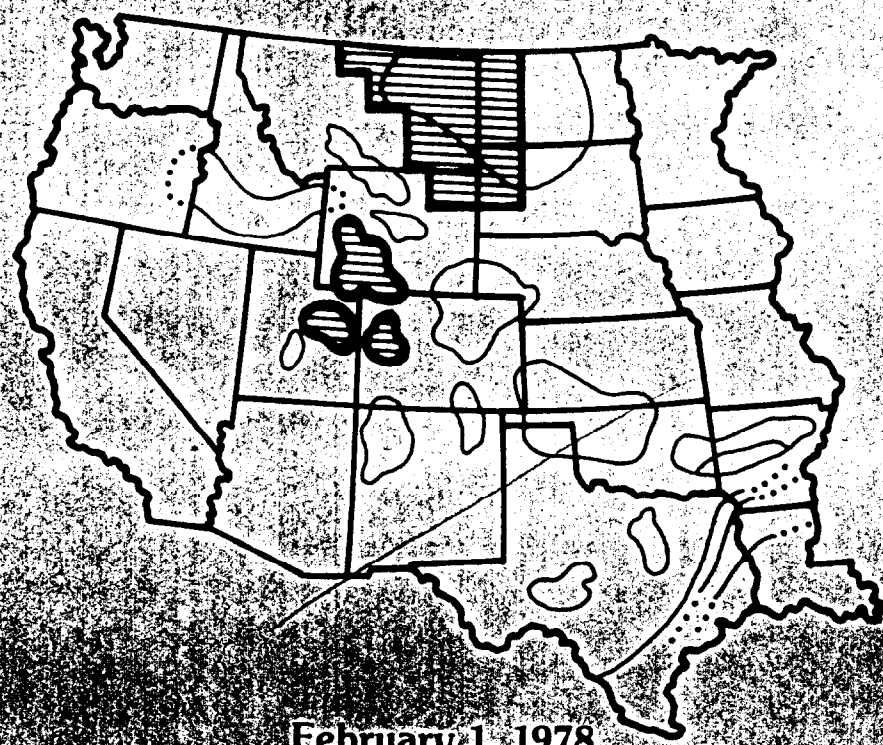
NVO/0655-104

Western Gas Sands Project Status Report



February 1, 1978

USGR FILE #C216/78

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

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States DOE, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

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

		Page
1.	SUMMARY	1
2.	PROJECT MANAGEMENT	3
3.	RESOURCE ASSESSMENT	5
	3.1 U.S. Geological Survey Activities	5
	3.2 Coring Program	6
	3.3 Study of Basin Activities	6
4.	RESEARCH AND DEVELOPMENT BY ENERGY RESEARCH CENTERS AND NATIONAL LABORATORIES	11
	4.1 Bartlesville Energy Research Center (BERC)	11
	4.2 Lawrence Livermore Laboratory	12
	4.3 Sandia Laboratories	14
	4.4 U.S. Geological Survey Borehole Gravity Meter	21
	4.5 U.S. Geological Survey/Menlo Park - Tiltmeter	21
5.	FIELD TESTS AND DEMONSTRATIONS	25
	5.1 Background	25
	5.2 CER Corporation	29
	5.3 Colorado Interstate Gas Company	31
	5.4 Gas Producing Enterprises, Inc.	33
	5.5 Mobil Research and Development Corporation	41
	5.6 Rio Blanco Natural Gas Company	45

FIGURES

		Page
FIGURE 3-1	TARGET BASINS WITH WELLS OF INTEREST LOCATED	7
FIGURE 4-1	PLOTS OF CHANGE IN SURFACE POTENTIAL IN A TWO HOUR PERIOD	15
FIGURE 4-2	TIME HISTORY OF THE SURFACE POTENTIAL ON A TYPICAL RADIAL	17
FIGURE 4-3	CURRENT MINEBACK ACTIVITIES, G TUNNEL, NEVADA TEST SITE	20
FIGURE 5-1	FLOW RATE PERFORMANCE OF NATURAL BUTTES NO. 14 WELL	34
FIGURE 5-2	FLOW RATE PERFORMANCE OF NATURAL BUTTES NO. 18 WELL	35
FIGURE 5-3	FLOW RATE PERFORMANCE OF NATURAL BUTTES NO. 19 WELL	36
FIGURE 5-4	FLOW RATE PERFORMANCE OF NATURAL BUTTES NO. 20 WELL	37
FIGURE 5-5	NATURAL BUTTES NO. 20 WELL SHOWING SANDS FRACTURED .	38
FIGURE 5-6	MOBIL F-31-13G WELL SHOWING SANDS FRACTURED	42
FIGURE 5-7	RIO BLANCO NATURAL GAS FEDERAL 498-4-1 WELL SHOWING SANDS FRACTURED	46

TABLES

TABLE 5-1	MHF CONTRACT LOCATIONS AND FRAC DATA	26

1. SUMMARY

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

A "Draft for Comment" document, containing input from the participants in the core acquisition and analysis program has been distributed. The document will be used to prepare for a core program meeting to be held on January 25, 1978 at CER Corporation's office in Las Vegas, Nevada. When completed, the document will be incorporated in the FY 78 Project Implementation Plan.

The Quarterly Basin Activities Report and the Project Status Report, January 1, 1978 , have been printed and are being distributed. The Project Plan Document FY 78 is being reviewed by DOE in Washington, D.C. and will be finalized in early 1978.

Project files which contain raw data and published reports from each Western Gas Sands Project contractor are being established.

The USGS is continuing geological and geophysical studies in the four major western basins to better characterize the resource base. Shipping arrangements for the core donated to the USGS by Inexco WASP (a well drilled for possible nuclear explosive stimulation in Wyoming) have been made, and cores for macrofossil and ostracode analysis from the Bowdoin Dome area have been collected.

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

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

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

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

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

Colorado Interstate Gas Company has initiated activity on its project with the installation of equipment, and Mitchell Energy Company's proposal to conduct an MHF test in the Cotton Valley lime gas reservoir in Texas is nearing the contract negotiation stage.

2. PROJECT MANAGEMENT

The core aquisition and analysis program, developed from input for core requirements and analysis capability of the participants, was assembled into a "Draft for Comment" document and has been distributed to the participants in preparation for a coordination meeting to be held January 25, 1978 at CER Corporation's office in Las Vegas, Nevada.

The Project Plan Document FY 78 is being reviewed in Washington and is expected to be finalized in early 1978. The Quarterly Basin Activities Report has been printed and is being distributed. The Project Status Report, dated January 1, 1978, is being printed and will be in distribution shortly. Work is proceeding on the Project Implementation Plan. The Oil and Gas Journal, dated January 16, 1978 contained a technical paper by J.A. Short, Northern Region Production Manager for Gas Producing Enterprises Inc. The paper presents the results of Gas Producing Enterprise's MHF stimulation of the low permeability Wasatch and Mesaverde Sands in the Uinta Basin. GPE's wells have been much more successful than earlier conventional completions which generally resulted in uneconomic production.

Mitchell Energy Company's proposal to conduct a MHF test in the Cotton Valley lime gas reservoir in Texas has been approved and contract negotiations are to commence shortly.

Files which will contain raw data and published reports on each Western Gas Sands Project contractor task are being established.

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

3.1.1 Greater Green River Basin

Shipping arrangements have been completed for the core donated to the USGS by Inexco WASP from the Wyoming Atomic Stimulation Project well drilled in 1969 as a candidate for nuclear explosive stimulation. Approximately 43,000 lb of core will be slabbed and sampled beginning in February.

C.W. Spencer made a presentation on petroleum exploration and oil and gas resource assessment to 30 U.S. Forest Service (USFS) rangers and supervisors. The USFS is making a study of all roadless forest areas in the United States; the Bridger-Teton Forest in particular. The potential for tight and near-tight gas resources underlying Forest Service land was explained.

Work is continuing on the correlation of well logs to construct cross sections.

A Washakie Basin cross section is in review prior to open-filing. Core analysis, X-ray data, descriptions, and photographs of eleven Mesaverde cores from the area are also in review.

Forest Oil is collecting selected drill cuttings from its wildcat well in T22N, R106W, Sweetwater County, Wyoming, for geochemical analysis.

3.1.2 Northern Great Plains Province

The open-file report entitled, Lineament Map of Western South Dakota by G.W. Shurr has been prepared. The recent gas discovery by Jerry McCutchin in Section 17, T16N, R2E, Harding County, South Dakota, lies on a build-up of Eagle (Shannon) sandstone along a lineament mapped from LANDSAT images.

Contracts were made with the South Dakota State Geological Survey concerning the study of Niobrara (chalk) core and the possibility of shallow coring near recent Eagle (Shannon) discoveries.

The USGS has collected core for macrofossil and ostracode analysis from the Bowdoin Dome area in north-central Montana. Organic carbon analyses of 300 core samples from the Bowdoin Dome area in north-central Montana, have also been received.

A report entitled Basic Data Tabulation of Tertiary and Cretaceous Oil and Gas Fields of Montana, North and South Dakota: by W.W. Mallory, has been completed.

3.1.3 Uinta Basin-Piceance Basin

The USGS has continued to obtain outcrop and well log data to facilitate correlation of rock, engineering and geophysical data from the Wasatch Plateau, an uplifted area, to the southeast Uinta Basin. The collecting and posting of engineering data and its relation to geophysical logs in areas of low permeability reservoirs in the Uinta and Piceance Basins will continue. There will be continued analysis of the characteristics of rocks related to or a part of the units containing "tight" reservoirs in the Uinta Basin outcrop sections.

Preparation of a chart relating stratigraphy, age, rock type, engineering and other data between the Altamont Oil Field and the low permeability gas reservoirs in the southeast Uinta Basin is continuing. A plan is being discussed to release the results as a USGS open file chart in about three months.

Petrographic analysis of core from areas of the Rio Blanco unit in the Piceance Basin has begun.

3.2 Coring Program

The core aquisition and analysis program, developed from input contributed by the participants, was assembled into a "Draft for Comment" document. This document has been sent to the participants of a core planning program to be held at CER Corporation's office in Las Vegas, on January 25, 1978.

Priorities and procedures will be established for core distribution and a report will be issued outlining the aquisition, handling, distribution, and analyses to be made of the cores. Regional sites will be identified in this report with specific site selection dependent upon negotiations with individual operators in the areas of interest.

3.3 Study of Basin Activities

Drilling and testing activities in the four main study areas are being monitored continuously. Figure 3-1 indicates the four areas and shows

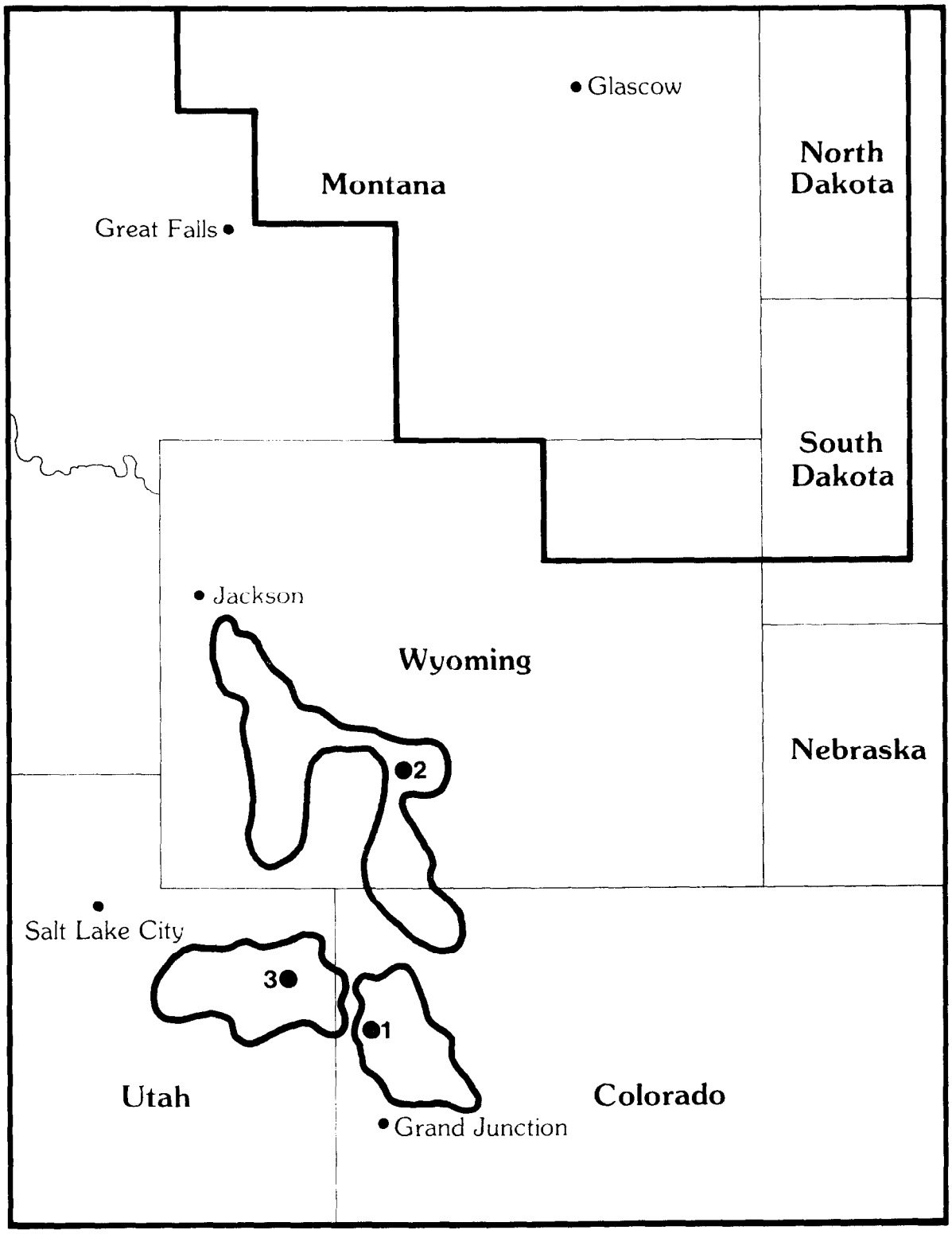


FIGURE 3-1 TARGET BASINS WITH WELLS OF INTEREST LOCATED

CALLOUTS

Callout 1

Continental Oil
17 Douglas Creek Unit
Sec 35, T2S, R102W
Rio Blanco County, Colorado
Mancos B Production (1,938-2,311 ft gross)
Development Gas Well
Frac: 19,400 gal emulsion, 24,800 lbs sand
IPF: 860 MCFD

Callout 2

Terra Resources
7-16 State
Sec 16, T27N, R99W
Sweetwater County, Wyoming
Commingled Lewis (3,522-3,533 ft) and Almond (4,280-4,484 ft gross) production
Development Gas Well
Frac: 53,000 gal emulsion, 21,000 lbs sand
IPF: 1,500 MCFD

Callout 3

Belco Petroleum
32-21 Chapita Wells Unit
Sec 21, T9S, R22E
Uintah County, Utah
Wasatch Production (5,470-6,388 ft gross)
Development Gas Well
Frac: 119,000 gal emulsion, 132,000 lbs sand
IPF: 1,270 MCFD

locations of recent wells of interest to the Western Gas Sands Project, with numbered callouts. The following paragraphs give a brief account of the activity in each basin study area. A detailed quarterly report is being compiled which will include pertinent drilling and testing information for the months of January, February and March in each area of study.

