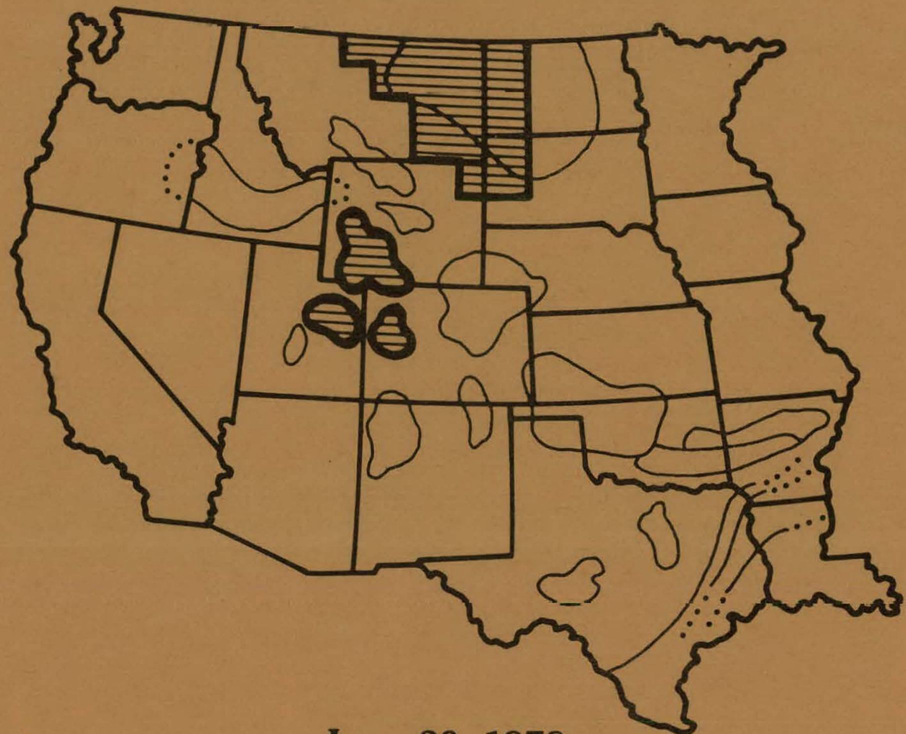
NVO/0655-109

Western Gas Sands Project
Status Report



June 30, 1978

Prepared for
U.S. Department of Energy

Bartlesville Energy Research Center
Charles H. Atkinson
Project Manager

Compiled by CER Corporation
Las Vegas, Nevada

Contract EY-76-C-08-0655

Available from the National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia 22161.

NATIONAL TECHNICAL INFORMATION SERVICE PAPER COPY PRICES
EFFECTIVE JAN. 1, 1976

Page range	Domestic price	Page range	Domestic price	Page range	Domestic price	Page range	Domestic price	Page range	Domestic price	Page range	Domestic price
001-025	$3.50	126-150	$6.00	251-275	$ 9.00	376-400	$10.75	501-525	$12.75	701- 800	$18.75
026-050	$4.00	151-175	$6.75	276-300	$ 9.25	401-425	$11.00	526-550	$13.00	801- 900	$21.25
051-075	$4.50	176-200	$7.50	301-325	$ 9.75	426-450	$11.75	551-575	$13.50	901-1000	$23.75
076-100	$5.00	201-225	$7.75	326-350	$10.00	451-475	$12.00	576-600	$13.75	1001-1100	$28.25
101-125	$5.50	226-250	$8.00	351-375	$10.50	476-500	$12.50	601-700	$16.25	1101-1200	$32.75

For additional pages, add $4.50 for each beginning 100 pages. Add $2.50 per copy for foreign price.

Microfiche $3.00 (domestic) $4.50 (foreign).

CONTENTS

FIGURES

TABLES

1. SUMMARY

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

The Department of Energy's (DOE) Nevada Operations Office (NVO), is finalizing a Request for Proposal (RFP) covering Technical and Administrative Support for the Project Manager for FY79.*

C.H. Atkinson, the Western Gas Sands Project (WGSP) Manager, was an observer of the third MHF treatment of Mobil Research and Development Corporation's well No. F-31-136. The fracture was performed on May 10, 1978.

R.L. Mann of CER Corporation, met with Dr. Steve Holditch of Texas A&M University to discuss the utilization of the PDP 11/10 computer to be installed in the Mobile Well Test Facility.

The second Quarterly Basin Activity Report, April 1, 1978 has been released and includes the new U.S. Geological Survey (USGS) core sites for each primary study area. The Project Plan Document FY79, Logging Program, and the Status Report - Financial Supplement, April 1, 1978 are being drafted.

The USGS is continuing geological and geophysical studies in the four primary study areas. Two flights were made in preparation for low-level oblique photography.

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.

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

---

* RFP issued July 14, 1978
** Spudded July 8, 1978.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

2. PROJECT MANAGEMENT

2.1 Technical Monitoring and Evaluation

C.H. Atkinson, DOE, was an observer at the May 10, 1978 MHF treatment of Mobil Research and Development Corporation's well No. F-31-13G. The treatment was performed on Zone 5,(8,765 to 8,972 ft).

The DOE Nevada Operations Office is finalizing an RFP covering WGSP Technical and Administrative Support for the Project Manager FY79.

Seven scopes of work for future WGSP RFPs for DOE/Industry field tests were drafted.

2.2 Technology Transfer

2.2.1 Documentation and Reports

The second Quarterly Basin Activity Report, April 1, 1978 covering the months of January, February and March, 1978, has been released. The Project Plan Document FY79, the Log Program, and the Status Report - Financial Supplement, April 1, 1978, are being drafted.

Two draft reports were reviewed during May by C.H. Atkinson and R.L. Mann. Comments on the first report, the Western Gas Sands Strategic Plan, by Booz, Allen and Hamilton were forwarded to Booz, Allen and also to D. Ward, DOE/HQ in Washington, D.C. The second report, Continuity and Permeability Development In the Tight Gas Sands of the Eastern Uinta Basin, Utah, by C.F. Knutson and C.R. Boardman of C.K. GeoEnergy Corporation, Las Vegas, Nevada, has been approved for publication.

The following papers have been submitted by CER Corporation personnel to the Fourth Annual Department of Energy Symposium on Enhanced Oil and Gas Recovery and Improved Drilling Methods. The symposium is to be held in Tulsa, Oklahoma August 29-31, 1978.

C.R. Appledorn, G.R. Luetkehans, and C.H. Atkinson, The Western Gas Sands Project.

G.C. Kukal, Log Evaluation of Compacted Shaly Sands of the Mesaverde Group, Uinta Basin, Utah.

H.E. Newman,III, R.L. Mann, and C.H. Atkinson, Western Gas Sands Coring Program.

The USGS has submitted a manuscript to DOE for the Tulsa symposium, The Relationship Between Facies in Low-Permeability (Plate) Reservoirs in the Northern Great Plains, by D.D. Rice.

Lawrence Livermore Laboratory (LLL) personnel presented two papers at the 19th U.S. Symposium on Rock Mechanics at Lake Tahoe, Nevada and prepared a paper for presentation at the Petroleum Division of the ASME Meeting at Houston, Texas in November, 1978.

2.2.2 Project Data Bank

Logs (film copies) on Gas Producing Enterprises Natural Buttes Well CIGE 21 were received at CER's Las Vegas Offices. Copies will be distributed to project participants in June.

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 geological studies for resource assessment. 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

The following information was originally published in the USGS Oil and Gas Resource Investigations Program, December, 1977 USGS Open-File Report 78-303, 1978.

> With the increased demand and the expectation of increased prices for natural gas, exploration in the Rocky Mountain region and elsewhere is being partially redirected toward "tight gas sands." Preliminary in-place resource estimates for these tight Cretaceous and Tertiary gas sands in the Rocky Mountain region are very large, and estimates by groups such as the Federal Energy Regulatory Commission range as high as 730 trillion cu ft (Tcf) of natural gas. The Resource Appraisal Group did not estimate resources in tight reservoirs in the recently published U.S. Geological Survey Circular 725 because basic geologic knowledge of these resources was considered insufficient to determine limitations on such resources (Miller and others, 1975). "Tight gas sands" are siltstone and sandstone reservoirs predominantly of continental sedimentary origin which contain significant resources of natural gas, but have been subeconomic in the past because of low permeabilities and low gas prices. Low reservoir permeability has resulted in low recovery volumes on an individual well basis, using existing technology. To date, most studies have been directed toward recovery technology. The objective of this study is to characterize these tight gas-bearing stratigraphic units and to identify areas which appear to be most favorable geologically for future gas extraction. This geological knowledge can be combined then with geophysical and petrophysical studies, including research on stimulation techniques by DOE, to guide present and future recovery research and to obtain an accurate assessment of recoverable gas resources.
>
> The areas of study include the Greater Green River, Sand Wash, Uinta, and Piceance Basins and the Northern Great Plains. The program is divided into two phases: (1) a one-year reconnaissance phase which commenced October 1, 1976, which includes computer processing of well information, core processing and study, construction of regional cross section net works using borehole logs and outcrop sections, petrography, and compilation of regional stratigraphic data; and (2) a four-year comprehensive geological characterization and resource assessment phase.

It is important to note that a major long-range effort is required to characterize these resources. Although these units have been penetrated by drilling and the existence of free gas established, efforts to develop these resources have not been successful. As a result, little development work has been done and the resource estimates that are now available are those based on extrapolations of data from widely scattered wells. In that sense, exploration for accumulations of gas in tight sands is at an early stage and there is a low level of understanding of the geologic and engineering characteristics of these reservoirs. However, because of the implied magnitude of the resource potential of tight sands, and its importance to the national energy supply picture, we must develop the data from which reliable estimates of the magnitude of this resource and the cost of its availability can be determined.

3.1.1 Greater Green River Basin

Two flights were made in preparation for low-level oblique photography of sandstone outcrops for a Sandstone Geometry and Fracture Pattern Study. A USGS T-41 aircraft equipped for low-level remote sensing will be used this summer in the Greater Green River Basin, and if successful, will be used in other areas.

Drill Stem Test (DST) potentiometric surface data were plotted for Tertiary and Cretaceous formations in the Greater Green River Basin. Field work is underway on Tertiary rocks in the Sand Wash Basin.

Work continued on the compilation of log cross section data and two additional cross sections in the Washakie Basin are being drafted.

3.1.2 Northern Great Plains Province

Additional enhanced LANDSAT photos were received from the USGS EROS Data Center, and will be used for a refined lineament and fracture study.

Several cores were acquired and are being described and sampled.

The 1978 field work program has been started.

3.1.3 Piceance Basin—Uinta Basin

Field work was conducted on the Maestrichtian, Campanian and Paleocene units in southeast Piceance Basin. These beds are equivalent to producing units in the central part of the basin.

Core from the Upper Cretaceous and Lower Tertiary units was examined after being obtained from Exxon Corporation drill holes in southeast Uinta Basin.

An x-ray diffraction analysis was completed on the clay fraction of core taken from the Pariette Bench Field near Vernal, Utah. A manuscript presenting results of investigations of reservoir characteristics in the vicinity of this field is in preparation.

3.1.4 Schedule Status

A milestone chart of the USGS activities is shown on Figure 3-1, and includes status through May 31, 1978.

3.2 Core Program

Two proposals have been received from Montana operators for core acquisition. Initial contacts were made by N. Newman of CER Corporation.

3.3 Log Program

A vital part of the resource assessment and reservoir analysis work in evaluating the potential for gas production from the western basins is the Log Program.

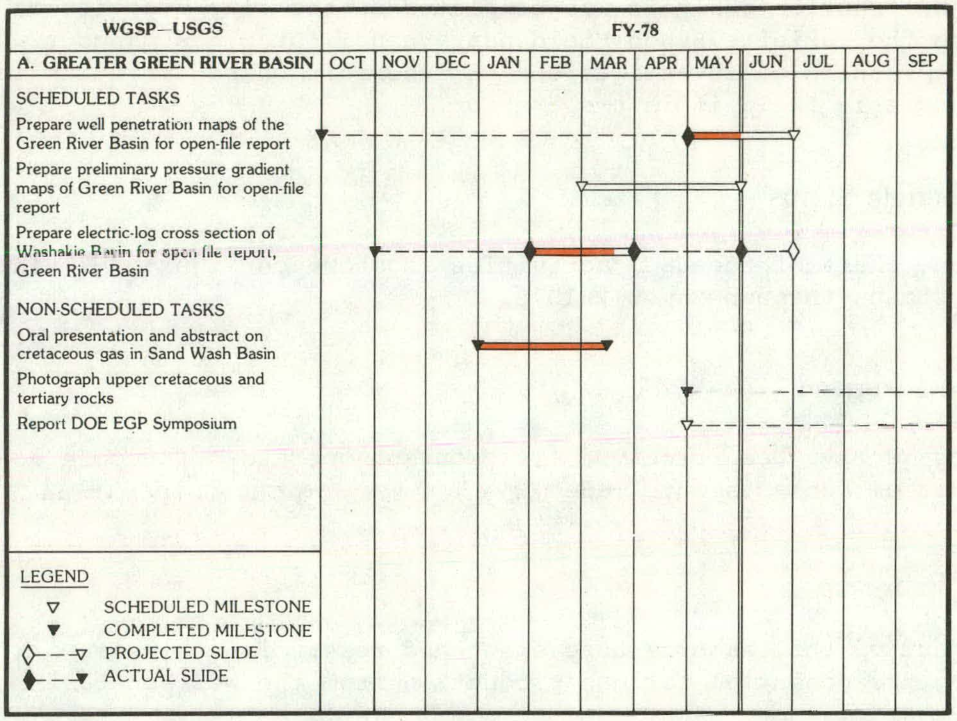
A document is being prepared to define and assist in the implementation of this program. The "Draft for Comment" will be distributed to WGSP participants in preparation for a coordination meeting. A Log Quality Control Checklist is being developed and will be included in the document.

3.4 Study of Basin Activities

Monitoring continues of drilling and testing activities in the four primary study areas, indicated in Figures 3-2 through 3-6. These figures show recent wells of significance to the WGSP and the new USGS core areas. Background information on these core areas is given in the WGSP Quarterly Basin Activities Report, April 1, 1978, NVO/0655-05.

3.4.1 Greater Green River Basin

Natural gas in the Greater Green River Basin is produced predominantly from Upper Cretaceous Sands utilizing fracture treatments to enhance recovery. Blue Gap Field in Carbon County, Nitchie Gulch and Hay Reservoir Fields in Sweetwater County and Tip Top, Figure Four Canyon and Fontenelle Fields in Lincoln and Sublette Counties all have one or more wells on production in zones of interest to the WGSP.



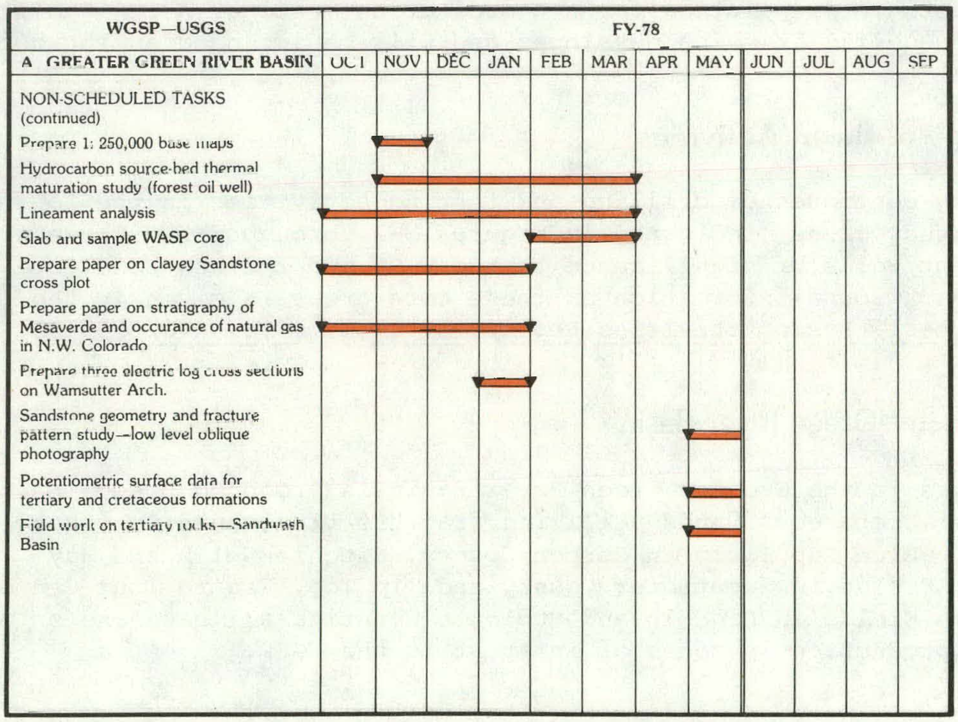
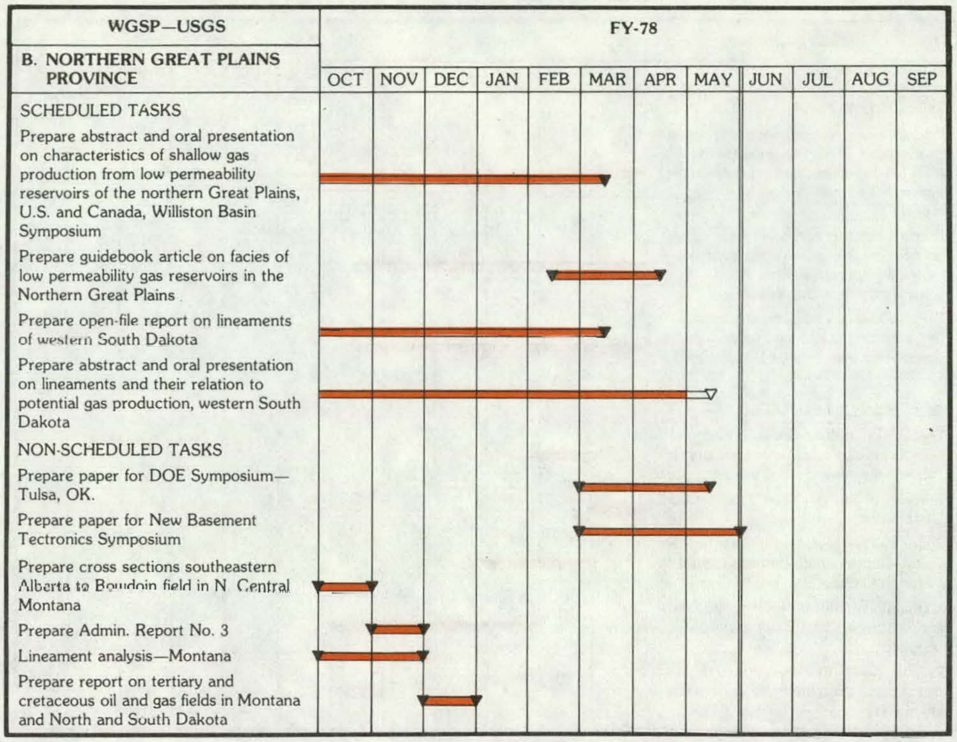


Figure 3-1 Milestone Chart — USGS



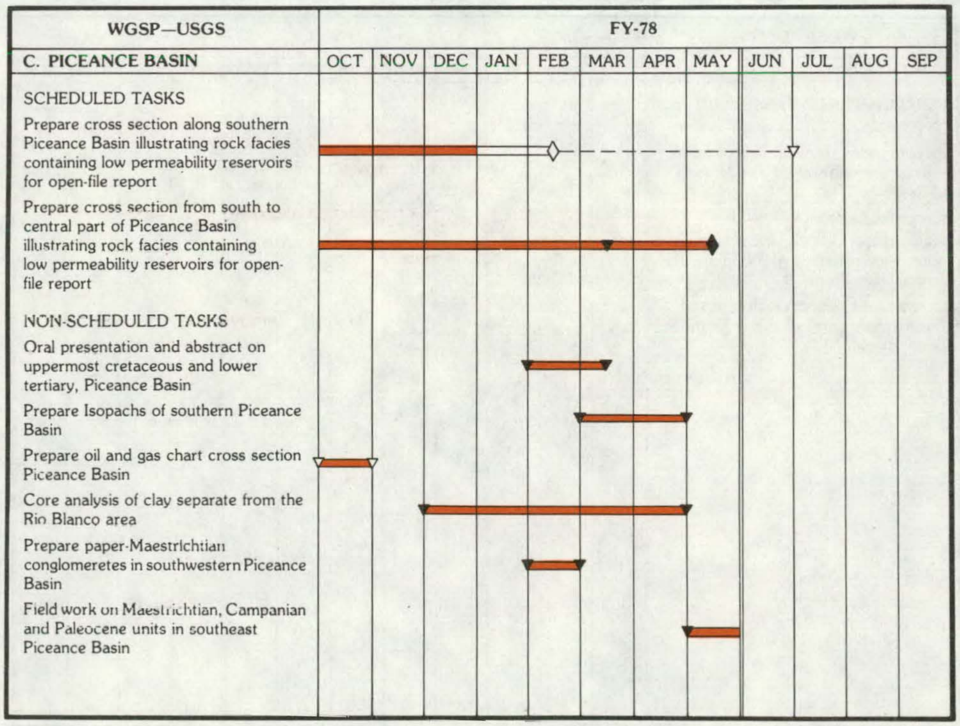
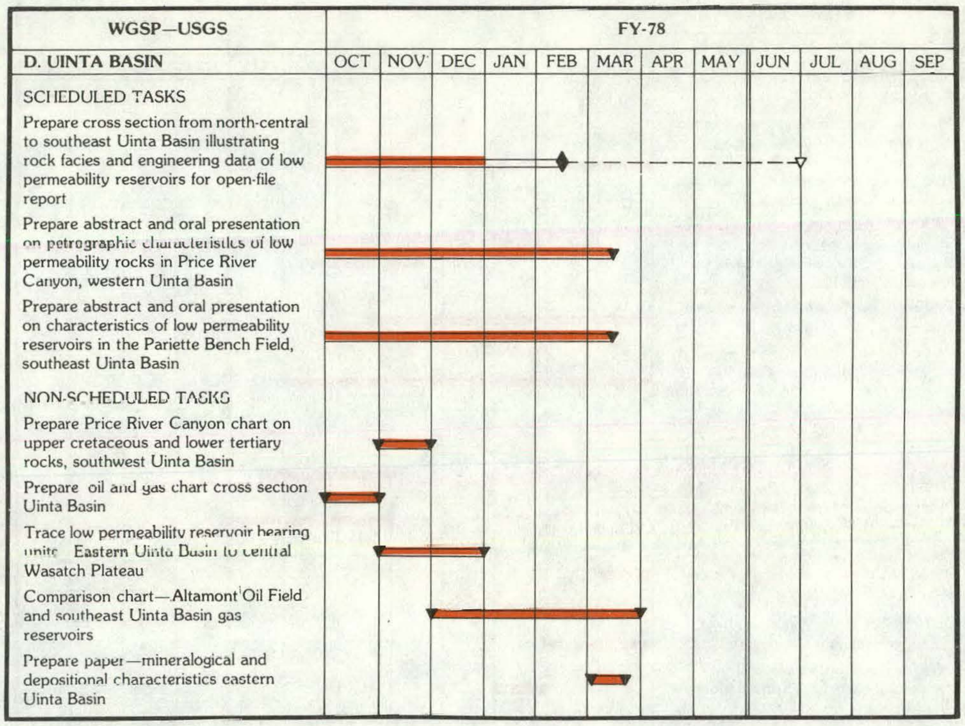


