTERSTATE GAS

Cyclic injection of dehydrated gas and production continued at the Miller No. 1 and Sprague No. 1 wells. The cycle period will be lengthened from one to two weeks. In the future the cycle will be reversed every other Friday.

July 1979
DOE/BG/01569-12
CER Corporation

DOE WELL TEST FACILITY

EY-76-C-08-0623

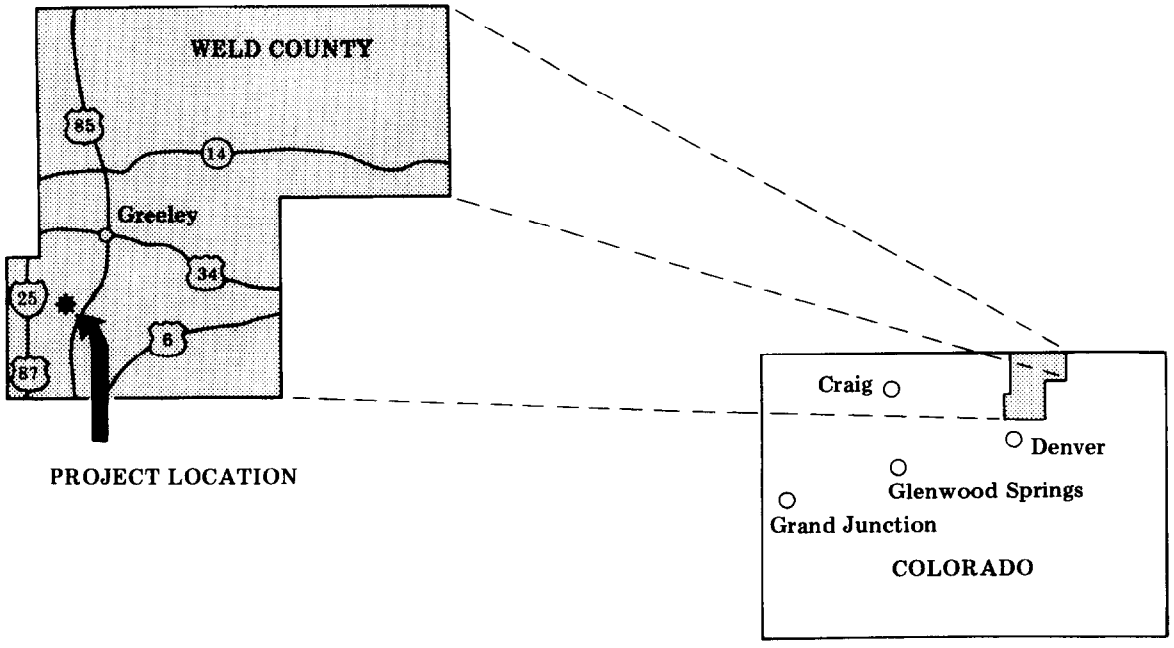
CER Corporation
Las Vegas, Nevada

Status: Operational

Principal Investigator: R. L. Mann
Technical Advisor for DOE: C. H. Atkinson

OBJECTIVE

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



5.4 DOE WELL TEST FACILITY

The DOE Well Test Facility was transported to the Rio Blanco Natural Gas Company well No. 397-19-1 Government during the second week of July. The facility was relocated at the Rio Blanco Cty, Colorado, site in order to acquire reservoir data and provide analytic support for the joint Gas Research Institute/Rio Blanco Natural Gas Company proposed fracture experiment.

The Chancellor well was perforated on July 14 and 2-7/8 in. tubing was set with a packer at 8,480 ft. Initial reservoir formation pressure could not be derived from pre-breakdown bottom-hole measurements due to poor communication with the formation; consequently it was necessary to perform a breakdown. The breakdown consisted of injecting 5,000 gal of 15 percent MSR acid. Small flow rates during the breakdown minimized the fracture length, thus permitting derivation of formation flow capacity, kh, from Horner Plots that would be relatively undisturbed by fracture effects. After breakdown and swabbing were completed, downhole measurements commenced. Flow time, although not definitive due to the swabbing time and sporadic blow-downs, was estimated to be about 10 to 15 hrs and the average flow rate was taken to be 25 MCFD. Table 5-2 is an output from the CER Corporation "Perm" program and lists the bottom-hole pressure, temperature, Horner time, slope, flow capacity (kh) and other parameters for the buildup of July 21-28. From the last several data points the value of kh is found to be ~ .006 md ft and, if the thickness of the perforated production intervals is taken as 22 ft, permeability is ~ 0.275 μd. The value of extrapolated initial reservoir pressure P* is found to be 4,030 psia. Figure 5-1 is a Horner Plot of the buildup data.

Flow testing resumed on July 28 at 70 MCFD; however, it was apparent that the well was loading with fluid and it subsequently died on July 30. Swabbing will commence when equipment is obtained.

Table 5-2 BHP Buildup Test Commencing July 21 RBNG 397-19-1 Gov't

Time (ΔT) (hrs)	Horner Time	Pressure (psi)	Slope (psi/ cycle)	P-Star (psi)	kh (md-ft)	Skin
.01	1,001.00	530.0	179.0	1,048.	.5072	-.16
3.50	3.86	639.0	179.0	1,048.	.5001	-2.24
6.00	2.67	1,257.0	3,728.0	2,828.	.2243E-01	-1.41
7.00	2.43	1,378.0	3,138.0	2,592.	.2636E-01	-1.46
8.00	2.25	1,489.0	3,512.0	2,730.	.2333E-01	-1.44
9.00	2.11	1,592.0	3,847.0	2,843.	.2112E-01	-1.43
10.00	2.00	1,686.0	4,251.0	2,970.	.1898E-01	-1.42
11.00	1.91	1,778.0	4,655.0	3,087.	.1721E-01	-1.40
12.00	1.83	1,862.0	4,930.0	3,161.	.1616E-01	-1.40
13.00	1.77	1,941.0	5,177.0	3,225.	.1530E-01	-1.39
14.00	1.71	2,013.0	5,627.0	3,333.	.1401E-01	-1.38
16.00	1.63	2,148.0	5,989.0	3,414.	.1305E-01	-1.37
18.00	1.56	2,266.0	6,436.0	3,504.	.1205E-01	-1.37
20.00	1.50	2,372.0	6,888.0	3,587.	.1119E-01	-1.36
22.00	1.45	2,467.0	7,247.0	3,648.	.1058E-01	-1.35
24.00	1.42	2,552.0	7,584.0	3,700.	.1007E-01	-1.35
28.00	1.36	2,695.0	7,774.0	3,727.	.9751E-02	-1.35
32.00	1.31	2,810.0	7,947.0	3,749.	.9487E-02	-1.35
36.00	1.28	2,903.0	8,340.0	3,794.	.9001E-02	-1.35
40.00	1.25	2,987.0	8,406.0	3,799.	.8897E-02	-1.35
44.00	1.23	3,050.0	8,539.0	3,813.	.8736E-02	-1.35
48.00	1.21	3,113.0	9,099.0	3,860.	.8178E-02	-1.35
54.00	1.19	3,188.0	9,114.0	3,862.	.8140E-02	-1.35
60.00	1.17	3,252.0	9,425.0	3,883.	.7852E-02	-1.35
66.00	1.15	3,306.0	9,527.0	3,890.	.7751E-02	-1.35
70.50	1.14	3,341.0	9,915.0	3,913.	.7439E-02	-1.35
73.00	1.14	3,361.0	.1059E+05	3,951.	.6957E-02	-1.33
75.50	1.13	3,379.0	.1032E+05	3,936.	.7137E-02	-1.34
78.50	1.13	3,399.0	.1062E+05	3,952.	.6931E-02	-1.34
92.50	1.11	3,479.0	.1061E+05	3,952.	.6918E-02	-1.34
95.00	1.11	3,490.0	.1069E+05	3,955.	.6863E-02	-1.34
96.50	1.10	3,498.0	.1099E+05	3,968.	.6672E-02	-1.33
100.00	1.10	3,513.0	.1051E+05	3,948.	.6979E-02	-1.34
104.00	1.10	3,529.0	.1216E+05	4,015.	.6026E-02	-1.32
116.00	1.09	3,579.0	.1255E+05	4,030.	.5828E-02	-1.31
120.00	1.08	3,593.0	.1255E+05	4,030.	.5826E-02	-1.31