3.3.1 Piceance Basin

Rio Blanco County, Colorado is the site of the most extensive drilling activity in the Piceance Basin. Garfield County and the northern half of Mesa County also have drilling operations of interest to the WGSP.

Tipperary Oil is responsible for most of the Mancos Zone testing in the western portion of Garfield County. Rio Blanco County activity is focused in the Cathedral, Dragon Trail, Lower Horse Draw, Douglas Creek and Thunder Fields, all on the Douglas Creek Arch in the western part of the county. Currently there are about 50 tests scheduled or ongoing in the Mancos Zones.

A test of significance by Continental Oil has recently been completed in the Douglas Creek Field for an initial production of 860 MCFD from the Mancos "B" Zone. This well was sand and emulsion fractured (callout 1). The Wasatch Formation in central Rio Blanco County is becoming increasingly important. Mobil Oil has staked eight Wasatch tests in the Piceance Creek Field. This represents a significant increase in the number of Wasatch tests over last month, and fracture treatment of these wells will be monitored and evaluated for application in the WGSP. To the north, in Powder Wash Field, there are four more such tests by American Resources Management.

The activity in Mesa County is concentrated in the Plateau Field where Flying Diamond and Adolph Coors are currently the most active operators. Objective horizons are the Corcoran, Cozzette and Rollins Formations of the lower Mesaverde-Mancos transition zone.

3.3.2 Greater Green River Basin

Sweetwater County, Wyoming is the most productive area in the Greater Green River Basin. It is currently the site of the most extensive drilling and testing operations. However, there is also important activity in Carbon, Sublette and Lincoln Counties. The objective in Carbon County is the Mesaverde Group, primarily the Ericson and Almond Formations. In Lincoln and Sublette Counties the main production goal is in the Frontier Formation. In the southeastern part of the basin, the Sand Wash sub-basin of Moffat County, Colorado, the main objectives are Mesaverde, Lewis and Ft. Union zones.

In Sweetwater County alone there are approximately 70 tests drilled to the Mesaverde Group. The Frontier and Lewis Formations are also significant objectives in this locale. The Terra Resources well (callout 2) shows the potential of the area. It is producing 1,500 MCFD from commingled completions in the Lewis and Almond Formations, after stimulation by a sand and gel fracture treatment.

3.3.3 Northern Great Plains Province

The drilling activity in the Northern Great Plains Province is being monitored with increased interest this month because the USGS has recommended four sites in Montana to be cored during the WGSP coring program. These areas appear to have potential for large-scale development of shallow tight Upper Cretaceous gas sands.

The major areas of activity continue to be the Bowdoin Dome of Phillips and Valley Counties and the Bearpaw Arch of Blaine, Chouteau and Hill Counties.

However, extremely severe winter weather, which began in mid-November and continues to date, has kept drilling operations at a near standstill level. Significant new developments include the staking of fourteen locations by Odessa Natural in the Bowdoin Field, Phillips County. Joseph J.C. Paine and Associates and Shenandoah Oil are also active in the vicinity of Bowdoin Dome. Directly west, in Blaine County, Tricentrol United States is active in the Tiger Ridge and Sherard Fields. Fuel Resources Development has nine tests scheduled in the Leroy Field located in the southern part of the county.

3.3.4 Uinta Basin

Drilling activity in the Uinta Basin of immediate interest to the WGSP is focused in the Natural Buttes area of Uintah County. Operators include Belco Petroleum, C.I.G. Exploration/GPE (both subsidiaries of Coastal States Gas Corporation), and Continental Oil. The principal objectives are the Mesaverde Group and Wasatch Formation. The Mancos Zone is currently being tested by C.I.G. Exploration/GPE in the Natural Buttes Field. Belco Petroleum recently completed a gas well which is considered typical of the better Wasatch producers in the Basin. The well, located in the Chapita Wells Unit of the Natural Buttes Field is producing 1,270 MCFD after being sand-emulsion fractured (callout 3).

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

4.1 Bartlesville Energy Research Center (BERC)

4.1.1 Improved Pressure Coring System

Maurer Engineering, Inc., the subcontractor, has begun the design work. Further testing of the non-invading gel, Dow Corning 200, was stopped temporarily while an additional supply was ordered. A seal failure on a core test rig stopped other tests and has resulted in the test set-up being redesigned. Drilling tests with the prototype corehead are now ready to be performed.

4.1.2 Measurements of Formation Characteristics for Western Tight Gas Sands

Contacts with certain educational organizations regarding measurements of formation characteristics have disclosed an academic interest in research instead of service. It appears that the formation characteristics will have to be determined by an industrial laboratory. The selection of a contractor is underway.

4.1.3 Interface Conductivity Effects on Electric Logs

The equipment and system design phase has been essentially completed. The designs show the valves and pressurized containers necessary to operate the systems in an efficient manner, including provisions to easily change pore fluids and to remove most of the air.

Modifications to the pressure vessel end plug, the Teflon insulating core support, and two stainless steel core end pieces, were completed. Three electrically-insulating Conax glands were obtained to carry conductance and thermocouple signals from the pressure vessel.

4.1.4 Mapping and Contouring Formation Water Resistivity

Over 500 water analysis reports were tabulated and given cursory examination with regards to resistivities and solids concentrations in various fields throughout the Uinta Basin. Preliminary base maps for the Uinta Basin and background geologic reports have been accessed.

4.1.5 Logging Techniques and Interpretations

A proposal from Texas A & M to study density, neutron and acoustic measurements on cores recovered in the Western Gas Sands Project is under consideration. This also involves the study of acoustic, density and neutron logs of western tight gas sands in order to develop understanding of the interpretation techniques for application to specific information.

A survey and critique of techniques to measure water resistivity has been proposed by Sandia and is under consideration.

4.1.6 Rock-Fluid Interaction

Initial assembly and testing of equipment components has been initiated.

Two high-pressure, low volume minipumps and a 50-ton hydraulic lab press were ordered to complete the system for proppant conductivity experiments. Halliburton Service Company has supplied several proppant samples and has agreed to supply fracturing fluid samples.

4.2 Lawrence Livermore Laboratory

4.2.1 Theoretical and Experimental Model Development and Application

The two-dimensional numerical hydraulic fracturing model, modified to allow expansion of the calculational grids near the boundary, and to reduce computer storage and time requirements, has been applied to analyze the effects of increases in pore pressure caused by the fracturing fluid migrating from the fracture into the surrounding medium. Results indicate that as the pore pressure surrounding the fracture increases, the stress concentration factor in the tip region decreases.

The current laboratory experiments and the experiments reported previously indicate the need to analyze crack penetration across a boundary which has no inherent strength. Crack penetration across a boundary of this type occurs because of friction along the boundary. Therefore, to analyze this type of phenomena, the models used must be able to treat the frictional effects along the boundary in a realistic way. The model should also treat the dynamics of the crack propagation phenomena and stress waves associated with it.

Frictional effects have been included in previous calculations but were not successful in adequately eliminating numerical interference in the results, a necessity for studying the frictional stick-slip processes.

This problem was eliminated by improving the representation of the inertial effects. A distributed mass matrix, a matrix which depends on the basic displacement function of an element, was derived for the finite elements and used to find nodal accelerations at each time step. This method replaces the old lumped mass matrix, a diagonal matrix formed by geometrically assigning mass to the nodes. The new method greatly improves the smoothness in the results of test calculations.

The effects of a layer on the surface deflection properties near a vertical hydrofracture are still being studied. However, the coding to determine the effects of multi-layers on surface deflections has been set aside temporarily. Instead, the single layer problems are being redone with the new grid which reduces the boundary effects. Alterations to the static finite element elastic model allow expansion of the grid boundaries. These modifications have been performed on the elastic flow model for application to the hydrofracturing model being put into the layer model for hydrofracture studies. The coding has been completed and debugged. Some calculations are required to determine the correct boundary expansion to use to strike a balance between accuracy of the solution near the hydrofracture and elimination of the boundary effects of the grid. These calculations are currently underway.

4.2.2 Experimental Program

During the month of December, a series of hydraulic fracture tests were performed using the new high pressure pump system. The material tested was dry Indiana limestone. The purpose of the tests was to observe under what conditions a crack would cross an unbonded interface under a normal load. Two types of surface finishes were used for the interfaces. One finish was a smooth machined surface, and the other was a surface roughened by sandblasting. No conclusions could be drawn as to the effect of surface finish on crack growth across the interface from this set of experiments. However, the experiments did indicate that the fluid pressure at which the crack initiates determines whether the crack does or does not cross an interface at a given normal interfacial stress. More experiments of this type are planned to further investigate these phenomena.

A series of laboratory hydraulic fracturing experiments was performed in a tri-axial test cell to (1) establish the effect of vertical stress on the direction and inclination for a set condition of horizontal stresses, and (2) determine the minimum difference between the two principal horizontal stresses for which hydraulic fractures cease to be randomly oriented and become aligned with the maximum horizontal stress direction. This experimental program has been pursued to the point where 23 tests of Montello granite were performed to determine

the effect of vertical stress magnitude on hydraulic fracture direction and 31 tests were performed to investigate the effect of the differences in the horizontal stresses ($\sigma_{Hmax} - \sigma_{Hmin}$) on the orientation.

It was found that if the vertical stress is less than the least horizontal stress, there is a good probability that the hydraulic fracture, which initiates vertically at the borehole will rotate and become horizontal as it extends. In the second set of tests, with the vertical stress greater than σ_{Hmin} the hydraulic fractures were vertical and parallel to σ_{Hmin} so long as $\sigma_{Hmax} - \sigma_{Hmin} > 75$ psi. This attests to the sensitivity of the hydraulic fracture direction to the principal of the path of least resistance.

4.2.3 Equation of State Measurements

Southwest Research Institute has experienced problems acquiring certain critical components for the Dry-Hole Sonic Logging Tool. There also has been some delay in completing the required machining. Expected delivery date is now March 1, 1978.

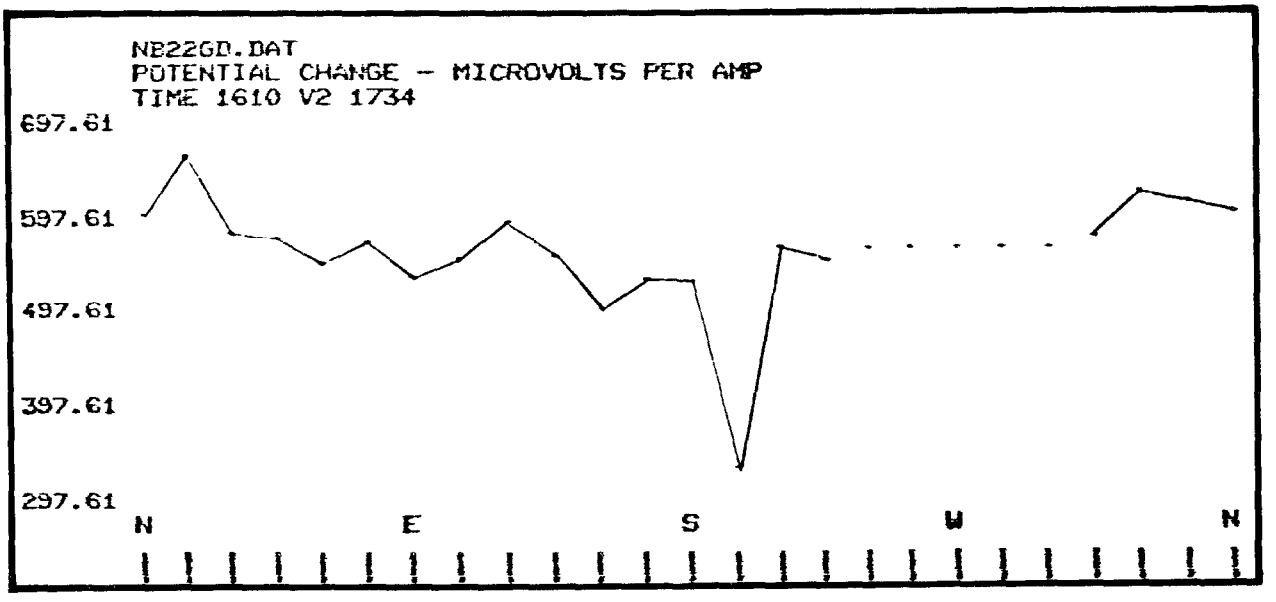
4.3 Sandia Laboratories

4.3.1 Hydraulic Fracture Mapping - Natural Buttes #22

Sandia Laboratories (Division 5733) participated in a MHF experiment on Gas Producing Enterprise's well Natural Buttes No. 22 southeast of Vernal, Utah, on November 21, 1977. The experiment, designed to create fractures through perforations at depths between 5,800 and 8,500 ft used a total of 13,135 BBL of fluid pumped at a rate of approximately 50 BPM.