Figure 3-1 Continued



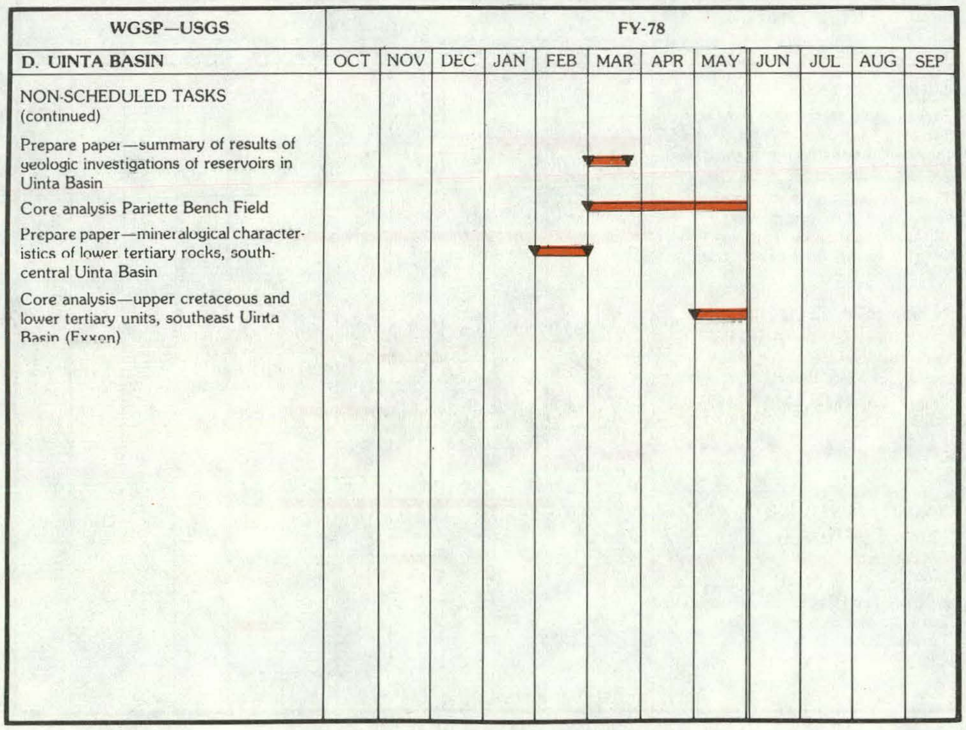


Figure 3-1 Continued

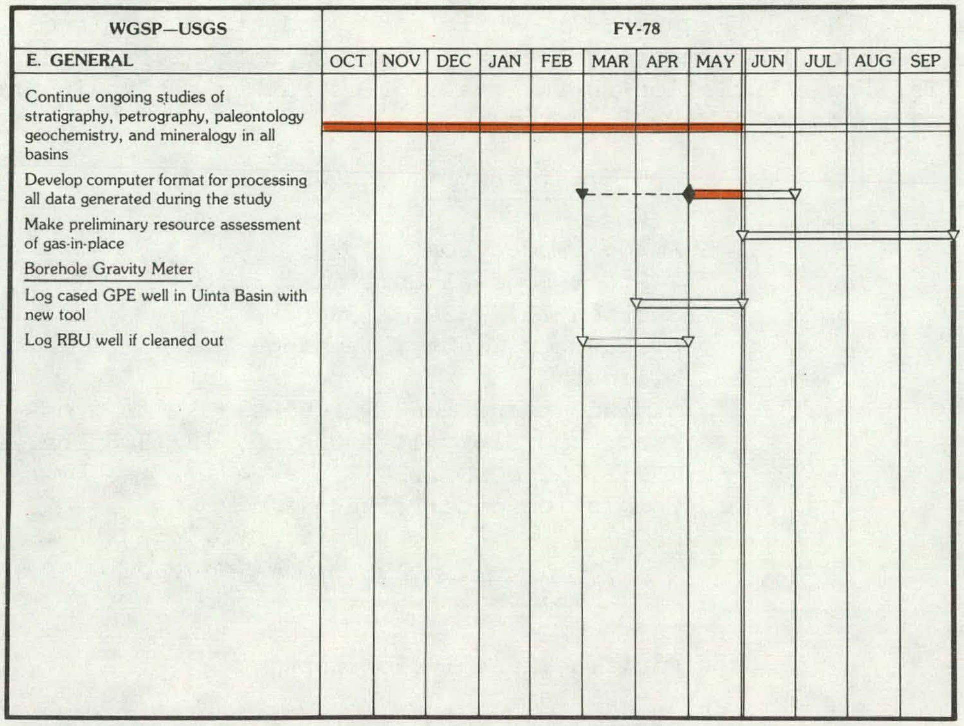


Figure 3-1 Continued

The Mesaverde Group is the major objective in Sweetwater and Carbon Counties (Well No. 1, Figure 3-2), while most production in Lincoln and Sublette Counties is from the deeper Frontier and Bear River Zones (Well No. 2). The Lewis Formation is the goal for operators active in Moffat County, Colorado (Well No. 3).

Well No. 1

Amoco Production
1 Stock Pond WI Unit
Section 11, T22N, R95W
Sweetwater County, Wyoming
Wildcat
Almond production (10,765-11,034 ft gross)
Frac: 98,910 gal. emulsion, 138,308 lbs. sand
IPF: 552 MCFD, 3BC
Completion date: 5-23-78

Well No. 2

Pacific Transmission Supply
24-36 State
Section 35, T26N, R112W
Lincoln County, Wyoming
Fontenelle Field
2nd Frontier production (8,388-8,481 ft gross)
Frac: 456,000 gal. emulsion, 900,000 lbs sand
IPF: 1,000 MCFD
Development gas well
Completion date: 5-25-78

Well No. 3

Northwest Exploration
1 Weaver
Section 9, T9N, R93W
Moffat County, Colorado
Unnamed field
Lewis production (7,306-7,541 ft gross)
Frac: 75,480 gal. emulsion, 160,000 lbs sand
IPF: 2,300 MCFD
New field discovery
Completion date: 5-18-78

A significant amount of new development is located in eastern Sweetwater County and western Carbon County. The objective is the Mesaverde and companies with new well sites are Sinclair Oil, Colorado Interstate Gas, Smokey Oil, Amoco Production, Mobil Oil, Davis Oil and Equity Oil (Wells No. 4 and 5, Figure 3-2).

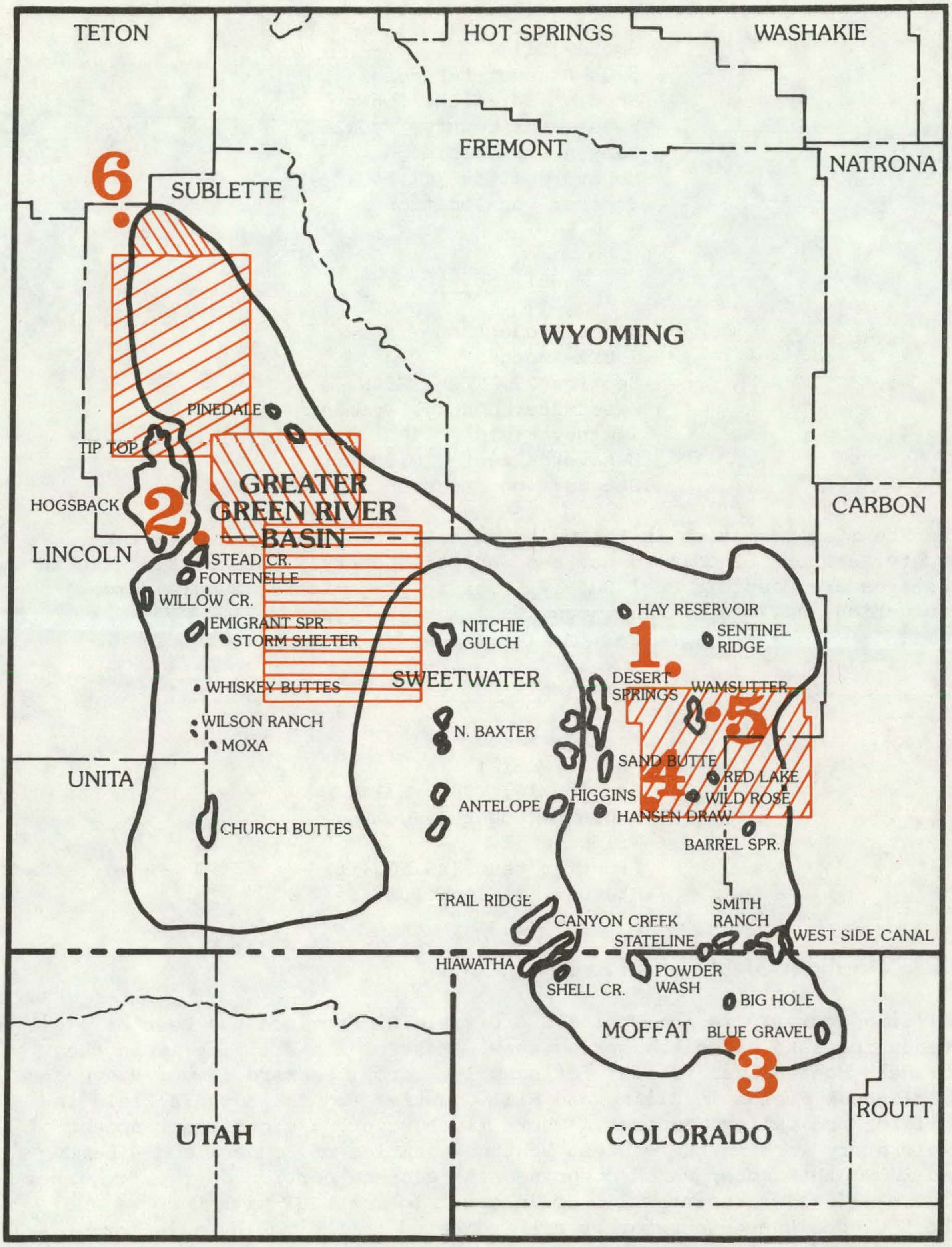


Figure 3-2 Greater Green River Basin Showing Wells of Interest and USGS Designated Core Areas

Well No. 4

Smokey Oil
2-34 Bluewater-Federal
Section 34, T18N, R96W
Sweetwater County, Wyoming
Hansen Draw Field
Mesaverde test (12,500 ft)
Status: on location

Well No. 5

Amoco Production
1 USA-Amoco-S
Section 22, T20N, R94W
Sweetwater County, Wyoming
Tierney Field
Mesaverde test (10,330 ft)
Status: on location

The Frontier Formation is the major objective in western Sweetwater County, eastern Lincoln County and Sublette County. Companies active in the area are Mountain Fuel Supply, Pacific Transmission Supply, Amoco Production and Rainbow Resources (Well No. 6, Figure 3-2).

Well No. 6

Rainbow Resources
32-10 Federal
Section 10, T38N, R114W
Sublette County, Wyoming
Wildcat
Frontier test (16,800 ft)
Status: on location

3.4.2 Northern Great Plains Province

Drilling activity in the Northern Great Plains Province has been on a steady increase since the spring thaw. Most of the activity is in the northern Montana gas fields; for example, Leroy, Sherard, Tiger Ridge and Battlecreek Fields in Blaine and Hill Counties and the Bowdoin Field in Phillips and Valley Counties. There is, however, a significant amount of exploratory work in the western Montana counties of Pondera and Liberty and in South Dakota, which comprises the eastern portion of the Province. Figure 3-3 shows recent wells of interest to the WGSP with numbers and the USGS designated core areas are indicated on the map by a letter.

Falcon-Colorado Exploration has staked 10 Phillips tests in the Swanson Creek Field. Seven of the locations are in Phillips County and three are in Valley County. Presently there are four producing wells in the field and cummulative production is about 140 million cubic feet of gas (Well No. 1, Figures 3-3 and 3-4).

Well No. 1

Falcon-Colorado Exploration
1-1 Mavencamp
Section 1, T32N, R34E
Phillips County, Montana
Swanson Creek Field
Phillips test (1,800 ft)
Status: on location

Fuel Resources Development has resumed operations on their Leroy Field development program. They have nine wells scheduled on the Blaine County-Fergus County line, to test the Eagle zone. This development adds new significance to the south flank of the Bearpaw Arch and its progress will be monitored accordingly (Well No. 2, Figure 3-3). Other operators in the area include J. Burns Brown, Midlands Gas, Kissinger Petroleum, Xeno, Inc., Montana Power, and Tricentrol United States.

Well No. 2

Fuel Resources Development
22-24-19-B Federal
Section 22, T24N, R19E
Blaine County, Montana
Leroy Field
Eagle test (1,758 ft)
Status: on location

Parts of North and South Dakota make up the eastern boundary of the Northern Great Plains Province. Montana Dakota Utilities has four Niobrara tests staked in Haakon and Stanley Counties, South Dakota. These wells are located in the southern-most part of the Williston Basin and will be monitored for possible application to the WGSP (Well No. 3, Figure 3-3).

Well No. 3

Montana Dakota Utilities
32X-10 Ferguson
Section 10, T5N, R21E
Haakon County, South Dakota
Wildcat
Niobrara test (1,560 ft)
Status: on location

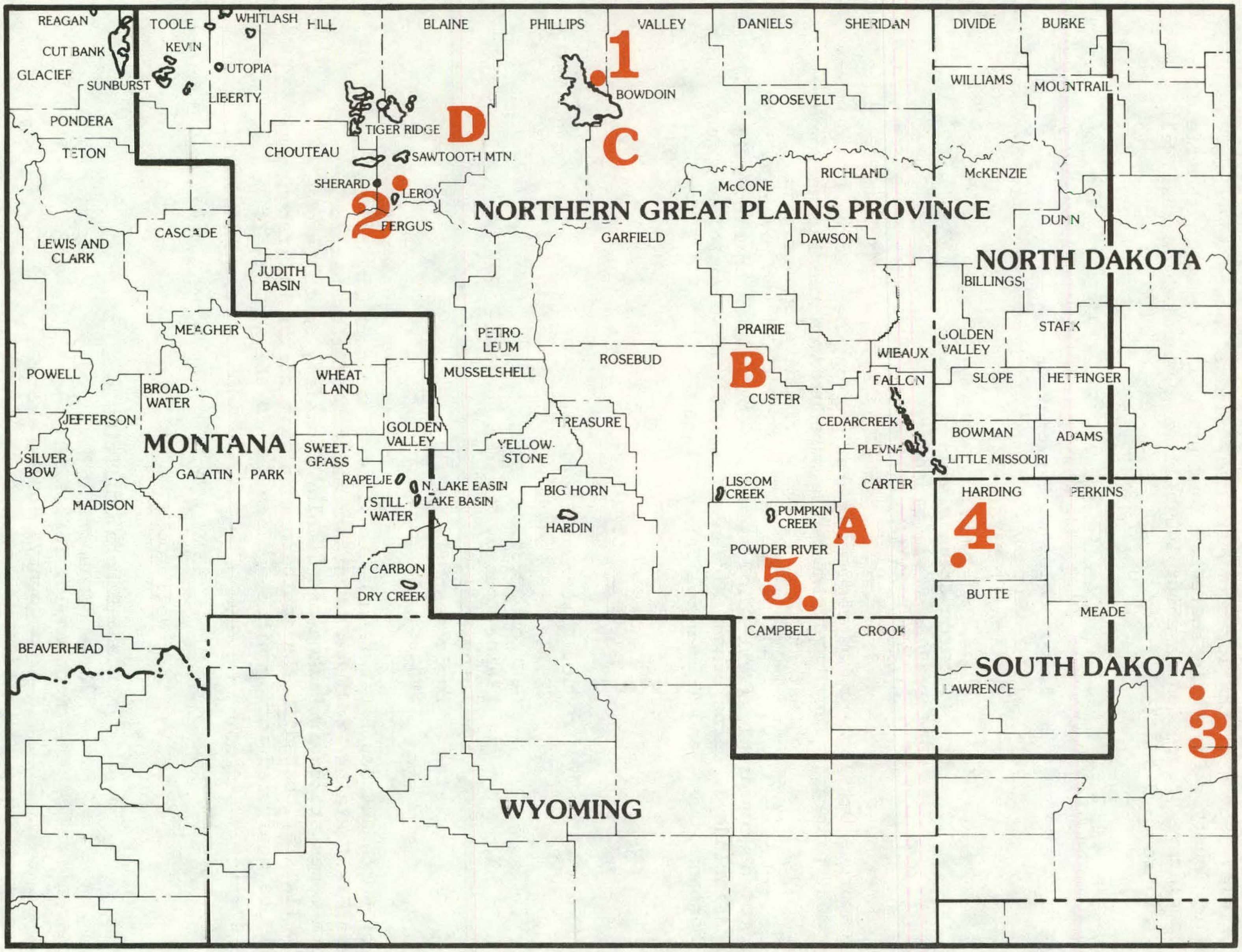


Figure 3-3 Northern Great Plains Province Showing Wells of Interest and USGS Designated Core Areas

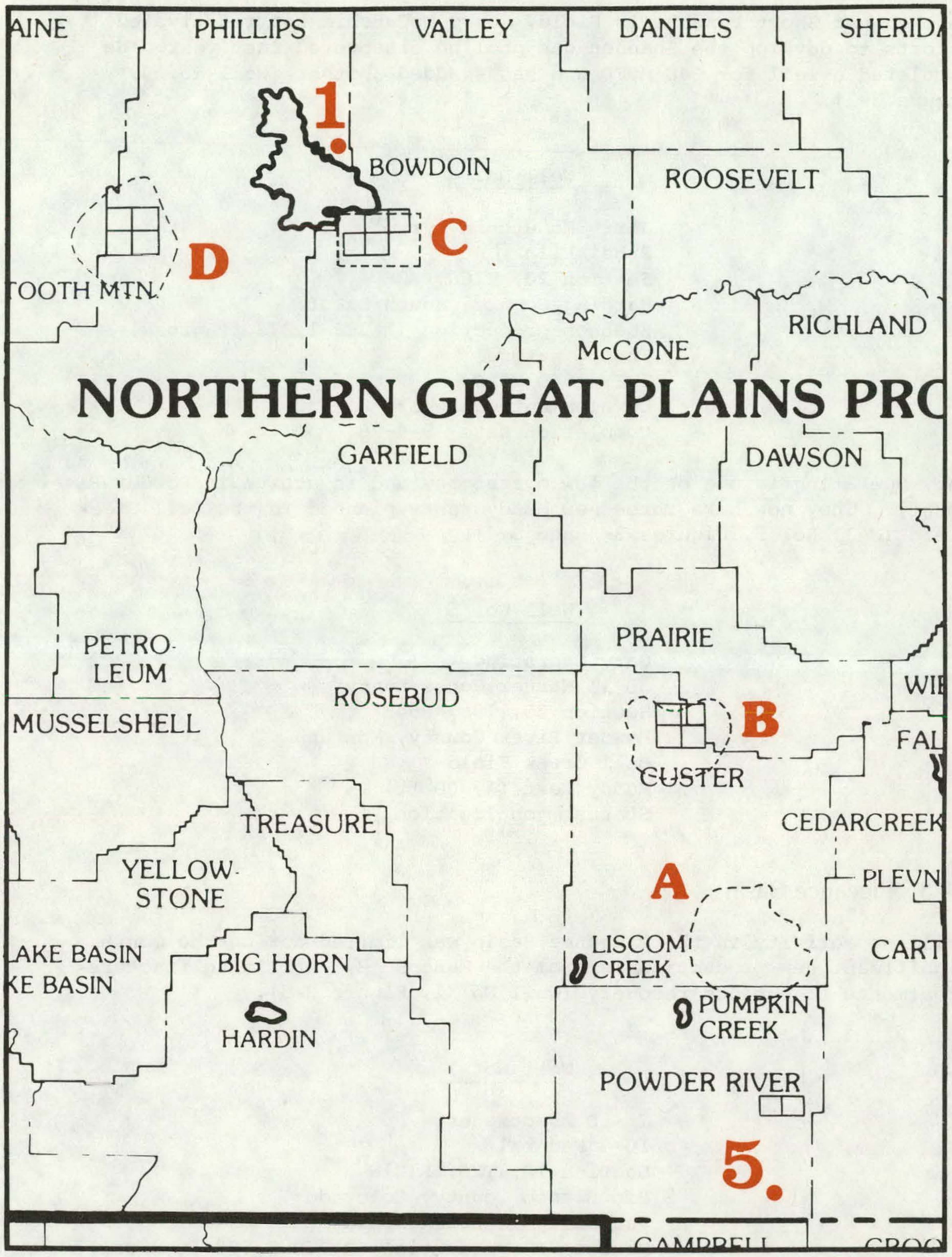


Figure 3-4 Detail of USGS Designated Core Areas and Wells of Interest, Northern Great Plains Province

In the West Short Pine Hills Field, Jerry McCutchin has reactivated efforts to develop the Shannon gas pool he discovered last year. He completed a well for 640 MCFD and has spudded another (Well No. 4, Figure 3-3).

Well No. 4

Jerry McCutchin, Jr.
2 Heikkila
Section 20, T16N, R2E
Harding County, South Dakota
Shannon production (1,368-1,373 ft gross)
Frac: natural
IPF: 640 MCFD
Development gas well
Completion date: 5-4-78

Gary Operating is one of the few operators, and is active in Powder River County. They now have three new Muddy tests planned in the Bell Creek Field (Well No. 5, Figures 3-3 and 3-4).

Well No. 5

Gary Operating
30-11 Warner-Jones-Bandy
Section 30, T9S, R54E
Powder River County, Montana
Bell Creek Field
Muddy test (4,300 ft)
Status: on location

3.4.3 Piceance Basin

Drilling activity in the Piceance Basin was limited during the month. Significant new production is from the Mancos "B," utilizing fracture treatments to enhance recovery (Well No. 1, Figure 3-5).

Well No. 1

J & D Associates
10-4 Federal
Section 10, T2S, R101W
Rio Blanco County, Colorado
Philadelphia Creek Field
Mancos "B" production (2,270-2,582 ft gross)
Frac: 84,000 gal. water, 162,500 lbs sand
IPF: 1,986 MCFD
Development gas well
Completion date: 5-4-78

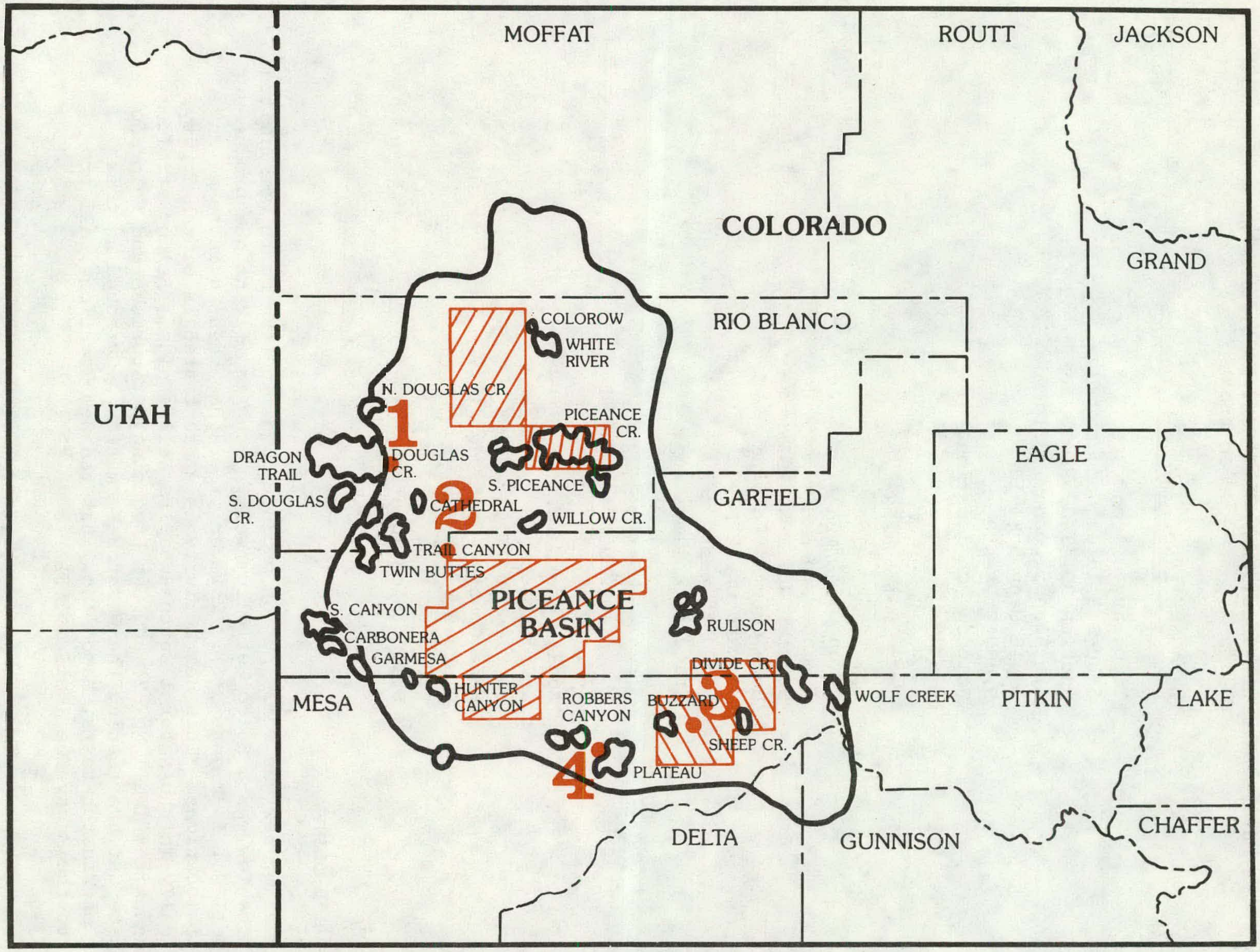


Figure 3-5 Piceance Basin Showing Wells of Interest and USGS Core Areas

New development is being monitored closely for possible inclusion in the WGSP Core Program. Tipperary Oil and Gas, Union Oil of California and Adolph Coors have staked new locations (Well Nos. 2, 3, and 4).

