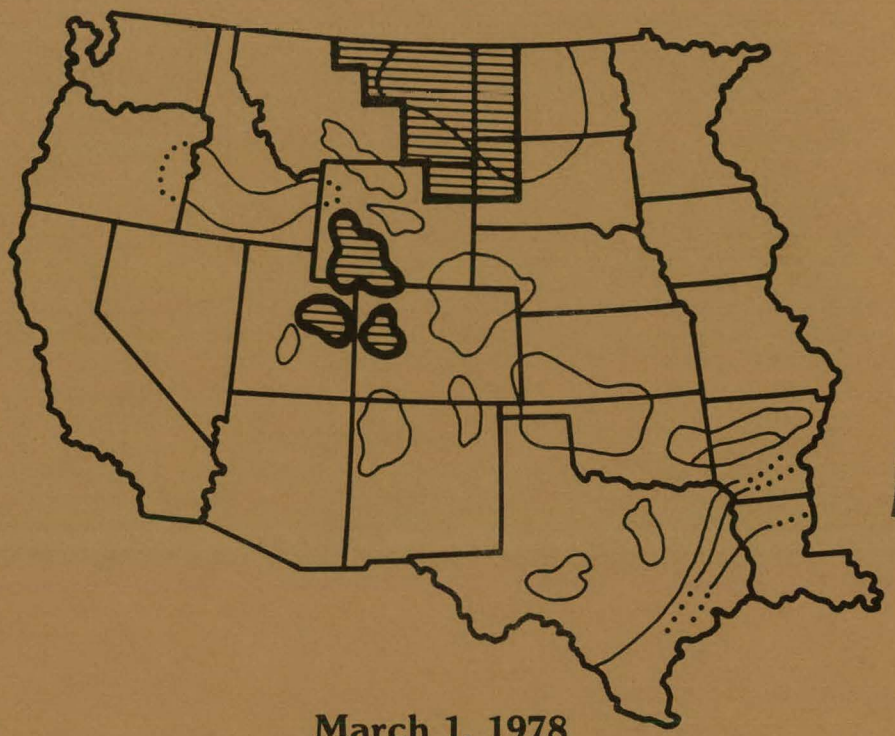
NVO/0655-105

Western Gas Sands Project Status Report



March 1, 1978

Prepared for
U.S. Department of Energy

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

Contract EY-76-C-08-0655

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1. SUMMARY

This report summarizes the progress during January, 1978 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 core program meeting was held on January 25, 1978 at the CER Corporation office in Las Vegas, Nevada. The core tasks to be performed on the available core supply were enumerated and each participant at the meeting expressed the interest and capabilities of his organization for the execution of specific analyses.

The Project Status Report, February 1, 1978 is being printed. The Project Plan Document FY 78 is being reviewed by DOE Headquarters, Washington, D.C., and will be finalized in early 1978.

A log file and 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 characterize the resource base. Petrographic examination, cross section construction and other studies are continuing in the Uinta and Piceance Basins. El Paso Natural Gas Company has supplied the USGS with additional well data from Pinedale Unit, Wyoming wells, and discussions have been held with Jerry McCutchin Jr. of Dallas on a recent Shannon (Eagle) discovery in South Dakota.

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

Mitchell Energy Company's proposal to conduct an MHF test in the Cotton Valley limestone gas reservoir in Texas has been approved. Contract negotiations are expected to commence shortly.

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2. PROJECT MANAGEMENT

A coordinating meeting to establish some of the requirements necessary for the Western Gas Sands Project Coring Program was held on January 25, 1978, at CER Corporation office in Las Vegas. Participants included representatives from USGS - Denver, Lawrence Livermore Laboratory (LLL), Bartlesville Energy Research Center (BERC), Los Alamos Scientific Laboratory (LASL), Sandia Laboratories, Department of Energy (DOE) and CER Corporation.

The meeting was held so that the participants could enumerate the core studies that they would perform on a routine basis and also what studies they could perform on request. This information will be used to establish usage priorities for an anticipated limited supply of core. Further information can be obtained from the "Draft for Comment" document developed from input for core requirements and analysis capability of the participants, and distributed prior to the meeting.

The Project Manager was asked by DOE Headquarters in Washington, D.C., to evaluate the western United States basins for Group II-type gas reservoirs for the Enhanced Gas Recovery (EGR) strategy study. Group II (speculative) resources were not included in the initial Lewin & Associates report. CER will assist in defining these areas and delineating the type of program required to determine the gas potential in the Group II areas.

The Project Plan Document FY78 is being reviewed in Washington and is expected to be finalized in early 1978. The Project Status Report, dated February 1, 1978, is being printed. Work is proceeding on the Project Implementation Plan and the second Quarterly Basin Activity Report.

Mitchell Energy Company's proposal to conduct an MHF test in the Cotton Valley limestone gas reservoir in Texas has been approved and the contract has been written in preparation for negotiations.

Files which will contain raw data and published reports on each Western Gas Sands Project contractor task are being established. A well log file is also being set up.

All reports generated from the activities of the Western Gas Sands Project are available from the DOE Technical Information Center (TIC), P.O. Box 62, Oak Ridge, Tennessee 37830. TIC is authorized to receive and redistribute reports sponsored by DOE and reports generated by other agencies that relate to DOE programs. The reports are distributed by broad subject categories (General, Miscellaneous and Progress Reports - UC2), and are provided in three forms: full-sized printed copy, microfiche, and enlarged eye-legible copy reproduced from microfiche.

The categories are defined by TIC with the assistance and concurrence of DOE Headquarters. The categories, their definitions, and the address to which reports are sent are published in Standard Distribution Lists for Unclassified Scientific and Technical Reports (TID-4500). This publication is available free of charge from the TIC.

3. RESOURCE ASSESSMENT

Resource assessment includes geological and geophysical studies to better define the resource base. The majority of the resource assessment work is being performed by the USGS. Other activities, however, provide data input and support to their work, primarily in the area of field tests, obtaining core samples, and special core tests.

3.1 U.S. Geological Survey Activities

U.S. Geological Survey activities follow:

Northern Great Plains Province:

a) The USGS Open File report entitled "Landsat Lineaments in Western South Dakota" by G.W. Shurr has been prepared.

b) Text is being prepared for a paper entitled "Potential for Major Natural Gas Resources in Shallow, Low Permeability Reservoirs of the Northern Great Plains" by D.D. Rice and G.W. Shurr for the Williston Basin Symposium.

c) Discussions have been held with Jerry McCutchin, Jr. of Dallas on a recent Shannon (Eagle) discovery in South Dakota.

d) Side wall cores from a well located in the north end of the Bowdoin Dome have been obtained.

Greater Green River Basin:

a) Considerable additional well data on nine wells in the Pinedale Unit, Wyoming has been acquired from El Paso Natural Gas Company.

b) USGS and DOE approval has been received for a talk and abstract to be presented at the AAPG-SEPM Rocky Mountain Section meeting in Salt Lake City, Utah, March 20-22, 1978. The paper is by L.W. Kiteley and entitled "Stratigraphy of the Mesaverde Group and Occurrence of Natural Gas in Northwest Colorado."

c) Ching Wu has developed a clayey sandstone cross plot and is preparing a report entitled "Shaly Sand Cross-Plot Analysis Using Hand-Carried Calculators." This report may be presented at the 1978 annual SPE meeting.

d) Eighty-five samples have been submitted for paleontologic analysis.

e) Work is continuing on the preparation and correlation of electric logs to cross sections.

f) T.F. Tyler has finalized three electric log cross sections on the Wamsutter Arch for publication and a USGS Open-File report.