Surface potential measurements were taken at two minute intervals during the experiment. Extremely rugged terrain prevented the installation of potential measurements in a 75° sector west of the well. Plots of change in surface potential for a typical two hour period are shown in Figure 4-1. The data fails to indicate that a fracture of definite orientation or significant length was produced.

Figure 4-2 is a time history of the surface potential on a typical radial. During the early period of pumping, the surface potential had a wider dispersion than has been observed on previous hydrofracture experiments. Also there was a large increase in surface potential at approximately 1610 hrs. This abrupt increase in surface potential has never been observed during normal pumping on previous hydrofracture experiments. Also, model calculations indicate that surface potentials should decrease during the growth of a hydrofracture. The reason for these discrepancies is not understood and has not been modeled.



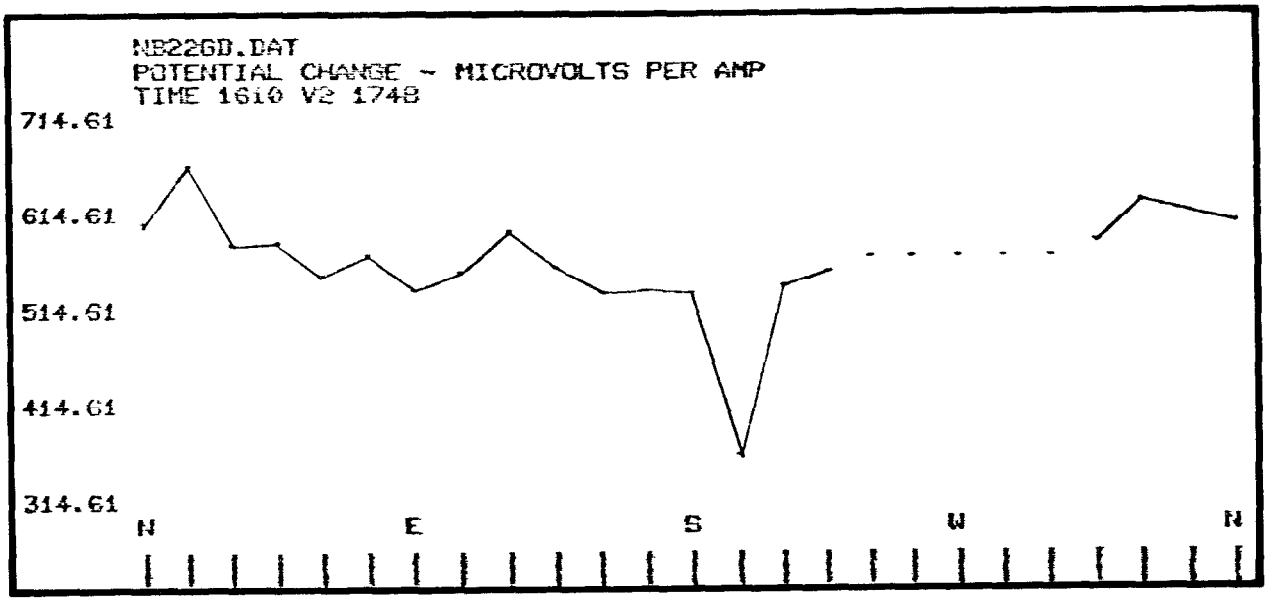
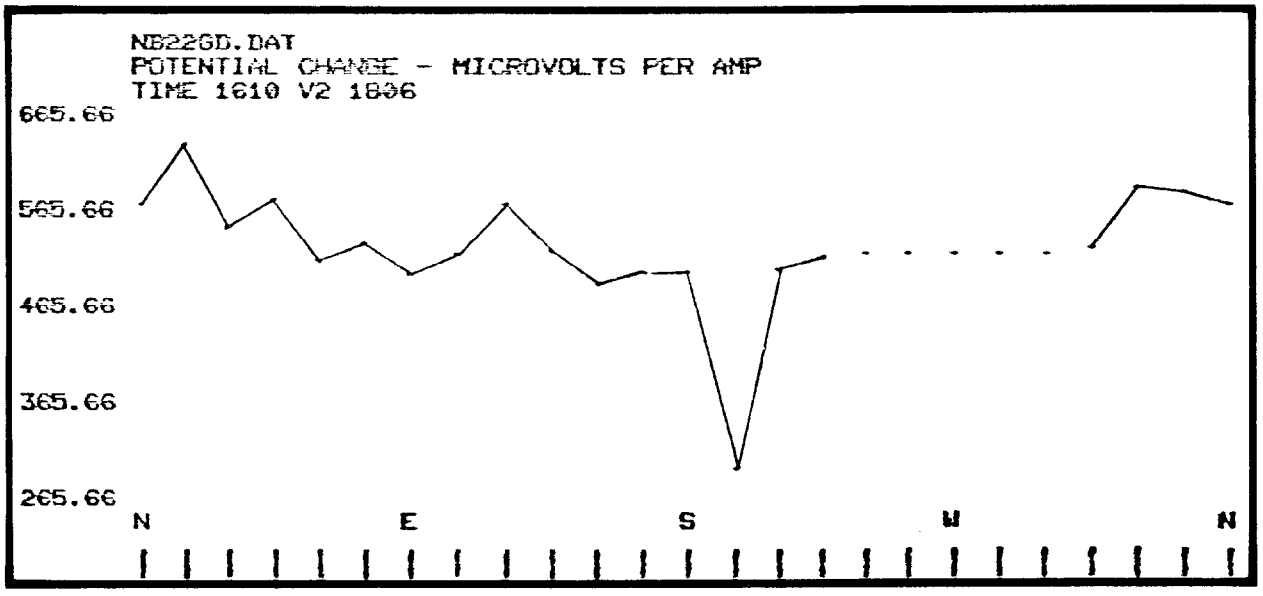


FIGURE 4-1 PLOTS OF CHANGE IN SURFACE POTENTIAL IN A TWO HOUR PERIOD


NB22GD.DAT
POTENTIAL CHANGE - MICROVOLTS PER AMP
TIME 1610 V2 1806
665.66
565.66
465.66
365.66
265.66
N
E
S
W
N

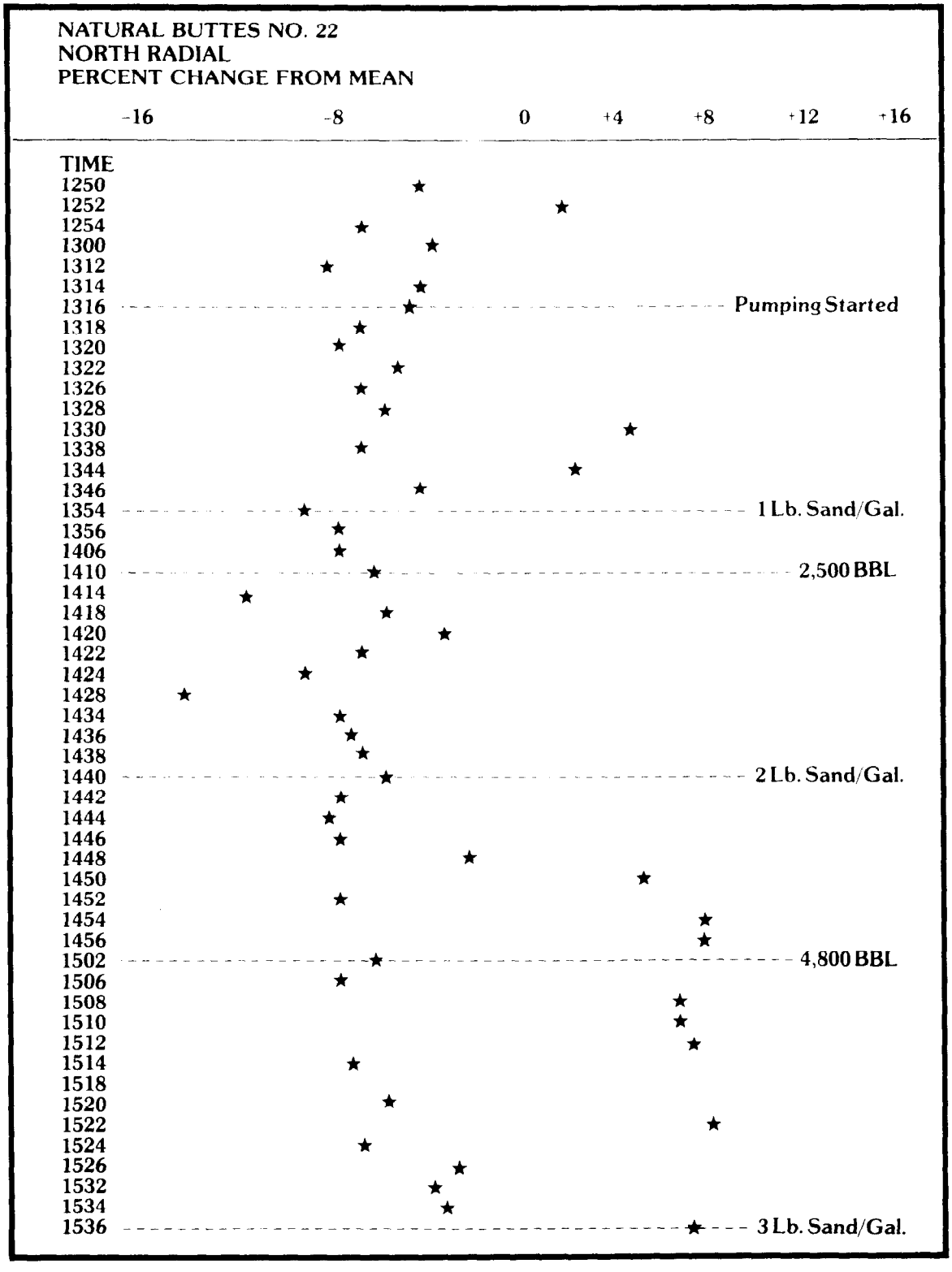
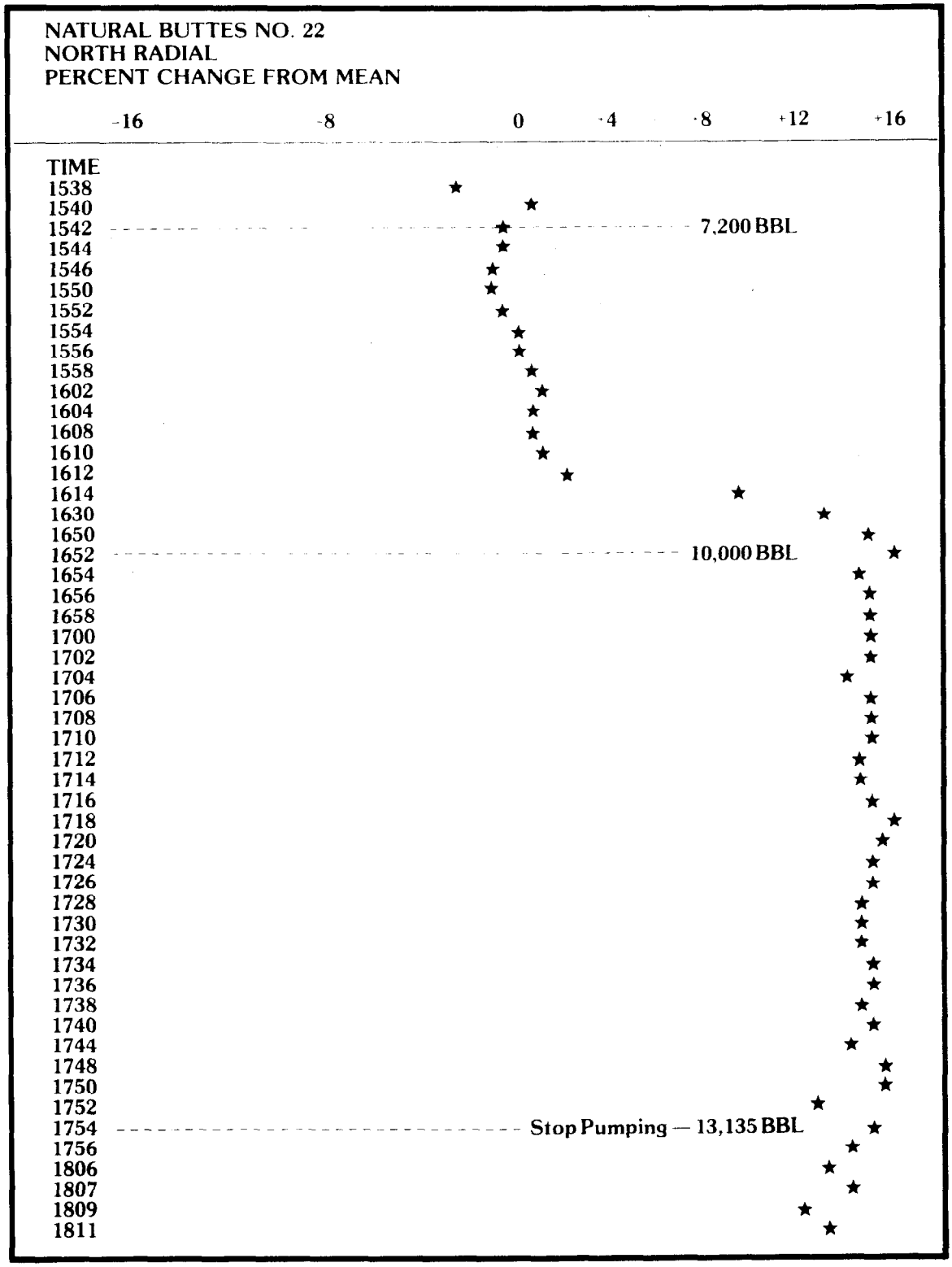


FIGURE 4-2 TIME HISTORY OF THE SURFACE POTENTIAL ON A TYPICAL RADIAL


NATURAL BUTTES NO. 22
NORTH RADIAL
PERCENT CHANGE FROM MEAN
-16
-8
0
+4
+8
+12
+16
TIME
1538
1540
1542
1544
1546
1550
1552
1554
1556
1558
1602
1604
1608
1610
1612
1614
1630
1650
1652
1654
1656
1658
1700
1702
1704
1706
1708
1710
1712
1714
1716
1718
1720
1724
1726
1728
1730
1732
1734
1736
1738
1740
1744
1748
1750
1752
1754
1756
1806
1807
1809
1811
7,200 BBL
10,000 BBL
Stop Pumping — 13,135 BBL

4.3.2 Mineback Stimulation Test Program

Actual mineback towards the UE12g 10#6 "Interface Experiment" was suspended in December. This was done to allow exploratory coreholes to be drilled so that approximate fracture orientations could be determined and the optimum mineback route planned. As shown in the updated tunnel map in Figure 4-3, an alcove was mined on the side of drift VDH#6 and corehole EV6#1 was drilled at S 39° W to a total length of 225 ft. The fracture in the ash-fall tuff (the lower fracture) was intercepted from 134.0 to 134.9 ft at an angle of 12° from the corehole's axis. Extrapolation of this orientation shows the fracture within a few feet of Hole 6. Both green and black grout were observed in the recovered core.