Well No. 2

Tipperary Oil and Gas
6-30-D Soldier Canyon Unit
Section 30, T4S, R100W
Rio Blanco County, Colorado
Trail Canyon Field
9,400 Ft test
Status: on location

Well No. 3

Union Oil of California
1 Gunderson
Section 20, T9S, R93W
Mesa County, Colorado
Buzzard Creek Field
8,200 ft test
Status: on location

Well No. 4

Adolph Coors Co.
1-19 Fetters
Section 19, T10S, R96W
Mesa County, Colorado
Plateau Field
3,200 ft test
Status: on location

3.4.4 Uinta Basin

The number of new gas wells put on production during the month was limited. One of the few was a Belco Petroleum well, with significant gas production (Well No. 1, Figure 3-6). However, there has been an increase in new well locations. This new activity is concentrated in Uintah County, specifically in the Natural Buttes-Chapita Wells Units. Belco Petroleum has 6 new sites (Well No. 2) and Gas Producing Enterprises and Colorado Interstate Gas are testing the Wasatch Formation. Surrounding this cluster of Wasatch tests, Mapco Inc., has ten new locations, all projected to the Mesaverde (Well No. 3).

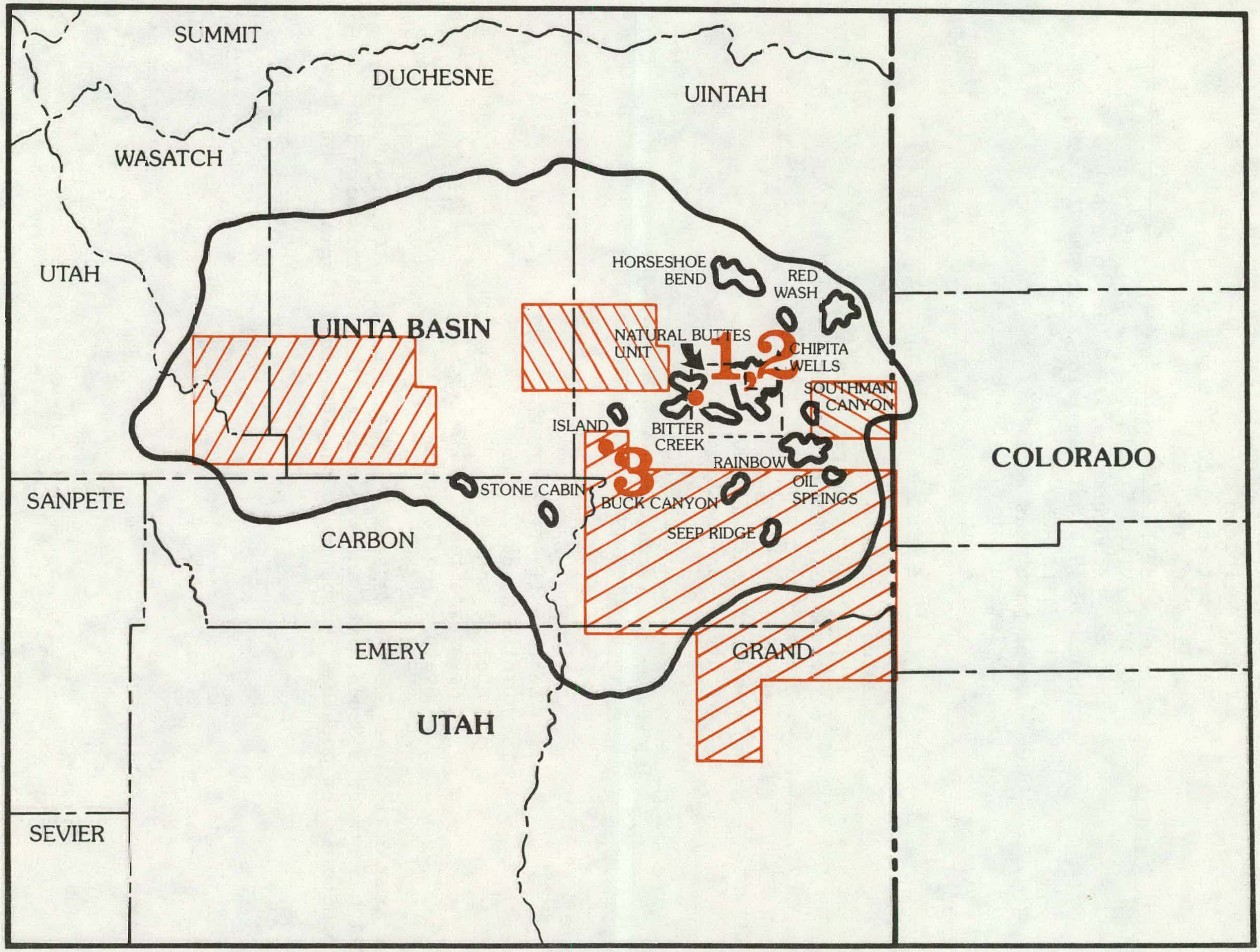


Figure 3-6 Uinta Basin Showing Wells of Interest and USGS Designated Core Areas

Well No. 1

Belco Petroleum
21-20B Natural Buttes Unit
Section 20, T9S, R20E
Uintah County, Utah
Natural Buttes Field
Wasatch production (6,092-6,916 ft gross)
Frac: 82,317 gal. emulsion, 212,000 lbs sand
IPF: 5,863 MCFD
Development gas well
Completion date: 5-25-78

Well No. 2

Belco Petroleum
37-13B Natural Buttes Unit
Section 13, T9S, R20E
Uintah County, Utah
Natural Buttes Field
Washatch test (7,400 ft)
Status: on location

Well No. 3

Mapco, Inc.
5-11D RBU
Section 11, T10S, R18E
Uintah County, Utah
Uteland Butte
Mesaverde test (8,455 ft)
Status: on location

Another area of interest to the WGSP is located in Duchesne County, where Gulf Oil has staked a Green River and two Wasatch tests. This area is being monitored for possible inclusion in the WGSP Core Program.

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

4.1 Bartlesville Energy Research Center

4.1.1 Improved Pressure Coring System

4.1.1.1 Core Retriever Design

The detailed design drawings are progressing on schedule, and a model of the ball valve with its actuating mechanism is currently being prepared for an industry review meeting. Mud pressure acting on hydraulic fluid is now utilized to rotate the valve.

4.1.1.2 Coring Fluid Selection

Invasion tests were conducted using Dow Corning 200 Silicon fluid (60,000 cs.) with a wettability modifier number Q1-3563. The intent is to change the wettability or surface tension of the coring fluid so that a lower viscosity fluid may be used while still maintaining invasion protection. Penetration was 2 cm. at 350 psig overbalance for five hours. This is greater than that observed for unmodified DC 200 (60,000 cs.). It has since been discovered that Dow Corning mailed the wrong additive and an actual reduction in viscosity had occurred upon mixing. The correct additive should arrive soon for further testing.

Fluid test candidates from Brinadd, Milchem, and Southwest Resources Institute (SWRI) have been ordered for invasion testing. The first two companies are supplying water based and oil based samples respectively while SWRI is sending a proprietary polymer FM-9.

Experiments were conducted to determine the force required to remove a frozen core from the inner barrel. Approximately one-foot long sections of sandstone cores were placed in thick walled (1/4") aluminum tubes, surrounded with DC 200 (60,000 cs.) fluid and then frozen in dry ice for 24 hours. In this condition the cores could not be removed from the tube. However, by running tap water over the exterior of the tube for about 30-45 seconds it was found that the core (still encapsulated in frozen fluid) could be removed by placing the tube in a vertical orientation and allowing the force of gravity to slide the core out. The silicon fluid has a strong insulating effect because its thermal conductivity (0.00037 gm-cal/cm sec C) is approximately three orders of magnitude less than that of the barrel material. This permits the inner wall of the tube to be heated sufficiently to remove the core without affecting its frozen state. A transient heat transfer analysis indicates that the coring fluid to core barrel interface can be heated from dry ice temperature to 40°F in about 18 seconds when 60°F water is placed in contact with the outside of the barrel. The assumption of a more typical forced water convection coefficient increases this time to 54 seconds; thus, experimental agreement looks good.

Tests are currently being set-up to examine this core removal technique as applied to a full 10-foot core. This will also enable the measurement of the forces and pressures created when the core enters the barrel.

4.1.1.3 Bit Design

Based on suggestions presented at the May review meeting, a new Stratapax pilot bit has been designed, Figure 4-1. A symmetrical pattern of two Stratapax cutters at four stations is utilized. The bit is HQ in size and has a rock removed to coring fluid extruded ratio of 1:31. This bit will not require a computerized milling machine for construction and drilling tests will be conducted in late June or early July. Work is continuing on shop drawings for the full diameter portion of the bit.

4.1.1.4 Project Review Meeting

A project review meeting was held on May 18th at Sandia Laboratories. Attending were C. Ward and D. Nagle of Maurer Engineering, R. Williams of BERC, and S. Varnado, A. McFall, R. Anderson, and F. Dumistra, of Sandia. Work to date was presented and critiqued. Some results of this meeting were:

a. Redesign the ball valve to be actuated by mud pressurized hydraulic fluid.

b. Design an alternative pilot bit that does not utilize the spiral cutter design.

c. Reduce or eliminate the four innermost mud ports on the full portion bit.

d. Schedule the industry review meeting for June 29, 1978; to be held at Mudtech in Houston, Texas.

4.1.2 Measurement of Formation Core Characteristics

A proposal from the Institute of Gas Technology entitled <u>Measurement of Formation Characteristics for Western Tight Gas Sands</u> has been studied and favorably evaluated. Upon approval by the Program Manager, contract action will be initiated.

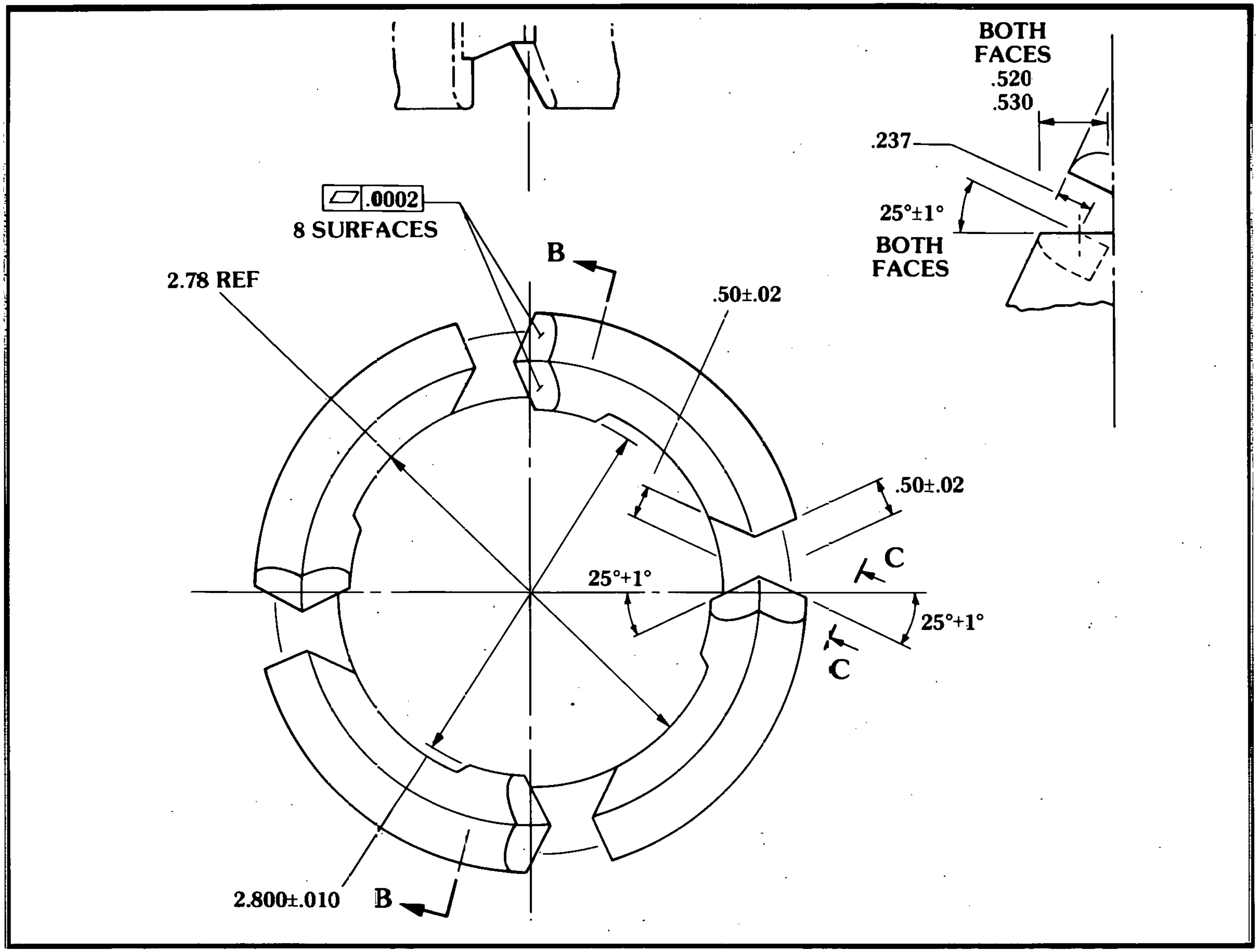


Figure 4-1 Redesigned Stratapax Bit

Terra Tek, Inc., is preparing a proposal to support the WGSP with certain rock mechanics tests and in situ stress determinations.

4.1.3 Interface Conductivity Effects on Electric Logging

Laboratory equipment was tested by measuring core resistivity at simulated reservoir conditions. This system allows pore pressure build-up to lag the simulated overburden pressure by a set pressure difference. A temperature control unit was added to the experimental apparatus and is able to control the core temperature to ± 2° C.

Tests were made on a core saturated with 2 percent KCl electrolyte. The measurement frequency was 10 KHZ, temperature was 79° C and pore pressure was 0.0. The resistivity of the core at 3,000 psi was 19.32 ohm-meters and at 500 psi, it was 17.50 ohm-meters. During core saturation flow measurements were made and liquid permeability was calculated at 0.01 md. This test illustrates the effect of pore pressure on resistivity. The experimental apparatus seems to work well up to the following conditions:

Temperature = 80°C
Overburden pressure = 3,000 psi
Pore pressure = 2,500 psi
Resistivity test frequency = 10 KHZ

A study of the literature relating to the surface conductivity of reservoir rock and a literature review of interface conductivity were completed. Most of the significant modern and historical papers were obtained. The study showed the Waxman-Smits model is widely accepted to describe the effects of surface conductivity in clayey formations. A newer model proposed by Clavier, Coates and Dumanor is a refinement of the Waxman-Smits model. Rink and Schopper and also Evers and Lyer have presented models that appear to apply to clean sands. The basic concepts of these models were studied.

4.1.4 Mapping and Contouring Formation Water Resistivity Rw

Topography maps of the Uinta Basin were received and studied, and assimilation and listing of available formation water analyses completed. Locations of R_w information were plotted on section sheets.

A large scale map was prepared depicting the areal extent of the R_w information gathered and small scale maps delineating well locations and R_w depths were completed. The data gathered has indicated significant vertical and horizontal R_w variations.

4.1.5 Logging Techniques and Interpretation

A contract was obtained with Texas A&M University to study acoustic, density and neutron logs of western tight gas sands for development of improved interpretation techniques. Logs, maps, core analyses, and production and test data are being obtained to proceed with the study.

A proposal by Sandia to survey and critique techniques to measure water resistivity was approved and the work has been funded.

Intercomp, Inc.'s proposal, Parametric Analysis of MHF Test Data; Engineering Study of Western Gas Sands was accepted and a contract executed.

4.1.6 Rock-Fluid Interaction

A medium pressure liquid-injection apparatus, assembled and tested in the laboratory, was used to pump a gelled frac-fluid, and a Hassler-type core holder was used to mount a typical tight gas sands core. Nitrogen gas was forced through the length of the core at three different flow rates, i.e., with pressures of 60, 80, and 100 psig, both in a forward and a reverse direction.

Data collected was used in the equation for permeability. However, the equation was first rearranged to show

$$k/u = \frac{2{,}000\ Q_O\ P_O\ L}{(P_i^2 - P_o^2)\ A}$$

Where:	2,000	conversion factor to md
	Q	Flow in cubic centimeters/sec.
	O	Base pressure
	P	Pressure
	L	Core length in centimeters
	i	Inlet pressure
	o	Outlet pressure
	A	Square centimeters

Then, a plot of $Q_o\ P_o/A$ versus $\frac{(P_i - P_o)}{2{,}000\ L}$ was made, whose slope was equal to k/u. The k (permeability) of 0.033 md was determined from the slope of the straight line. Pore volume, bulk volume, and porosity of the same core were 0.5 ml, 9.2 mls, and 5.44 percent.

An 0.5 in. slice of a 1.5 in. diameter tight core, identical to the above core was prepared and mounted in the liquid-injection apparatus. Then, a 2 percent KCl solution and a 40 lb. gel of Guar gum in KCl were pumped across the face of the core at 4,000 psig for several hours. In both cases, liquid was forced through the core and collected; however, the quantities collected were extremely small, only a ml or two. With the gel, a filter cake of guar particles collected on the face of the core. The particles contained in the fluid and the filter cake were not counted because the particle counting apparatus had been sent for repair.

4.1.7 Schedule Status

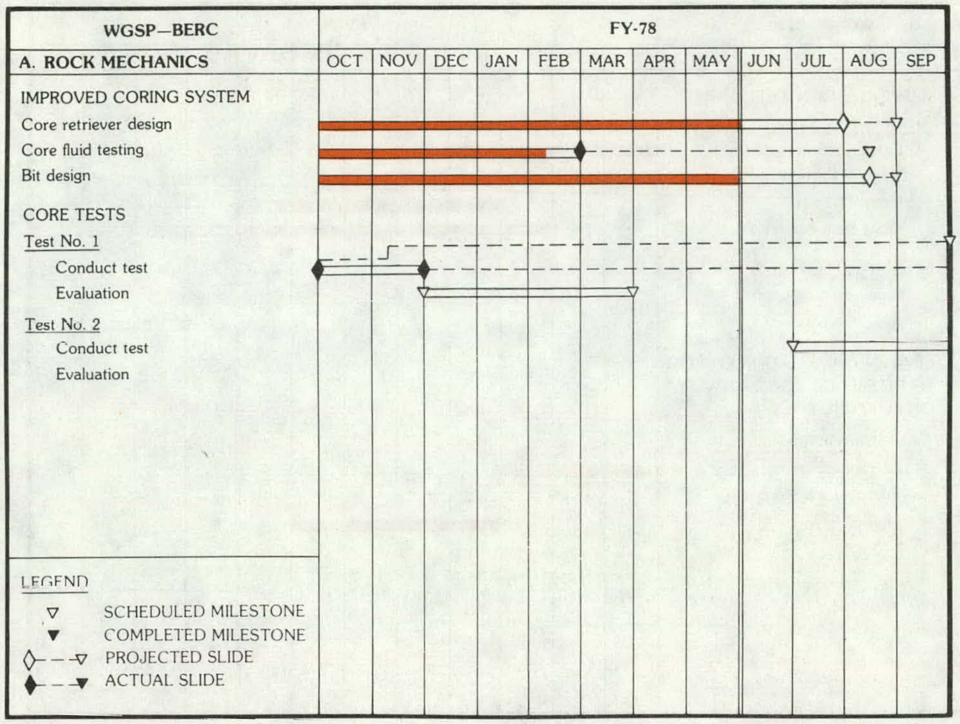
A milestone chart showing FY78 activity is shown in Figure 4-2, and includes status through May 31, 1978.

4.2 Lawrence Livermore Laboratory

4.2.1 Theoretical and Experimental Model Development and Application

One of the largest uncertainties in the application of hydraulic fracturing treatments is the geometry of the created fracture. Experiments have shown that the created fractures are perpendicular to the least principal stresses and in general, below a thousand feet or so, the horizontal stresses are smaller (in compression) than the vertical stress. Hence, the created fractures will be vertical; however, the factors which control the vertical extent of the fractures have not been determined. Usually, the height is believed to be controlled by some stratigraphic change or layering, but the physical phenomena which can control this vertical extent and thereby the final horizontal extent of the fractures are not understood.

LLL has begun a series of calculations to ascertain and understand how a pressurized fracture behaves in the neighborhood of a material interface. In these calculations it was assumed that the materials were perfectly bonded at the interface and that Young's modulus on one side of the interface was twice the Young's modulus on the other side. Poisson's ratio was taken as 0.25 and was identical for both materials. Additionally, it was assumed that the medium was impermeable. Some of the effects of permeability on the hydraulic fracturing process were presented in the last quarterly report (Hanson, et al., 1978).