Uinta Basin - Piceance Basin:

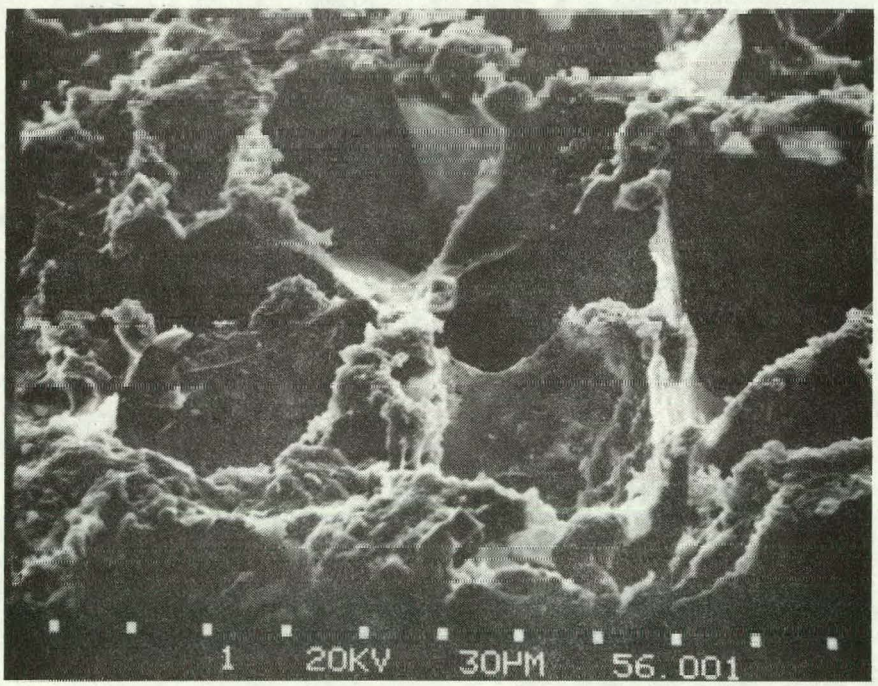
a) There will be continuing petrographic examination of rock from Rio Blanco Unit RB-E-01 core.

b) Cross section controls are being constructed through the Rulison area, utilizing electric logs and lithologic control.

c) The construction of Uinta Basin engineering and geologic cross sections is continuing.

d) There will be a continuation of microscope studies of core from the southeastern part of the Uinta Basin.

e) The core illustration below is from the western Uinta Basin and shows a scanning electron microscope photograph (taken by C.W. Keighin of the USGS).



This photograph is an epoxy mold of pore space and pore throats in a surface sample from a "braided-stream" setting in the Cretaceous Castelgate Sandstone in the western Uinta Basin, Utah. The rock specimen was injected with colored epoxy in a vacuum oven and then the mineral grains removed by acid leaching to reveal the geometry of pores and volume of void space in the original rock specimen. Future work will involve similar studies of samples from cores to accurately describe subsurface conditions. For scale, the white squares are 30 micrometers (μm) apart. The upper size limit of silt is about 60 μm; therefore, this specimen would be considered a fine-grained sandstone.

3.2 Coring Program

The core acquisition and analysis program, developed from input contributed by the participants in the program was assembled into a "Draft for Comment" document. The document was distributed to the participants prior to a core program planning meeting held at CER Corporation offices in Las Vegas on January 25, 1978. The following participated in that meeting:

Ray Williams	BERC
Herb Carroll	BERC
Robert Mann	CER
Gerald Kukal	CER
Charles Atkinson	DOE/BERC-NV
Bob Clarke	DOE/NV
Nick Vanderborgh	LASL
Jasper Jackson	LASL
Don Emerson	LLL
Merle Hanson	LLL
George Griswold	Sandia
Chuck Spencer	USGS

Each participant expressed the interest and capabilities of his organization for the execution of specific analyses.

The results of the meeting are being assembled into a report entitled Western Gas Sands Project Core Program, January 12, 1978. The report will outline the aquisition, handling, distribution and analyses to be made of the cores. Regional sites where core data are needed in each study basin have been delineated by USGS personnel. Drilling activity in the areas of interest will be monitored so that when applications for drilling permits are filed in areas where coring is desirable, contracts for the coring, logging, and possible testing operations can be negotiated with the individual companies.

3.3 Study of Basin Activities

Drilling and testing activities in the four main study areas are being monitored. Figure 3-1 indicates the four areas and shows locations of recent wells of significance to the Western Gas Sands Project with numbered callouts. The following paragraphs give a brief account of the activity in each basin. A detailed quarterly report is being prepared 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 continues to be the most active drilling area in the Piceance Basin. At the first of the year, 126 wells were listed as active by one industry news reporting company. At month's end, the same publication listed 148 wells as active, uncompleted or on holding status.

The most active operators in Rio Blanco County include Mobil Oil in the Piceance Creek Field, with projected Wasatch sandstone objectives; Chandler & Associates in Dragon Trail Field, a Mancos shale objective and Twin Arrow and Fuel Resources Development in the Cathedral Field area, also a Mancos play.

Drilling activity was also maintained at a high level in Garfield County by Tipperary Oil and Palmer Oil and Gas with primary objectives in the Mancos and Dakota Formations, respectively.

Two new wildcats were slated for Mesa County; one by Teton Energy, Denver, Colorado, the other by Adolph Coors, Golden Colorado. The Adolph Coors wildcat is a scheduled 3,500 ft venture with probable objectives in the Rollins, Cozzette and Corcoran sandstones. Teton's projected total depth is 7,500 ft in Morrison beds, deeper Cretaceous producing horizons below the already gas productive Mesaverde beds, in the Coon Hollow Field.

A completion of considerable interest to the WGSP was reported January 26, 1978 by David A. Munson, in Divide Creek Field, Garfield County, Colorado. Mesaverde gas production was established from the gross interval 6,985 to 7,695 ft, IP 1,207 MCFD and 50 BPD of water after a frac using 65,000 gal of emulsion and 132,000 lb of sand (Table 3-1, Callout 1).

3.3.2 Greater Green River Basin

Major activity in the Greater Green River Basin continues to be Mesaverde testing in Sweetwater County, Wyoming. Amoco, Marathon, and Davis Companies are some of the major operators in the eastern portion of this