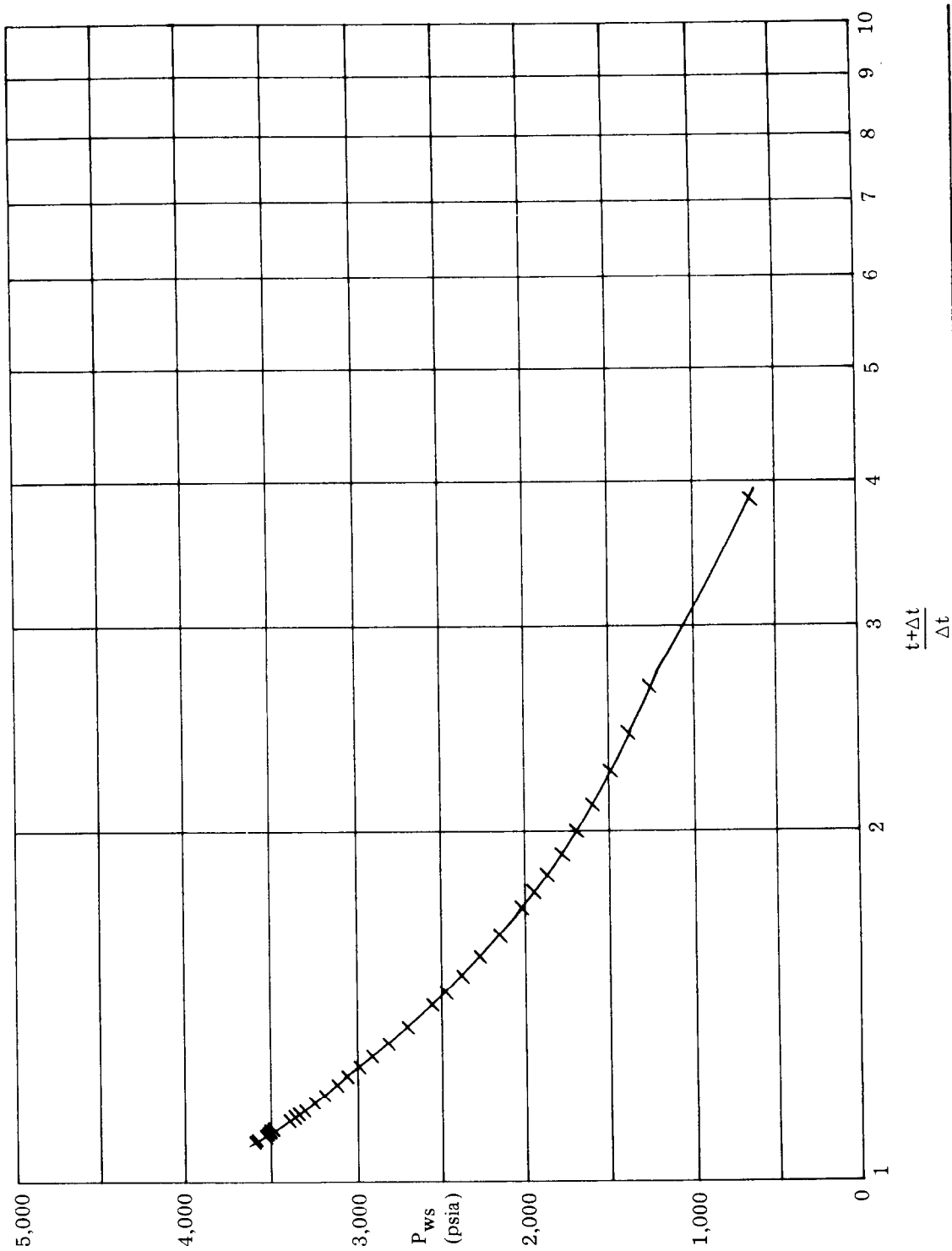


Figure 5-1 Horner Plot for July 21 BHP Test, RBNG 397-1 Gov't

July 1979
DOE/BG/01569-12
CER Corporation

NATURAL BUTTES UNIT, UINTAH COUNTY, UTAH MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

EY-76-C-08-0681

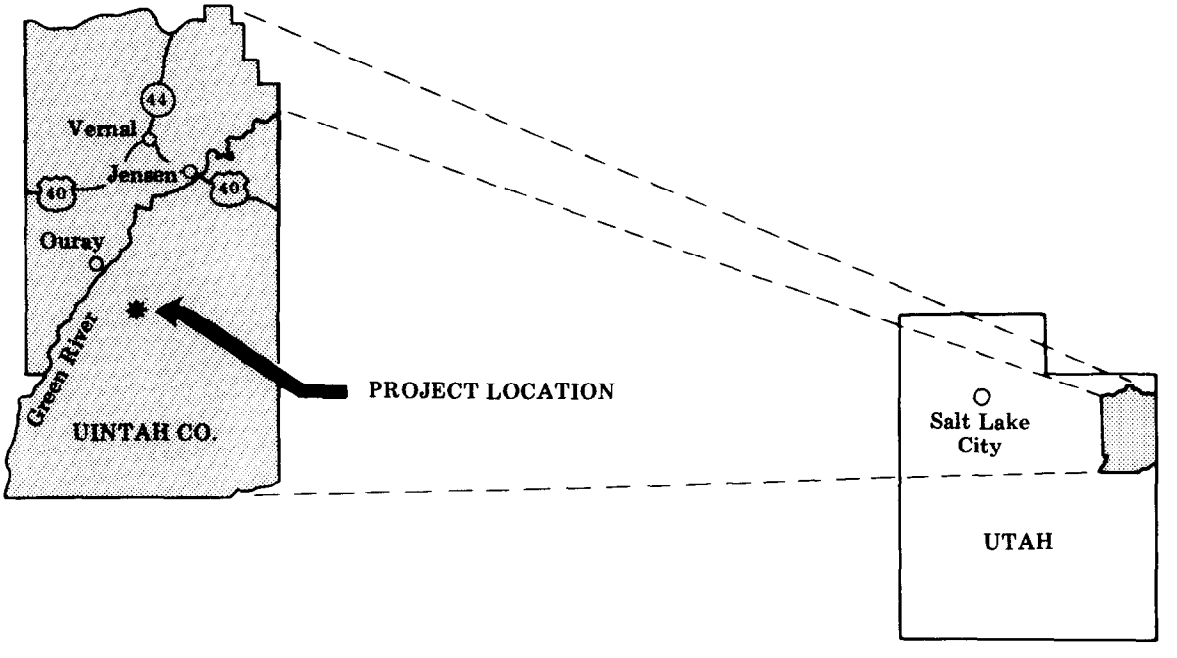
Gas Producing Enterprises, Inc.
Subsidiary of Coastal States Gas Co.
Houston, Texas