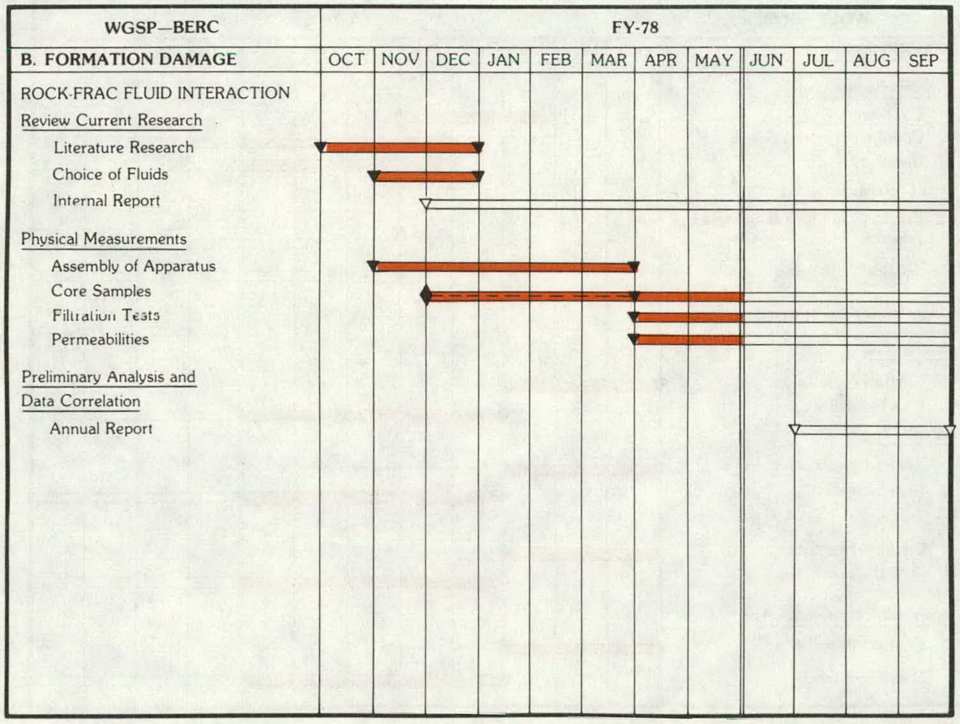
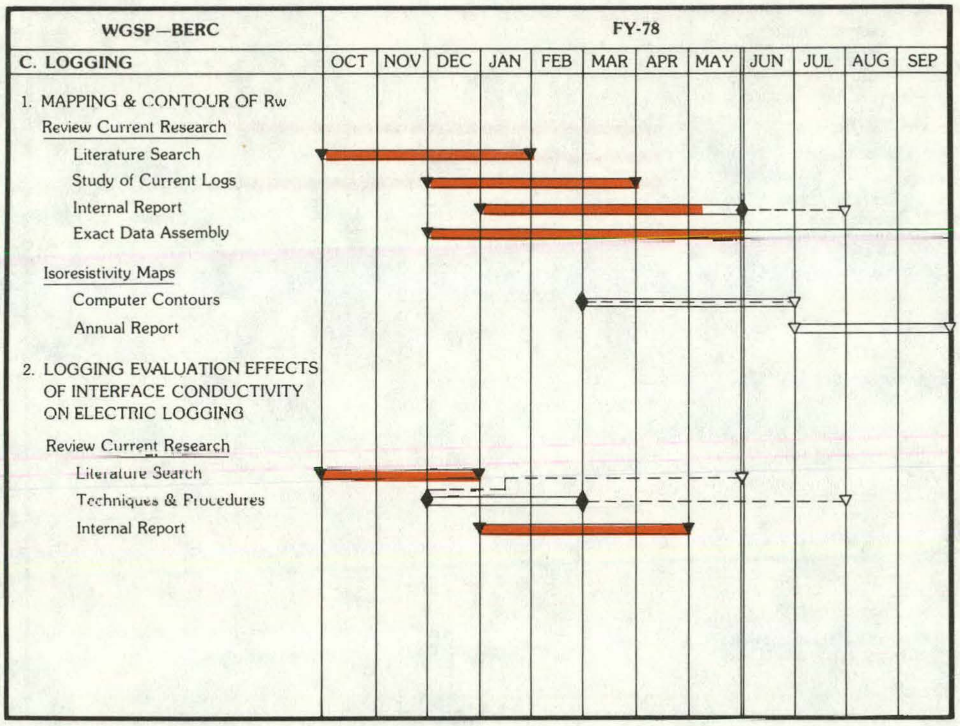


Figure 4-2 Milestone Chart — BERC



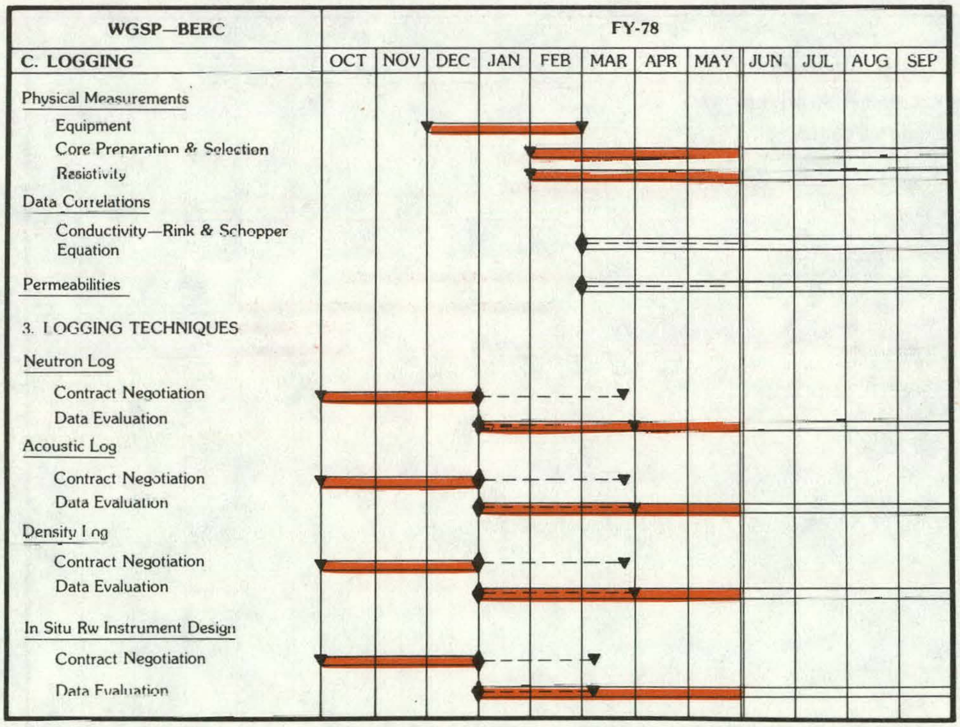


Figure 4-2 Continued

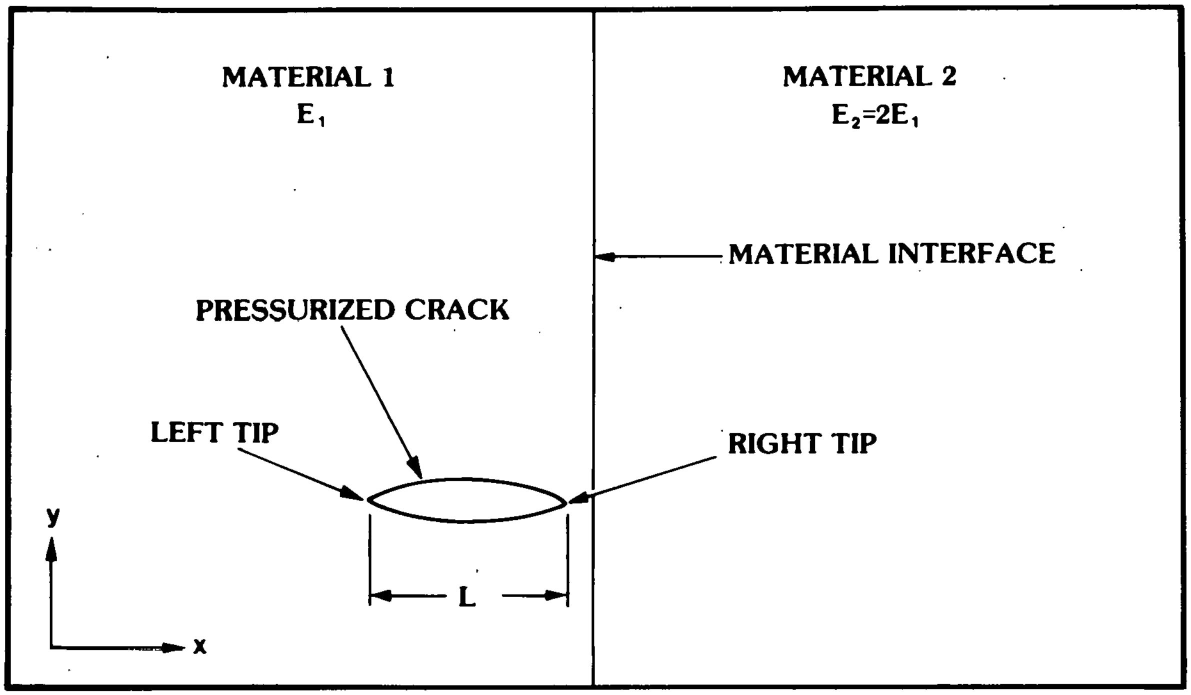


Figure 4-3 Geometry of Fracture near Interface

A sample of the geometry of the class of problems calculated is shown on Figure 4-3. To obtain a quantitative understanding of the effects of a fracture in the neighborhood of an interface, Mode I stress intensity factors were calculated for both tips of the fractures. Stress intensity factors provide an indication of the onset of fracture propagation. For presentation here, the Mode I stress intensity factor was normalized by the factor $P\sqrt{a}$. The factor $P\sqrt{a}$ is the classical Sneddon Mode I stress intensity factor for a pressurized crack in an infinite continuum where "P" is the pressure in the crack and "a" is the semi-major axis of the fracture ellipse.

Figure 4-4 shows some preliminary results from these calculations. On this plot, the ordinate (Y-axis) is the normalized Mode I stress intensity factor and the abscissa (X-axis) is the position of the crack tips with respect to the material interface. The coordinates of the fracture tip positions were normalized with respect to the crack length and the origin of the abscissa was arbitrarily set at the material interface. For these calculations, a constant fracture length was maintained, and the crack was positioned at various distances from and through the material interface. The material to the right of the X-axis origin had a Young's modulus which was twice the Young's modulus on the left side. The normalized stress intensification factors at both the right and left tips of the fracture are labeled. These results show that as a fracture approaches a material interface from a lower modulus material toward a

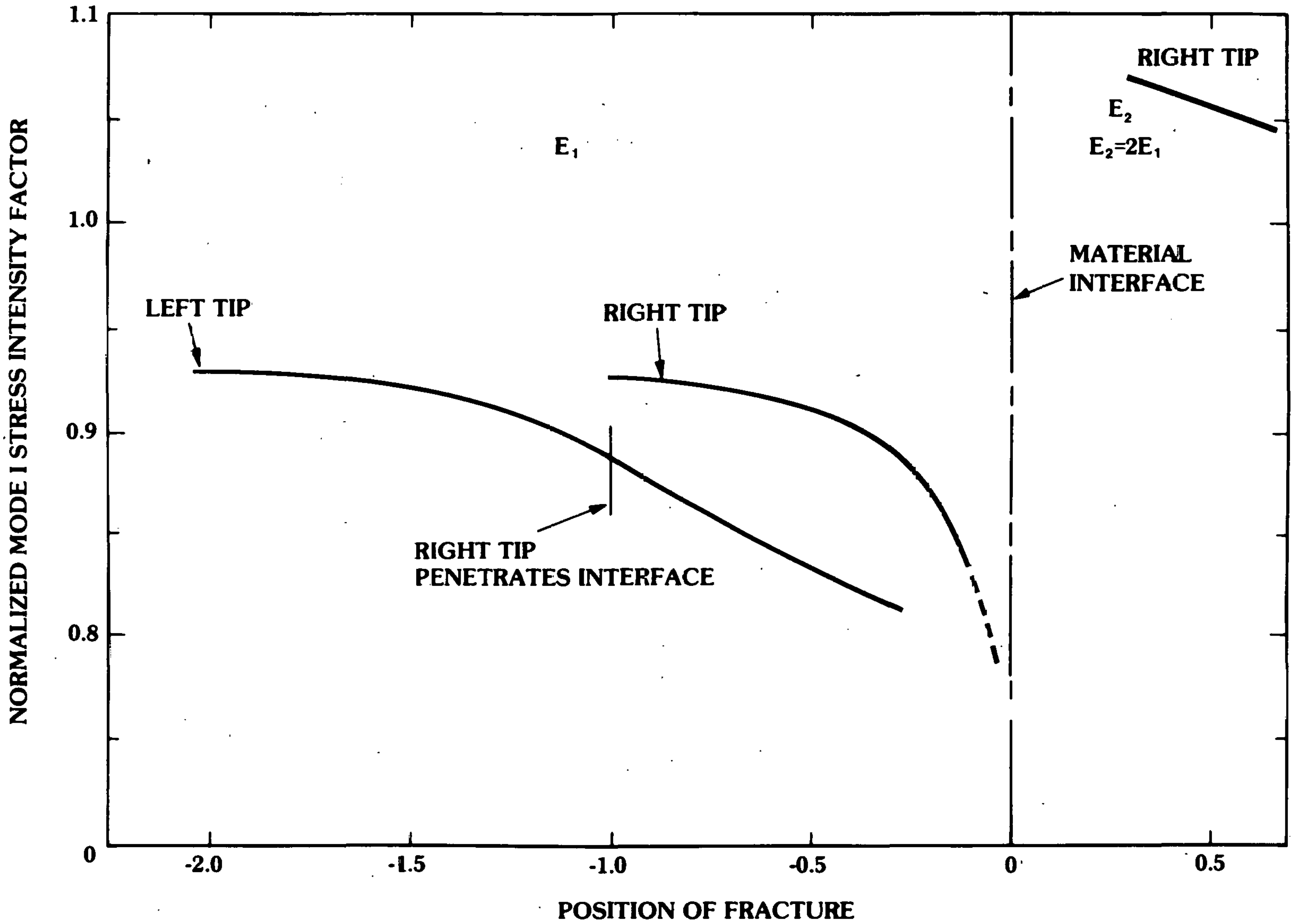


Figure 4-4 Position of Fracture Tips with Respect to Material Interface

higher modulus material, the stress intensification factor decreases. However, as the right tip penetrates the interface into the higher modulus material, the intensification factor at this tip dramatically increases while the intensification factor in the lower modulus material (left tip) decreased.

4.2.2 Experimental Program

During the past month, two series of experiments on crack growth across unbonded interfaces in Nugget sandstone and Indiana limestone were completed. These experiments consist of a stack of three blocks with the fracturing fluid injected into the center block and a load applied to the outer blocks such that a normal stress exists across the two interfaces between the two outer blocks and the interior block. One of the interfaces consists of two smooth-machined surfaces in contact while the other interface consists of two roughened surfaces in contact. A hydraulic fracture is initiated in the central block, and observation is made as to whether or not the fracture will cross either of the interfaces as a function of the magnitude of the fluid breakdown pressure at which hydraulic fracture occurs. The applied load is generated by a hydraulic press in which the assembly is located and is easily varied in desired increments. The fluid breakdown pressure at which fracture initiation occurs, however, is controlled by flaws or weaknesses in the vicinity of the borehole and is therefore a more random parameter not easily controlled. These series of experiments have been completed in the sense that the range of applied loads over which the cracks cease to terminate at the interfaces and begin to cross them for a fairly large range of breakdown pressures has been spanned. To gain more precision in pinning down the critical stresses for crack crossover at the interfaces, more experiments are required to gather statistics since rocks are quite variable.

The results are presented in Figures 4-5 and 4-6. Figure 4-5 is for the (DRNU) series in which all three blocks are Nugget sandstone. Figure 4-6 is for the (DRLM) series in which all three blocks are Indiana limestone. Along the abscissa is the fluid breakdown pressure at which fracture occurred, and along the ordinate is applied load. Each point on the figures is for a separate experiment and indicates whether or not the crack crosses an interface under those conditions. In Figure 4-5, the data for Nugget sandstone fall into three regions. Below loads of about 500 psi and 830 psi, cracks cross the roughened interface. For loads above about 830 psi, the cracks cross both interfaces. The dashed lines in Figure 4-5 denote these threshold regions. These results suggest that some frictional effect at the interface influences the stress field in the adjacent blocks and determines crack growth across the interface. The data for the Indiana limestone experiments do not fall into such well-defined regions. The data suggest that for low breakdown pressures ($P_C \leq 4,500$ psi) the cracks will cross only the smooth interfaces or none at all for applied loads up to about 1,000 psi. For breakdown

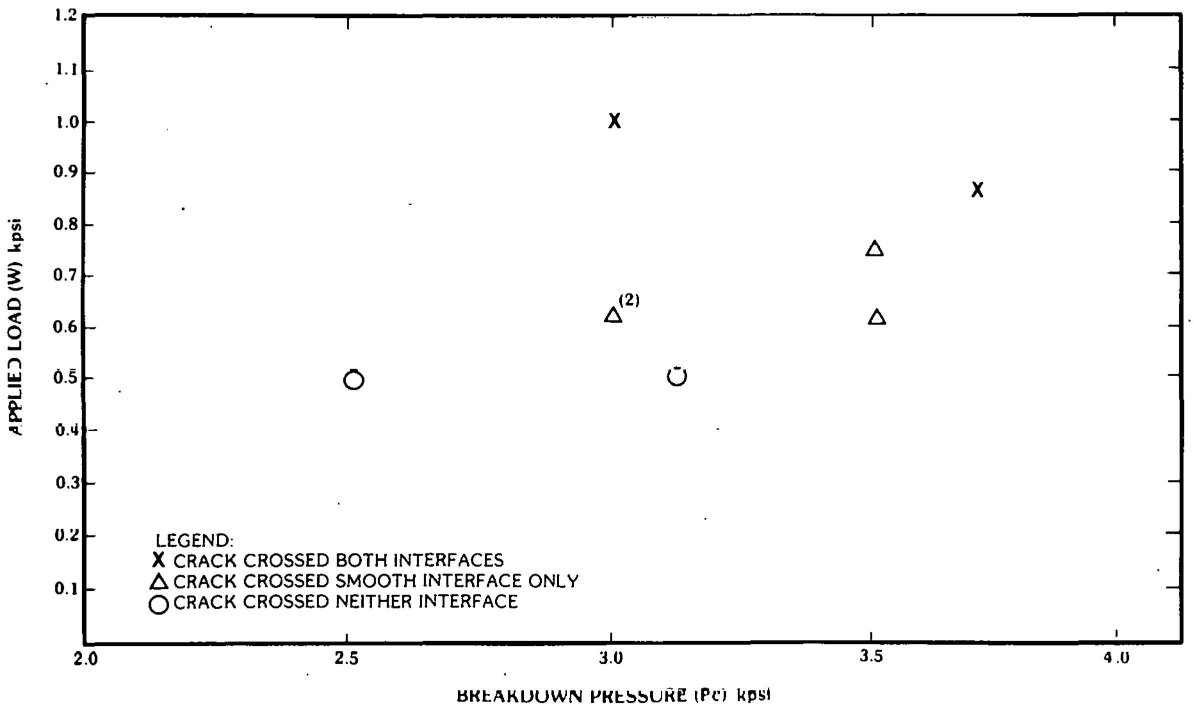


Figure 4-5 Results for Experiments with Unbonded Interfaces in Nugget Sandstone

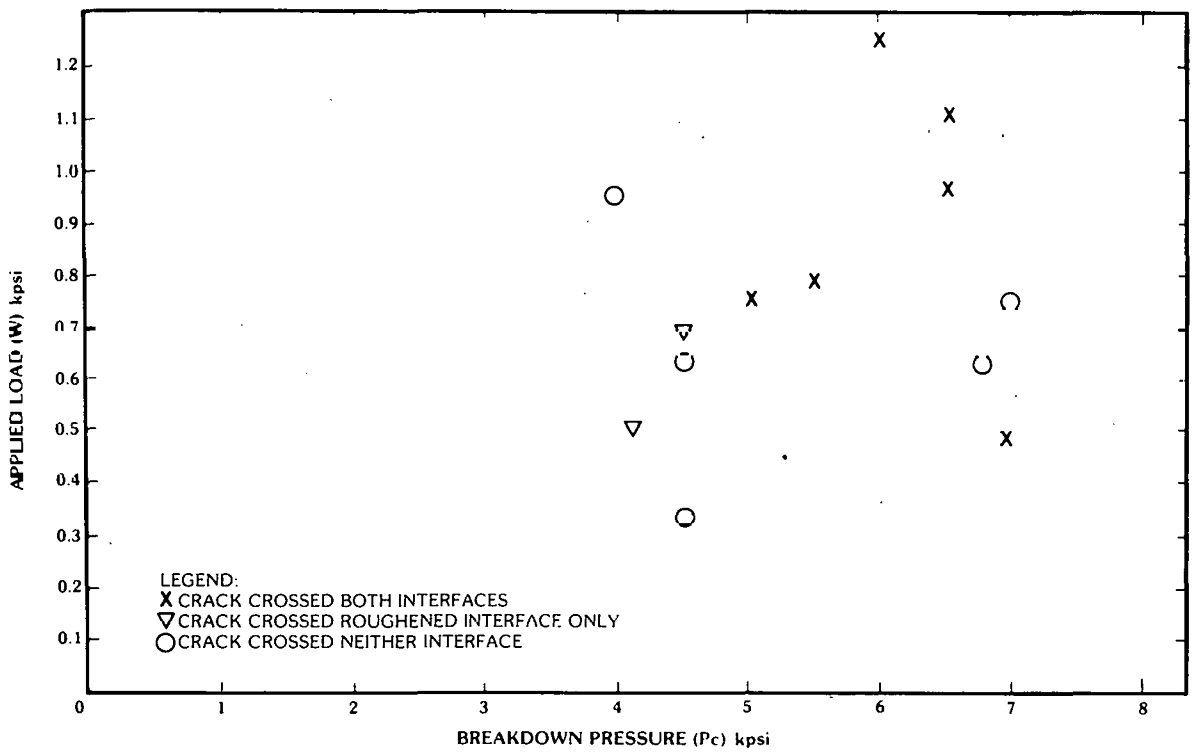


Figure 4-6 Results for Experiments with Unbonded Interfaces in Indiana Limestone

pressures above 5,000 psi and loads above about 750 psi, the cracks generally cross both interfaces. However, at loads below 750 psi and at high breakdown pressures, cracks crossed neither interface in two experiments and both interfaces in one experiment. This random behavior could be due to variability of the rocks and is an example of where more experiments are needed to obtain statistics. Further study is continuing to better understand what is occurring in these rocks.

4.2.3 Log Interpretation and Development

Tests of an improved version of a carbon/oxygen logging system have been made. This system measures the ratio of carbon to oxygen in a formation and thus, estimates the amount of carbonate plus hydrocarbon. The improvement consists of using a detector much larger than that used in the commercial system.

Results indicate that an improvement of a factor of four to ten in sensitivity can be made with this detector, depending on the method used to analyze the data. Whether the larger improvement in sensitivity is accompanied by an equivalent improvement in accuracy remains to be seen.

Coda waves of small local earthquakes have been interpreted as backscattered waves from numerous heterogeneities distributed uniformly in the earth's crust.[1] Analysis of coda wave amplitudes in terms of a first order (Born) scattering theory or a diffusion theory yields a measure of the quality factor Q and the density of scatterers σ. Simple expressions for the decay of acoustic energy of the coda in terms of Q and σ for both of the above models have been derived[1] and applied to the interpretation of P wave scattering under the Montana Lasa.[1,2] Using the Chernov theory of scattering[3] for an acoustic random medium, one can also obtain a correlation distance between scatterers. The correlation distance is directly related to the dimensions of the inhomogenieties in the medium.

In addition to the above-cited papers, LLL has accumulated a fairly large number of papers concerning the problem of acoustic scattering in random inhomogeneous media.

---

[1] Aki, K., and Chouet, B., Origin of Coda Waves: Source, Attenuation, and Scattering Effects, J. Geophys. Res., 80, 23, 1975.

[2] Aki, K., Scattering of P Waves Under the Montana Lasa, J. Geophys. Res., 78, 8, 1972.

[3] Chernov, L.A., Wave Propagation in a Random Medium, McGraw-Hill, New York, 1960.

There is some indication that the above methods may be applicable to the interpretation of coda waves observed on borehole sonic logs. A 3-D sonic log was run in Columbia Gas Well No. 20402 with a total sweep time of 30μsec, or a maximum depth of investigation of about 64 m. Using this data, Hanson, et al[4], have found a correlation of the root mean square (RMS) value of the coda amplitude with the degree of fracturing in the formation near the wellbore. This observation is consistent with the small earthquake studies mentioned above, indicating that the fundamental scattering mechanisms behave in a similar fashion over a very large spatial scale.

A digitally recorded sonic log was run in Columbia Gas Well No. 20403 with a total sweeptime of 5μsec, or a maximum depth of investigation of about 9m. Since the software for reading the tapes already exists, LLL feels that this data would be very useful to determine the applicability of "Aki's Method" to borehole sonic data, and to see if anything is gained over simply using the RMS coda amplitude as an indicator of fracture density. Since the logging tool used for this data had several receivers, several interesting experiments could be conducted with the data. One would be the reduction of the P&S amplitudes between two receivers as an indicator of fractures.[5] A comparison of this method with the scattering theory approach would be quite useful.

4.2.4 Other Program Related Activity

Work continued on the preparation of the environmental assessment report for the cyclic dry gas injection project being performed by Colorado Interstate Gas Company in the Wattenberg Field of Colorado.