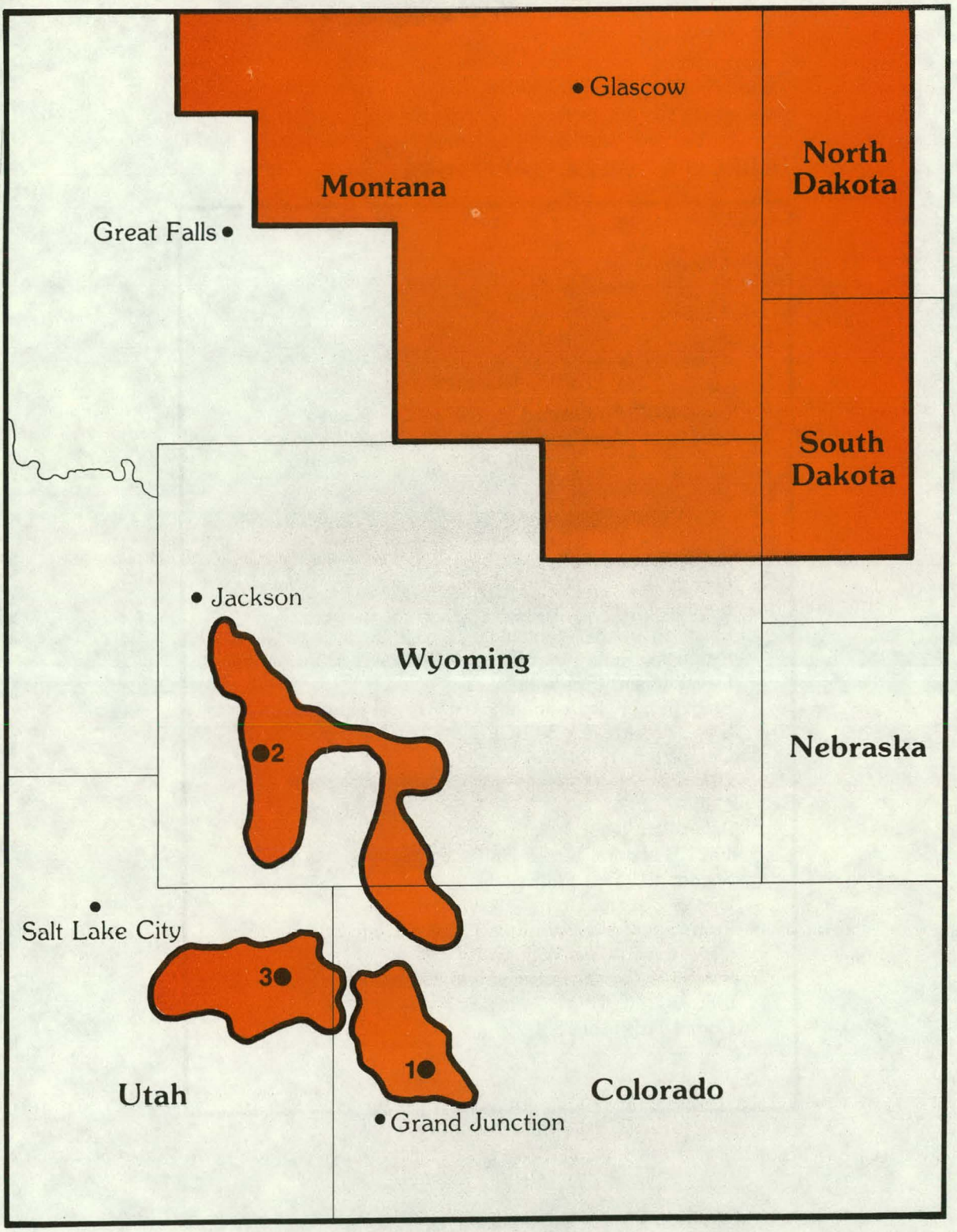


FIGURE 3-1 TARGET BASINS WITH WELLS OF INTEREST LOCATED

TABLE 3-1 WELL CALLOUTS

Callout 1
David M. Munson
1 Rifle Boulton
Section 23, T7S, R91W
Garfield County, Colorado
Divide Creek Field
Mesaverde Production (6,982-7,695 ft. gross)
Frac: 65,000 gal emulsion, 132,000 lbs sand
IPF: 1207 MCFD, 50 BWPD
Completed: 12/31/77

Callout 2
Amoco Production
Unit #5
Section 14, T21N, R112W
Lincoln County, Wyoming
Producing Zone—2nd Frontier (10,929-11,030 ft. gross)
Development Gas Well
Frac: 691,740 lbs. sand and 338,310 gal emulsion
IPF: 3,687 MCFD, 33 BCPD
Completed: 12/29/77

Callout 3
Belco Petroleum
19-21 B Natural Buttes Unit
Section 21, T9S, R20E
Uintah County, Utah
Producing Zone—Wasatch (5,598-6,854 ft. gross)
Development Gas Well
Frac: 114,234 gal emulsion and 308,000 lbs. sand
IPF: 930 MCFD
Completed: 1/23/78

county. This is significant due to the thickness of tight gas section and the area is located on both the north and south flanks of the Wamsutter Arch. Consequently, it is an optimum core site. The central and western part of Sweetwater County remain most active in Frontier exploration with Amoco and Davis the major operators. Amoco is also currently exploring for Lance (top of Cretaceous) production in this area. Lincoln and Sublette Counties are also significant for Frontier exploration (Table 3-1, Callout 2) with Amoco, Pacific Transmission Supply, Chevron and Rainbow Resources as key operators. Other areas for optimum core sites are in the northwestern part of Sweetwater County, and that portion of Sublette County occupied by the Greater Green River Basin.

3.3.3 Northern Great Plains Province

Areas of drilling activity in shallow Cretaceous sands range from the Sweetgrass Arch, Toole County, Montana to the west flank of Bowdoin Dome, Valley County, Montana. This activity includes all northern tier counties between Toole and Valley Counties; Liberty, Hill, Blaine and Phillips. Prospective shallow gas horizons encompass the entire Upper Cretaceous sequence over most of the area: Judith River, Eagle, Niobrara/Bowdoin and Greenhorn/Phillips sandstones in the eastern two-thirds of the region, or in all areas where these beds do not outcrop, such as on the Bearpaw Arch, Little Rocky Mountains and on the Sweetgrass Arch proper. However, nearly equal drilling emphasis is being placed on Lower Cretaceous sandstones in the western two-thirds of the north tier region, i.e., the Mowry, Muddy and Skull Creek Formations and their stratigraphic equivalents and the Bow Island sandstones and/or the Blackleaf Formation members.

Examples of recent and continuing successful shallow drilling are demonstrated by programs being carried out by Damson Oil on the Blackfeet Indian Reservation, Glacier County, Montana and to the south in Pondera County, Montana, Balcron Oil in Pondera County and Milan Ayres et al in Toole County and Pondera Counties, Montana. Totally, these three operators have drilled scores of successful, shallow Blackleaf/Bow Island gas wells in the past year. This drilling and that done by other operators accounted for at least thirteen new gas fields above 2,000 ft drilling depth in 1977.

Weather continues to be the main deterrent to the continuation of 1978 scheduled development/wildcat drilling and the spudding of the several newly announced Upper and Lower Cretaceous drilling programs for the entire Northern Great Plains Province.

3.3.4 Uinta Basin

Most of the activity in the Uinta Basin has been in the Natural Buttes and Chapita Wells Units of Uintah County, Utah. The major objectives are the tight Tertiary Wasatch and Upper Cretaceous Mesaverde Formations.

Pacific Transmission Supply and Continental Oil have staked five tests in the Mesaverde Formation in the eastern part of the Chapita Wells Unit. Gas Producing Enterprises is involved in an extensive coring and logging program in the CIGE #21 well as part of their contract with DOE.

Belco Petroleum has recently completed four wells in the area resulting in significant gas production from the Wasatch Formation utilizing sand-emulsion fractures (Table 3-1, 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

The design work for the pressure core barrel is progressing. The barrel chosen is 7-3/8 in. outside diameter for use with an 8-1/2 in. bit. The initial design work concentrates on the bottom of the barrel which contains the rotating ball valve. The achievement guidelines state that core size is not to be less than 3 in. This will probably result in a working pressure barrel in the 6,000 to 7,500 psi range.

The coring fluid tests have centered on the Dow Corning 200 fluid which is about 60,000 centistokes viscosity, but is not a gel. Invasion tests were performed with 500 psi differential pressure for 24 hours using Berea sandstone. An invasion depth of 5 mm, which may be acceptable, was observed. Other coring fluids will be evaluated and tests at dry ice temperatures will be made.

The first designs for the core bit, using Stratapax cutters, have been made using a computer. The design involves the removal of 0.212 cc per revolution for each Stratapax. This should enable a 10 ft core to be cut in 20 minutes. Coring tests are being planned using a prototype pilot bit.

4.1.2 Interface Conductivity Effects on Electric Logs

Attempts at measuring surface areas of cores from tight gas sands gave conflicting results. Several problems with the modified B.E.T. type apparatus were detected. To compensate for these, a new type of sample holder for thin core wafers, approximately 1-1/2 in. diameter, has been designed and constructed. The design uses a single Woods metal layer to seal the sample in the holder and to hold the core end pieces.

Further testing of the design is in progress.

4.1.3 Mapping and Contouring Formation Water Resistivity

Data acquisition continues.

4.1.4 Logging Techniques and Interpretation

A contract has been prepared for submission to Texas A&M University to study acoustic , density, and neutron logs of western tight gas sands for development and understanding of interpretation techniques.

4.1.5 Rock-Fluid Interaction

A medium-pressure liquid-injection apparatus has been assembled in the laboratory. Additional high pressure components (on order or being built) will be added so the apparatus can be used at pressures up to 8,000 psi.

A cell for measuring permeabilities under high overburden pressure has been completed.

4.1.6 Measurement of Formation Core Characteristics

These measurements are to be made on core recovered from wells drilled during the remainder of FY 78. While some of these measurements will be made by participating government laboratories, the WGSP will use industrial laboratories to perform routine analyses.