Status: Active

Contract Date:	July 1, 1976	
Anticipated Completion:	September 30, 1979	
Total Project Cost (estimated):	DOE	$2,827,000
	Industry (prior costs)	1,881,000
	Industry (new costs)	3,051,000
	Total	$7,759,000
Principal Investigator:	W. E. Spencer	
Technical Project Officer for DOE:	C. H. Atkinson	

OBJECTIVE

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



5.5 GAS PRODUCING ENTERPRISES

The GPE well Natural Buttes Unit No. 18 flowed to sales in July. Natural Buttes Unit Nos. 9, 14, 19, 20 and 22 were shut in and No. 21 was temporarily abandoned. Work is proceeding on the final report. Figures 5-2 through 5-7 show production figures.

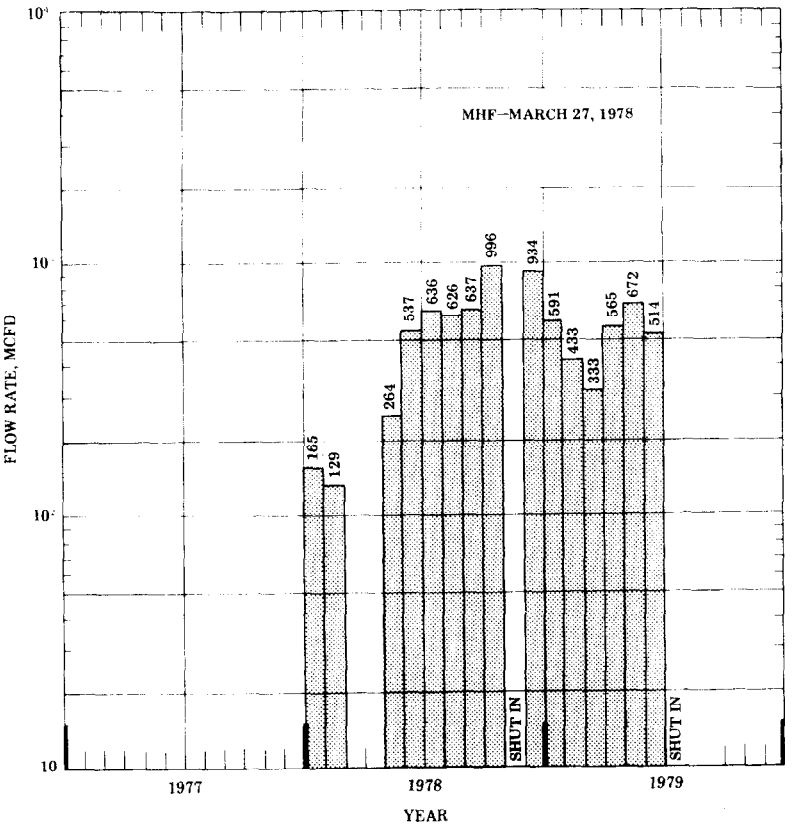


Figure 5-2

Flow Rate Performance of Natural Buttes No. 9 well

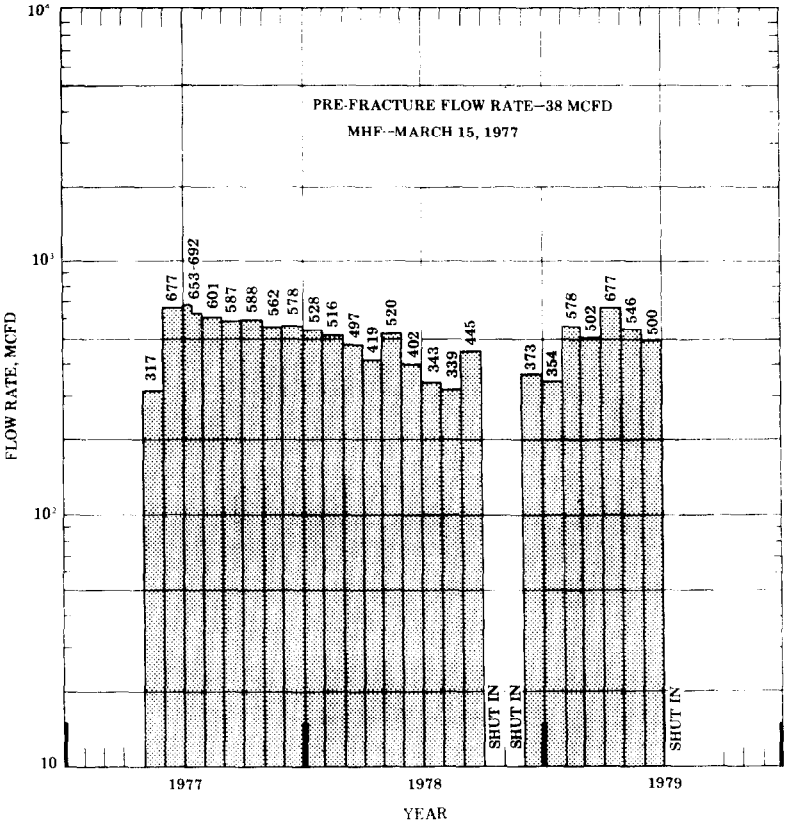
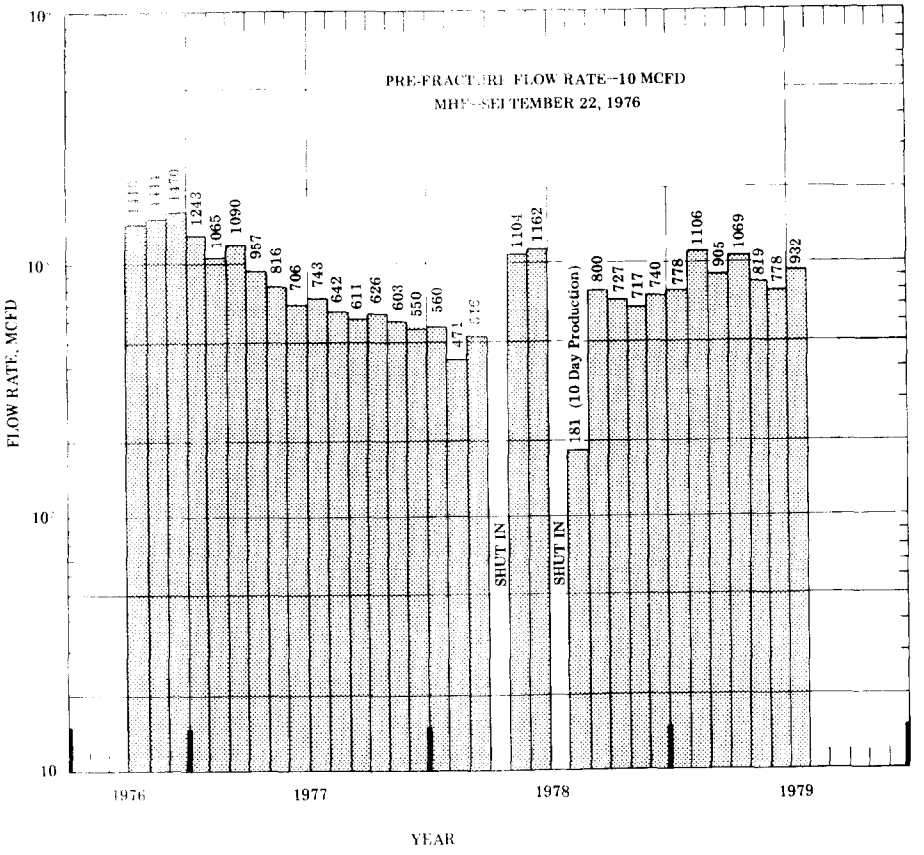