4.2.5 Schedule Status

A milestone chart of LLL FY78 activities is shown on Figure 4-7. Status for these tasks is not available.

---

[4] Hanson, M.D. and others, UCRL-50036-76-3, 1976.

[5] Morris, R.L., Grine, D.R., and Arkfeld, T.E., Using Compressional and Shear Acoustic Amplitudes for the Location of Fractures, J. Petr. Tech., 16, 6, 1964.

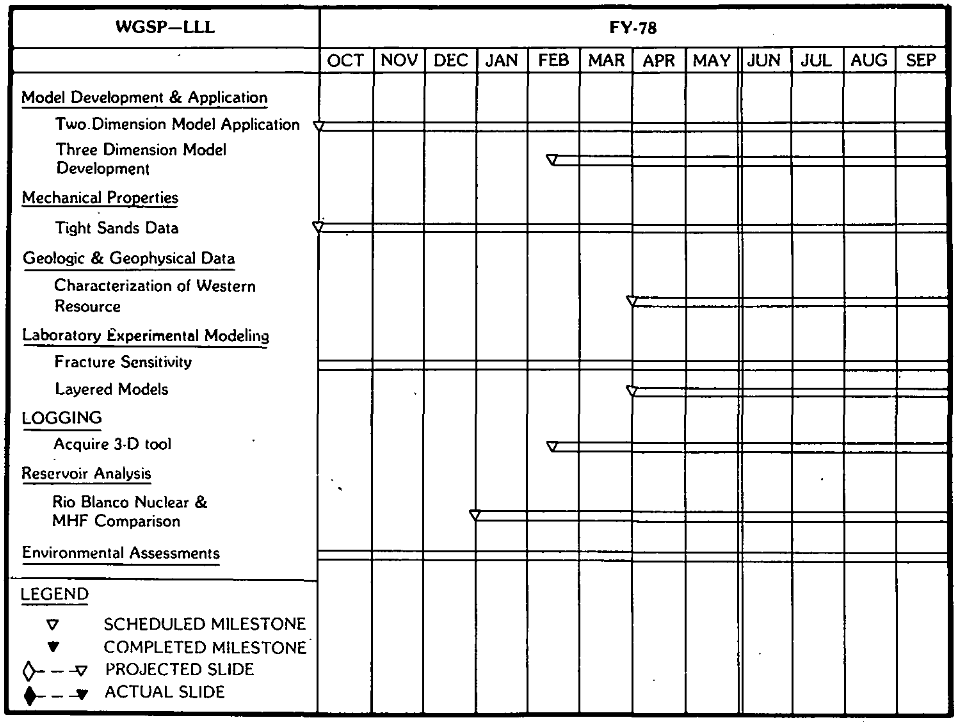


Figure 4-7 Milestone Chart — LLL

4.3 Sandia Laboratories

4.3.1 Hydraulic Fracture Mapping

4.3.1.1 Wattenberg Fracturing Equipment

The surface electrical potential data analysis has been continuing with the new PDP 11/34 computing system. Completion of this analysis will probably require an additional month or two. The borehole seismic data has been partially digitized and these digitized records are being filtered and displayed. This data analysis also will require a few months to complete. A series of local tests have been initiated to more thoroughly evaluate the borehole seismic system.

4.3.1.2 Surface Electrical Potential Systems

A considerable effort has been undertaken to redesign and upgrade the surface electrical potential system since its return from the Wattenberg experiments. The electrical potentials that can be monitored are being increased from 24 to 48 to facilitate the measurement of two radial locations. The current pulser is also being updated to include an internal solid state timing system to more accurately control current pulses. Basic control for the current pulser will remain in the PDP 11 computer; however, the pulser itself will control pulse lengths and complete pulse cycle times.

A calibration capability has been added to the entire system whereby a programmable voltage source can be inputted into each of the potential measurement boxes at any time during the experiment. This will allow each location to be calibrated and the voltage measurements corrected during the entire experiment. In addition to the calibration of each box, a bandpass filter has been added to enhance the data relative to telluric current potentials. Telluric current potentials outside the pulse spectrum should be reduced considerably.

A general maintenance and updating of trailer B-59 has occurred. The heater and air conditioner have been refurbished and are now ready for operation. The motor generators required during field experiments are being mounted permanently to a lowboy trailer for transportation to and from field sites. The complete system should be reassembled during June and checked out and ready for testing in July. Experimental plans are being formulated.

4.3.2 Mobile Test Facility

The WGSP Mobile Test Facility, which includes a mast truck, instrumentation trailer, diesel generators, and associated equipment, is being finalized by the Sandia Laboratories for acceptance by CER Corporation. CER personnel traveled to Sandia Laboratories in Albuquerque, New Mexico, during the last week of May to inspect and partially test the equipment as an integral system. On May 31, the mast truck was driven to the DOE facility in Grand Junction, Colorado, for temporary storage. The instrumentation trailer will be moved, along with the two diesel generators and the mast truck, to CER Corporation's RB-MHF 3 well in Rio Blanco County, Colorado, during the week of June 11th. See Section 5.7 for information on field operations.

A major portion of the instrumentation, which includes a meter run, static and differential pressure transducers and temperature probe, is scheduled for shipment from the vendor on or about June 20. The HP pressure transducer, temperature probe and GO pressure data processor should be delivered to the Sandia Laboratories during the first week of July.

4.3.3 Schedule Status

Figure 4-8 shows a milestone chart of Sandia's activities during FY78. Status for these tasks is not available.

4.4 U.S. Geological Survey Borehole Gravity Meter

Design and fabrication work continued during May on the surface recording equipment.

The following information was originally published in the USGS Oil and Gas Resource Investigation Program, December, 1977, USGS Open-File Report 78-303, 1978.

> The high-precision Borehole Gravity Meter, pioneered by the U.S. Geological Survey, has the capability to: 1) discover overlooked oil and gas zones in existing wells; 2) generate data useful in improving recovery of oil from producing reservoirs; 3) evaluate low quality reservoirs such as fractured shales, tight sands, oil shales, and coal deposits; 4) serve as a proximity indicator for detection of salt domes, pinnacle reefs, or nearby oil and gas deposits; and 5) provide highly accurate measurements of physical properties of rocks for use in seismic modeling. To date, the full potential of borehole gravity is unrealized because of limitations of prototype instruments and resultant lack of utilization by industry.

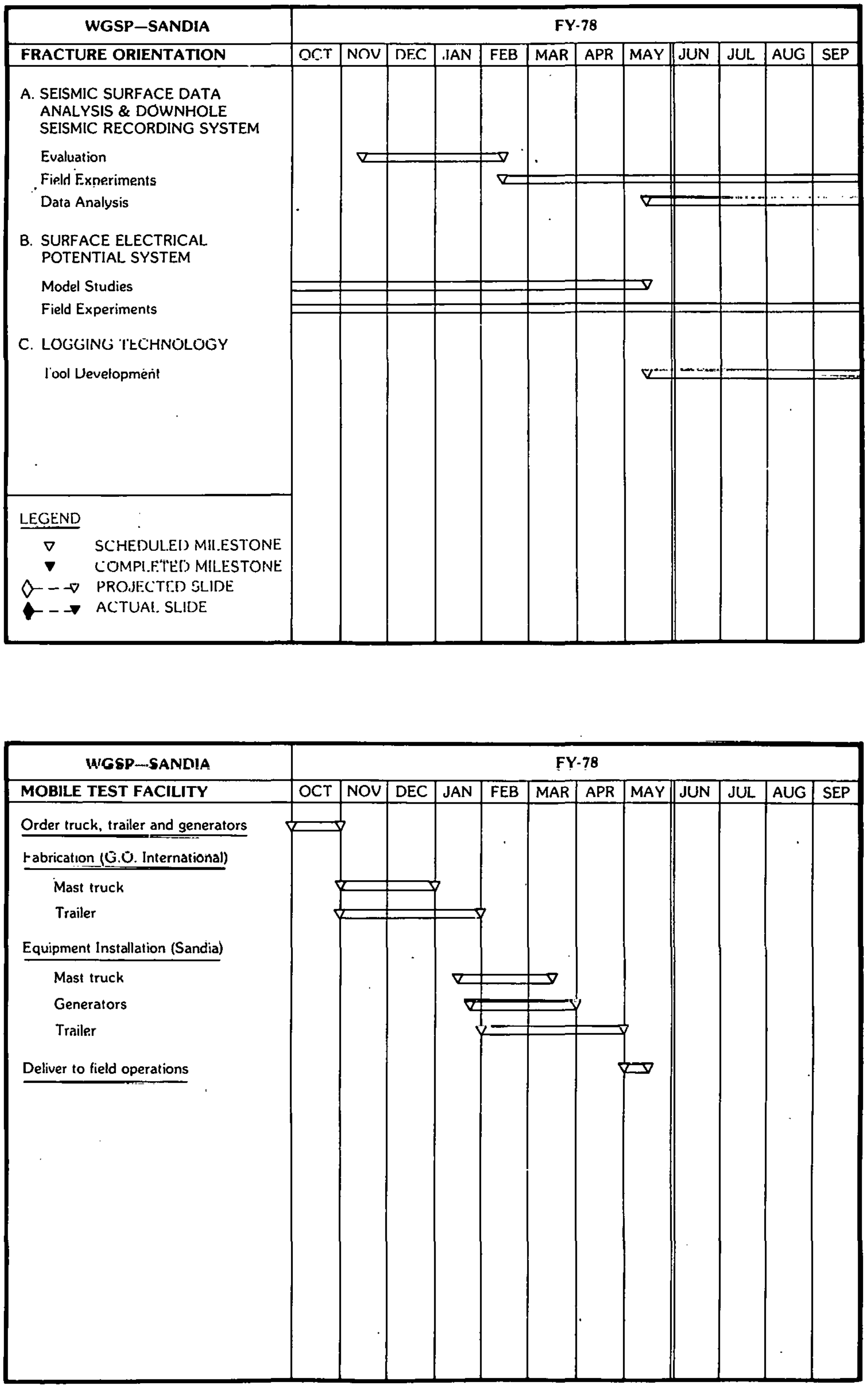


Figure 4-8 Milestone Chart — Sandia

This program is proceeding along three lines of investigations: 1) miniaturize, develop, and improve the existing equipment to expand its use in modern slim holes; 2) demonstrate utility of the device to industry; and 3) relate results of the method to other borehole geophysical logging methods and to the physical properties of sedimentary rocks.

It is believed that borehole gravity logging will become a very important tool in the energy and other mineral industries in the future. As exploration proceeds into lower quality reservoirs (for example, fractured low-permeability or inhomogeneous shale, sandstone, and limestone) evaluation tools will have to become more sophisticated in order to provide the data required for the evaluation of problem reservoirs. Borehole gravity logs have advantages over conventional logging tools because they measure responses from very large rock volumes. Conventional tools commonly investigate rocks only in very close proximity to the well bore.

Certainly, further development of the tool will improve its application to petroleum problems, but the demonstration of its utility will also encourage industry to work on its development. In the last two years, one major oil company has begun to use its own borehole gravity logging tool on a routine basis.

4.5 M.D. Wood, Inc., Tiltmeter

Phase I of the Talley Energy Systems, Incorporated (TESI) oil shale in situ retorting test was completed on May 14, 1978. Located approximately ten miles west of Rock Springs, Wyoming, the MHF was performed at a depth of 400 ft. Sandia Laboratories monitored the treatment with a variety of instrumentation.

M.D. Wood, Inc. fielded a tiltmeter array over an eight-week period. Site selection and preparation began in mid-March and recording continued until May 15. The principal accomplishment of the fracture mapping was the long sought goal of real-time data acquisition, interpretation and application of the results for the purpose of modification of the injection parameters. On more than one occasion, the TESI Principal Investigator used real-time interpretation to restore the treatment from anomalous flow and rate conditions to a more stable condition. The communications link through Sandia Central to the Principal Investigator was such that M.D. Wood, Inc. was unaware of how this information was being used and therefore was unbiased in the interpretation of the tilt data as a response of the fracture to changes in treatment parameters or as a response to changes in the properties of the material being fractured. Real-time observations indicated onset of lift, propagation rate, stabilization of the fracture, collapse of the fracture, restoration of lift and propagation as well as response to shut in.

Equally important was the absence of lift associated with the first attempt, which indicated failure to initiate a fracture and in the last attempt (May 14), inability to propagate the fracture after achieving breakdown and initial propagation.

The real-time mapping was sufficient to indicate the asymmetry of each fracture. The magnitude of the peak signals was accurately predicted from previous work at site 12 at a depth approximately one-half of that at the TESI site. A thorough computer analysis for determination of crack width, improved estimates on geometry and the relation of injection parameters to the fracture (tilt) response, and estimates of the influence of background noise on the real-time analysis are planned.

5. FIELD TESTS AND DEMONSTRATIONS

5.1 Background

Active field 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 a 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 WGSP 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	6,170 6,333	8 25 76	1,110,000	613 gel H_2O
CONSORTIUM MANAGED BY CER CORPORATION Piceance, Mesaverde	3S, 98W, S11 Rio Blanco Co. 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	400,000 880,000 815,000 448,000	117 Gel 285 Gel 400 Gel 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	8,909-9,664 7,224 8,676	9-21-76 9-28-76	424,000 784,000	280 Gel 365 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
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 8,765-8,972	6-22-77 8-24-77 5-10-78	580,000 600,000 332,300	316 Gel 260 Gel 166 Gel
PACIFIC TRANSMISSION Uinta, Mesaverde	8S, 23E, S25 Uintah County Utah	Fed 23-25	NO FRACS PERFORMED			
RIO BLANCO NATL. GAS Piceance, Mesaverde	4S, 98W, S4 Rio Blanco Co. Colorado	Fed 498 4 1	6,150 6,312 5,376-5,960	10-22-76 11-30-77	776,000 243,000 + 22,500 Beads	276 Gel 164 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

5.2 Mobile Test Facility

5.2.1 Current Status

The Mobile Test Facility, is being finalized by Sandia Laboratories for acceptance by CER Corporation. On May 31, the mast truck was driven to the DOE facility in Grand Junction, Colorado, for temporary storage. The instrumentation trailer will be moved, along with the two diesel generators and the mast truck, to RB-MHF 3, CER Corporation's well, during the week of June 11th.

Subsequent to moving the Mobile Test Facility to the RB-MHF 3 well, it is anticipated that during the first three weeks, CER personnel will perform an inventory of all the equipment, inspect and become familiar with the facility and its instrumentation, and prepare procedure and maintenance manuals. Once these activities are completed, about the second week in July, and assuming that delivery dates for the associated instrumentation are monitoring of the RB-MHF 3 well will commence. Several flow tests and buildups are anticipated in order to evaluate the performance of the entire well testing facility, particularly the computer data acquisition system.

Following a meeting of R.L. Mann, CER, and Steve Holditch, Texas A&M, programs are being written for the PDP-11 computer for well test monitoring and data analysis. A milestone chart of FY78 field activity is shown in Figure 5-1.

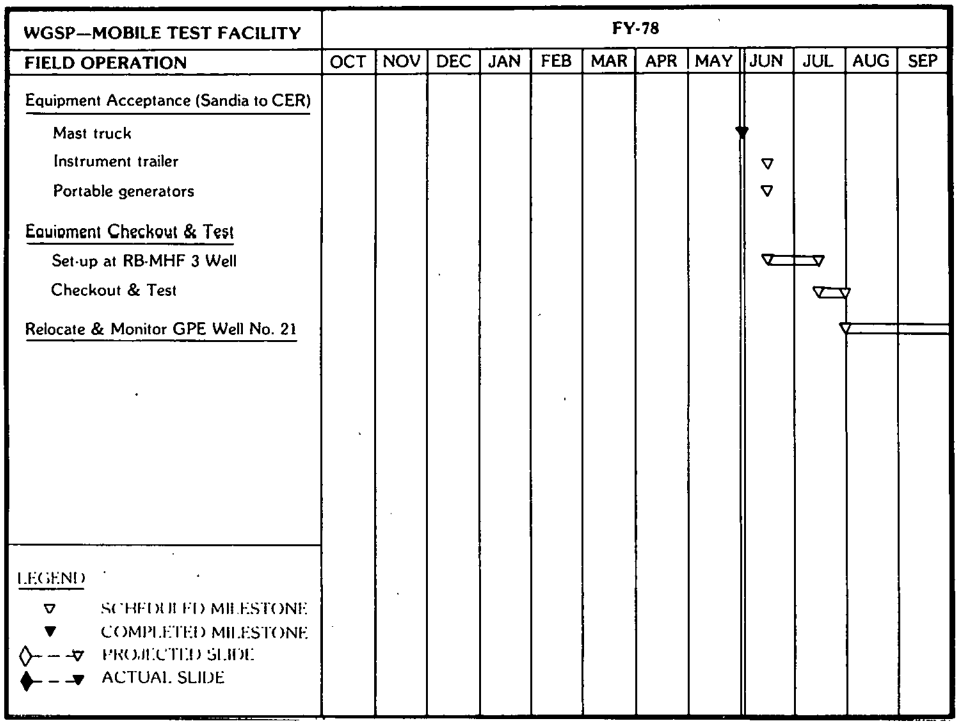


Figure 5-1 Milestone Chart — Mobile Test Facility

RIO BLANCO MASSIVE HYDRAULIC FRACTURING EXPERIMENT

EY-76-C-08-0623

CER Corp.
Las Vegas, Nevada

Status: Awaiting Advisory Committee Decision

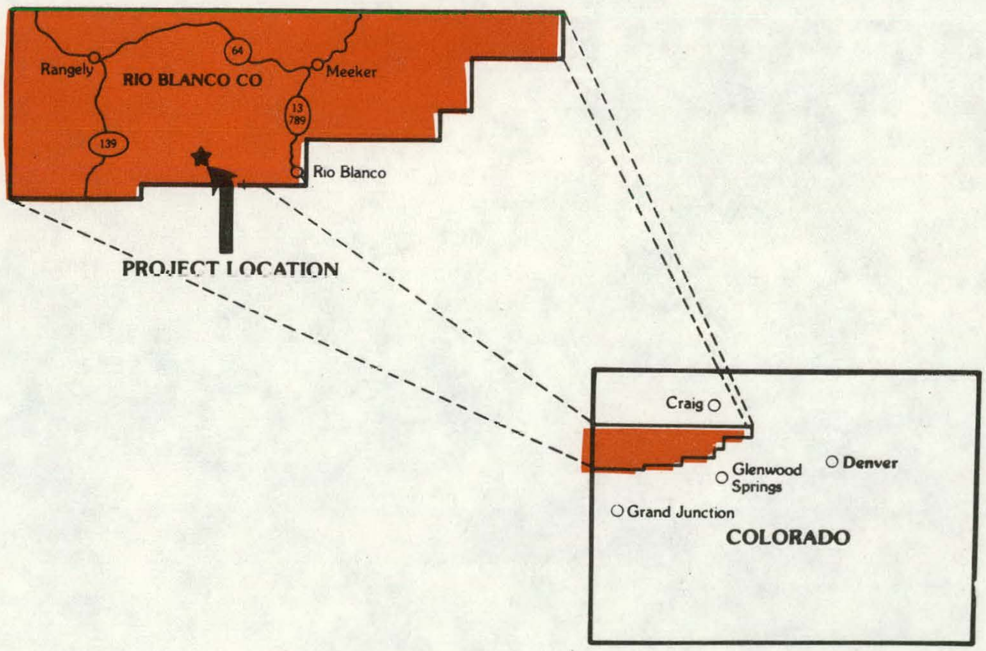
Interagency Agreement Date: June 19, 1974
Anticipated Completion Date: September 30, 1978

Project Cost (estimated):	DOE	$1,975,000
	Industry	1,630,000
	Total	$3,605,000

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.



5.3 CER Corporation

5.3.1 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.

5.3.2 Current Status

Field activities on the RB-MHF 3 well have been suspended because of lack of funds. Negotiations have taken place 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. Legal documents are being prepared for distribution to the project participants for their concurrance.

WATTENBERG FIELD

EY-77-C-08-1514

Colorado Interstate Gas Company
Colorado Springs, Colorado

Status: Active

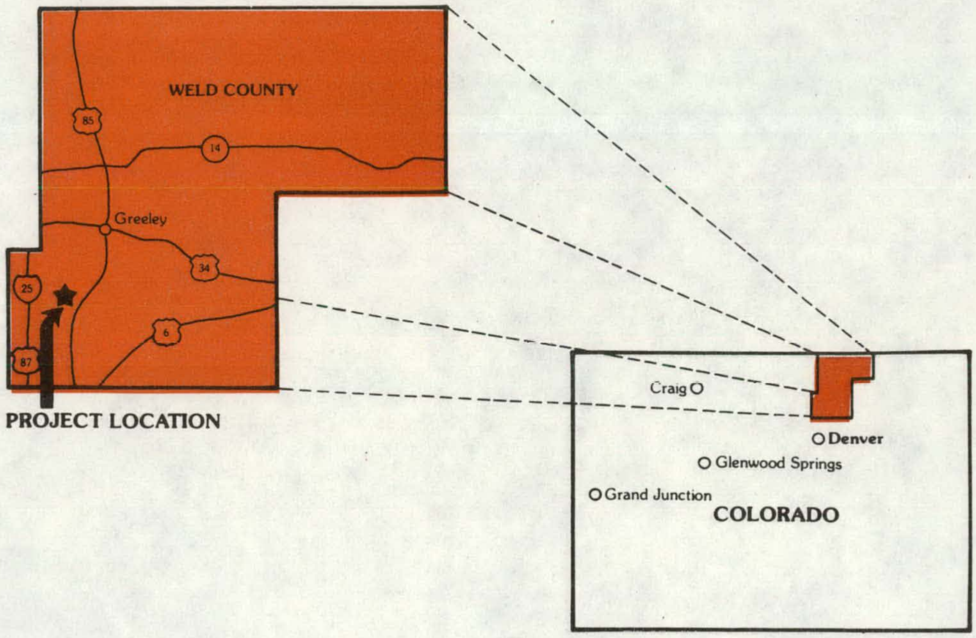
Contract Date: September 1, 1977
Anticipated Completion Date: March 1, 1981

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

OBJECTIVE

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



5.4 Colorado Interstate Gas Company

5.4.1 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.

5.4.2 Current Status

A compressor has been ordered and the first cyclic injection-withdrawal period is now estimated to start February 1, 1979. A revised milestone chart is shown in Figure 5-2.