4.2 Lawrence Livermore Laboratory

4.2.1 Theoretical and Experimental Model Development and Application

Application of the two-dimensional hydraulic fracturing models with the expanded boundaries has been directed toward two areas. These are the analysis of pore pressure across layer boundaries for various formation parameters and the effects of layering on the in situ stress fields and surface deformations for a pressurized hydraulic fracture.

The pore pressure effects are being analyzed by computing the case of a pressurized fracture which is perpendicular to and symmetric across a material interface. The interface is cemented so that parting along this interface does not occur. Some calculations have been completed for the cases where the materials on either side of the interface have the same elastic characteristics but have different hydraulic conductivities. As indicated by some previous calculations, the stress concentration factor decreases more rapidly at the crack tip in the material with the higher fluid conductivity.

The models with the expanded grid are being used to complete the calculations of the effect of layers on the surface deflections near a pressurized hydraulic fracture. This problem has been studied previously,

but the results had limited value due to interference from the boundary of the grid. These boundary effects are reduced by expanding the zone size near the mesh boundary. The programming required for the zone expansions in the model has been completed. Several calculations, each corresponding to a different grid size or expanded zone size, have been completed for a test problem. In the test problem there is no layer and the surface displacements and slopes are monitored to determine changes due to grid size or relative expanded zone size. The results appear to converge as the relative zone size is expanded near the boundary for a moderately sized grid. Currently, grid size is being altered to determine the smallest grid that can be used to obtain consistent answers. In addition, calculations which include the effects of layering have been initiated.

4.2.2 Experimental Program

During January, experiments continued to study the growth of a hydraulically driven crack across loaded, unbonded interfaces. The material used was Nugget sandstone with the crack growing along the bedding planes. As in the limestone experiments described last month, two types of interface surface finishes were used. One type of surface was a smooth ground finish while the other was a ground finish which has been roughened by sandblasting. All sandstone blocks used had the loaded surfaces ground flat and parallel to 0.001 inch. The sandstone block into which fluid was injected had one smooth surface and one rough surface. A block with a roughened surface was placed adjacent to the rough surface of the injection block and a block with a smooth surface was placed adjacent to the smooth surface of the injection block so that the experiment contained three blocks. A load was then applied across the interface. The block into which the fluid was injected fractured into two pieces when the fluid reached a pressure of normally 3,000 psi. Examination of the former surface indicated that a small crack may have initiated at some lower fluid pressure. It was found that when the normal load across the two interfaces was 1,000 psi, the crack crossed both the rough and smooth interfaces into the adjacent blocks. When the normal load was reduced to 625 psi, the crack crossed the roughened interface but did not cross the smooth interface. When the normal load was further reduced to 500 psi, the crack crossed neither of the interfaces. These experiments clearly indicate that the nature of the interface itself is important in determining whether or not a crack will cross it.

4.2.3 Reservoir Analysis

Modeling the post fracture behavior of Zone 1 of the Piceance Creek Unit Well F31-13G has continued. A detailed examination of the pressure build-up data (via a Horner plot) shows some interesting features. There are

two points of inflection. The curvature starts out (at early times) positive, goes slightly negative and then becomes slightly positive. The Laboratory is unable to adequately model this behavior with a "simple" model whose parameters are formation properties, fracture length and well bore/fracture storage. The pressure vs Horner time histories of such models exhibit positive curvature only and, at best, the data points wander around the calculated line. Since at this time there is no reason to question the accuracy of the data, an additional parameter was added to the model. This parameter is a flow resistance at the formation-fracture interface and may be physically related to formation damage by fracturing fluid, such as plugging and clay swelling. Preliminary calculations using this model are showing very good results and indicate a kh of about 1.1 md ft for Zone 1.

4.3 Sandia Laboratories

4.3.1 Hydraulic Fracture Mapping

4.3.1.1 Wattenburg Fracturing Experiment

Sandia Laboratories, USGS, and Texas A&M University are participating with Amoco in a series of fracturing experiments in the Wattenberg Field northeast of Denver, Colorado. The initial experiment had the formation breakdown on January 31 and the main fracture on February 1. Sandia participation on the first experiment included surface potential measurements, downhole wall clamped geophone package and the Hewlett Packard (HP) quartz pressure gauge system. The electrical potential experiment attempted to utilize a downhole current probe for injecting the current at the bottom of the well. The current probe had to be abandoned because of failures in the current switching system that could not be rectified prior to the fracture treatment.

The downhole seismic package was installed in the open hole section during the 15,000 gal breakdown. The breakdown pumping was divided into three phases of 5,000 gal each with a quiet period between each phase. During the time the fluid was being pumped into the wellbore or when fluid was flowing back to the surface, the geophone package was completely masked by noise. Even the smallest amount of fluid flowing by the package induced extreme seismic activity.

During the quiet periods, several seismic signals were observed. Preliminary playbacks have been made; however, the interpretation of these signals is not understood. These interpretations will be pursued in the upcoming months.

The HP pressure gauge was installed at the well head and connected to the casing for the breakdown and to the tubing for the main fracture treatment. Several interesting pressure phenomena were observed and this data will be further analyzed. Copies of the data were supplied to Amoco who then

informed Sandia that, to their knowledge, this was the first fracturing experiment where high quality and high resolution pressure data were obtained. At least two additional fracture experiments are presently planned for February and March in the Wattenberg area.

4.3.1.2 Logging and Formation Evaluation

A three-member task force has been formed at Sandia to study advanced logging and formation evaluation requirements and techniques. The task force has been charged with determining the state-of-the-art for permeability and hydrocarbon saturation measurements. After the state-of-the-art survey is completed, several advanced techniques will be evaluated including the use of downhole pulsed neutron generators.

4.3.2 Mineback Stimulation Test Program

Further attempts were made during January to locate the hydraulic fractures of the UE 12g 10 #6 "Interface Experiment" via exploratory coring. Figure 4-1 shows EV6 #2 was drilled horizontally at S19°W to a total length of 133 ft, but there was no evidence of the grouted fractures in the recovered core. Drilling was also initiated in EV6 #3 (not shown but at approximately the same azimuth as EV6 #1) at +7° in an attempt to locate the upper fracture in the welded tuff zone. At the end of January, coring was in progress and no additional fractures had yet been intercepted. Mineback toward UE 12G 10 #6 may resume in February, depending upon the results from this coring and development of a mining plan.

Examination of the in situ stresses in the vicinity of the UE 12g 10 #5 "Staged Proppant Experiment" is continuing. Small volume hydraulic fractures with dyed water were created in boreholes from the tunnel to determine breakdown, fracturing, and instantaneous shut-in pressures. Subsequent mineback along the boreholes will provide information on fracture behavior and stress orientation. Boreholes HFS #23 and EV5 #2 are being used to evaluate the Hole #5 region. Seven zones in HFS #23 were fractured in December. This month, nine zones in EV5 #2 were fractured and mineback through six of the seven HFS #23 fracs was completed. Hydraulic fracture data for HFS #23 and EV5 #2 are shown in Tables 4-1 and 4-2 respectively. These preliminary results indicate that fractures were initiated in only half the zones while fluid probably entered pre-existing fractures in the other zones. Initial inspection of the fractures in HFS #23 confirm this assumption, as quite complex fracture systems and faulting have been noted.