Figure 5-3

Flow Rate Performance of Natural Buttes No. 14 well

Figure 5-4

Flow Rate Performance of Natural Buttes No. 18 well



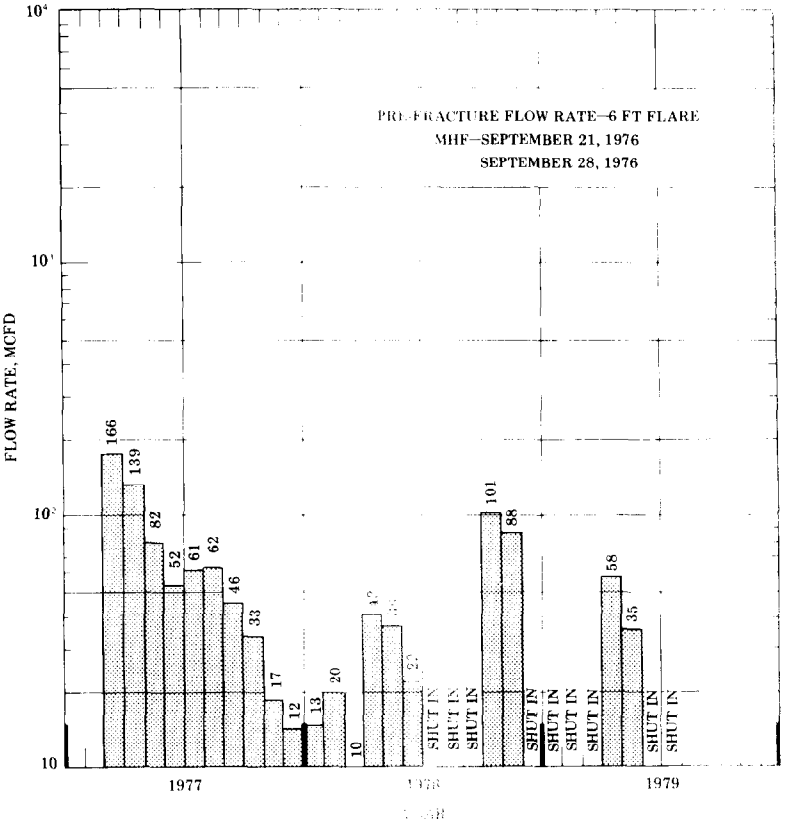


Figure 5-5

Flow Rate Performance of Natural Buttes No. 19 well

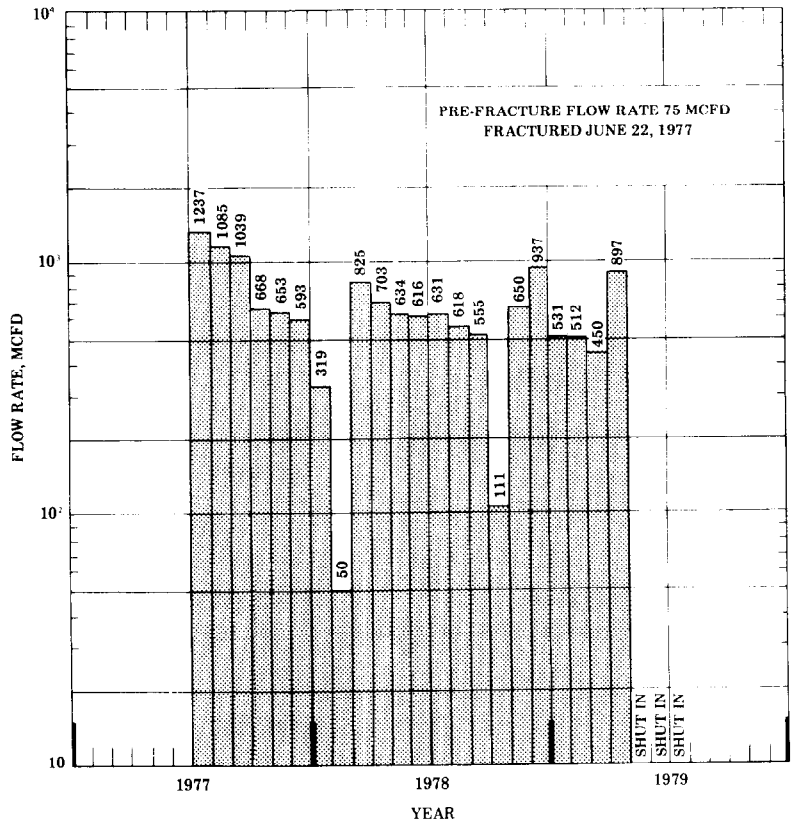


Figure 5-6

Flow Rate Performance of Natural Buttes No. 20 well

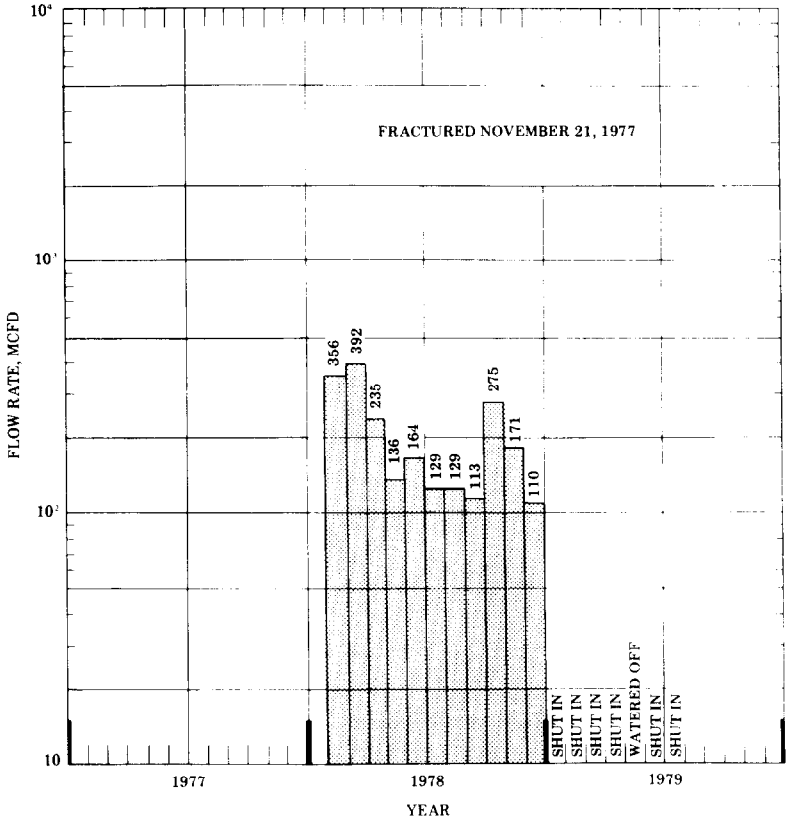


Figure 5-7

Flow Rate Performance of Natural Buttes No. 22 well

July 1979
DOE/BG/01569-12
CER Corporation

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

EF-78-C-08-1547

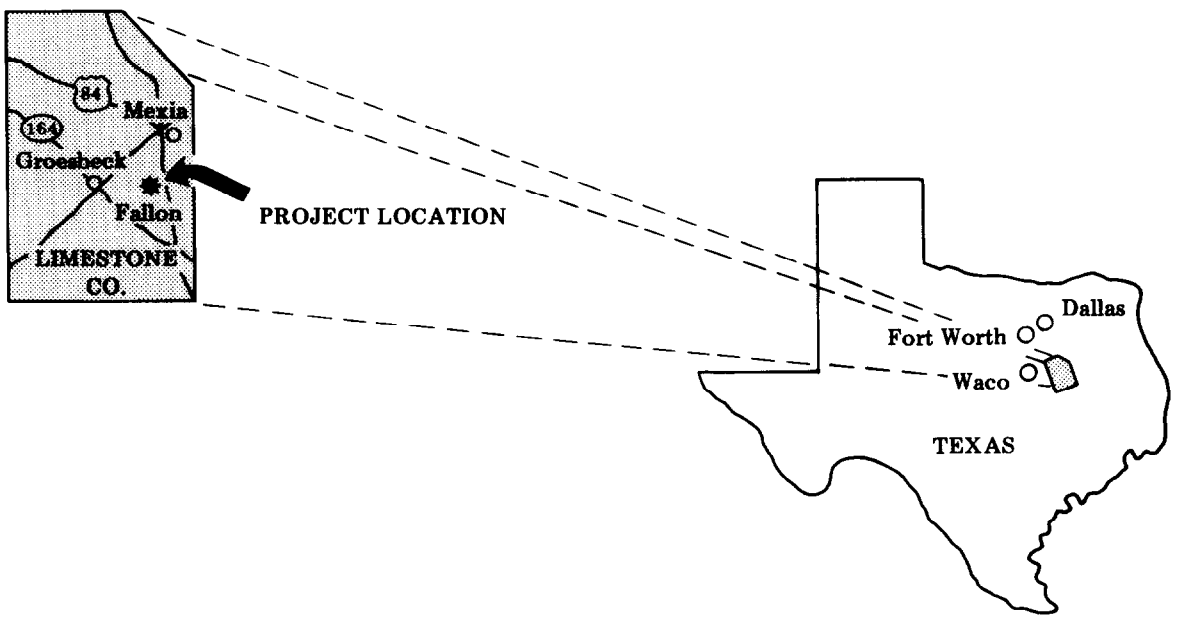
Mitchell Energy Corporation
Houston, Texas

Status: Active

Contract Date:	March 15, 1978
Anticipated Completion:	April 30, 1979
Total Project Cost (estimated):	DOE ..... $ 553,771
	Industry 1,074,550
	Total $1,628,321
Principal Investigator:	F. D. Covey
Technical Project Officer for DOE:	C. H. Atkinson

OBJECTIVE

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



5.6 MITCHELL ENERGY CORPORATION