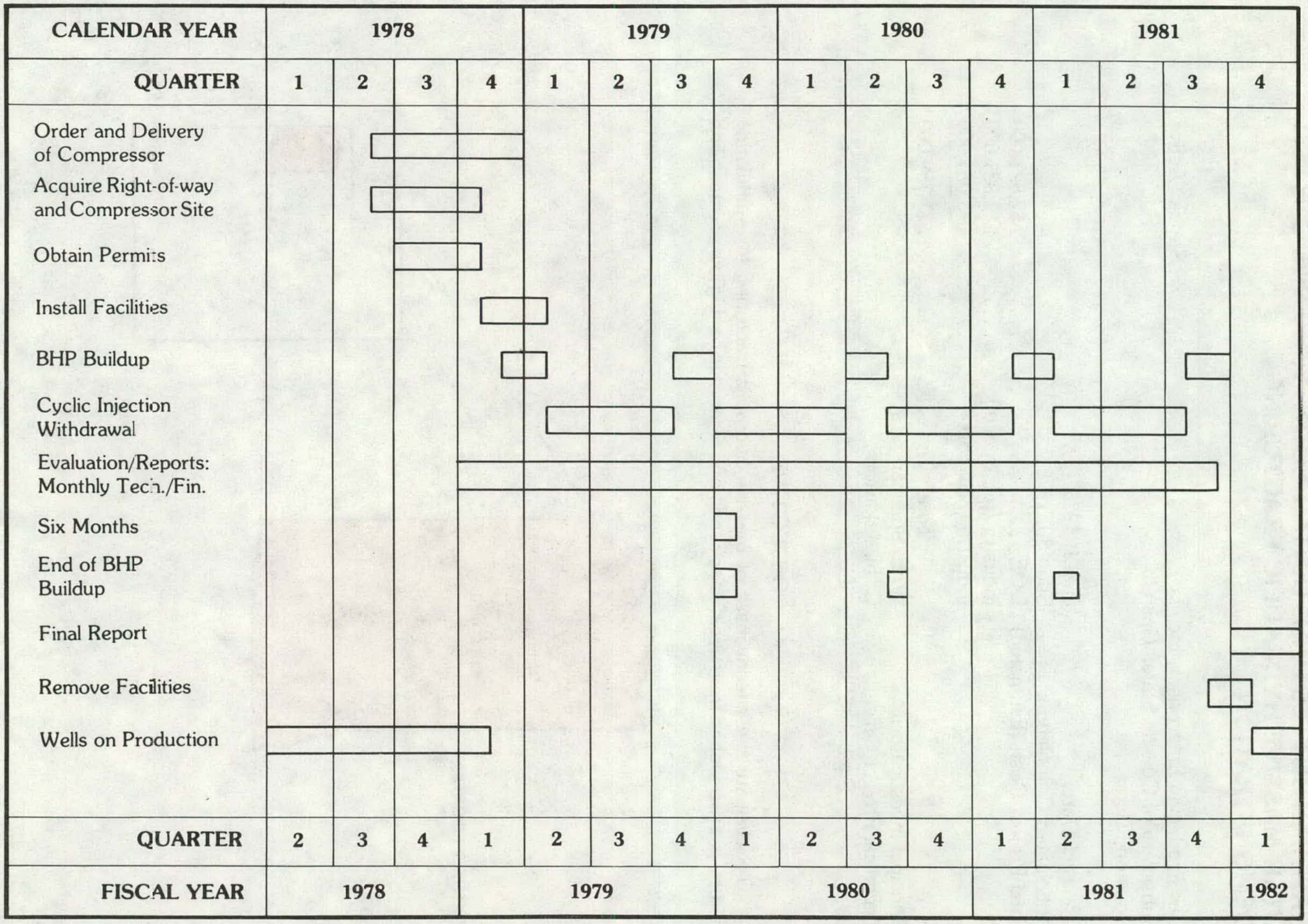


Figure 5-2 Milestone Chart (Revised) — Colorado Interstate Gas Company

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

EY-76-C-08-0681

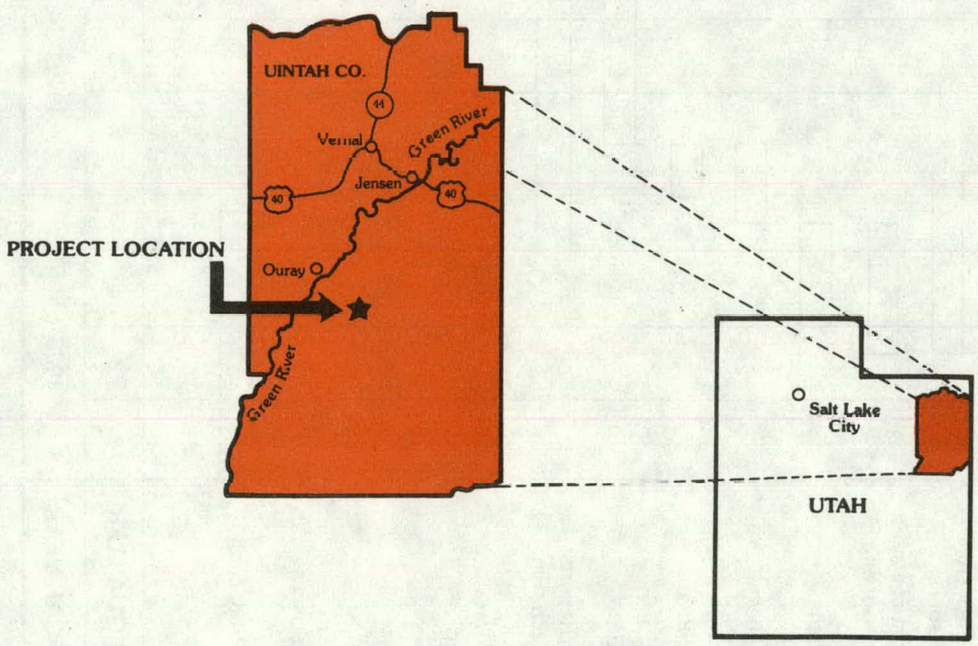
Gas Producing Enterprises, Inc.
Subsidiary of Coastal States Gas Co.
Houston, Texas

Status: Active

Contract Date:	July 1, 1976	
Anticipated Completion:	Sept. 30, 1978	
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:	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, Inc.

5.5.1 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.

5.5.2 Current Status

Natural Buttes Unit Wells No. 9, 14, 18, 19, 20 and 22 were flowing to sales during May. Specific production data on these wells appears in Figures 5-3 through 5-8.