Helium permeability measurements have been made on samples taken from the Hole 6 core and are presented in Table 4-3. The same sample was tested under "as-received" and "oven-dried" conditions under confining

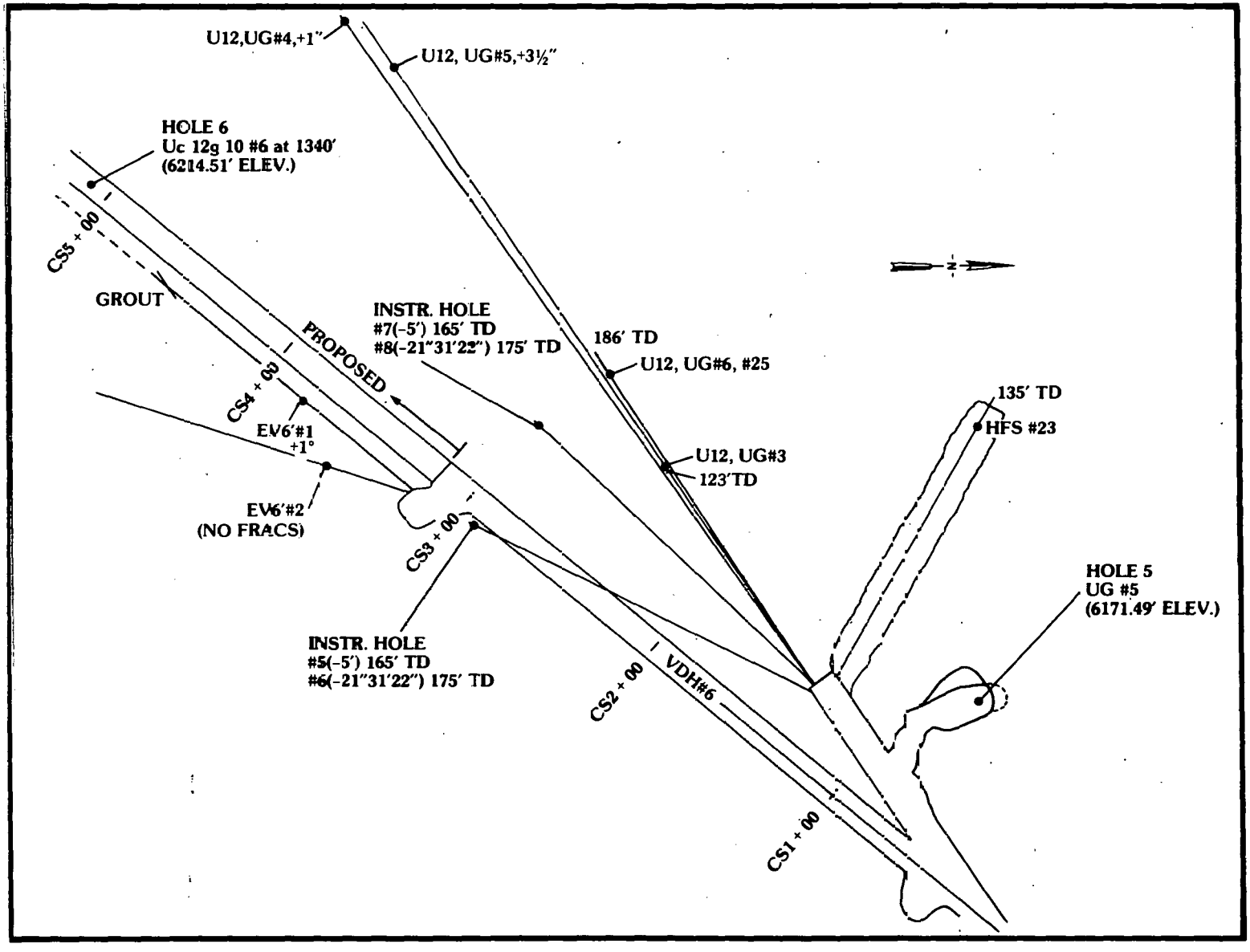


FIGURE 4-1 CURRENT MINEBACK ACTIVITIES, G TUNNEL, NEVADA TEST SITE

TABLE 4-1 HFS #23 HYDROFRAC DATA — PRELIMINARY LOOK

Zone (ft)	P	P (initial)	P (final)	P (3 sec)	P (30 sec)
9	631	566	757	673	449
23	538	421	421	331	252
42	—	687	687	561	485
54	—	561	729	701	505
71	911	757	729	687	586
99	813	701	729	533	280
126	—	603	701	645	463

Pressures in psi: P_c — breakdown
P_f (initial) — fracture pressure shortly after breakdown
P_f (final) — fracture pressure shortly before shut-in
P_{ic} (3 sec) — pressure 3 seconds after shut-in
P_{ic} (30 sec) — pressure 30 seconds after shut-in

TABLE 4-2 EV5 #2 HYDROFRAC DATA — PRELIMINARY LOOK

Zone (ft)	P	P (initial)	P (final)	P (3 sec)	P (30 sec)
12	—	603	556	492	408
20	—	721	680	536	350
33	—	628	577	499	381
58	1195	968	725	618	556
78	824	777	762	659	577
100	—	680	680	542	437
111	680	597	556	484	433
119	—	618	597	412	284
129	639	453	453	443	383

Pressures in psi: P_c — breakdown
P_f (initial) — fracture pressure shortly after breakdown
P_f (final) — fracture pressure shortly before shut-in
P_{ic} (3 sec) — pressure 3 seconds after shut-in
P_{ic} (30 sec) — pressure 30 seconds after shut-in

TABLE 4-3 HELIUM PERMEABILITY MEASUREMENTS TAKEN FROM HOLE 6 CORE

No.	Depth	Formation	Confining Pressure, psi	Permeability As-Received, md	Permeability Oven-Dried, md
5539	1297.0	Ash-Fall	0	1.3-2.4	3.9
			500	0.017	0.21
			1000	0.007	0.11
5540	1305.5	Ash-Fall	0	—	2.3
			500	0.19	1.6-2.1
			1000	0.33	1.2-1.7
5541	1313.0	Cracks and Voids	0	150	235
			500	10	70-85
			1000	18-25	60-75
5542	1323.0	Welded	0	0.006	0.018
			500	0.000	0.005
			1000	0.000	0.002
5543	1339.0	Transition	0	3.7	2.6-4.3
			500	0.35	1.3
			1000	0.16	1.0
5544	1343.0	Transition	0	0.004	0.066
			500	0.000	0.027
			1000	0.000	0.009
5545	1354.0	Ash-Fall	0	1.3-1.6	4.8-6.4
			500	0.17	1.9-3.0
			1000	0.20	1.2-1.6
5546	1363.0	Ash-Fall	0	0.56	—
			500	0.008	1.2-2.4
			1000	0.042	—

*Sample tested in the order: As received—500, 1000, 0 psi; then Oven-dried—500, 1000, 0 psi

pressures of 0, 500, and 1,000 psi. The order of tests should be considered, as water flow was often noted during the first one or two tests in the "as-received" state. The very low permeabilities in the welded and ash fall tuffs should also be noted.

4.3.3 Mobile Well Test Facility

The mobile test unit needed for testing experimental wells in the Western Gas Sands Project consists of the following major pieces of equipment:

A mast truck for installing lubricator and running instruments in the well without a workover rig.

A 10' x 50' trailer which will include the instrumentation, draw works and controls, surface recording equipment, work space and a minimum living facility for the operators.

A generator trailer for supplying power to the test system equipped with one 30 kw and one 90 kw generator.

The mast truck, now at Sandia Laboratories, is to receive additional equipment. The grease injection system will be mounted on the bed of the truck and the flood lamps mounted on the mast. Other minor additions are planned.

Remaining items to be completed on the instrumentation trailer are: installation of the voltage regulator for the instrument power system and spooling of logging cable on the winches. The voltage regulator is expected to be delivered during the week of February 21.

The 90 kw electric generator is awaiting housing available from the manufacturer. Delivery is also expected during the week of February 21. When completed, the 90 kw generator will be transported to GO, Fort Worth, Texas and will be used to supply power to the winch system of the instrument trailer during the spooling of the logging cable. March 1, 1978 is the optimistic transportation date for the completed instrument trailer to Sandia Laboratories.

Temperature probes for the downhole Hewlett Packard pressure gauge will be ordered by Sandia Laboratories.

CER Corporation has forwarded to Sandia lists of flow measuring equipment, appropriate recorders, spare parts and tools needed in the mobile test facility.

4.3.4 Other Program Related Activities

R.L. Bullick and F.J. Humphrey, Exxon Production Research, toured G-Tunnel during January. Carl Schuster and Bob Seavey visited CER on January 5 to discuss the status of the mobile well testing laboratory and the supporting equipment.