Before being shut-in for testing, the Muse-Duke No. 1 well was flowing 3,000 MCFD and 18 BBL of water with a flowing tubing pressure of 970 psi. The cumulative production as of July 31, 1979, was just over one billion cubic feet of gas.

The post-fracture pressure transient tests were delayed. They will be completed by September 1.

July 1979
DOE/BG/01569-12
CER Corporation

PICEANCE CREEK FIELD, COLORADO, MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

EY-76-C-08-0678

Mobil Research and Development Corporation
Dallas, Texas

Status: Active

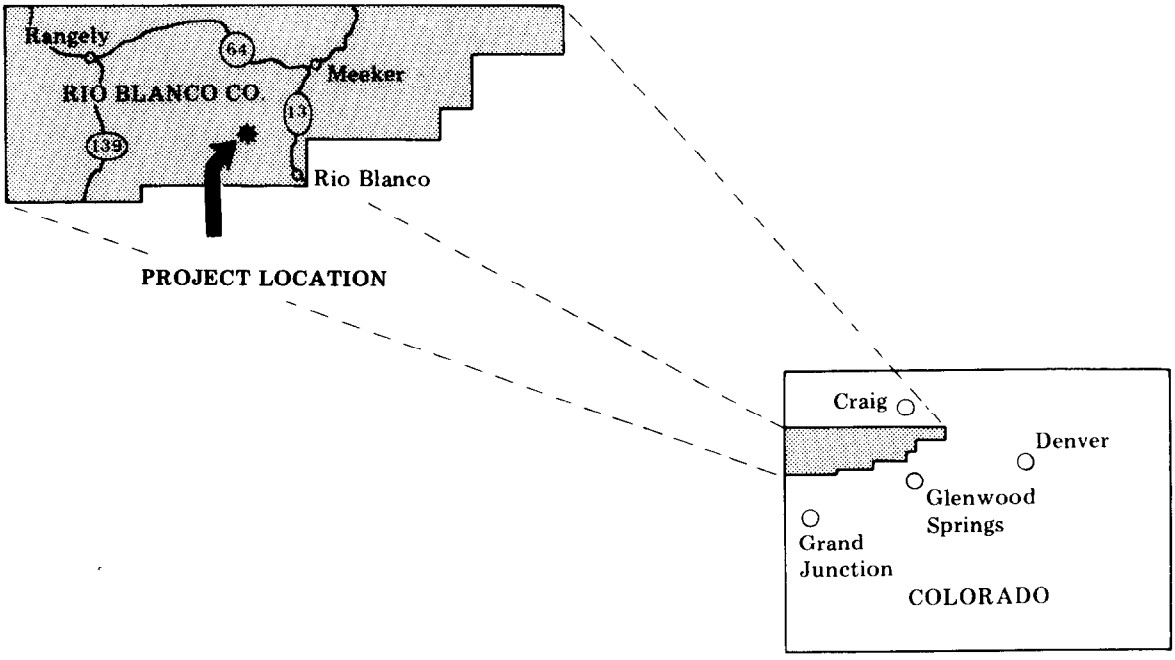
Contract Date:	July 1, 1976
Anticipated Completion:	June 1st 1979

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 for DOE:	C. H. Atkinson

OBJECTIVE

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



5.7 MOBIL RESEARCH AND DEVELOPMENT CORPORATION

Table 5-3 lists the flow rates for the Mobil PCU F31-13G well during July. On July 26 a flow log was run. Water slugging prevented quantitative analysis of the log, but flow is clearly coming through the by-pass in the bridge plug. When the flow rate was increased, flow through the bridge plug increased. The bridge plug will be left in place.

The final report is in preparation.