The examination and analysis of the HE12G 10#5 " Staged Proppant Experiment" is nearly completed. Seven mini-hydraulic fracture breakdown tests were conducted in HF#23 at the locations indicated in Figure 4-3 to obtain the orientation and magnitudes of the principle stress on either side of the faults that were intersected by the HE12G 10#5 fracture and were observed during mineback. Further breakdown tests are proposed for hole EV5#2, as well as a few overcores. These results should be sufficient to define the state of stress around this experiment. Together with the previously obtained material properties, pumping schedule and geologic structure, these data should provide all the important fracture parameters.

4.3.3 Mobile Well Test Facility

Work on the mast truck has been completed by Gearhart Owen Industries (GO) of Fort Worth, Texas. Sandia Laboratories has transported the truck to Albuquerque, New Mexico where additional items will be added.

Work on the instrument and recording trailer continues at GO. Major items of work remaining to be completed are:

Refrigeration

Painting

Spooling of logging cables on winch drums

Estimated completion date of the trailer is February 21, 1978 by GO. Sandia will transport the trailer to Albuquerque, New Mexico for further additions.

CER Corporation is preparing a list of tools, supplies, spare parts and additional logging equipment to complement the equipment procured by Sandia.

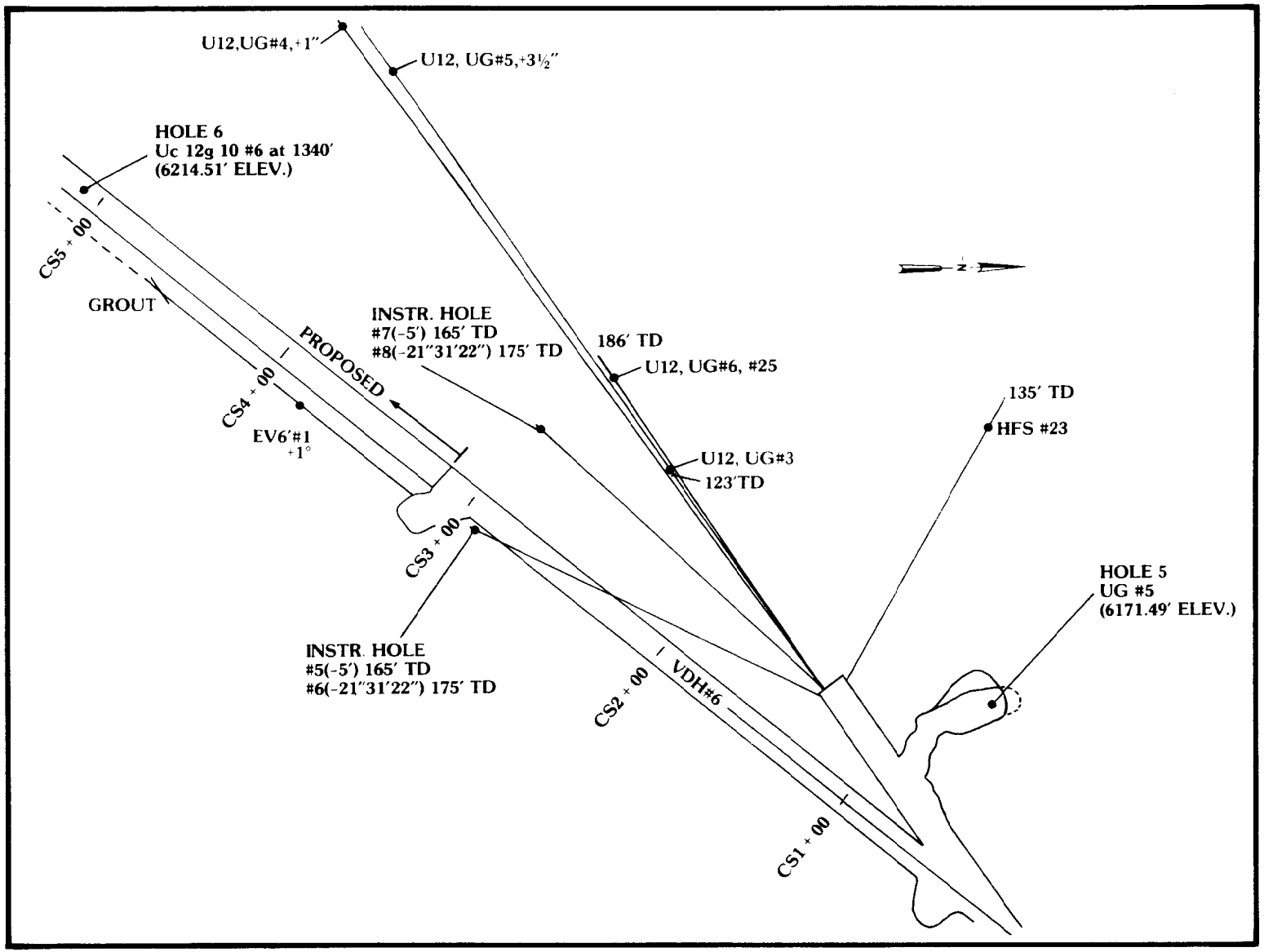


FIGURE 4-3 CURRENT MINEBACK ACTIVITIES, G TUNNEL, NEVADA TEST SITE

4.3.4 Other Activities

Robert P. Trump, Gulf Research and Development Company, visited Sandia Laboratories on December 12, 1977, to discuss Sandia's enhanced gas recovery programs. The next day, he visited the mineback activities at G tunnel, Nevada Test Site. The discussions were mutually beneficial and possible future interaction will be pursued.

4.4 U.S. Geological Survey (USGS) Borehole Gravity Meter

The meter has been bench tested and found thermally and mechanically stable. Bench-test circuitry is now being miniaturized for tool installation.

4.5 U.S. Geological Survey/Menlo Park—Tiltmeter

Considerable effort has been concentrated on the completion of analyses for all past experiments. Reports have been issued to all coinvestigators for comments and correction prior to Open-File Release.

The Laredo MHF experiment performed in two steps on two successive days at a depth of approximately 5,000 ft, proved difficult to analyze due to the short pre and post frac records and the extreme thermoelastic strains superimposed on the fracture signal. It appeared that the overall fracture signal was sufficiently cospectral with the thermal noise so that standard procedures for removing this noise would not be successful. The complement of the RMS error of fit derived from a Wiener filter operation provided the means to map the azimuth. The correlation of injection pressure and temperature with the tilt response for all components of the tilt was derived. Though temperature was the dominant effect, it remained unchanged across the array for the two days. On the other hand, the correlation between pressure and all tilt components more than doubled for most components from the first to the second day. The first day's injection involved less than one-third of the total treatment. By previous theoretical calculations, it probably generated a length that was too short to provide a significant tilt signal at the given noise level. Thus, the significant increase in correlation at the end of the second day was considered to be related to the increased length of the fracture. It was assumed that the tilt component most parallel to the fracture would have the least correlation with the pressure record compared to the most perpendicular components. Utilizing this assumption, vectors were formed from the coefficients for each site for both days. A well defined fracture is suggested at N44E for the first day and N34E on the second day. Confidence in the second azimuth was about twice as good as the first day, thus an azimuth of N34E has been suggested.

A joint project between AOSTRA of Canada and DOE involved mapping two attempts to produce hydraulic fractures at a 30 ft spacing near a depth of 1,000 ft in the Athabasca Tar Sands of Northern Alberta, Canada. A method similar to that described above was used to establish the degree of coupling between fracture flexure and tilt response. Injection pressure was used. The correlation coefficients derived over the entire treatment indicated that the best coupling outlined a semicircular area.

The best fit of the Wiener filter between pressure and tilt for a brief time period was used to calculate the change of tilt associated with the change of pressure. These tilt vectors indicated an incomplete but clearly horizontal fracture. A set of theoretical models of the geometry of the fracture were generated using the following input variables: pressure, shear modulus, Poisson's ratio, external stress, and fracture geometry relative to the tiltmeters. A reasonable fit was obtained for the measured parameters that indicated a crude semicircular horizontal geometry with the greatest width at the well bore. The second fracture failed to fit any model of a horizontal fracture. A vertical fracture of azimuth somewhat the same as that of the diameter of the semicircular fracture was posted. This fit was, considering all sites, poor compared with the data from the first fracture experiment. The conclusion is that the fractures did not attain design geometry.

The Rock Springs report involves six different monitoring experiments. The overall results were reported last month. More modeling work should be done, but it is clear that there is excellent agreement between the theory and the data. A fundamental observation bears repeating: If a natural fracture system is encountered during a hydraulic fracture treatment, its effect on creating new surface must be evaluated. It is especially important to determine the overall volume of the system. This determination was eventually made with a tilt flexure experiment at Rock Springs. In this case it is suggested that the lack of a tilt signal was due to injecting with improper design parameters. Improper design resulted from ignorance of the presence of the fracture system.

A similar result may have occurred in West Virginia. A massive fracture treatment was performed at anomalously low injection pressures for several hours up to 95 percent of the job. No discernable tilt signal was recorded until the pressure abruptly rose by more than an order of magnitude. Absence of tilt signal for the size and depth of such a job could not be easily explained. The primary cause of the abrupt pressure rise may not be due to a "near-hole" problem. That is, the cause of the screenout may have been sourced far from the well bore. Thus, as in the Wyoming shale experiment, the Devonian Shale experiment may have encountered a pervasive natural fracture system. The natural fracture system would make it easier to dispose of the fracture material without producing significant tilt signals until the natural fractures were filled. The fracture toughness of the new rock initiated a chain

of events that quickly led to screenout. The difference between these two shale experiments may be only in the pervasiveness of the systems. Thus, experiments in areas of extensive natural fractures might be more successful, if upon encountering low injection pressures and absence of tilt signals the treatment is modified in a manner that produces reasonable response to reasonable injection parameters.

5. FIELD TESTS AND DEMONSTRATIONS

5.1 Background

The Uinta Basin in Utah and the Piceance Basin in Colorado are the sites of three active MHF projects in which Upper Cretaceous tight gas-bearing sands are being stimulated. The following organizations and wells are involved:

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

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

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

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.

Colorado Interstate Gas Company has been awarded a contract to determine if productivity in low permeability reservoirs can be improved by reducing the interstitial water saturation. They intend to conduct experiments in two wells, the Sprague No. 1 and Miller No. 1, completed in the Dakota J Formation in the Wattenberg Field, north of Denver, Colorado.

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

TABLE 5-1 MHF CONTRACT LOCATIONS AND FRAC DATA

COMPANY, BASIN AND FORMATION	LOCATION	WELL	INTERVAL FRACTURED	FRAC. DATE	FRAC TREATMENT	FLUID INJECTED
	T / R / Sec		Feet		Lbs. of Sand	10^3 Gal.
AUSTRAL Piceance, Mesaverde	7S, 94W, S3 Garfield Co. Colorado	Federal 3-94	5,170-6,333	8-25-76	1,140,000	542 gel H_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	7,224-9,664	9-21-76 9-28-76	1,053,000	655 Gel
	9S, 21E, S22 Uintah County Utah	Natural Buttes No. 14	6,646-8,004	3-15-77	1,093,000	544 Gel
	9S, 21E, S28 Uintah County Utah	Natural Buttes No. 20	8,498-9,476	6-22-77	826,000	322 Gel
	10S, 22E, S21 Uintah County Utah	Natural Buttes No. 21				
	10S, 22E, S18 Uintah County Utah	Natural Buttes No. 22	6,858-8,550	11-21-77	1,091,000	479 Gel

TABLE 5-1 CONTINUED

COMPANY, BASIN AND FORMATION	LOCATION	WELL	INTERVAL FRACTURED	FRAC. DATE	FRAC TREATMENT	FLUID INJECTED
	T / R / Sec			Feet	Lbs. of Sand	10^3 Gal.
DALLAS PRODUCTION Fort Worth, Bend Cong.	Ben D. Smith Survey A-779 Wise County, Texas	Ferguson A-1	5,957-6,794	9-10-76	506,000	139 Foam 198 Emul.
EL PASO NATL. GAS Northern Green River, Fort Union	30N, 108W, S5 Sublette Co. Wyoming	Pinedale Unit No. 5	10,950-11,180 10,120-10,790	7- 2-75 10-20-75	518,000 1,422,000	183 Emul. 8 Gel 459 Gel
MOBIL Piceance Mesaverde	2S, 97W, S13 Rio Blanco Co. Colorado	F-31-13G	10,549-10,680 9,392- 9,534	6-22-77 8-24-77	580,000 600,000	316 Gel 260 Gel
PACIFIC TRANSMISSION Uinta, Mesaverde	8S, 23E, S25 Uintah County Utah	Fed 23-25	NO FRACS PERFORMED			
RIO BLANCO Piceance, Mesaverde	4S, 98W, S4 Rio Blanco Co. Colorado	Fed 498-4-1	6,150-6,312 5,376-5,960	10-22-76 11-30-77	776,000 275,500	276 Gel
WESTCO Uinta, Mesaverde	10S, 19E, S34 Uintah County Utah	Home Fed. No. 1	7,826- 9,437 10,014-10,202	12-21-76 10- 1-76	500,000 600,000	412 Gel 248 Gel