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

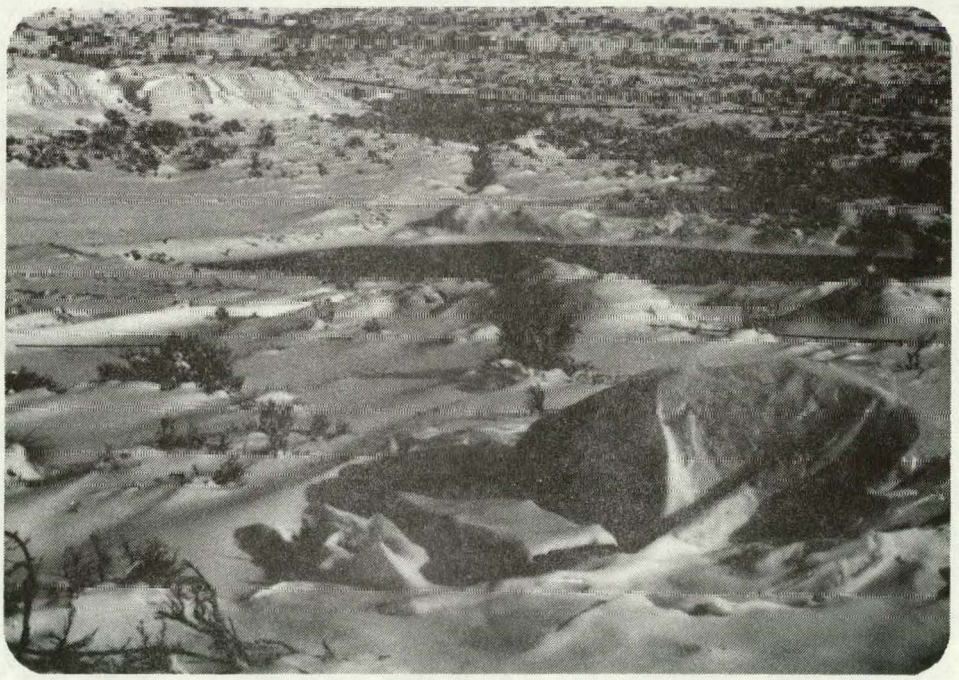
Circuitry is being installed and preparations are being made for the second phase of testing.

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

Principal activity centered on a three-well MHF sequence in the Sussex Formation near Ft. Lupton, Colorado. Two of the wells are separated by about the depth of the pay zone (i.e. 5,000 ft) and the third well to be completed on March 7 will be a few miles away. Amoco is providing the wells and support logistics as well as running thermal logs and televiewer logs of the formation before and after treatment. Sandia deployed, in addition to their resistivity array, a downhole seismic package and an HP pressure package near the injection zone. This series of experiments is the most comprehensively monitored set to date.

A more elaborate site preparation aimed at minimizing the coupling of the ground surface to transient ground noise was employed for the Sussex experiments. A preliminary analysis of the data indicates a considerably improved noise reduction.

Tiltmeter Site Preparation, LERC Site, Laramie, Wyoming, 1977



"Secured" Tilt Site, Laramie, Wyoming, 1977

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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 the experiment using 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 treatments. 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 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

RIO BLANCO MASSIVE HYDRAULIC FRACTURING EXPERIMENT

EY-76-C-08-0623

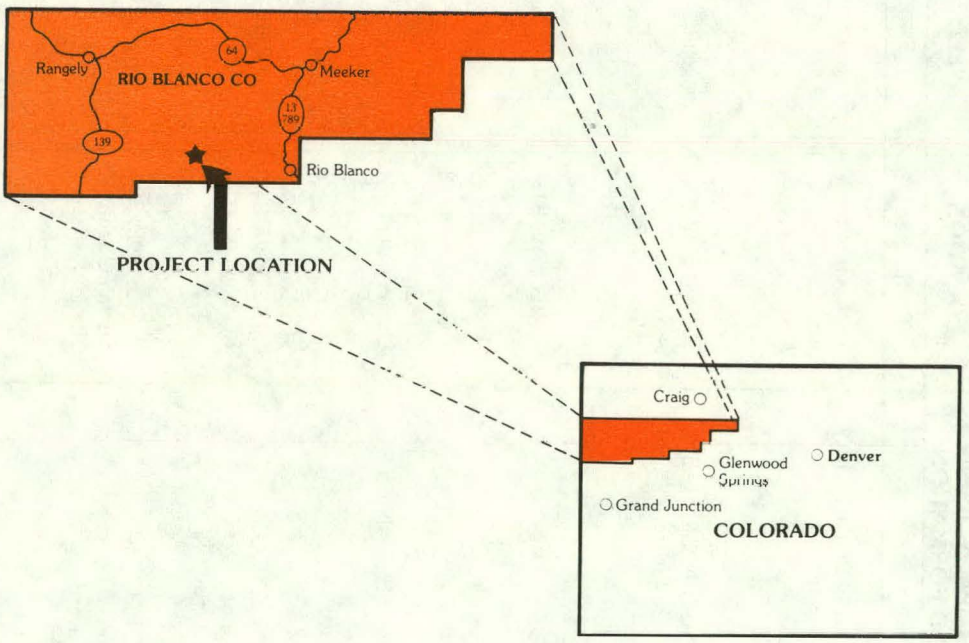
CER Corp.
Las Vegas, Nevada

Status: Awaiting Advisory Committee Decision

Interagency Agreement Date:	June 19, 1974
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 comingling 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:

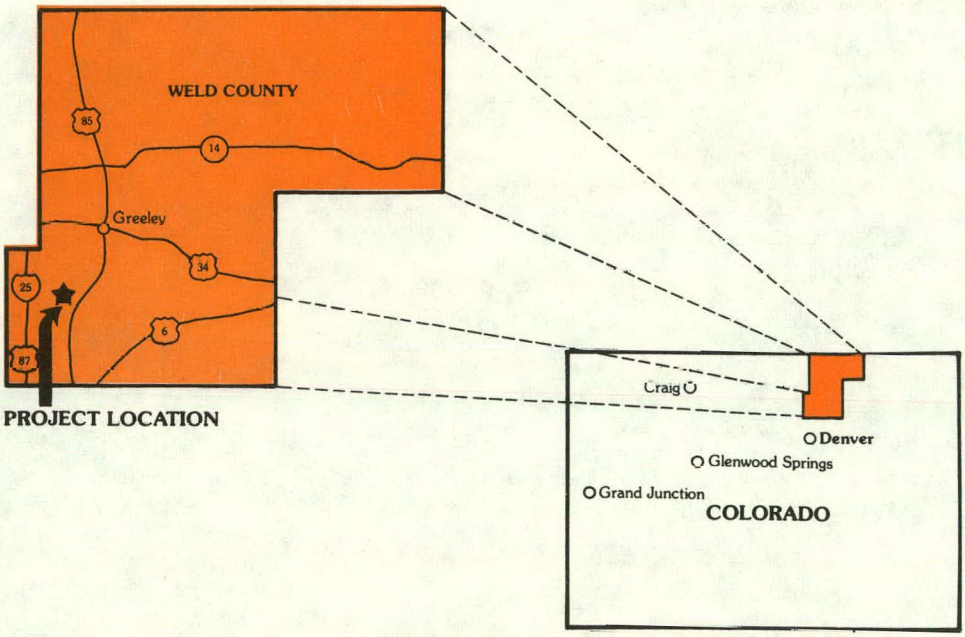
DOE	$ 75,000
CIG	99,000
Total	$174,000

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 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

A survey of a pipeline route between the two wells has been completed. Right-of-way drawings will be completed and issued to CIG's Land Department the first week in March.