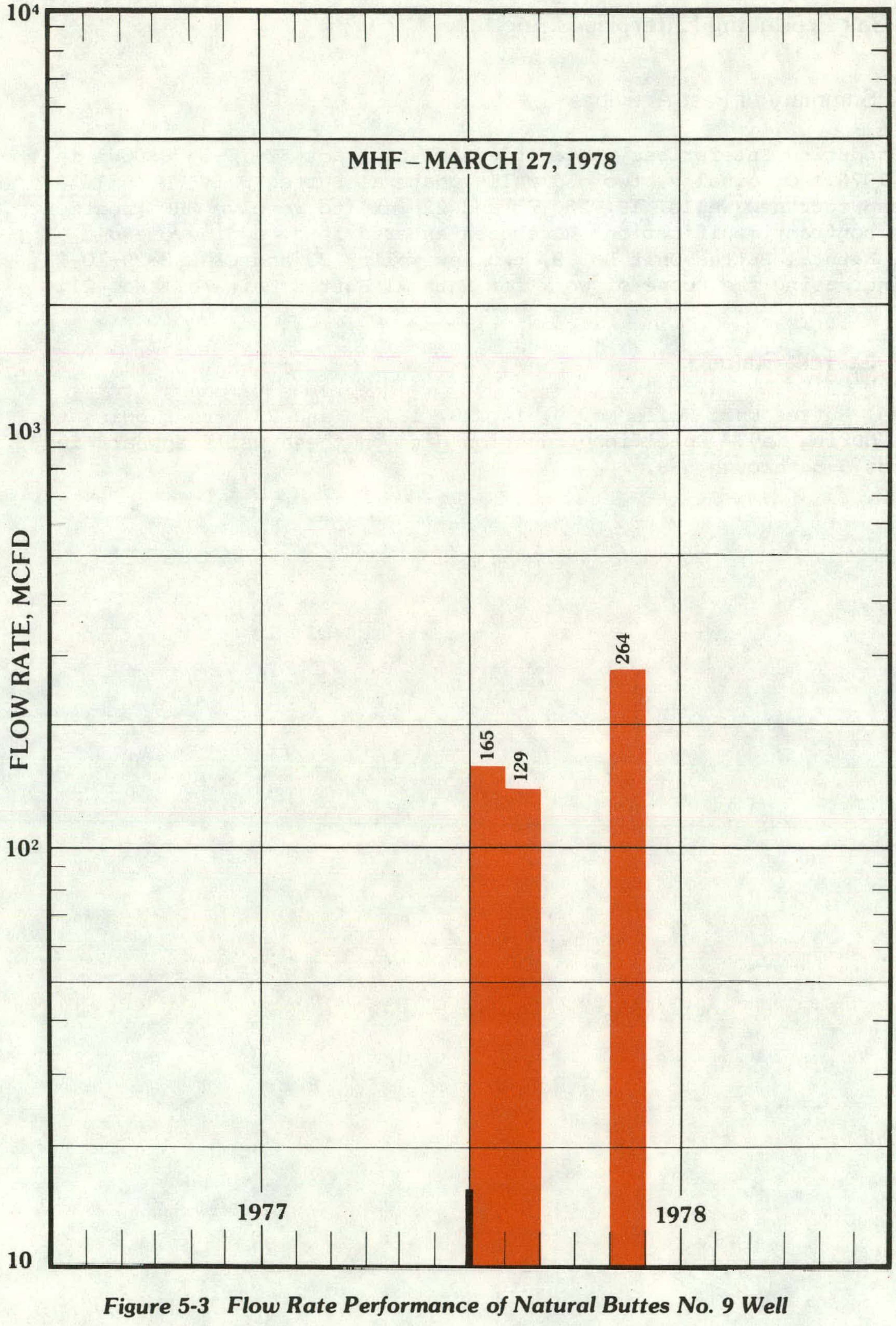


Figure 5-3 Flow Rate Performance of Natural Buttes No. 9 Well

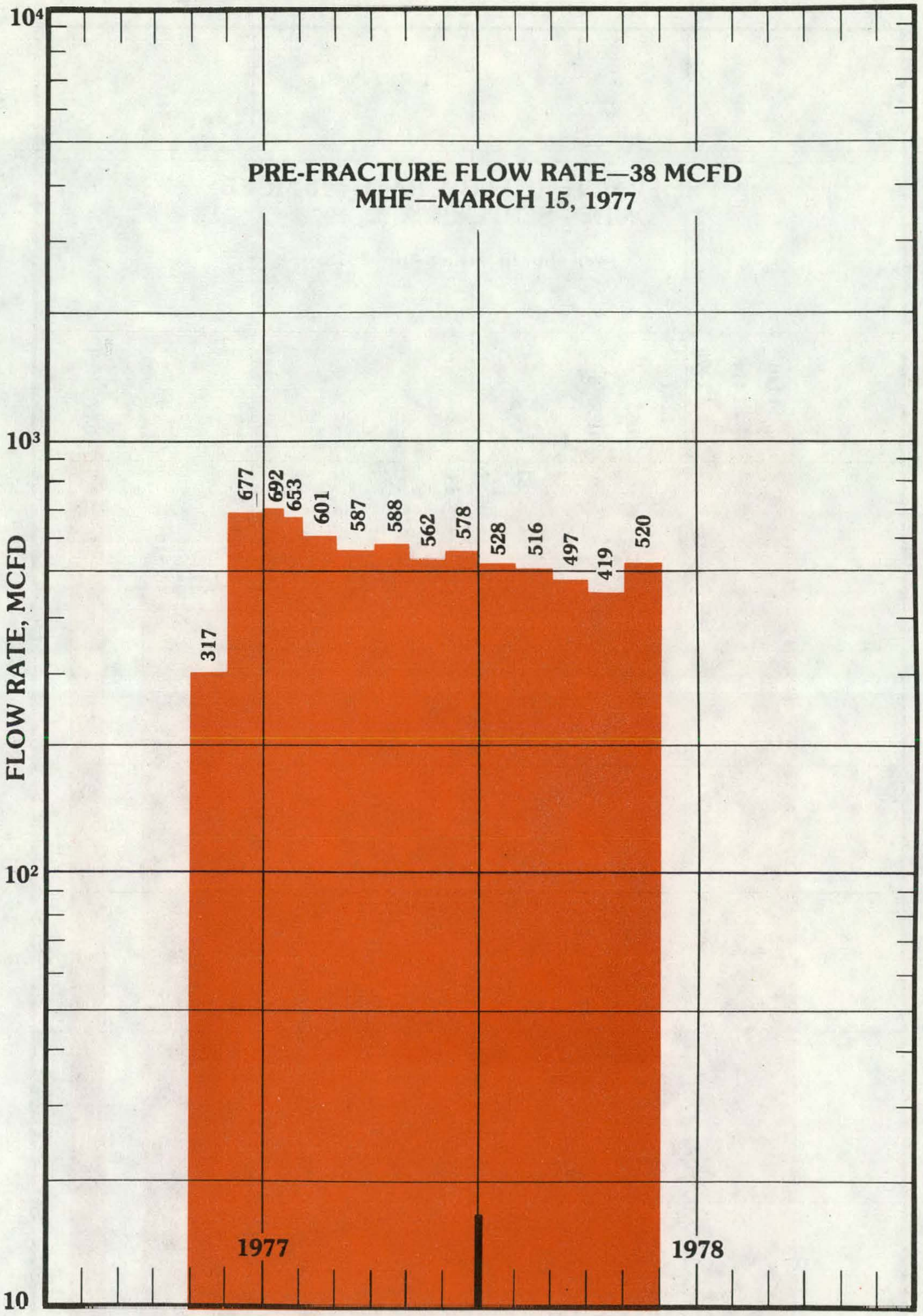


Figure 5-4 Flow Rate Performance of Natural Buttes No. 14 Well

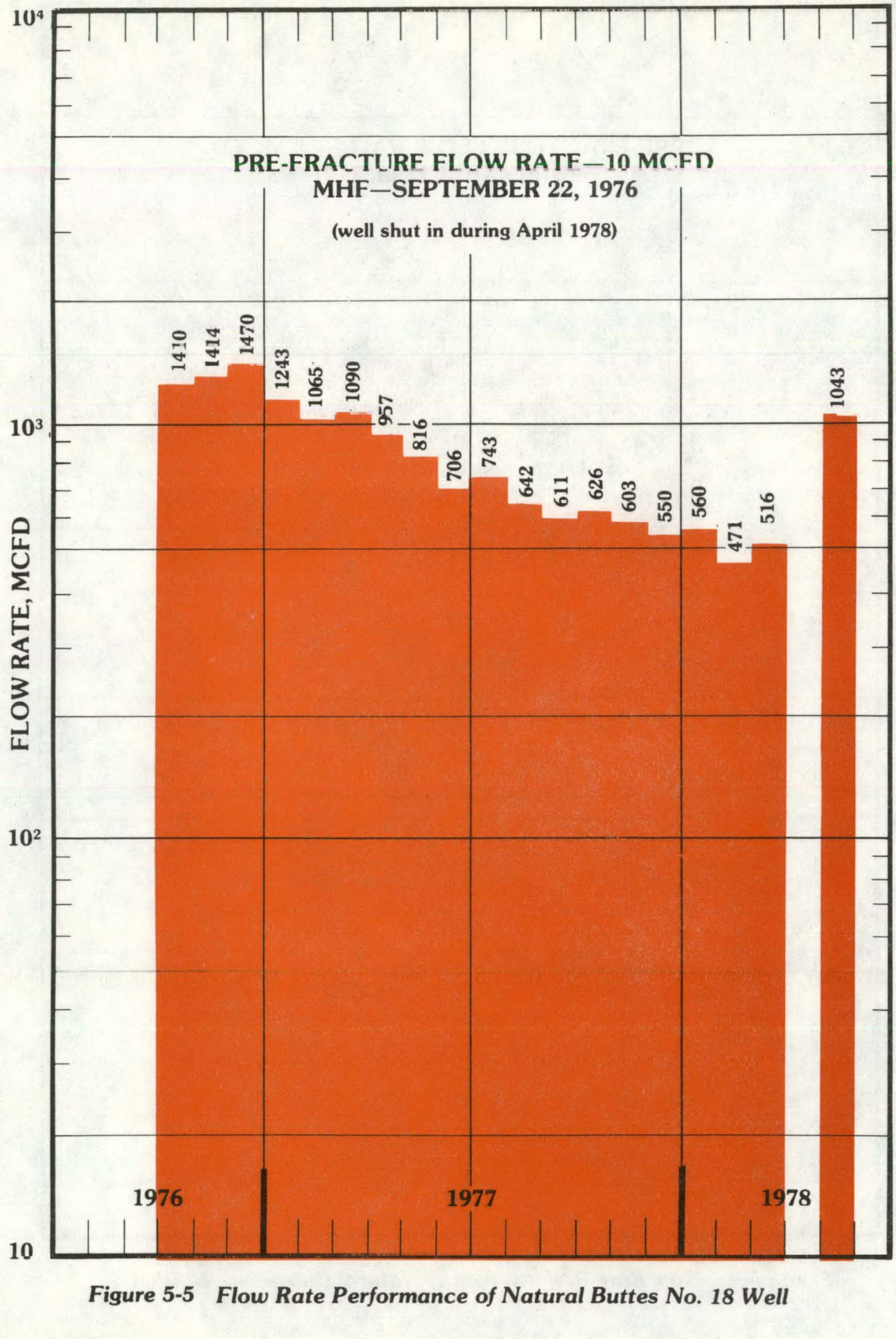


Figure 5-5 Flow Rate Performance of Natural Buttes No. 18 Well

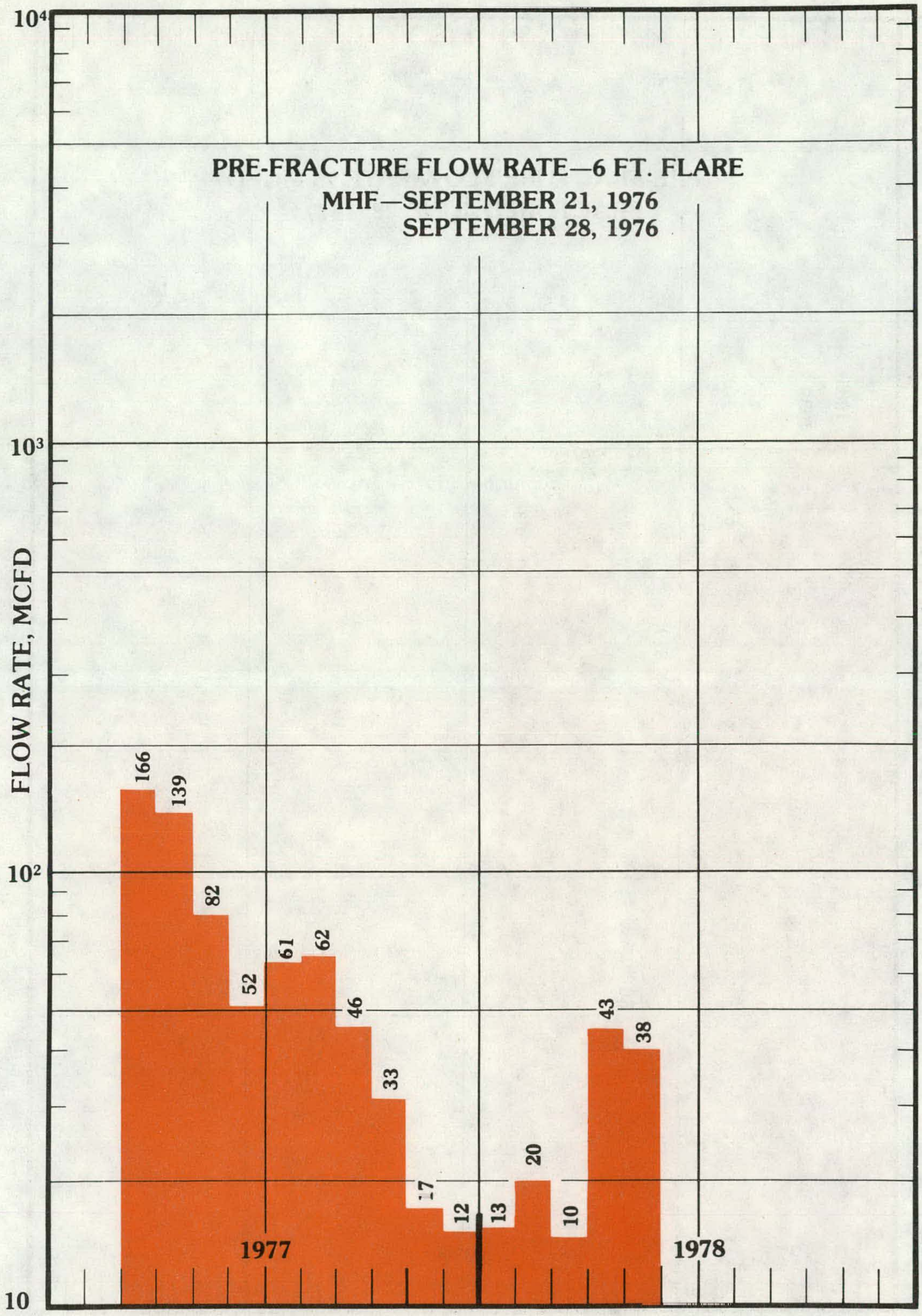


Figure 5-6 Flow Rate Performance of Natural Buttes No. 19 Well

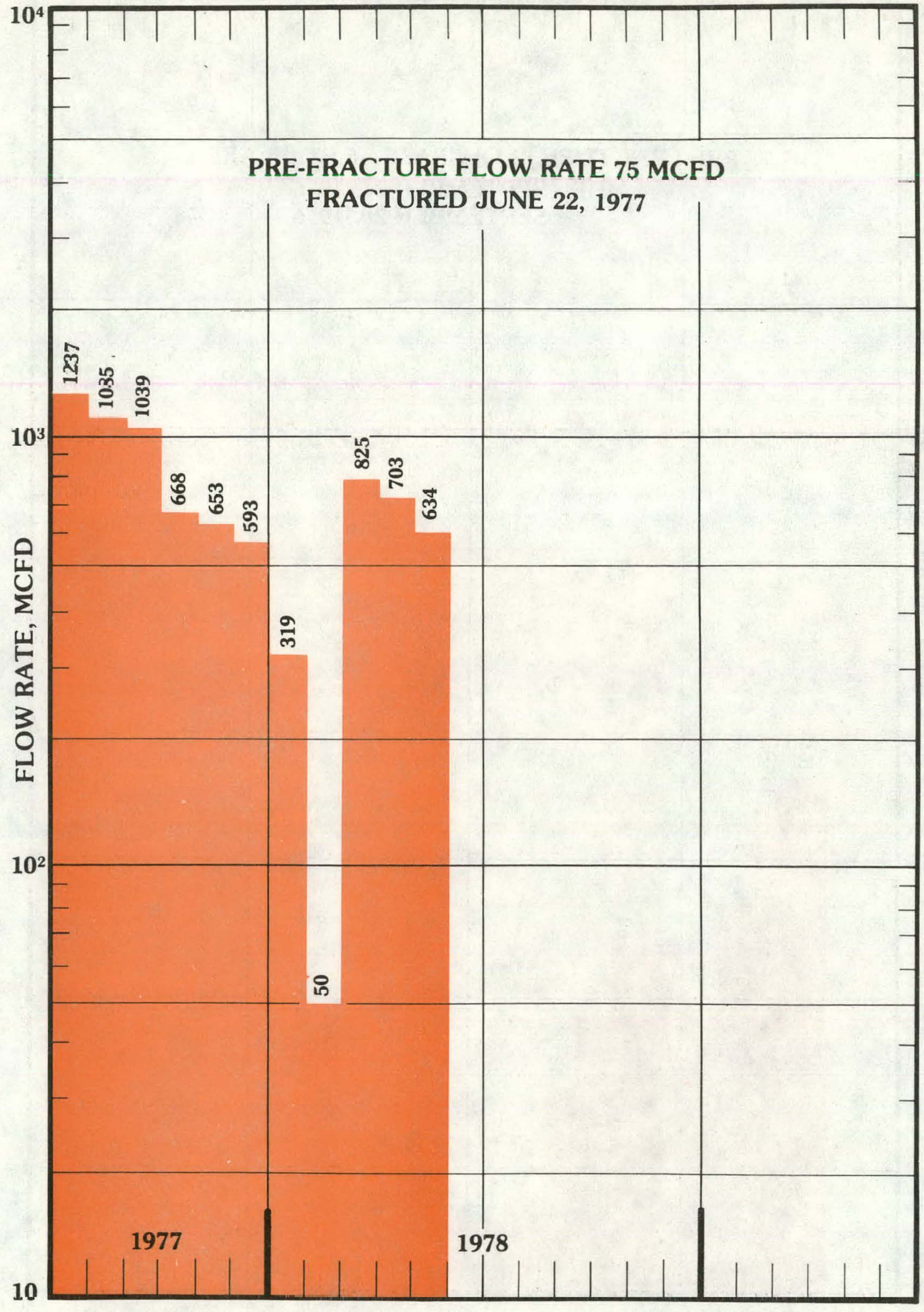


Figure 5-7 Flow Rate Performance of Natural Buttes No. 20 Well

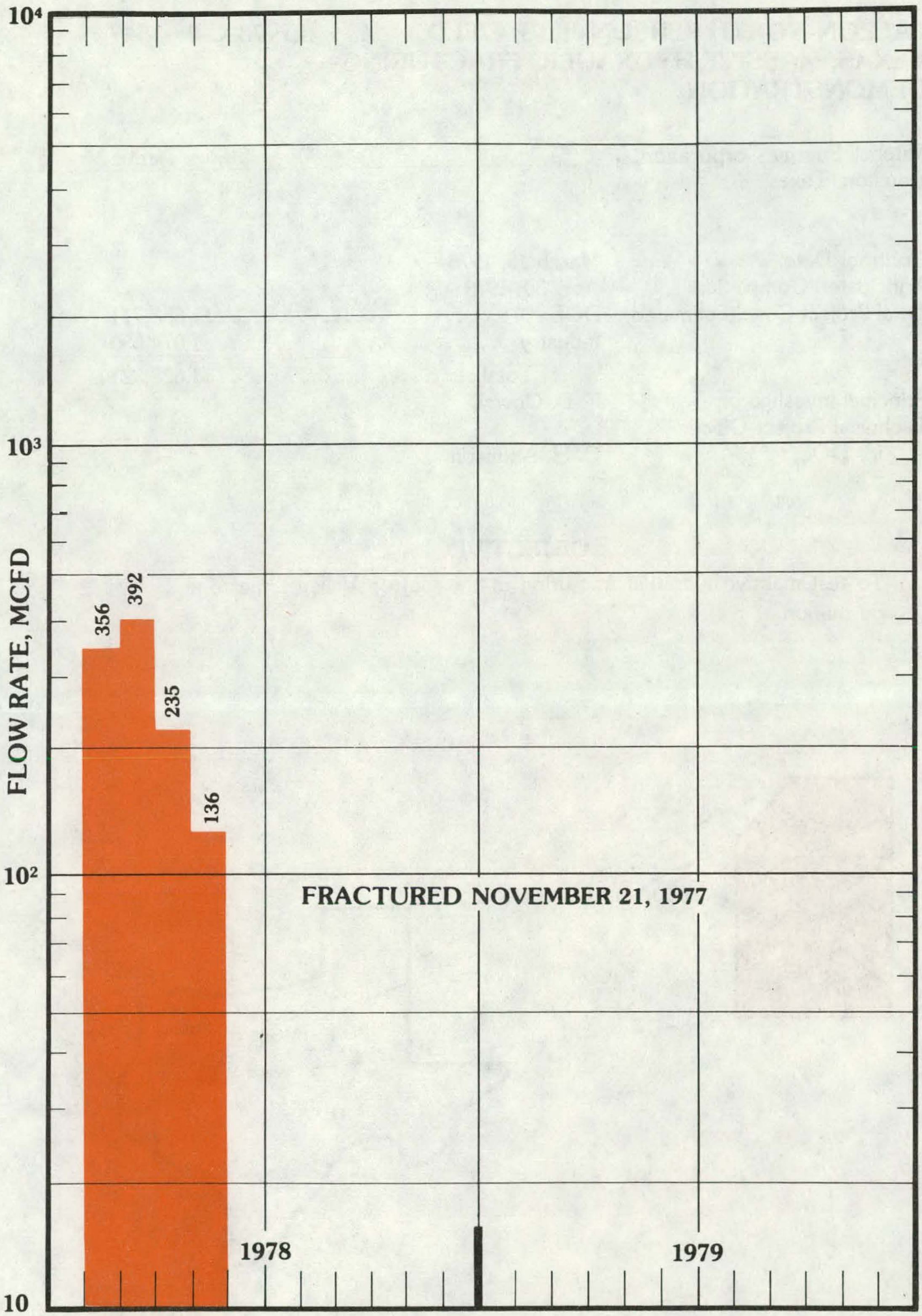


Figure 5-8 Flow Rate Performance of Natural Buttes No. 22 Well

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

EF-78-C-08-1547

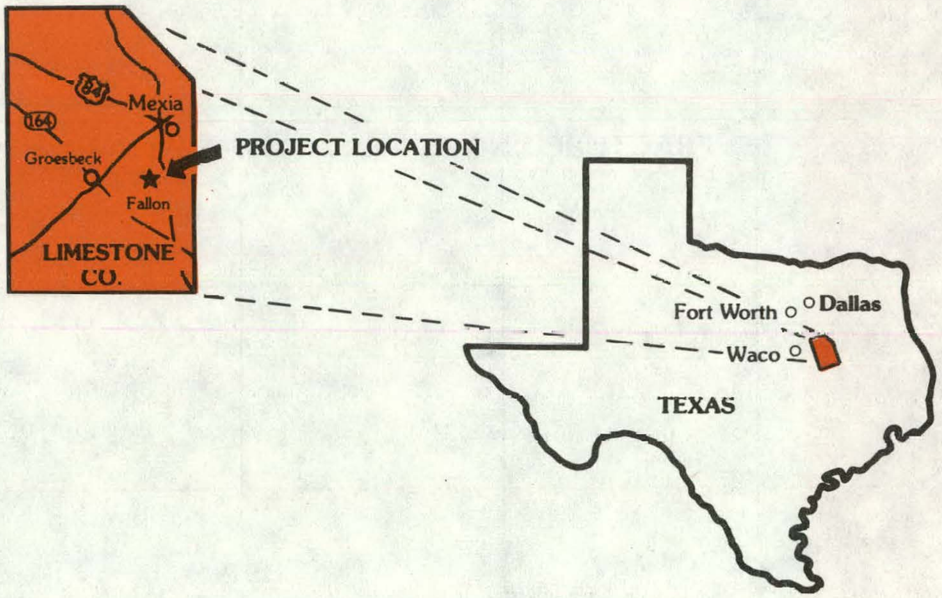
Mitchell Energy Corporation
Houston, Texas

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

5.6.1 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, McGillivary Muse No. 2, treating with MHF and evaluating results.

5.6.2 Current Status

The well was spudded July 8, 1978.

PICEANCE CREEK FIELD, COLORADO, MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

EY-76-C-08-0678

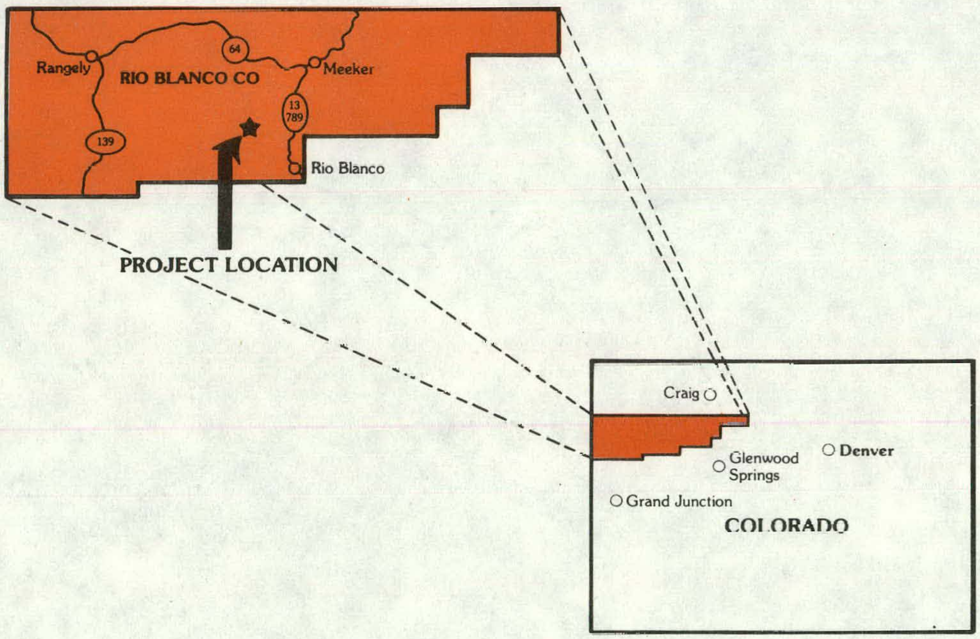
Mobil Research and Development Corporation
Dallas, Texas

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	

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

5.7.1 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. The third MHF treatment was performed in May, 1978.

5.7.2 Current Status

Production From Zones 1-4

The production during the period January 1, 1978 to April 11, 1978 is plotted in Figure 5-9. Based on history match of these data the production rate after one year was projected to be about 600 MCF/day with an average production rate for the first year of about 1 MMCF/day.

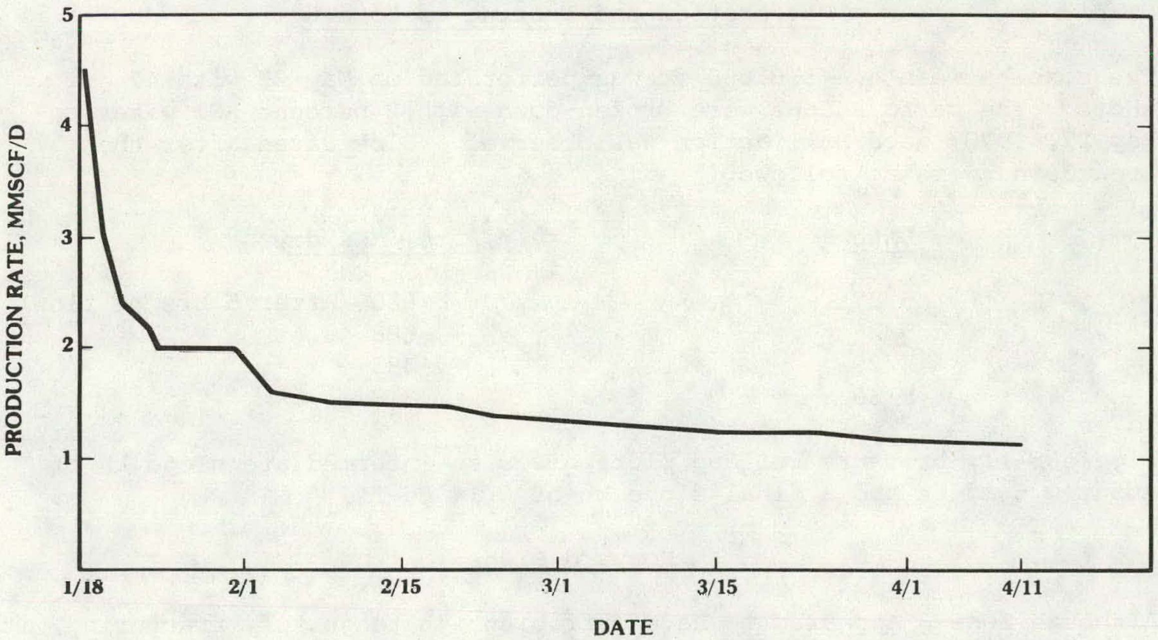


Figure 5-9 Production Rate—Mobil F-31-13G Well, January 18-April 11, 1978

Flow profiles were run in April and the data are shown in Table 5-2.

Fracturing and Testing of Zone 5

The zone from 8,765 to 8,972 ft was fractured May 10, 1978. The treatment was terminated by a screen-out after 388,000 pounds of sand were injected. Cause of the screen-out is thought to be excessive fracture width resulting from increasing pressure during the treatment. The rise in treating pressure probably was associated with rock properties. The treating pressure record is shown on Figure 5-10.

Clean-up of Zone 5 after fracturing was slow. Production data are given in the table below. Although the initial flow rate was less than the initial pre-frac rate, the zone is clearly stimulated by the fracture since the decline rate is much less after fracturing. Because of water slugging, the rates given below are only approximate 24-hour averages.

Date	Flow, MCF/day
5/14	330
5/15	360
5/16	350
5/17	370
5/18	430
5/22	260

Perforation and Testing of Zone 6

The zone between 8,443-8,650 ft was perforated on May 25 with 47 jet shots. The perforations were broken-down with 2 percent KCl water on May 27, 1978; good ball action was observed. Flow rates after the breakdown were as follows:

Date	Rate, MCF/day
5/27	850 (after 5 hrs of flow)
5/28	688
5/29	383
5/30	318

Figure 5-11, pressure buildup plot, gives an intermediate slope kh of about 0.5 md-ft and a final slope kh of 0.14 md-ft.

Forward Plans

Although Zone 6 appeared to have sufficient kh to justify fracturing, it was decided to perforate and test Zone 7 at 8,163-8,372 ft, and then to fracture both zones in one stage. The frac design calls for a 900,000 pound treatment.

Plans are proceeding for remedial cementing and testing of Zones 8 and 9 at 7,700-7,820 and 7,324-7,476 ft. All zones in the well are shown on Figure 5-12.

Table 5-2 Flow Survey Data Comparison — Mobil Well No. F-31-13G

LOG RUN NO. 1 (a) % TOTAL FLOW	DEPTH, FT.	LOG RUN NO. 2 (b) TOTAL FLOW	ZONE NO.	PERFORATION LOCATION, FT.	FRAC DATE
	9100 9120	5-10	4B SAND	9086-9125 32 PERFS	
			4A SAND	9254-9320 33 PERFS	
70	9390 9420 9520	45-70	3B SAND	9392-9432 18 PERFS	8-24-77
15	9520 9530	10-15	3A SAND	9517-9538 16 PERFS	8-24-77
5	10,170				
	10,185	5	ZONE 2-4 SANDS PERFORATED AND TESTED DID NOT MEET REQUIREMENTS FOR FRAC	10,186	
	10,210	5			
5	10,340				
5	10,420 10,425 10,460	5-10 5		10,476	
	10,515 10,535	5			
	10,550 10,560	5-10	ZONE 1-46 PERFS	10,549	6-22-77
	10,600 and below	5-10		10,680	

(a) Run No. 1
Commercial Specimen Flowmeter Log
Temperature Log
Gradiomanometer Log
(b) Run No. 2
Noise/Temperature Log (Mobil)