RIO BLANCO MASSIVE HYDRAULIC FRACTURING EXPERIMENT

EY-76-C-08-0623

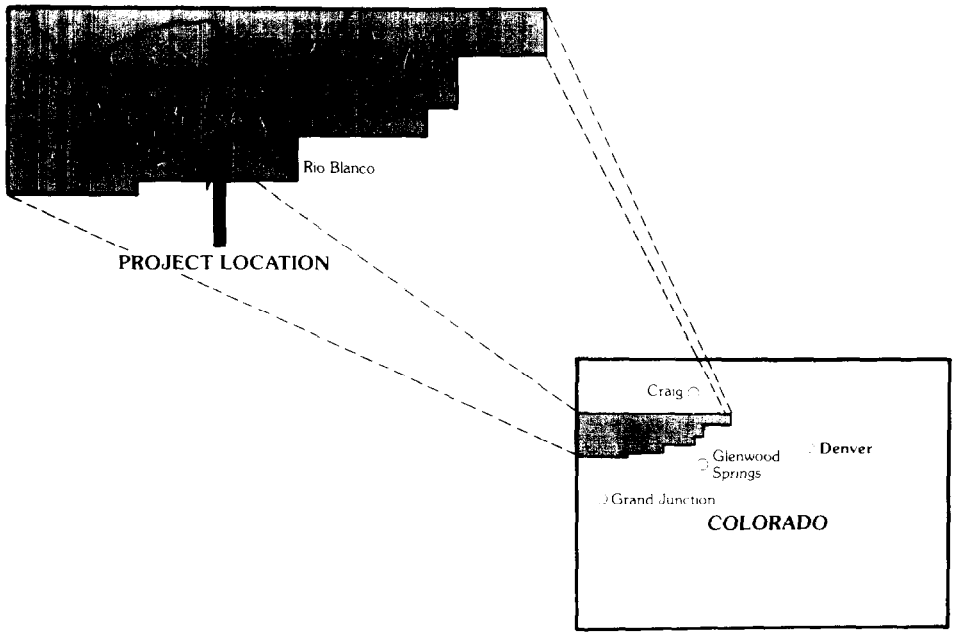
CER Geonuclear Corp.
Las Vegas, Nevada

Status: Awaiting Advisory Committee Decision

Interagency Agreement Date:	June 19, 1974	
Project Cost (estimated):	DOE	$1,975,000
	Industry	1,630,000
	Total	$3,475,000
Principal Investigator:	G. R. Luetkehans	
Technical Advisor for DOE:	Charles H. Atkinson, Bartlesville Energy Research Center	

OBJECTIVE

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



5.2 CER Corporation

5.2.1 Scope of Work

DOE Contract EY-76-C-08-0623 was signed with CER Corporation in March, 1974. This initiated the fielding of the Rio Blanco Massive Hydraulic Fracturing Project, a joint Industry/DOE demonstration to test the relative effectiveness of MHF in gas-bearing formations that were previously stimulated by the Rio Blanco Nuclear Fracturing Experiment, which took place in May, 1973. Both demonstrations are located in the northern part of the Piceance Basin of northwestern Colorado.

5.2.2 Current Status

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

WATTENBERG FIELD — EY-77-C-08-1514

Colorado Interstate Gas Company
Colorado Springs, Colorado

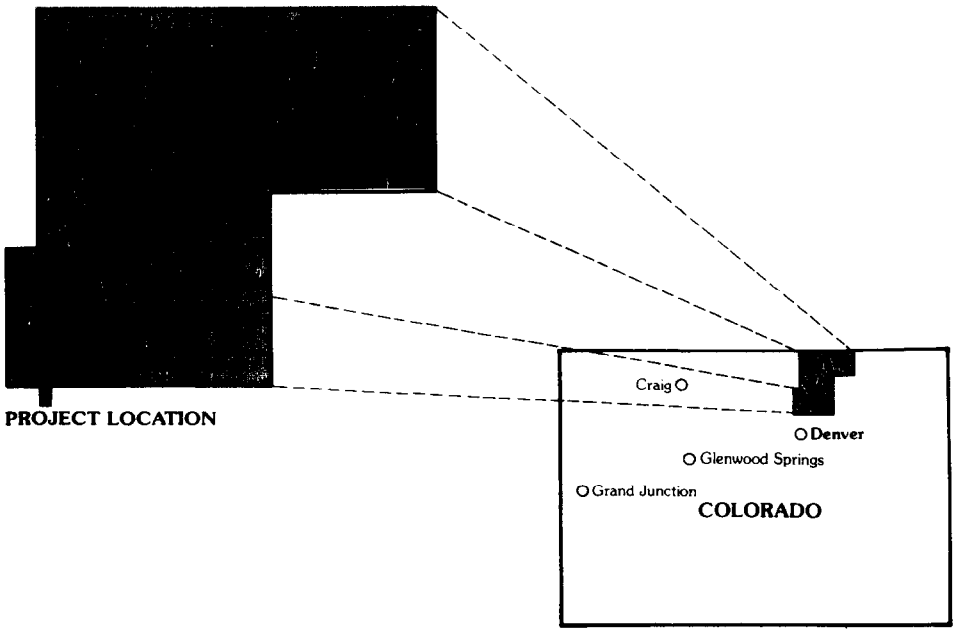
Status: Activity to Commence January 1, 1978

Total Project Cost:	DOE	$ 75,000
	CIG	99,000
	Total	$174,000

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

OBJECTIVE

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



5.3 Colorado Interstate Gas Company

5.3.1 Scope of Work

DOE and Colorado Interstate Gas Company (CIG) entered into Contract No. EY-77-C-08-1514 on September 1, 1977. The contract is in the amount of $75,000 with the contractor funding the project in the amount of $99,000.

The experiment will attempt to determine if the productivity of wells completed in low permeability natural gas reservoirs can be improved by reducing the interstitial water saturation. The method used to accomplish this will be a cyclic injection of dry natural gas. In addition to reducing the water saturation, cyclic injection of dry natural gas may improve the productivity by dehydrating matrix clays and by removal of formation damage adjacent to the surfaces of induced fractures.

5.3.2 Current Status

Field activities for this project, presently scheduled to commence on January 1, 1978, will begin with the installation of equipment. CIG is presently awaiting response to an "Invitation to Bid" sent to seven vendors for the compressor. The initial bottom hole pressure buildup will be conducted during February and March. Cyclic injection and withdrawal will be performed during the second and third quarters of the calendar year, after which, during October and November, a 60-day pressure buildup is planned. The first evaluation and report will be submitted during December 1978.

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

EY-76-C-08-0681

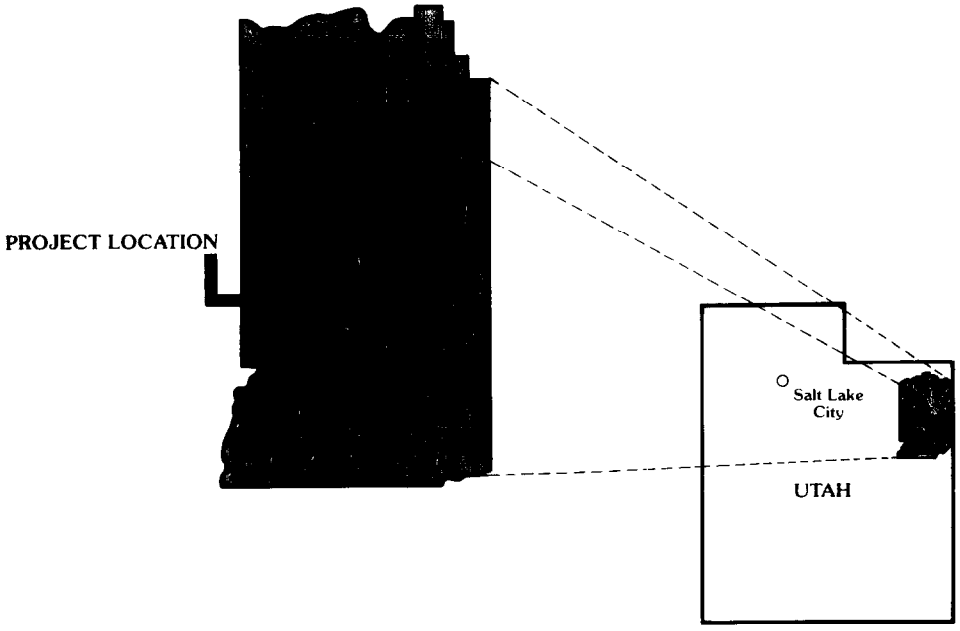
Gas Producing Enterprises, Inc.
Subsidiary of Coastal States Gas Co.
Houston, Texas

Status: Active

Contract Date:	July 1, 1976	
Anticipated Completion:	Sept. 30, 1978	
Total Project Cost:	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, Bartlesville Energy Research Center	

OBJECTIVE

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



5.4 Gas Producing Enterprises Inc.

5.4.1 Scope of Work

On July 1, 1976, a contract, EY-76-C-08-0681, was entered into between DOE and Gas Producing Enterprises, Inc. providing for a MHF experimental program. The GPE program, greater in scope than other MHF contracts, comprised the stimulation of six wells; two using old wells, Natural Buttes 18 and 14; and four new wells, 19, 20, 21 and 22. Variations in treatment between wells included fracturing fluid volume, sand size, porosity of zone tested and fracturing fluid design. Contract Modification No. 1 for Phase VI of the MHF demonstration contract provides for the addition of Natural Buttes No. 9, an old well. Contract modification for Phase V of the contract provides for an add-on to the Natural Buttes No. 21 (tentative new designation is CIGE No. 21) including coring, running extra logs, and running production and buildup tests on approximately six individual sand members within two sections of the Mesaverde. The core data, including special interpretation, log data and production test data will be correlated. In addition, there will be an attempt to obtain post-MHF performance of these individual sand members in order to develop techniques to predict the potential productivity of a sand member by electric log interpretation alone. This contract modification provides for DOE contribution of an extra $672,000 with GPE contributing roughly $100,000.

Contract Modification No. 3, effective December 9, 1977, provides for an extension of the contract to include two new wells, Natural Buttes Unit No. 23 and CIGE #2-29-10-21.

5.4.2 Current Status

Natural Buttes Unit Wells No. 14, 18, 19 and 20 are still on production and will continue flowing to sales through January. Specific production data for these four wells appears in Figures 5-1, 5-2, 5-3, and 5-4.

Natural Buttes Well No. 19 will be evaluated for possible remedial work, or it will be plugged and abandoned.

Natural Buttes Well No. 22, fractured on November 21, 1977, is flowing to clean-up. A gamma ray log has been run to determine the location of the fractured intervals.

The Natural Buttes Well No. 9 MHF treatment design is being re-bid and recommendations will be prepared and submitted to DOE for approval.