Information from compressor manufacturers indicates that the original design conditions are so broad that a unit to encompass all pressures and volumes will be difficult to furnish with available standard engine and compressor sets. The principle problem is the very low volume (50 MCFD) to be compressed initially. The smallest standard cylinders operating at the slowest rpm have too much capacity. Because not all of the gas leaves the cylinder and only a small amount of new gas enters, the temperature in the cylinder quickly exceeds the design temperatures of compressor valves, cylinder liners, piston rings, etc. The compressor manufacturers have been asked to quote the unit which will come nearest to the design requirements. The vendors are also working on possible electric power compressors, and with bypassing gas from discharge back to suction to maintain an artificial high volume, which combined with other modifications may make a standard unit suitable. These modifications will entail significantly higher fuel gas for electricity consumption.

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

EY-76-C-08-0681

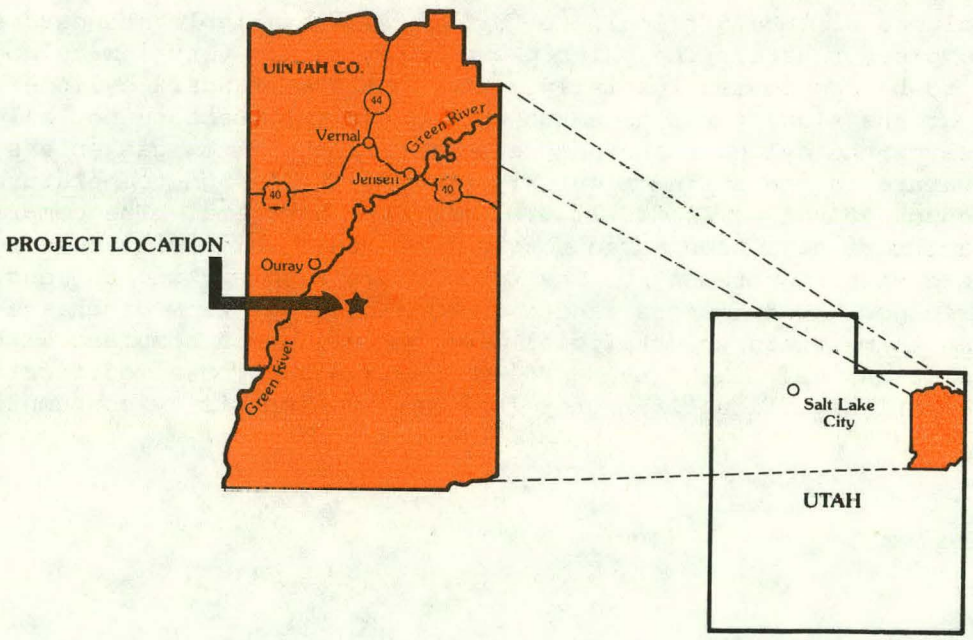
Gas Producing Enterprises, Inc.
Subsidiary of Coastal States Gas Co.
Houston, Texas

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 of which are 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, extra logs, and 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. Effort will be directed to development of techniques to predict the potential productivity of a sand member by electric log interpretation alone. This contract modification provides for DOE contribution of an additional $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, CIGE #2-29-10-21 and CIGE #23-7-10-22.

5.4.2 Current Status

Natural Buttes Wells No. 14, 18, 19 and 20 are still on production and will continue flowing to sales through February. 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 now flowing to the pit to clean up.

The Natural Buttes Well No. 9 MHF treatment design is being re-bid and recommendations will be prepared and submitted to DOE for approval. A subcontractor has been recommended to DOE for the proposed stimulation treatment.

The CIGE #2-29-10-21 well has been drilled to 9,895 ft and 4-1/2 in., 13.5#, N-80, 8rd, R-3 casing has been run to the same depth and cemented.

The logs run in the open hole are a Dual Induction Log, a Compensated Neutron-Formation Density Log and a BHC Sonic-Gamma Ray log. The logs are being studied to pick perforations and to prepare a MHF design. Bids will be obtained and submitted to DOE for approval.

The CIGE #23-7-10-22 well was drilled to 9,560 ft and 4-1/2 in., 13.5#, N-80, 8rd, R-3 casing has been run to 9,560 ft and cemented. Logs are being studied and a MHF design is being prepared. Bids will be solicited and submitted to DOE for approval.

Cores and logs from the Natural Buttes Well No. 21 will be analyzed and Natural Buttes Well No. 22 will continue to flow to clean up.