Table 5-3 July Flow Rates for Mobil PCU F31-13G well

Date	MMCFD Gas	BBL/Day Water	BBL/Day Condensate	TP psi	CP psi
6/23	1.0+	--	—	—	—
6/26	2.0	80	28	1,720	2,250
7/2	5.0	900	—	—	—
7/4	3.1	792	13	800	1,750
7/11	2.9	—	—	--	—
7/15	2.9	720	14	—	—
7/15-7/25		Shut in for gas plant turn-around			
8/17	2.5	638	14	635	1,440

July 1979
DOE/BG/01569-12
CER Corporation

RIO BLANCO COUNTY, COLORADO MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

EY-76-C-08-0677

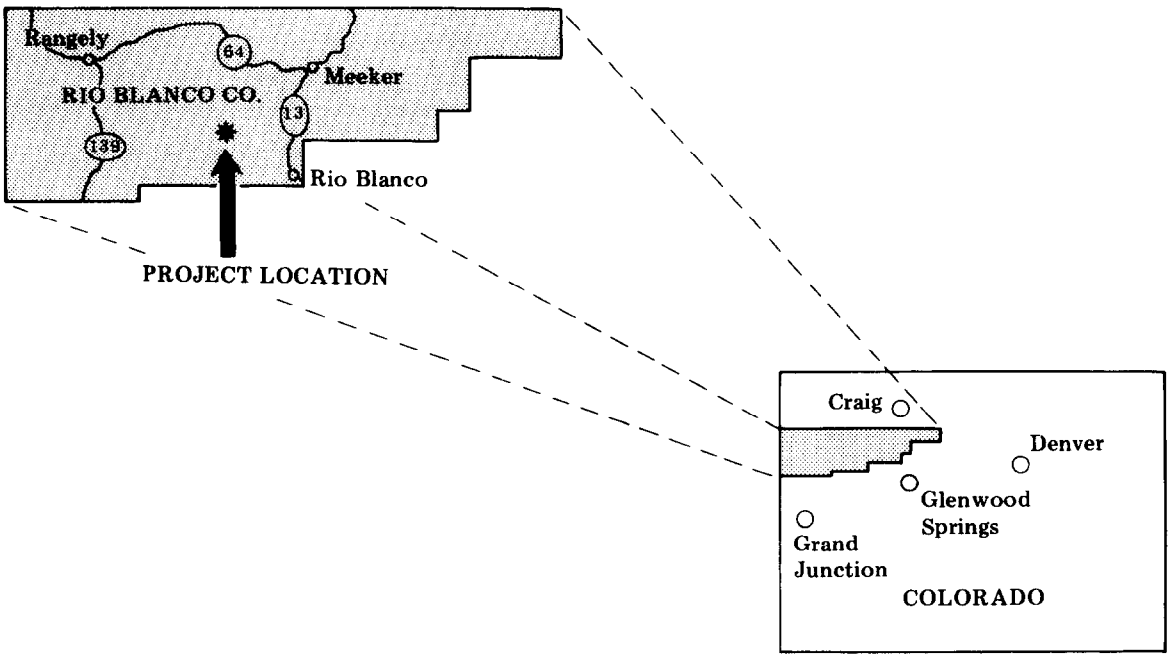
Rio Blanco Natural Gas Company
Denver, Colorado

Status: Active

Contract Date:	August 1, 1976	
Anticipated Completion:	December 15, 1978	
Total Project Cost (estimated):	DOE	$ 410,000
	Contractor	593,000
	Total	$1,003,000
Principal Investigator:	Robert E. Chancellor	
Technical Project Officer for DOE:	C. H. Atkinson	

OBJECTIVE

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



5.8 RIO BLANCO NATURAL GAS COMPANY

DOE Contract 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.

The draft form of the final report is being reviewed. Pending approval, it will be sent back to Rio Blanco Natural Gas Company for final printing.

July 1979
DOE/BG/01569-12
CER Corporation

NEVADA TEST SITE
NYE COUNTY, NEVADA
MINEBACK TESTING

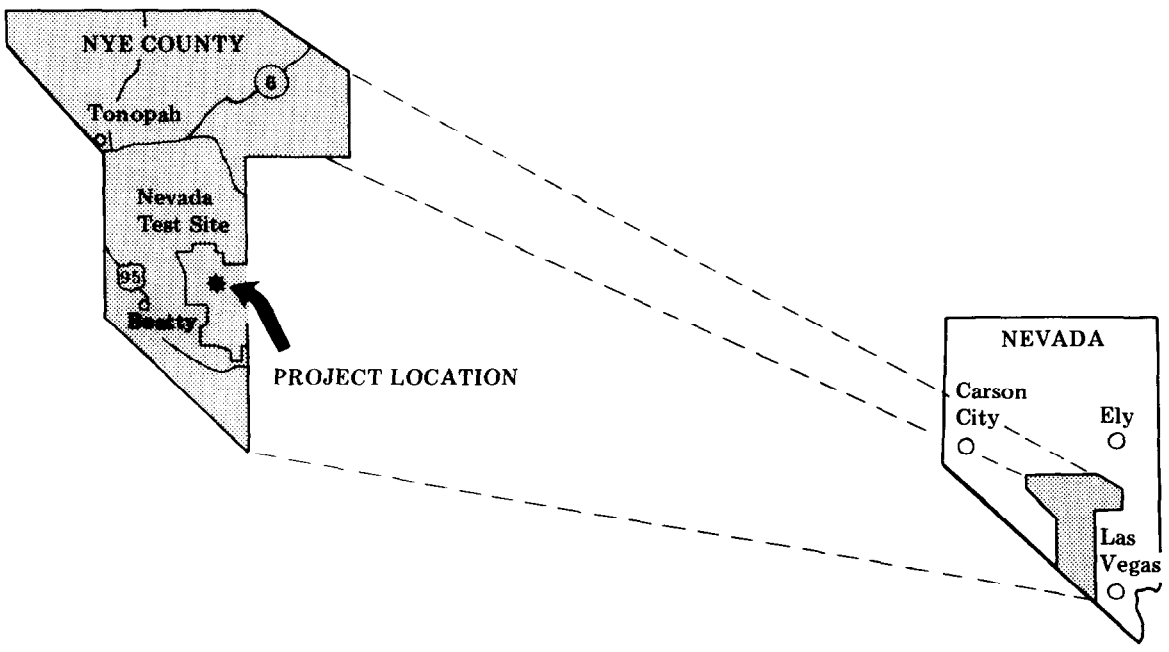
Sandia Laboratories
Albuquerque, New Mexico

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.



5.9 SANDIA LABORATORIES — MINEBACK

5.9.1 Summary of Past Activities

Exploratory coring of the Hole No. 6 Formation Interface fractures continued in June, with corehole EV6-24 failing to detect evidence of a fracture at 190 ft below the interface. Mineback of the fractures created in the second hole (CFE-2) of the Interface Test Series was initiated in June. Results showed the fracturing pressures of this region were nearly twice that of CFE-1, which was only 40 ft away.

5.9.2 Current Status

5.9.2.1 Hydraulic Fracturing Containment Experiments

The exploratory coring program for the delineation of the Hole No. 6 fractures continued in July with the completion of two additional holes. Corehole EV6-25 failed to detect grout at approximately 110 ft below the interface but green grout was located in EV6-26 approximately 60 ft below the interface (Figure 5-8). A significant portion of the grout was forced downward (possibly due to the high density of the grout), but the defined limits of the fractures still account for only about 6,000 to 14,000 gal grout. Further coring will be directed towards determining the upper boundary of the fracture.