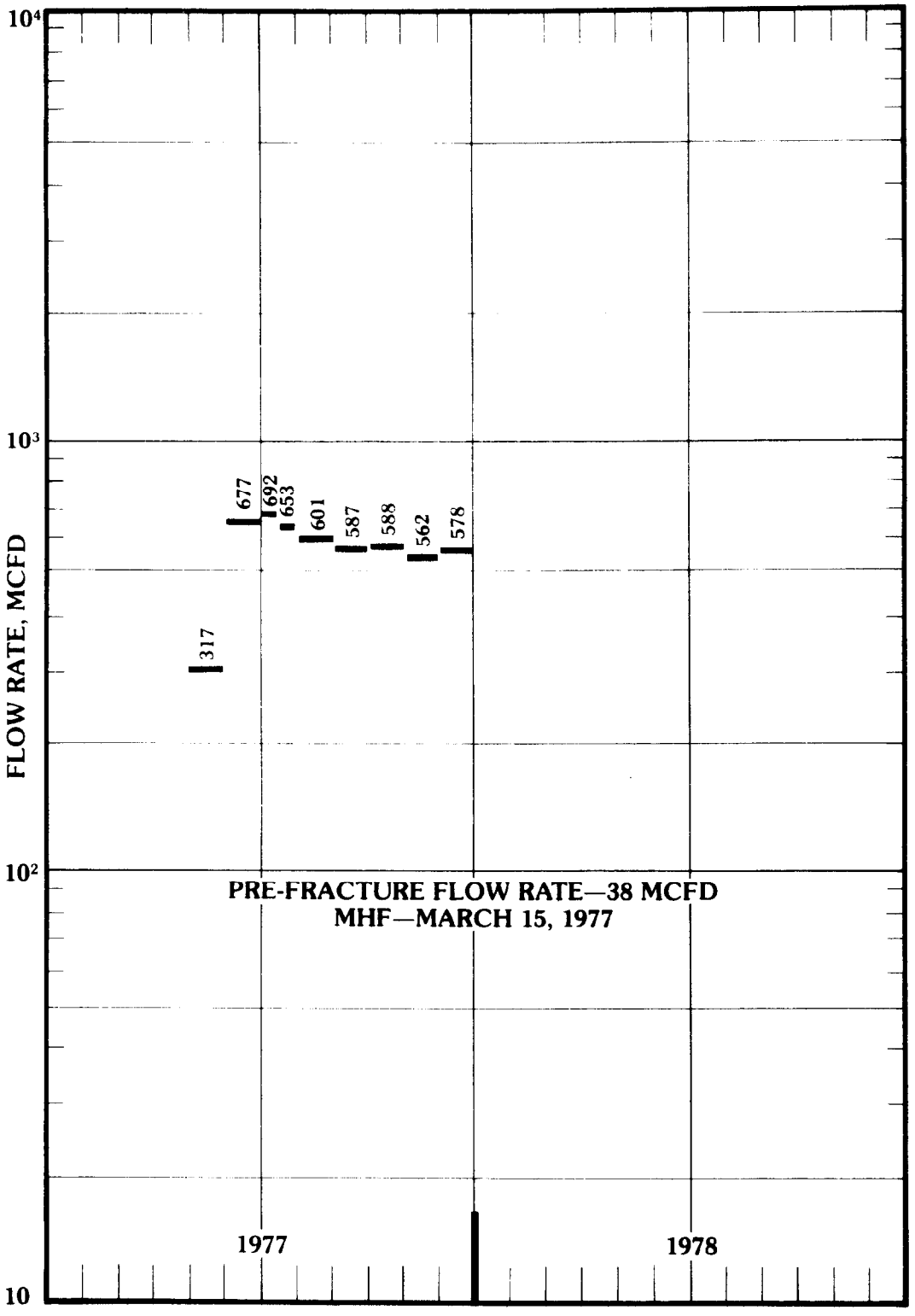


FIGURE 5-1 FLOW RATE PERFORMANCE OF NATURAL BUTTES NO. 14 WELL

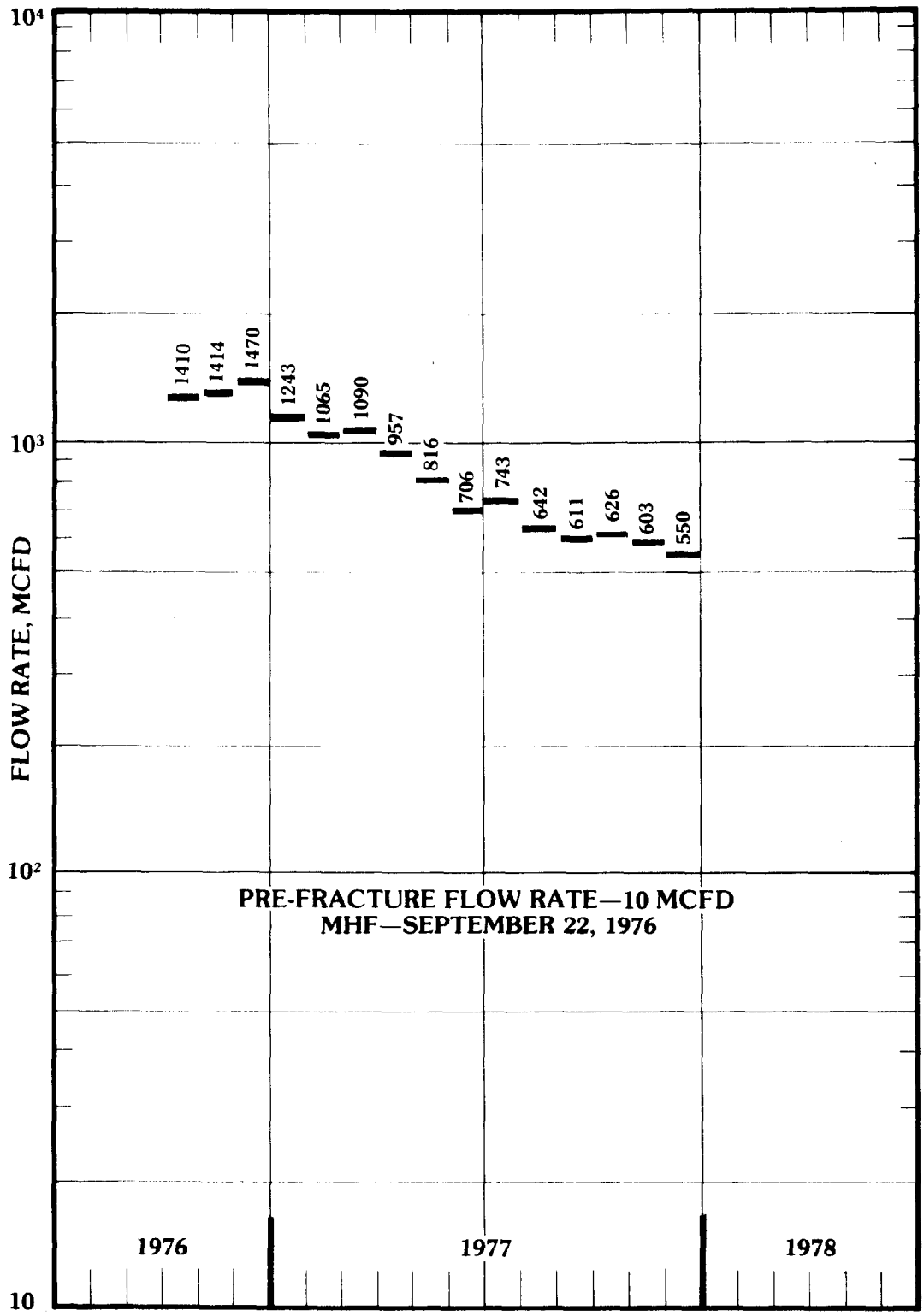


FIGURE 5-2 FLOW RATE PERFORMANCE OF NATURAL BUTTES NO. 18 WELL

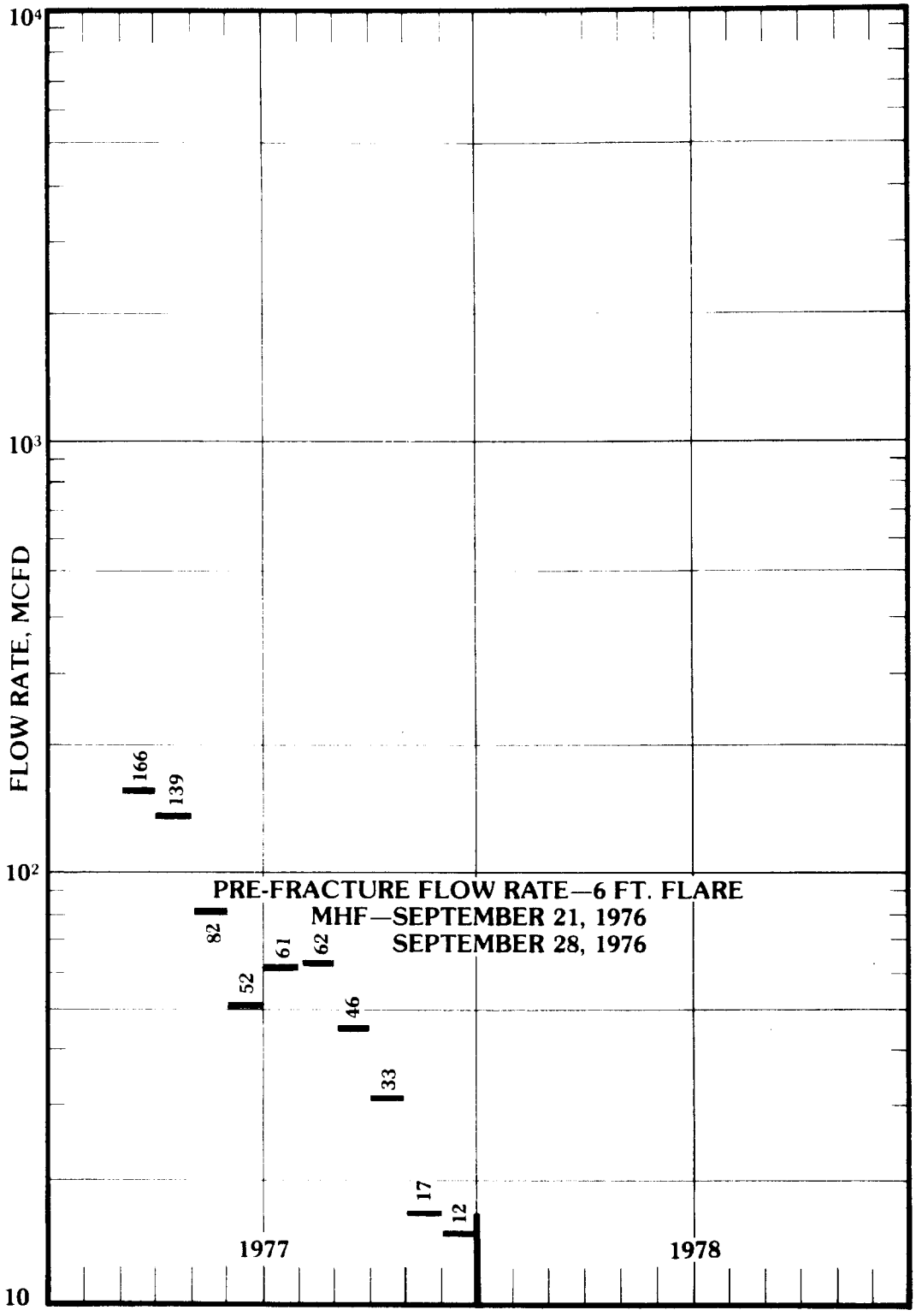


FIGURE 5-3 FLOW RATE PERFORMANCE OF NATURAL BUTTES NO. 19 WELL

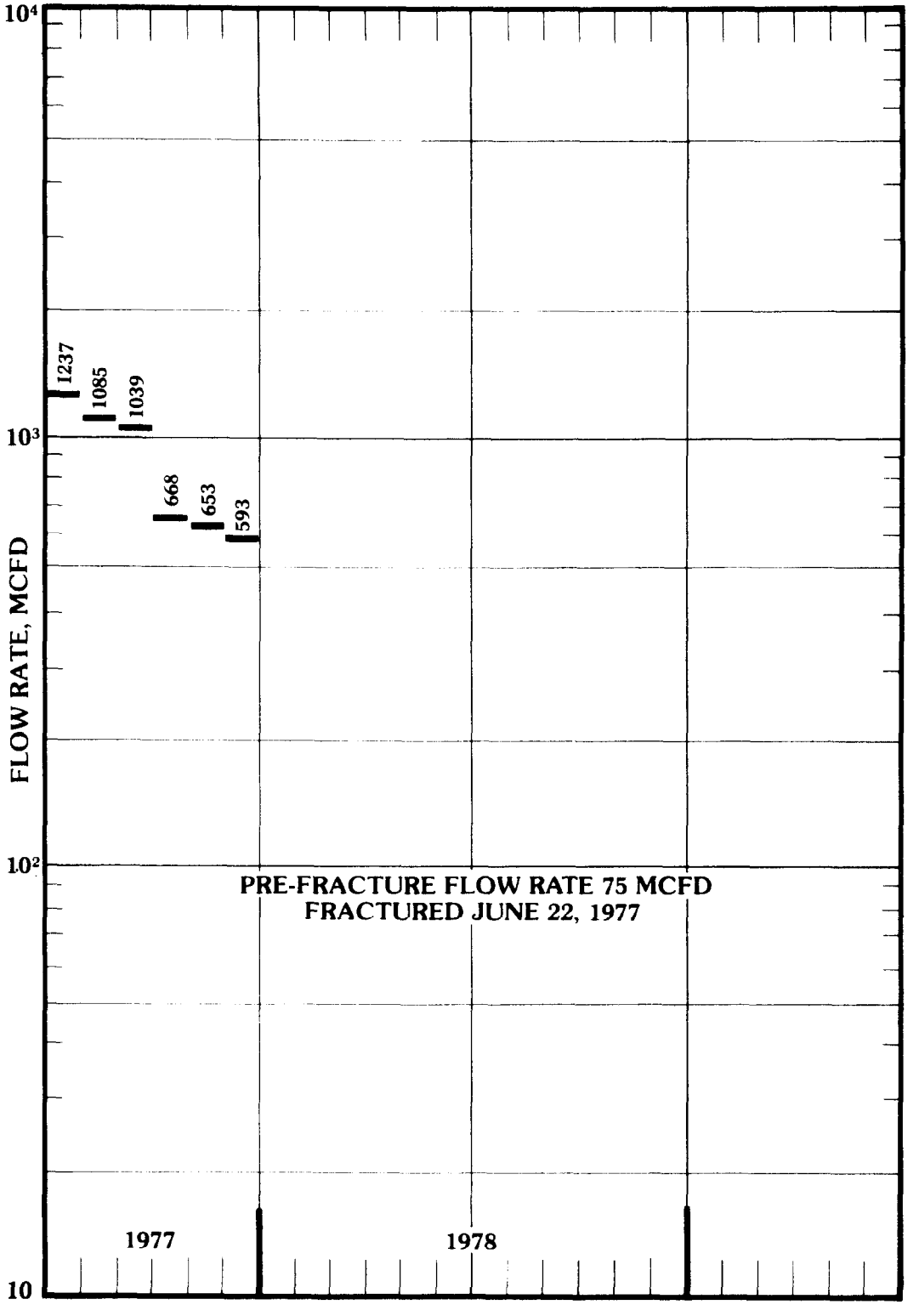


FIGURE 5-4 FLOW RATE PERFORMANCE OF NATURAL BUTTES NO. 20 WELL

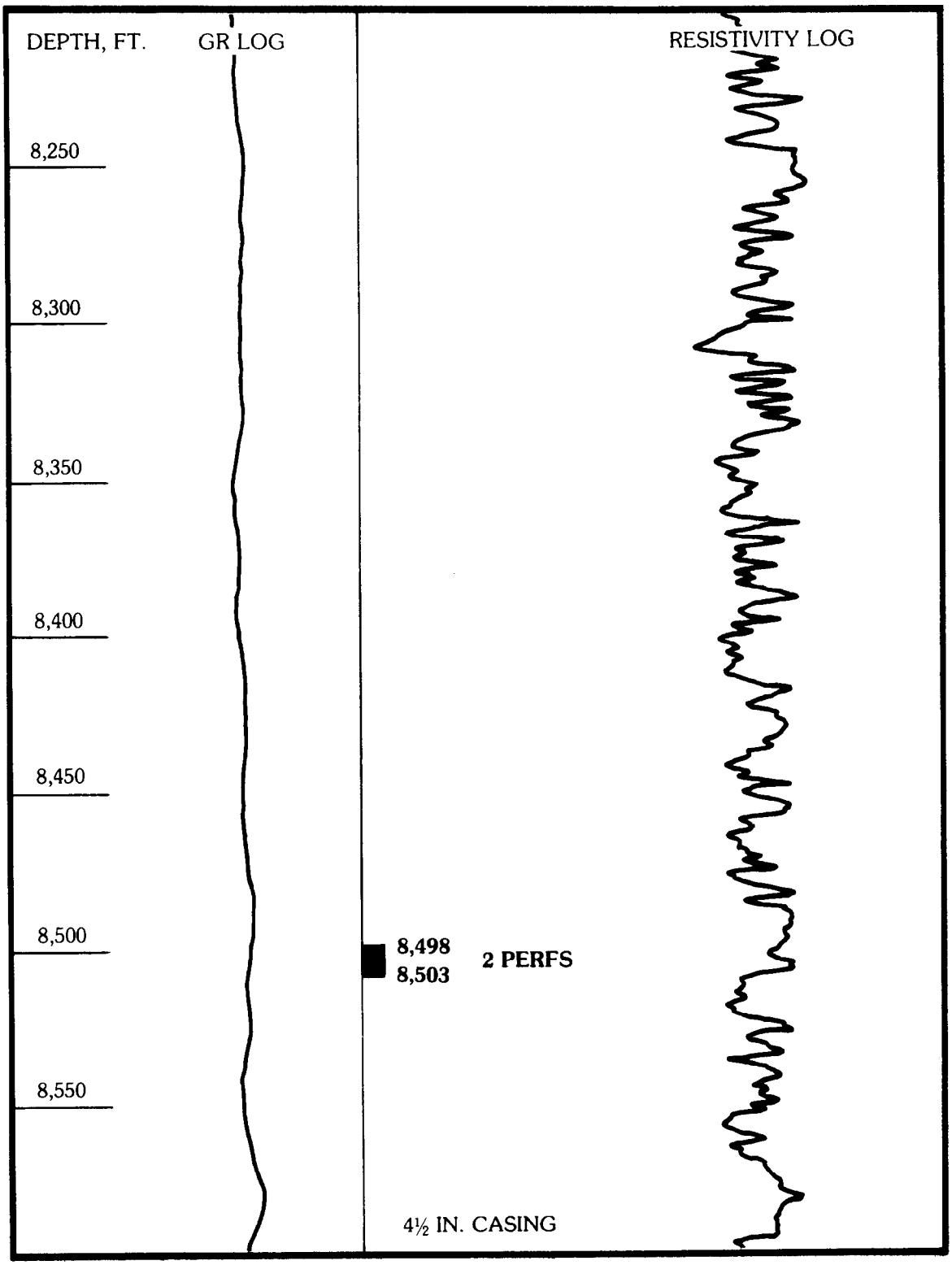


FIGURE 5-5 NATURAL BUTTES NO. 20 WELL SHOWING SANDS FRACTURED

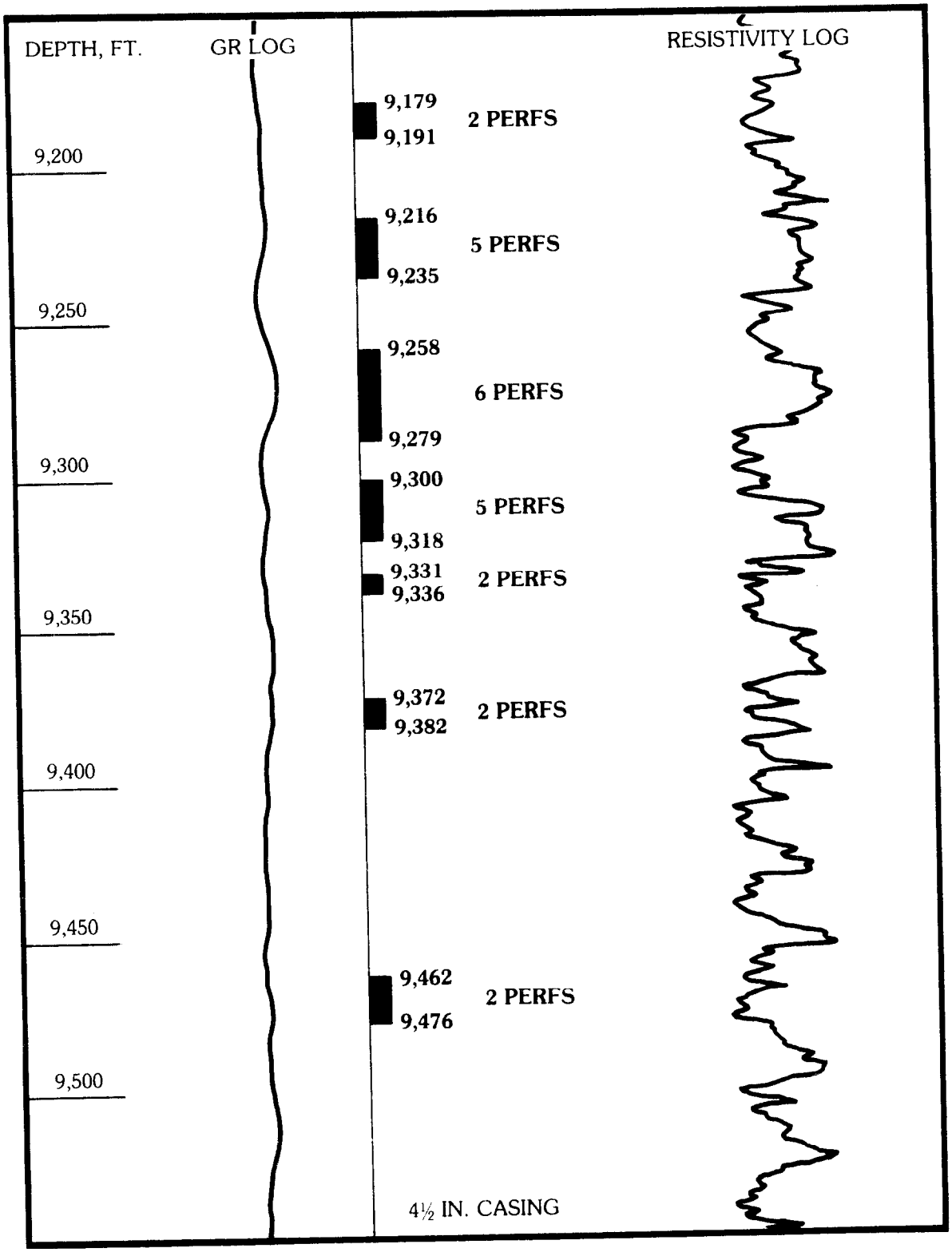


FIGURE 5-5 CONTINUED

PICEANCE CREEK FIELD, COLORADO, MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

EY-76-6-08-0678

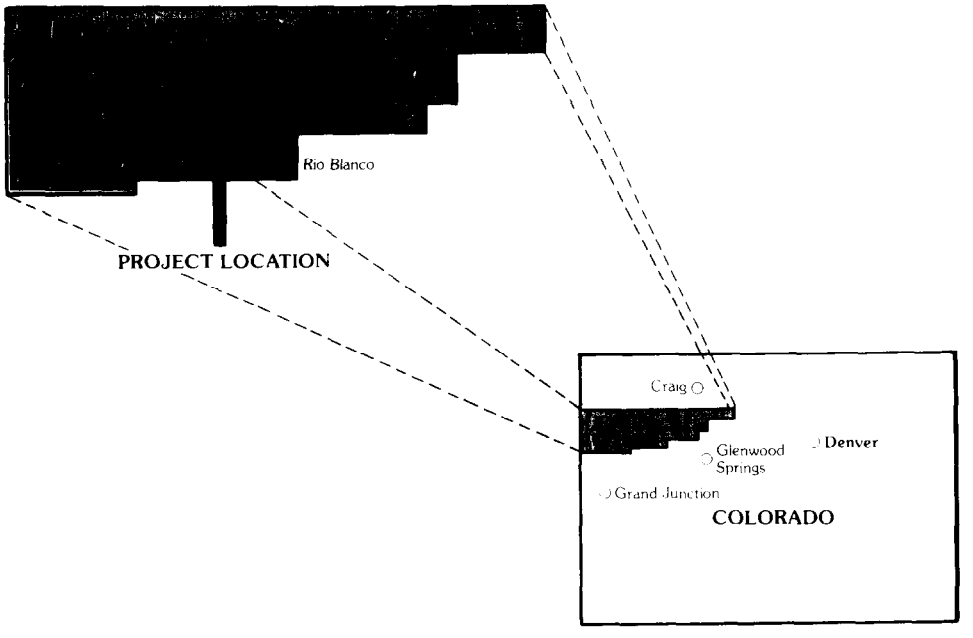
Mobil Research and Development Corporation
Dallas, Texas

Status: Active

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

OBJECTIVE

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



5.5 Mobil Research and Development Corporation

5.5.1 Scope of Work

Mobil was awarded DOE Contract EY-76-C-08-0678, in the amount of $2.6 million for a MHF experiment in Rio Blanco County, Colorado. The scope of work under the contract is to be performed in three phases involving a well to be drilled in the Piceance Creek Gas Field, Rio Blanco County, Colorado.

5.5.2 Current Status

Plans are being made for testing additional zones for fracture No. 3. Field work is anticipated to begin in April 1978. Plans are also being made to obtain bids on the major items of work for 1978.

Mobil Well F-31-13G has had two bridge plugs and the sand fill removed as of December 13. The well was flowed to the pit from December 14 to 17. At the end of the flow period the well was making an estimated 350 BBL of load water and an amount of gas between 1 and 3 MMCFD at 225 psi tubing pressure, 1,200 psi casing pressure on a 3/4 in. choke. When the well was shut in, it was anticipated that a pipeline connection would be made on or before January 1, 1978. Northwest Pipeline Company has now informed Mobil that the well will be connected on January 15. Winter weather and other problems are blamed for this delay.