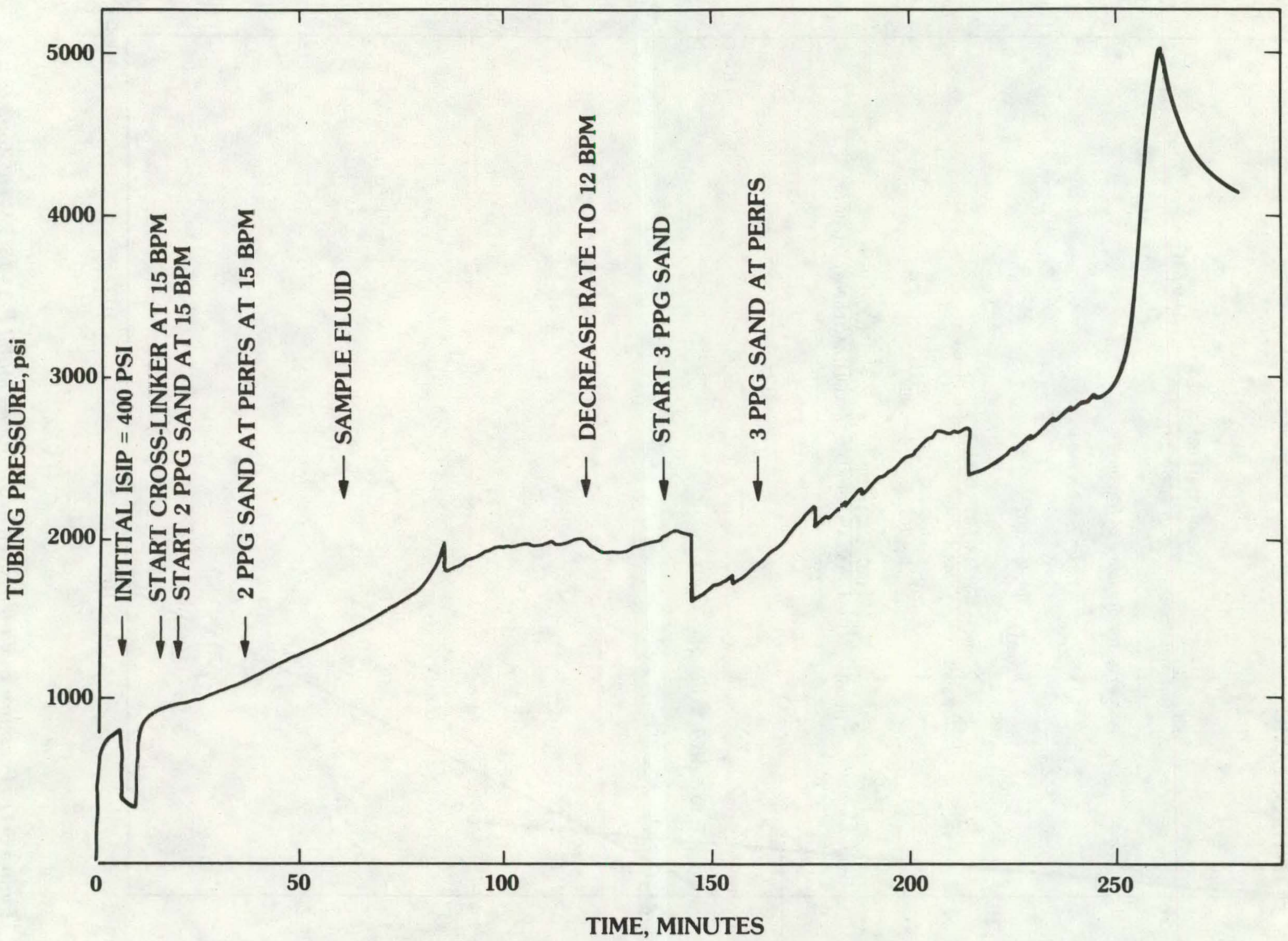


Figure 5-10 Treating Pressure Record, Mobil F-31-13G Well, Zone 5 Frac

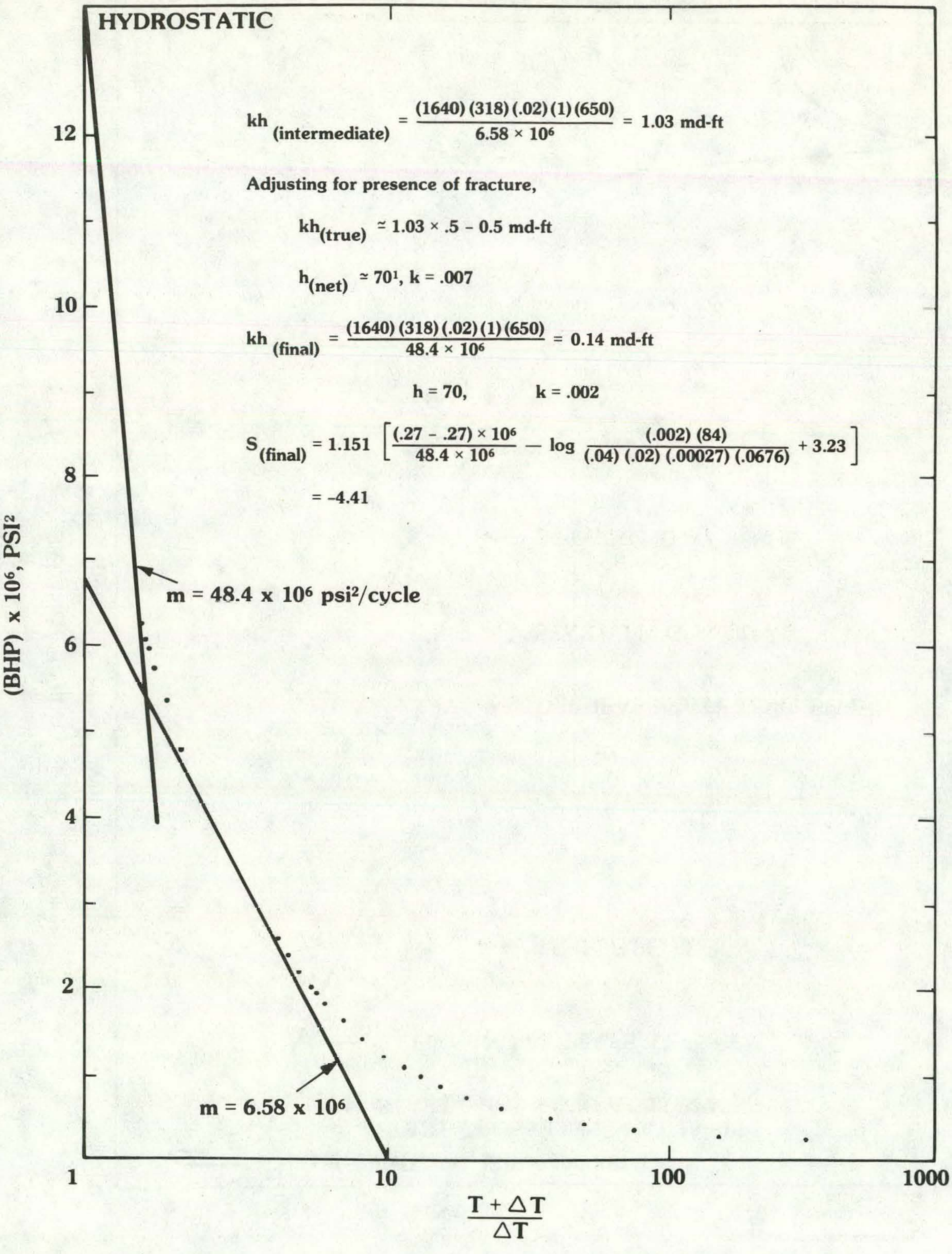


Figure 5-11 Pressure Build-Up after breakdown, Mobil F-31-13G Well, Zone 6

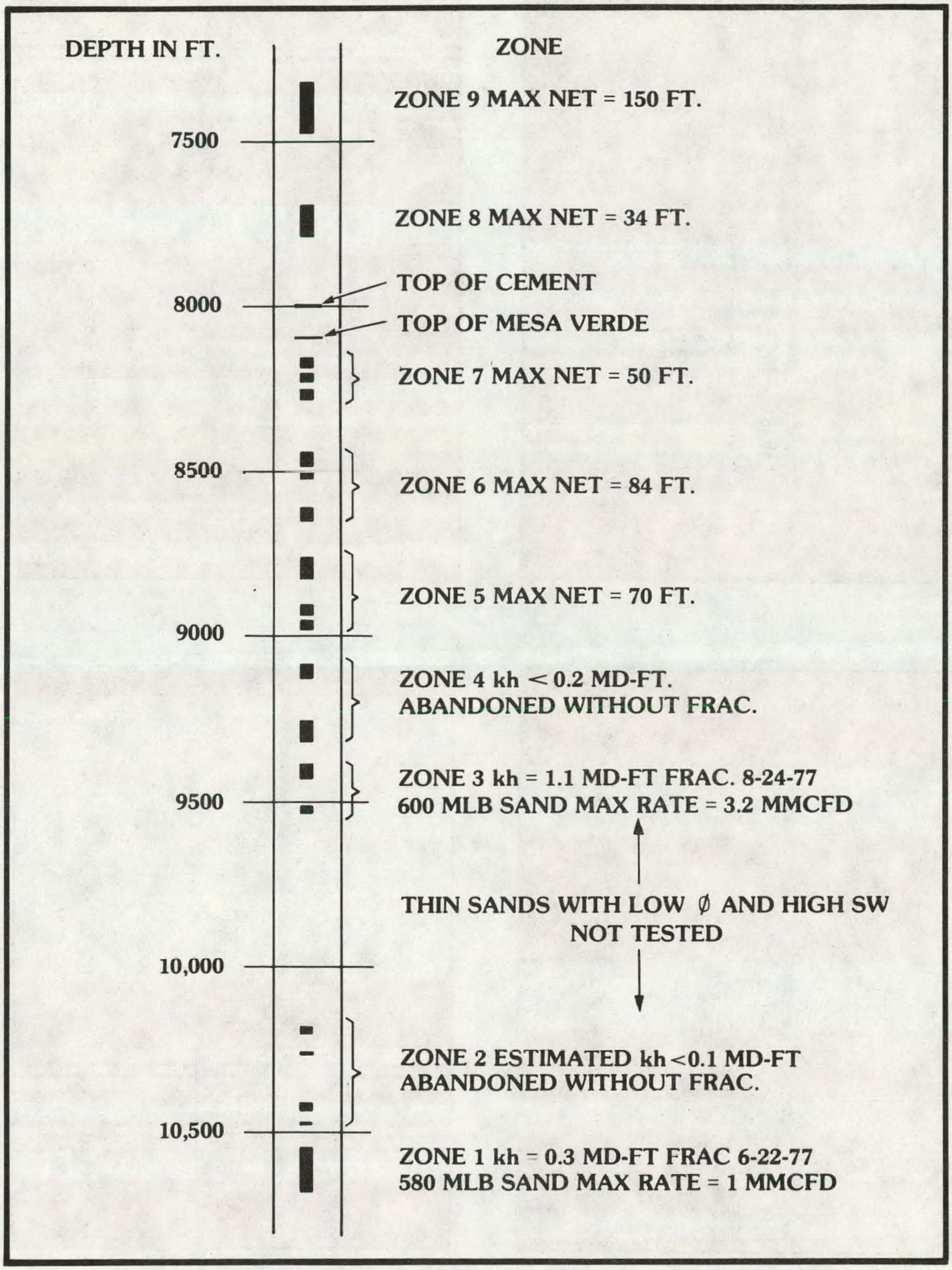


Figure 5-12 Zone Summary, Mobil F-31-13G Well

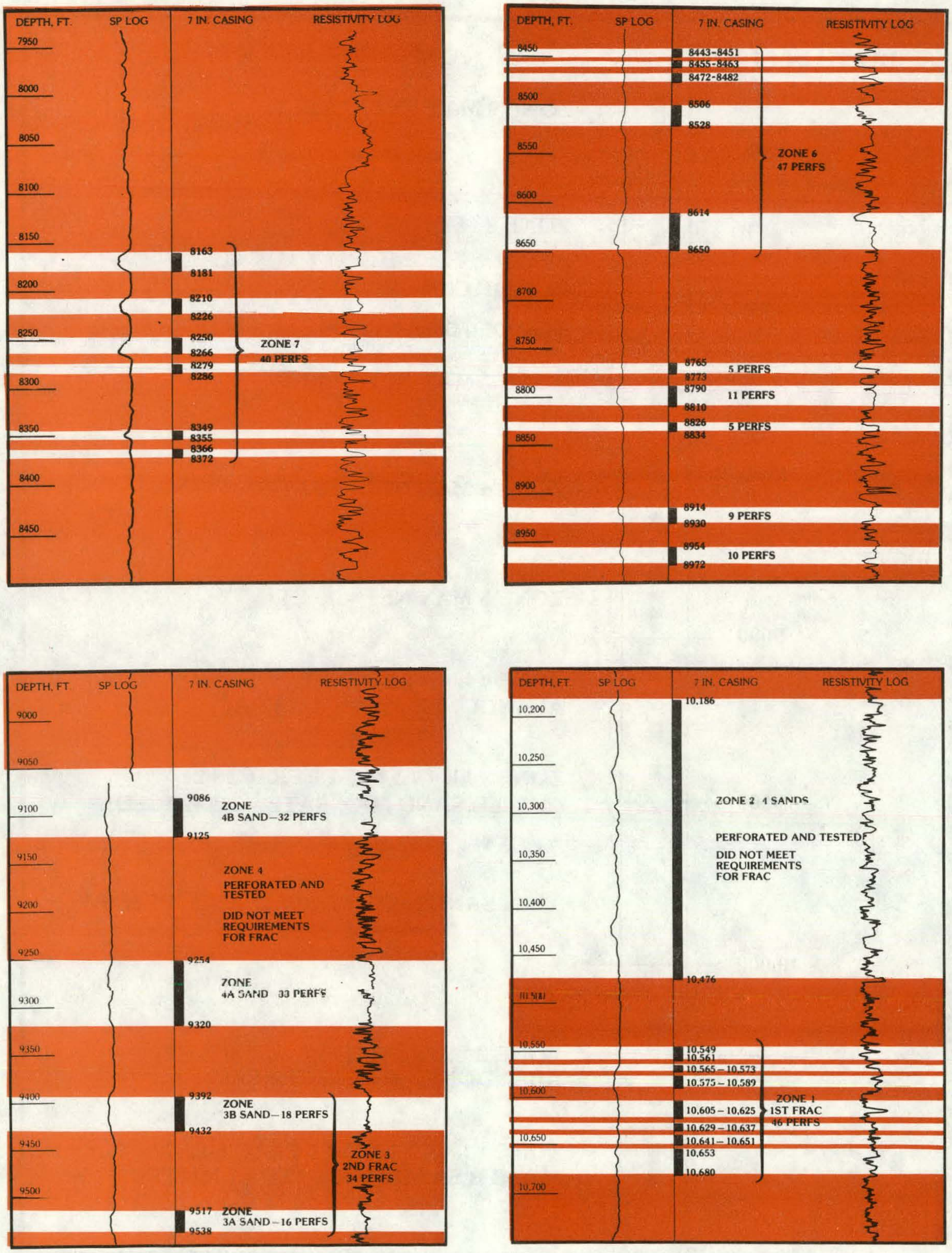


Figure 5-13 Mobil F-31-13G Well showing Sands Fractured

RIO BLANCO COUNTY, COLORADO MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

EY-76-C-08-0677

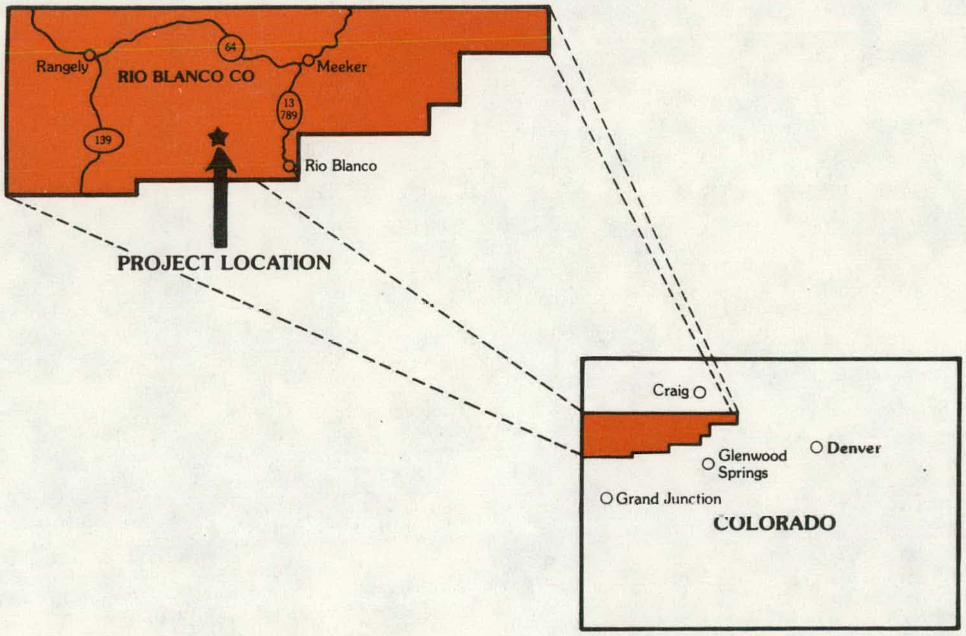
Rio Blanco Natural Gas Company
Denver, Colorado

Status: Active

Contract Date:	August 1, 1976	
Anticipated Completion:	March 31, 1978	
Total Project Cost:	DOE	$ 410,000
	Contractor	593,000
	Total	$1,003,000
Principal Investigator:	Robert E. Chancellor	
Technical Project Officer:	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

5.8.1 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 supplenental agreement, effective October 1, 1977, provided for a second MHF treatment, which was performed on November 30, 1977.

5.8.2 Current Status

Production testing is being resumed.

NEVADA TEST SITE
NYE COUNTY, NEVADA
MINEBACK TESTING

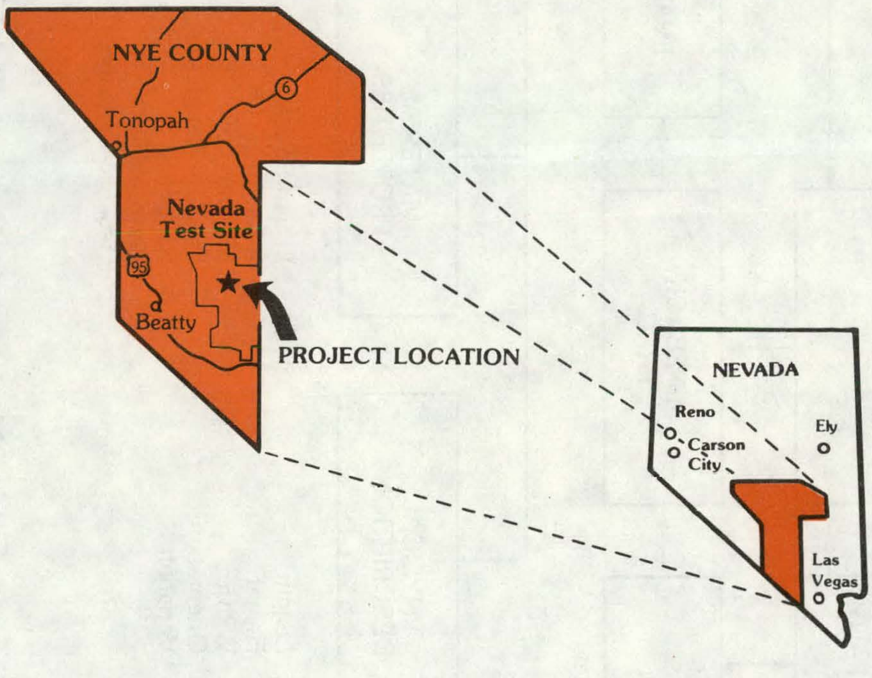
Sandia Laboratories
Albuquerque, New Mexico

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.



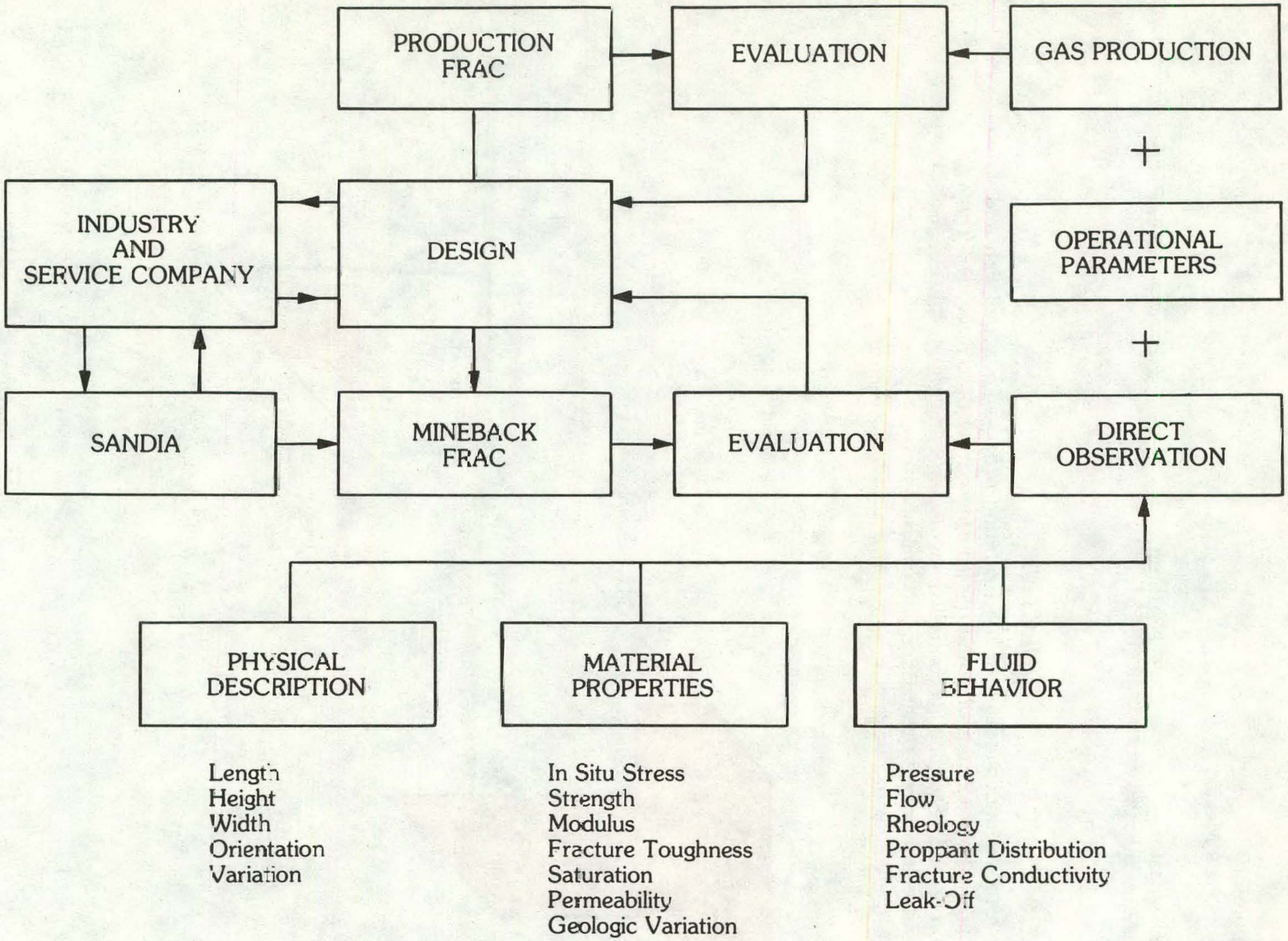


Figure 5-14 Schematic showing the Role of Mineback Testing

5.9 Sandia Laboratories—Mineback

5.9.1 Summary of Past Activities

The objective of the project is to develop an understanding of the fracturing process for stimulation and thereby improve the production of natural gas from low permeability reservoirs. This is accomplished by conducting controlled fracture experiments which are accessible by mineback for direct observation and evaluation. The role of mineback testing is shown schematically in Figure 5-15.

5.9.2 Current Status

The lower fracture of the Hole #6 Formation Interface Fracture Experiment was intercepted in early May. This fracture was initiated in the ashfall tuff below the welded tuff-ashfall tuff interface, and 5,000 gal. of green grout, followed by 4,000 gal. of black grout, were injected into the formation at 6 bbls/min. Although the fracture was designed to create 300 ft wings, at tunnel level the tip of the fracture is only about 90 ft from the borehole.

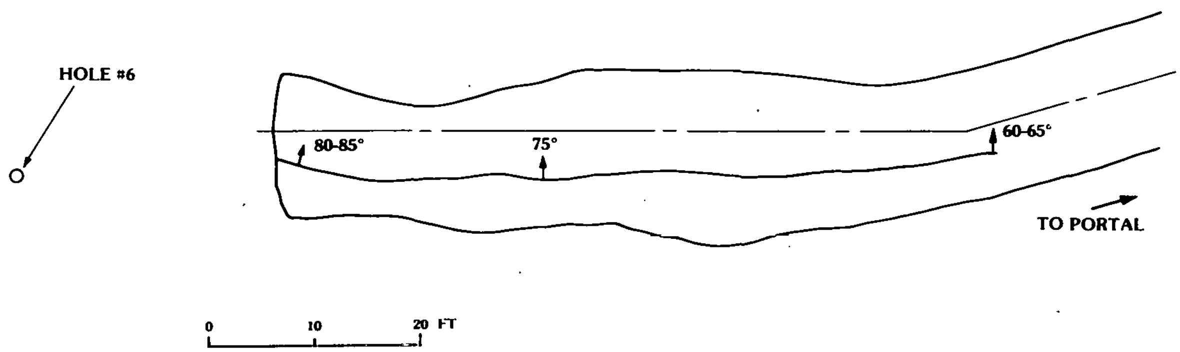


Figure 5-15 EV-6 Planview at 6 ft. above Grade Fracture Dip indicated in degrees

Figure 5-15 shows a plan view of the mineback and the location of the fracture. The location of this region in relation to the tunnel complex is found in Figure 5-16. During May, about 60 ft of the grout-filled frac was uncovered. Occasional stranding is observed but, in general, one prominent fracture is evident. Near the tip of the fracture, the grout is entirely green but, closer to the borehole, black and green grout are both present in distinct, colored laminae. As shows in Figure 5-15, the fracture dips at 60^{o}-65^{o} near the tip of the fracture but is nearly vertical close to the borehole.

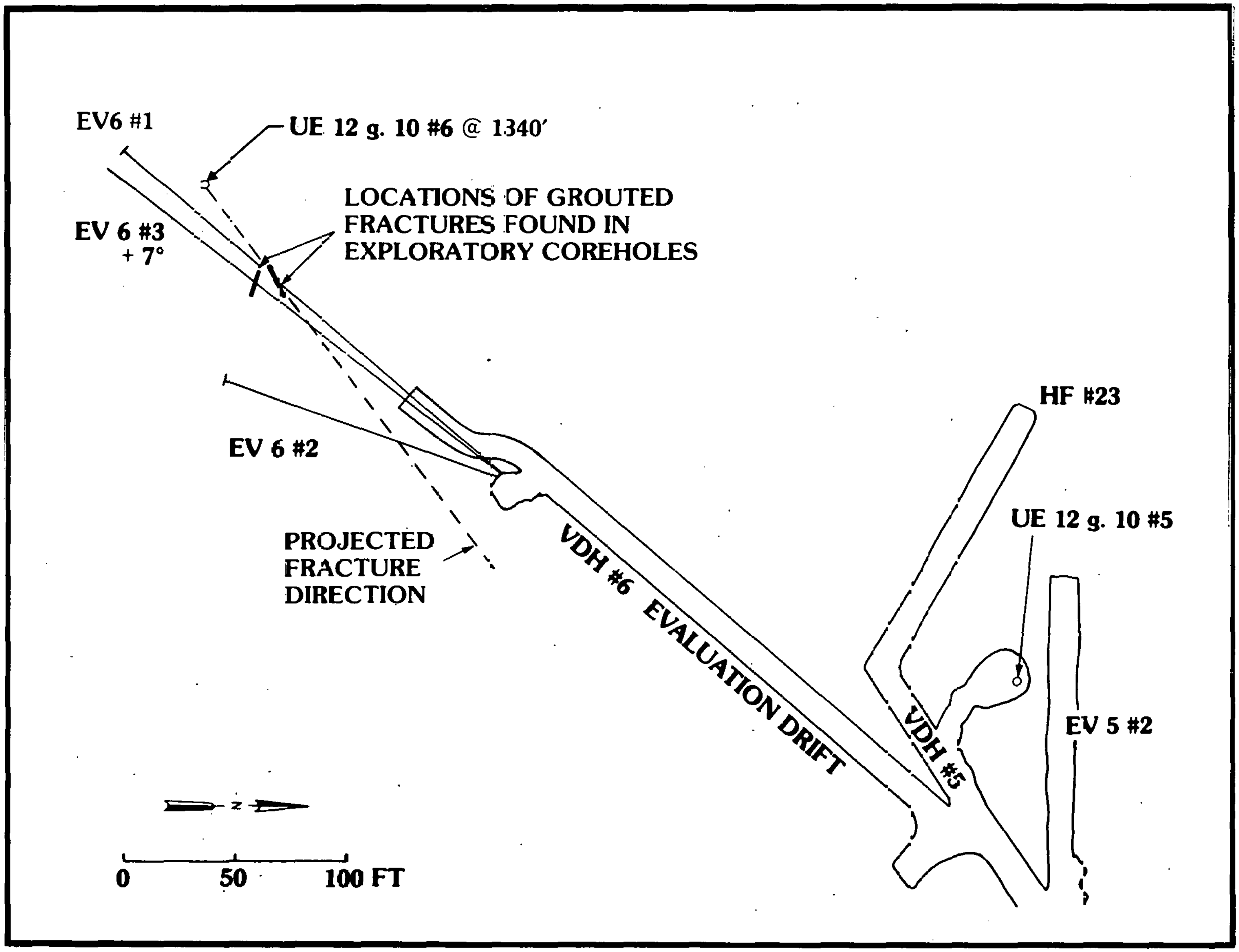


Figure 5-16 Current Mineback Activities, G Tunnel, Nevada Test Site

The mineback is proceeding through the transition zone that separates the densely welded tuff from the ashfall tuff. The ashfall tuff is typically observed in the lower 2-6 ft of the drift. Above the ashfall tuff are distinct ashflow zones having considerably different degrees of welding and number and size of breccia. The very densely welded tuff is a few feet above the back of the drift and the mineback is proceeding at a +5 percent grade to intercept this zone and evaluate fracture behavior there.

At about 20 ft from the borehole, the fracture was 4-10 mm wide and about 6-7 mm average width. Although the fracture does not appear to have been inhibited by the transition region, it does vary in width in the different zones. No evidence of the blue, upper fracture (initiated in the welded tuff) has yet been found. During June, the mineback will advance to the borehole and drill and blast up along the borehole to locate the upper frac and determine its direction. When the mineback is complete, core samples from the different zones will be obtained for material property measurements, and exploratory coring to determine the extent of the fracture will be initiated.

RS-2, a 64 lb high explosive containment experiment, was detonated earlier this year. Although the stemming was blown out of the hole, a cavity was formed and a residual stress field was set up. Small volume hydrofracs were subsequently conducted near the cavity to investigate the stress field and then mined back to determine the orientation of the stresses. The zone nearest the cavity broke down at a very low pressure and exhibited an instantaneous shut in pressure that was $\sim$ 600 psi less than the minimum principal stress normally obtained in this region. The mineback revealed a spherical fracture that partly encircled the cavity. The fracture was in the region where hydrodynamic calculations predict a reduced stress level due to the residual stresses. Figure 5-17 shows a milestone chart of this activity during FY78. Status for these tasks is not available.

C.R. Fast has been retained by Sandia Laboratories as a consultant to the Stimulation and Mineback Experiment Project. His initial trip to view the activities at the Nevada Test Site and discussions with program personnel at Sandia in Albuquerque was held on May 9 and 10, 1978. Subsequently, he provided a supportive critique of the program activities, plans and priorities.

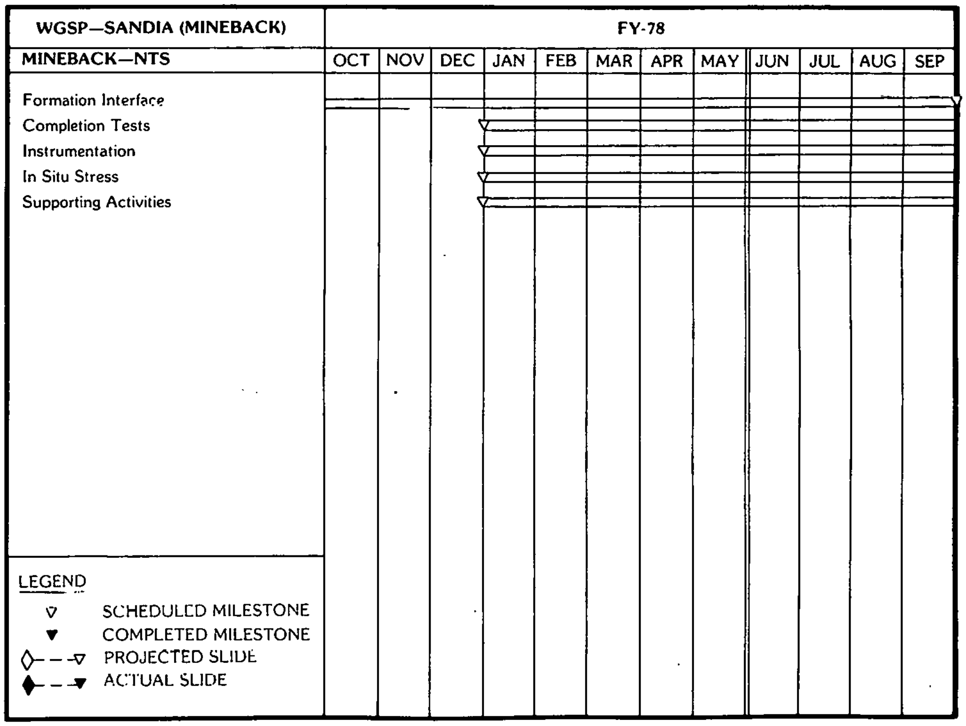


Figure 5-17 Milestone Chart—Sandia (Mineback)
CER CORP.