Mineback of the four remaining fracture zones of CFE-2 of the Interface Test Series was completed in July. There were no mechanical difficulties and the correct volume of fluid was pumped into each zone, yet the created fractures in all six zones of this hole were only about 5 percent of their expected size. None of these fractures propagated more than 2 ft from the borehole so they never interacted with the interface (5-8 ft away). The small size of the fractures is probably due to a much higher permeability in this region than found elsewhere in the G tunnel.

Nevertheless, the results from CFE-2 were useful for defining the stress state near the interface. Figure 5-9 shows the minimum *in situ* stress increases rapidly a few feet below the interface, reaches a peak value about 3-4 times greater than the average stress in this area and then decreases. The location of the peak as determined from CFE-2 data corresponds with the location where CFE-1 fractures terminated their downward growth (4-6 ft below the interface). This demonstrates that *in situ* stress changes can act as barriers to fracture growth.

A third hole (CFE-3) is now being drilled and another set of experiments will be conducted in August to further define the *in situ* stress state and determine fracture behavior as a reaction to that stress state.

A number of thin sections intersecting the Hole No. 6 fractures have been made to observe sand embedment in hydraulic fractures. These fractures were propagated three years ago and show that a significant portion of the individual grains can be embedded, with the result that fracture conductivity is reduced considerably. It should be noted that the rock medium (ash-fall tuff) is considerably softer than most reservoir rocks.