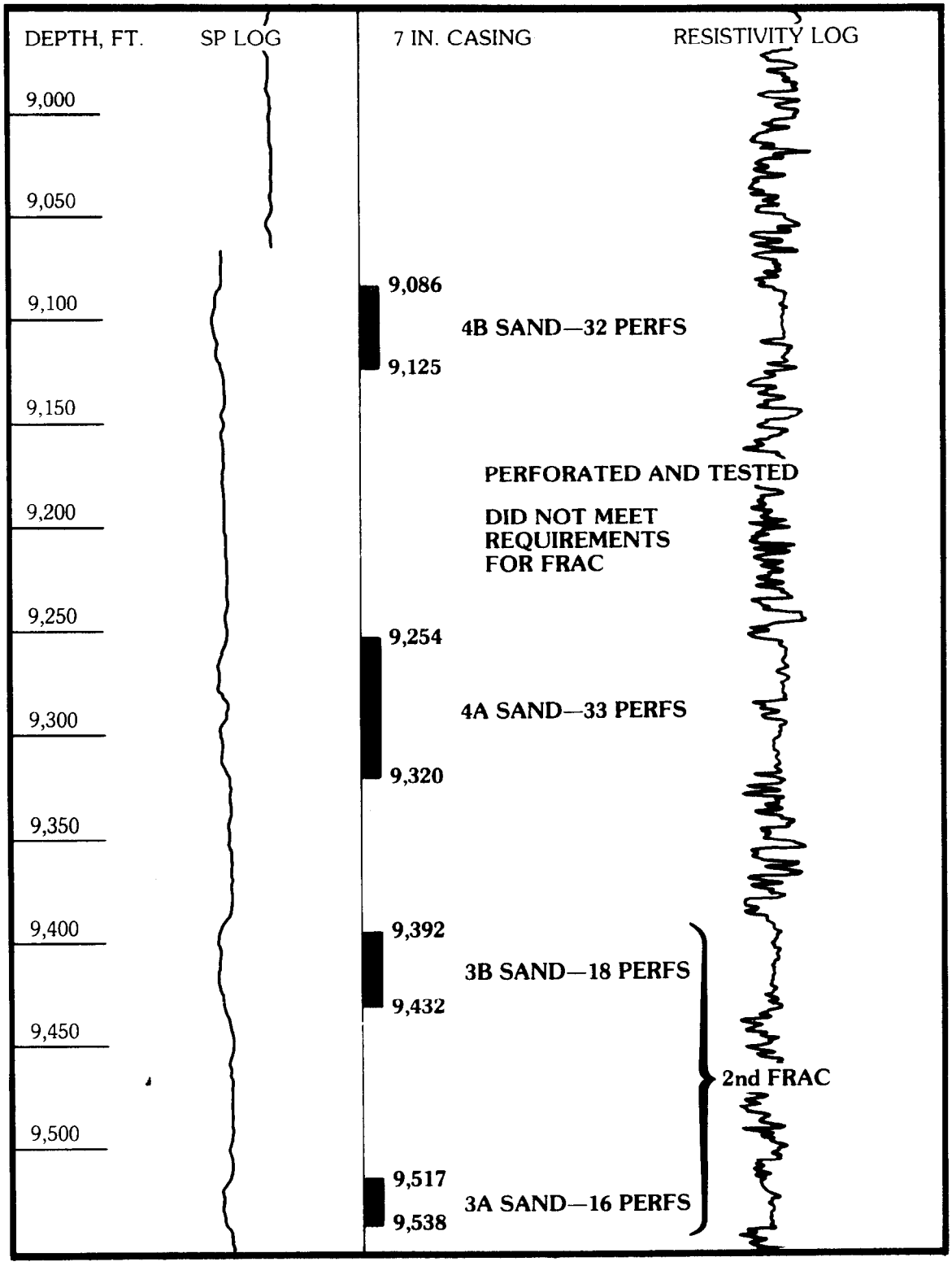


FIGURE 5-6 MOBIL F-31-13G WELL SHOWING SANDS FRACTURED

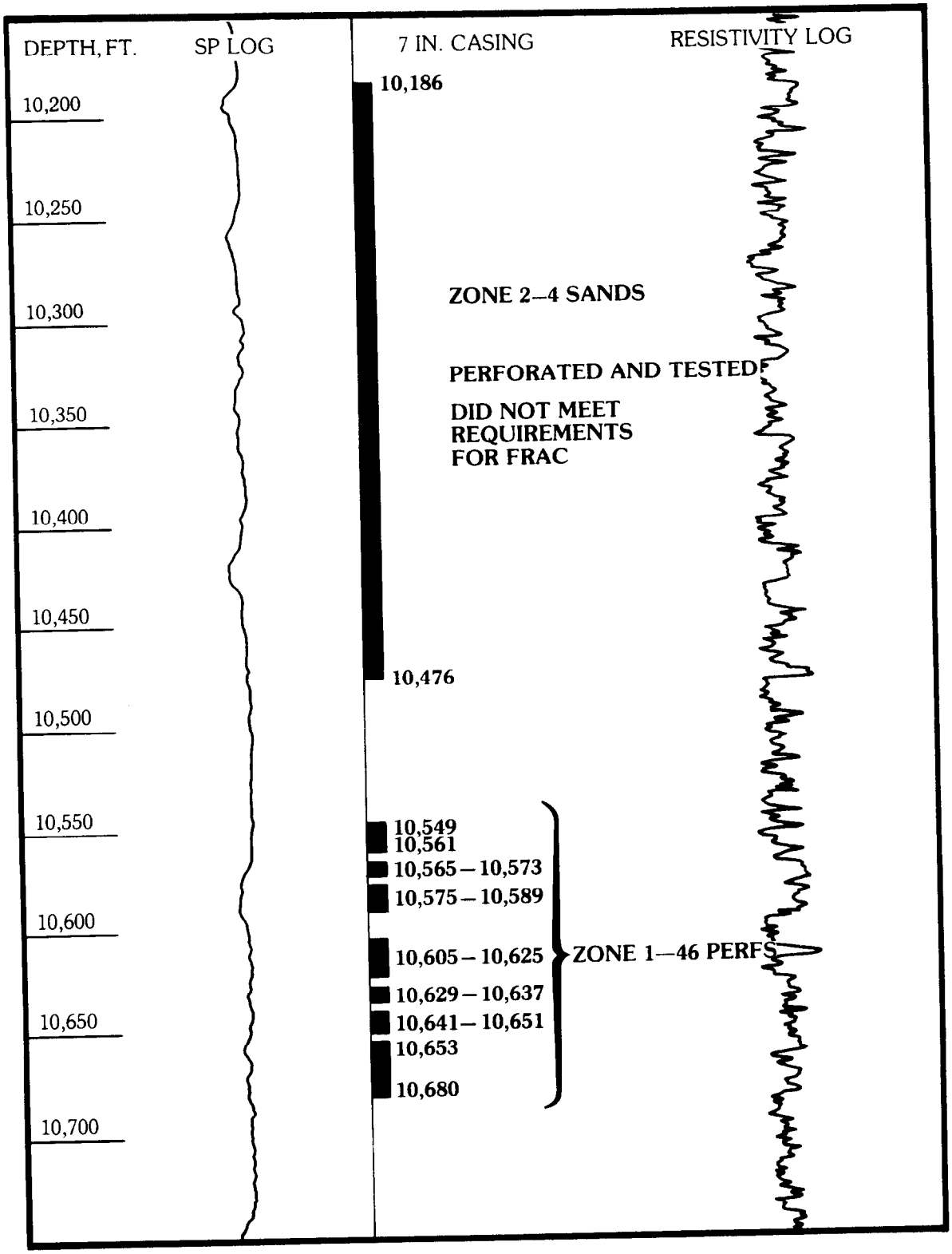


FIGURE 5-6 CONTINUED

RIO BLANCO COUNTY, COLORADO MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

EY-76-C-08-0677

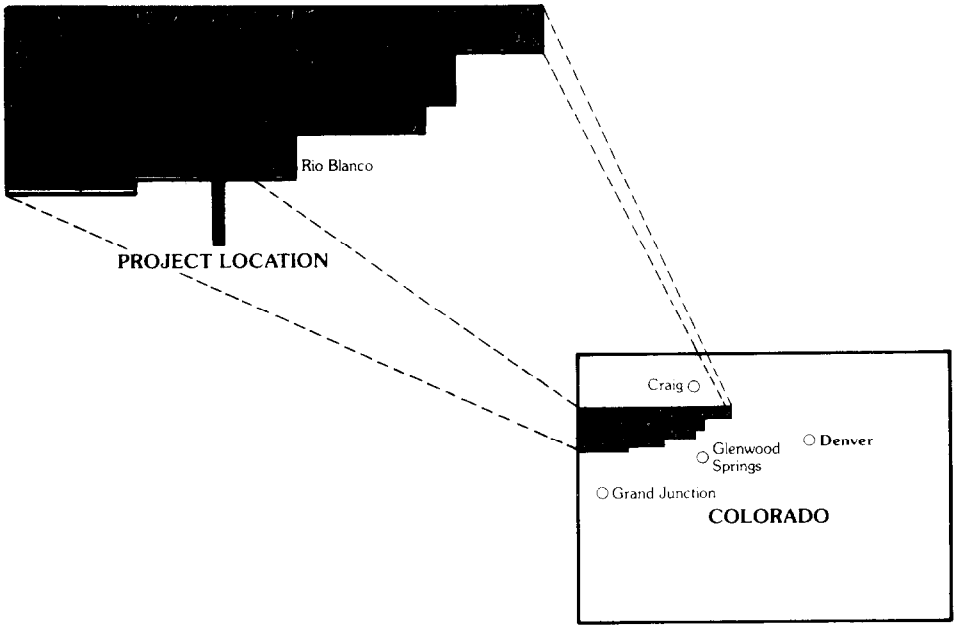
Rio Blanco Natural Gas Company
Denver, Colorado

Status: Active

Contract Date:	August 1, 1976	
Anticipated Completion:	March 31, 1978	
Total Project Cost:	DOE	$ 410,000
	Contractor	593,000
	Total	$1,003,000
Principal Investigator:	Robert E. Chancellor	
Technical Project Officer:	C. H. /'inson, Bartlesville Energy Rese. Center	

OBJECTIVE

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



5.6 Rio Blanco Natural Gas Company

5.6.1. Summary of Past Activities

DOE Contract EY-76-C-08-0677 was signed with Rio Blanco Natural Gas Company in June, 1976. The intention of the work was to prepare an existing well (Federal 498-4-1) for a MHF treatment. This well, located in Section 4, T4S, R98W, Rio Blanco County, Colorado, was drilled and cased to a total depth of 6,963 ft in March, 1975. The Mesaverde Formation was stimulated in two separate treatments before the contract MHF was performed.

The MHF treatment was performed on October 22, 1976. A total of 276,000 gal of fluid was designed for the treatment of which 12,000 gal were used as pad. The remaining fluid carried a total of 775,000 lb of sand.

5.6.2 Contract Modifications for an Additional Fracture

DOE and Rio Blanco Natural Gas Company entered into a supplemental agreement, effective October 1, 1977. The scope of work is to determine whether the previous fracture may have closed due to proppant crushing or whether it would be beneficial to perform an additional fracture. The new fracture treatment will use 12/20 mesh glass beads as a high strength propping material mixed in the last stage of the frac with the normally-used sand proppant.

5.6.3 Current Activities

The Rio Blanco Natural Gas Well, Federal 498-4-1, was fractured on November 30, 1977. During clean-up, sustained water production prevented high gas flow rates. The upper sand member of the fractured zone was suspected of producing formation water and was isolated by setting the production packer just below it. Production was resumed with a substantial reduction in water production. During the last three weeks in December, the production rate was steady at 285 MCFD. On January 2, 1978, the well was shut-in for pressure buildup.

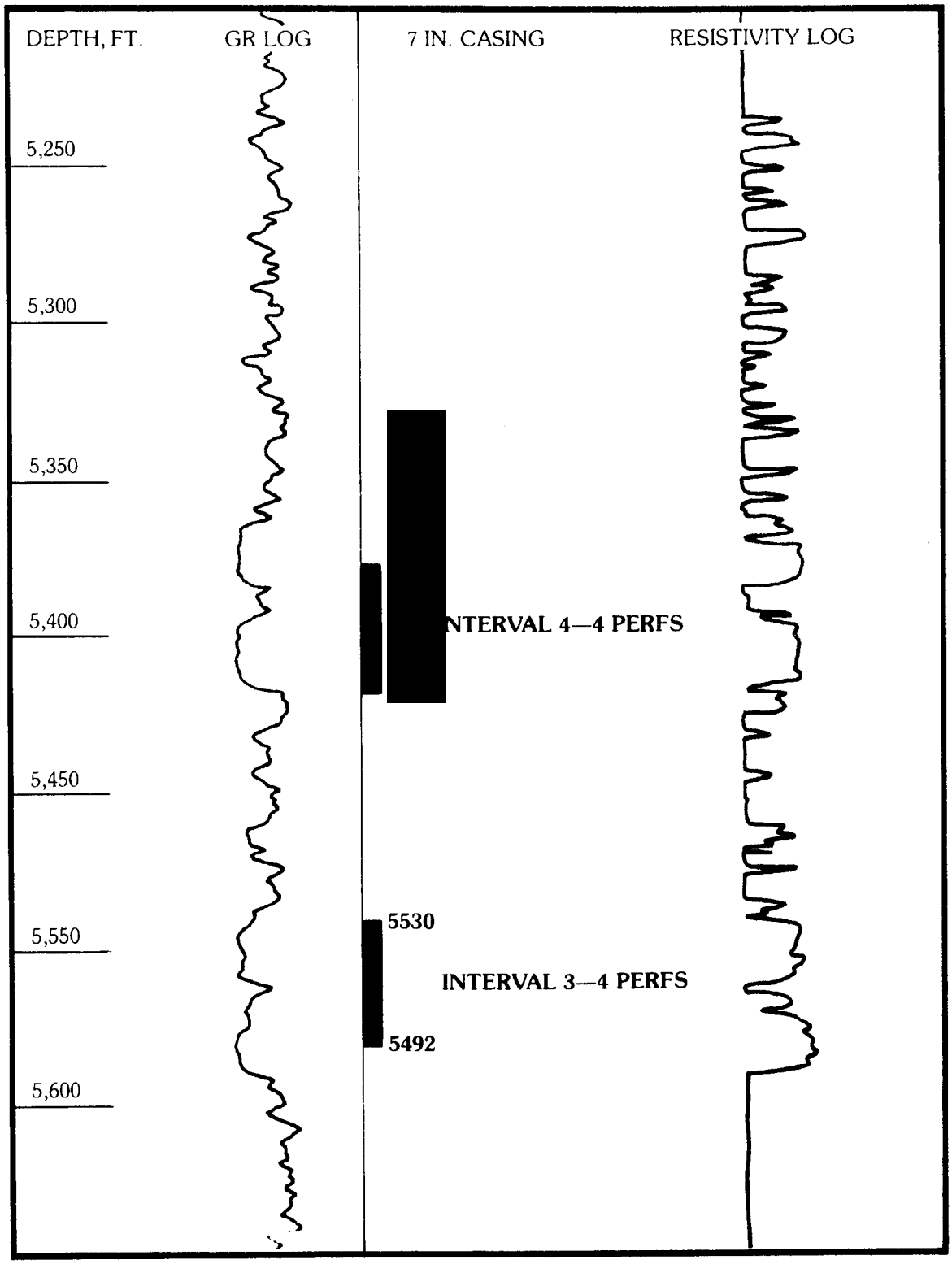


FIGURE 5-7 RIO BLANCO NATURAL GAS FEDERAL 498-4-1 WELL SHOWING SANDS FRACTURED

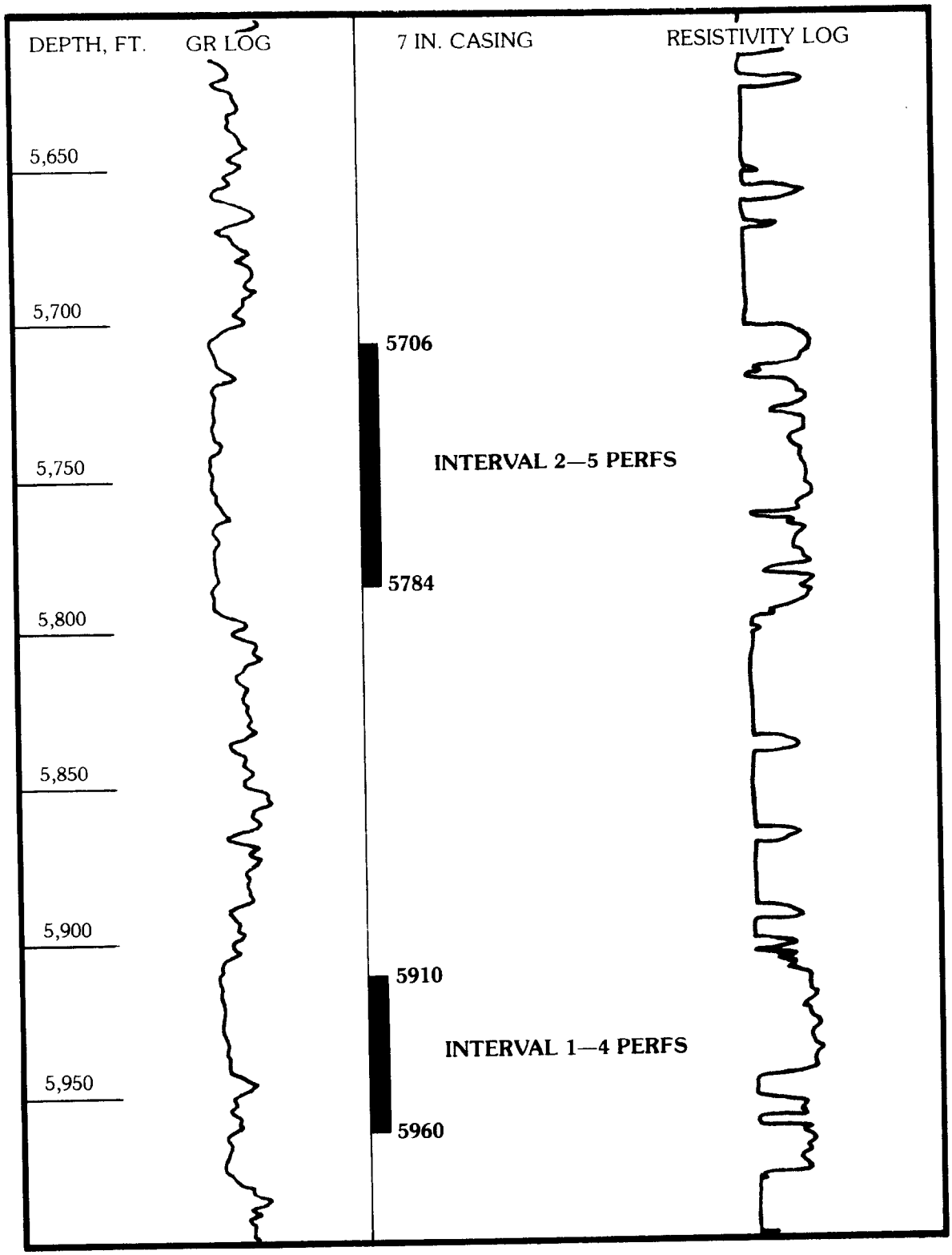


FIGURE 5-7 CONTINUED