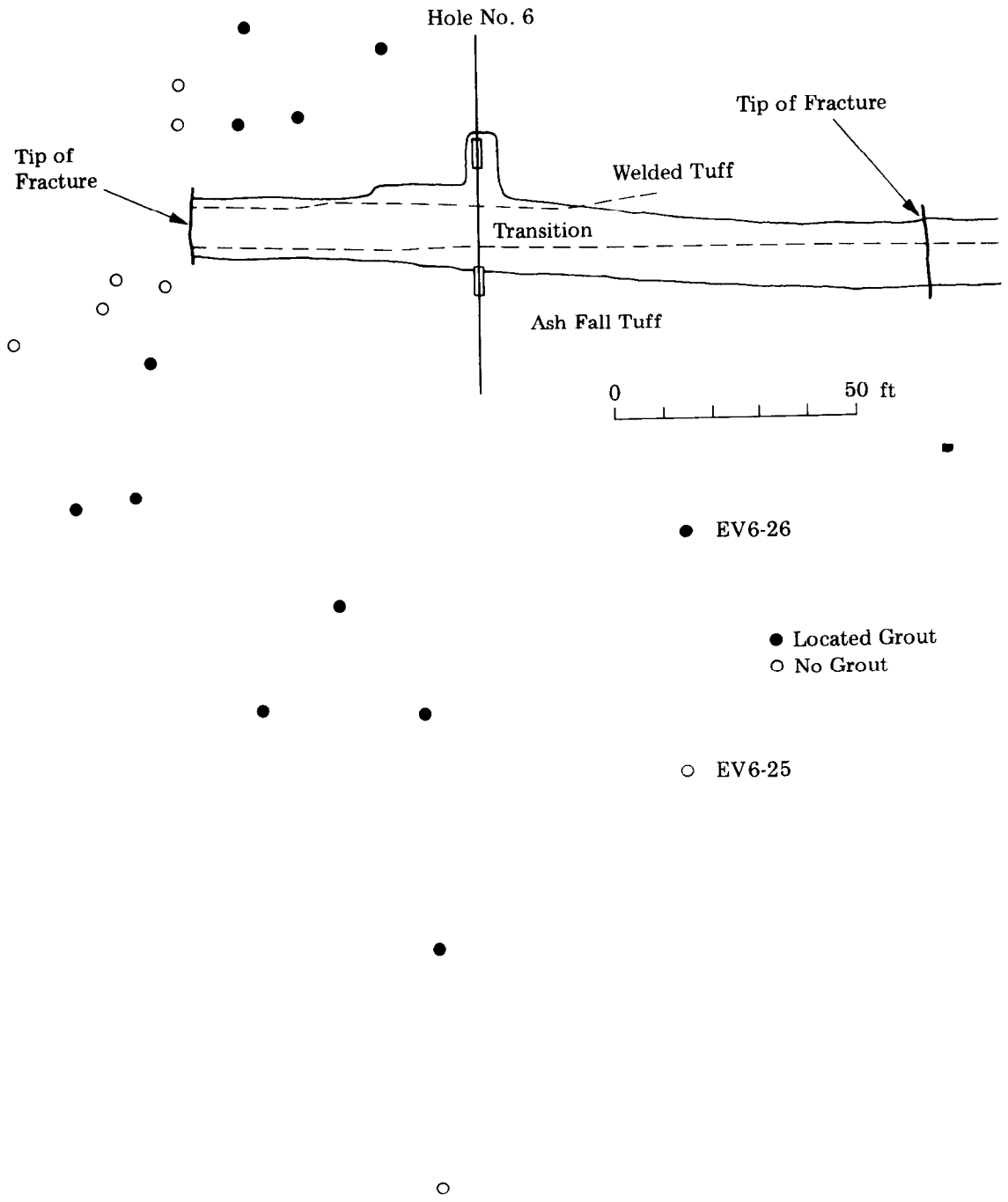


Figure 5-8 Results of Exploratory Coring Hole No. 6 Experiment

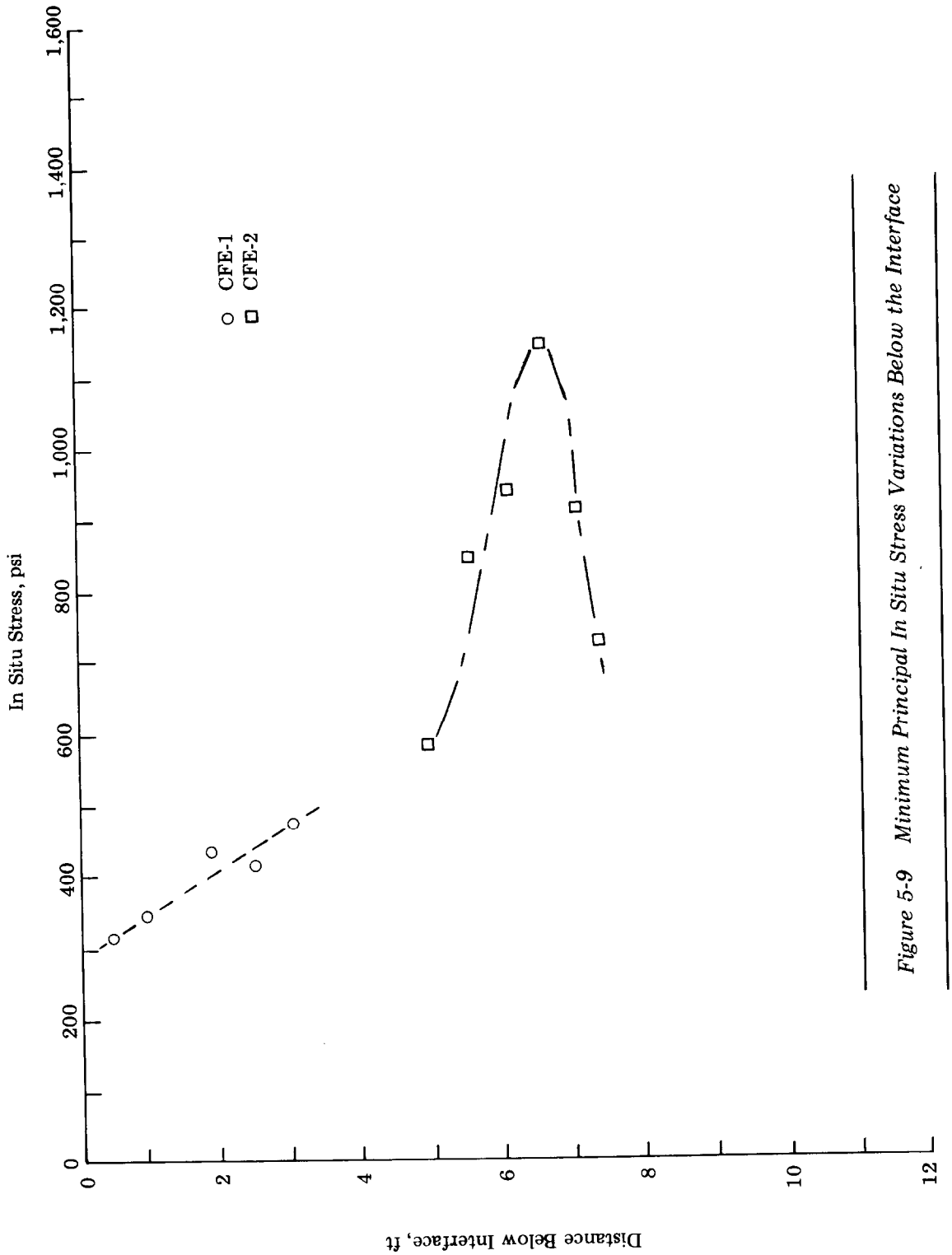


Figure 5-9 Minimum Principal In Situ Stress Variations Below the Interface

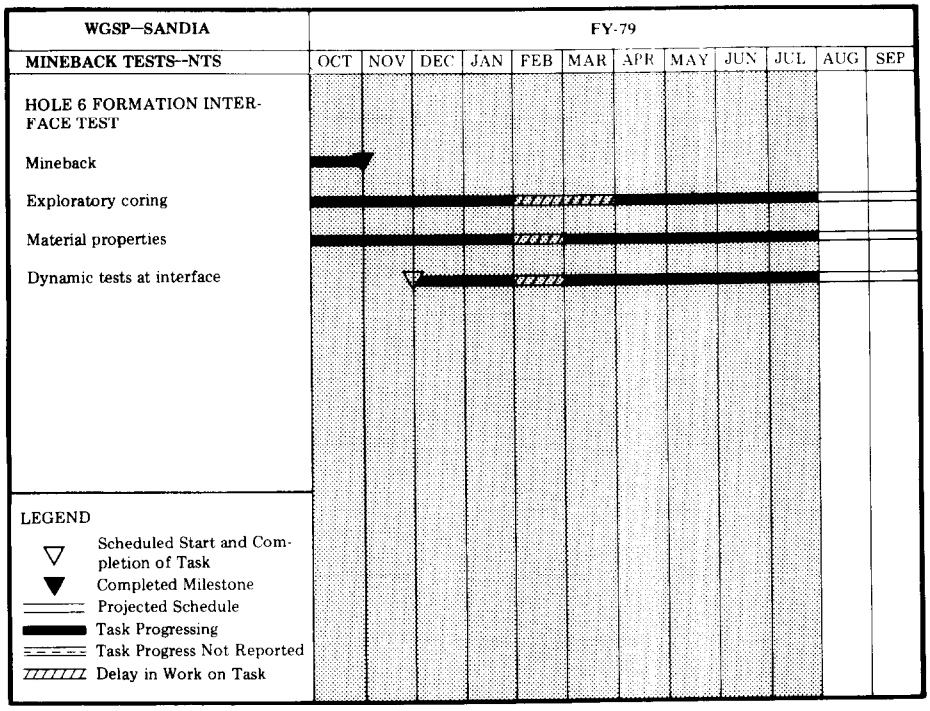
5.9.2.2 Multi-Well Experiment

The objectives of the multi-well experiment are to obtain comprehensive geologic characterizations of representative, and particularly lenticular, low permeability reservoirs in the western United States and to evaluate state-of-the-art and developing technology for the recovery of gas from these reservoirs.

Initially, the sites being considered for the multi-well experiment were located southwest of the Piceance Creek Dome Field, near the Rio Blanco MHF 3 well. This area has a representative Wasatch-Mesaverde section with good gas potential as well as both wet sands and tight zones. Furthermore, previous experiments have been carried out in the area and the area is better understood than most. During July, CER Corporation personnel obtained logs and other data in order to evaluate the locations under consideration.

5.9.3 Schedule Status

Figure 5-10 is a milestone chart of Sandia mineback progress.



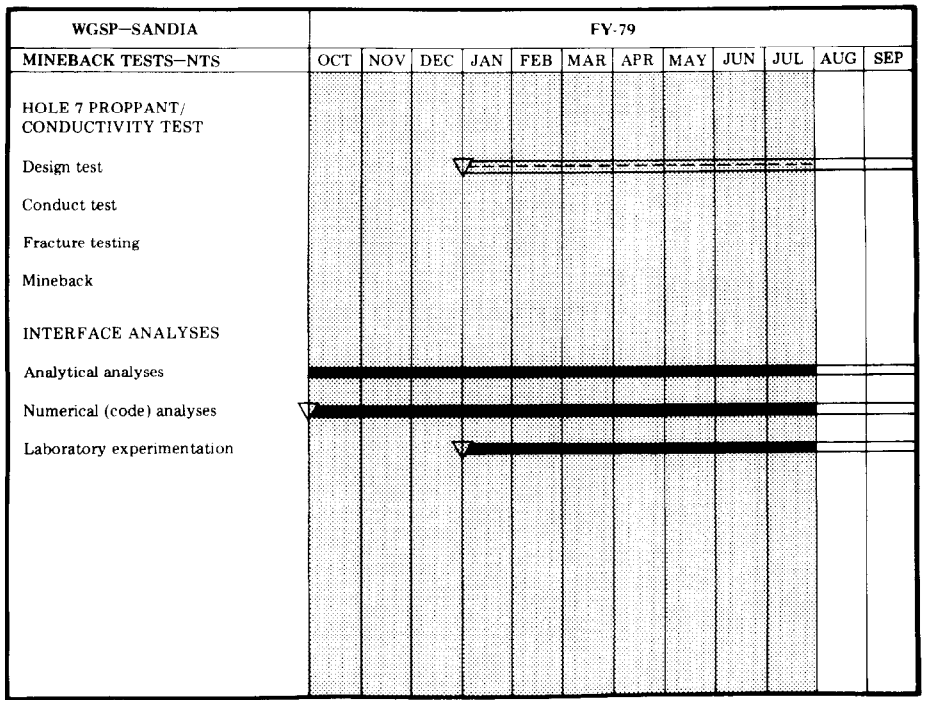


Figure 5-10 Milestone Chart — Sandia Mineback