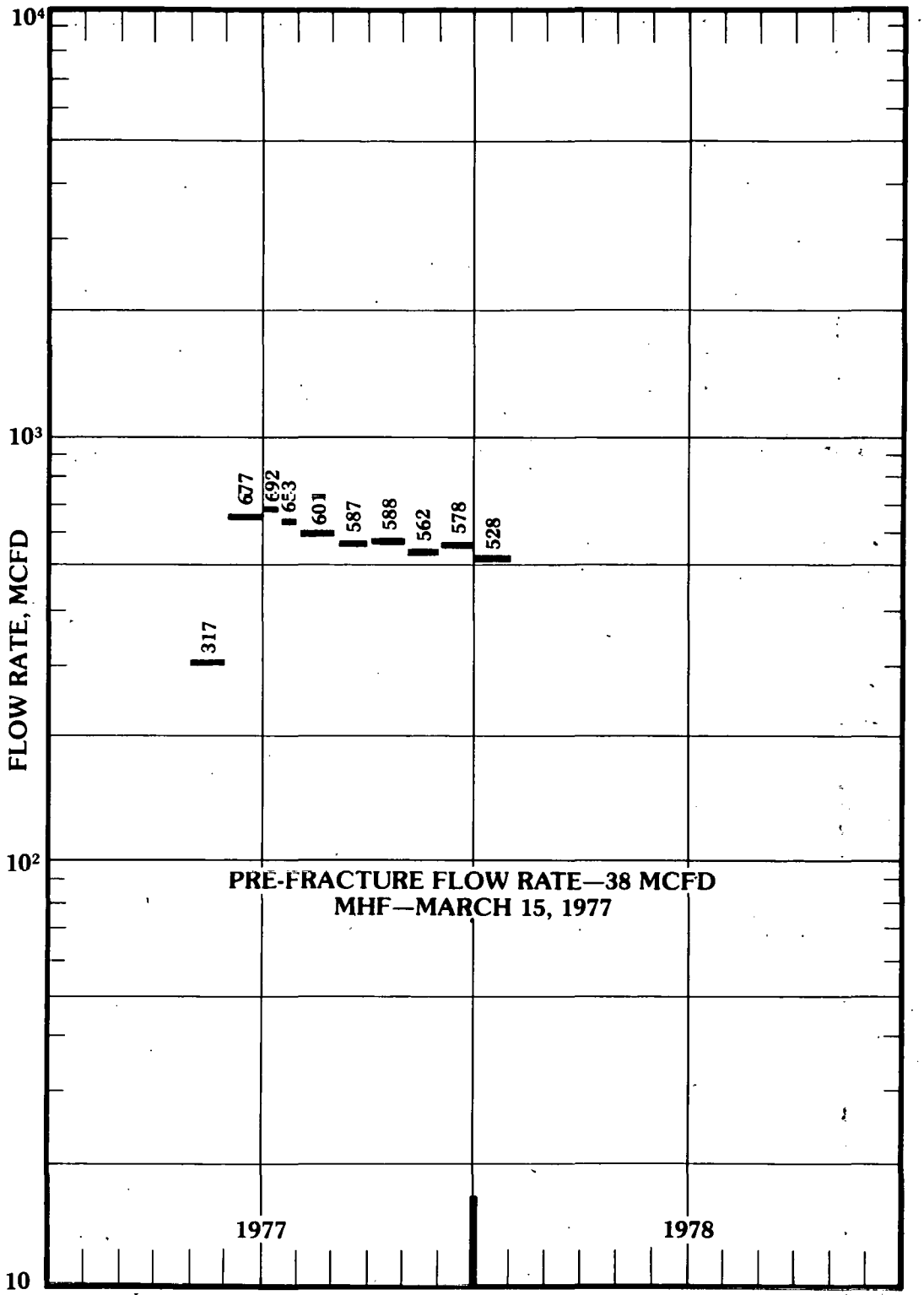


FIGURE 5-1 FLOW RATE PERFORMANCE OF NATURAL BUTTES NO. 14 WELL

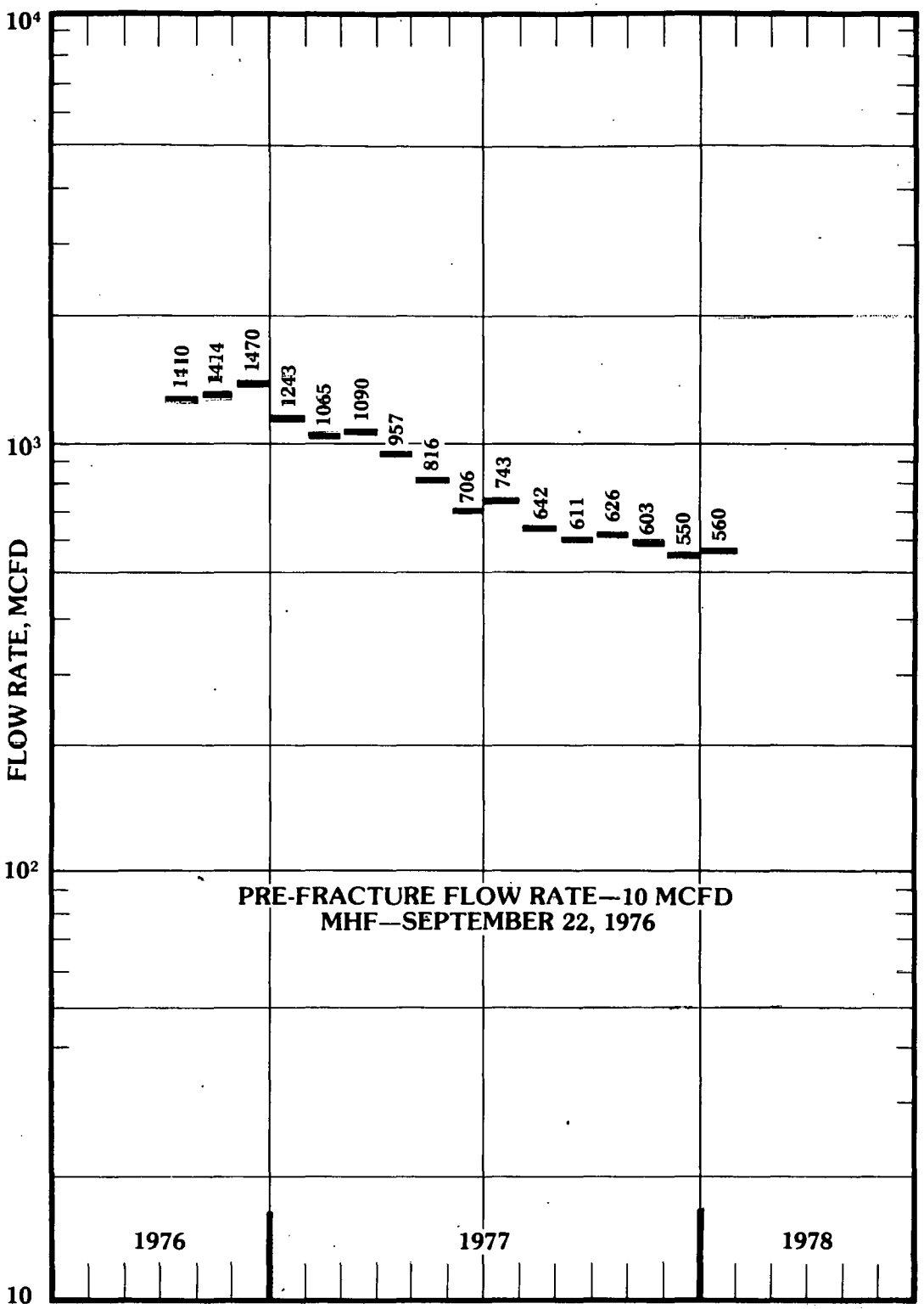


FIGURE 5-2 FLOW RATE PERFORMANCE OF NATURAL BUTTES NO. 18 WELL

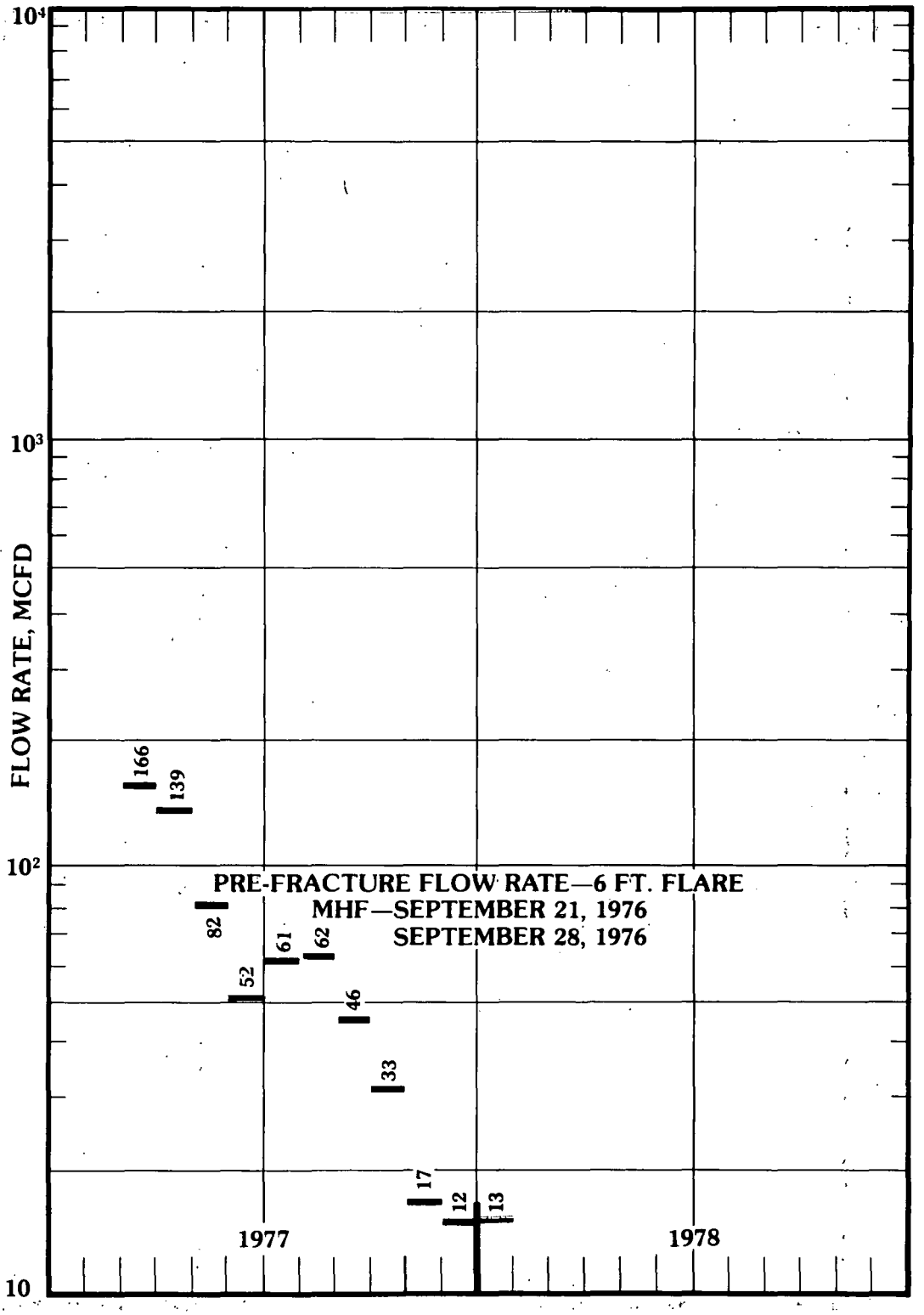


FIGURE 5-3 FLOW RATE PERFORMANCE OF NATURAL BUTTES NO. 19 WELL

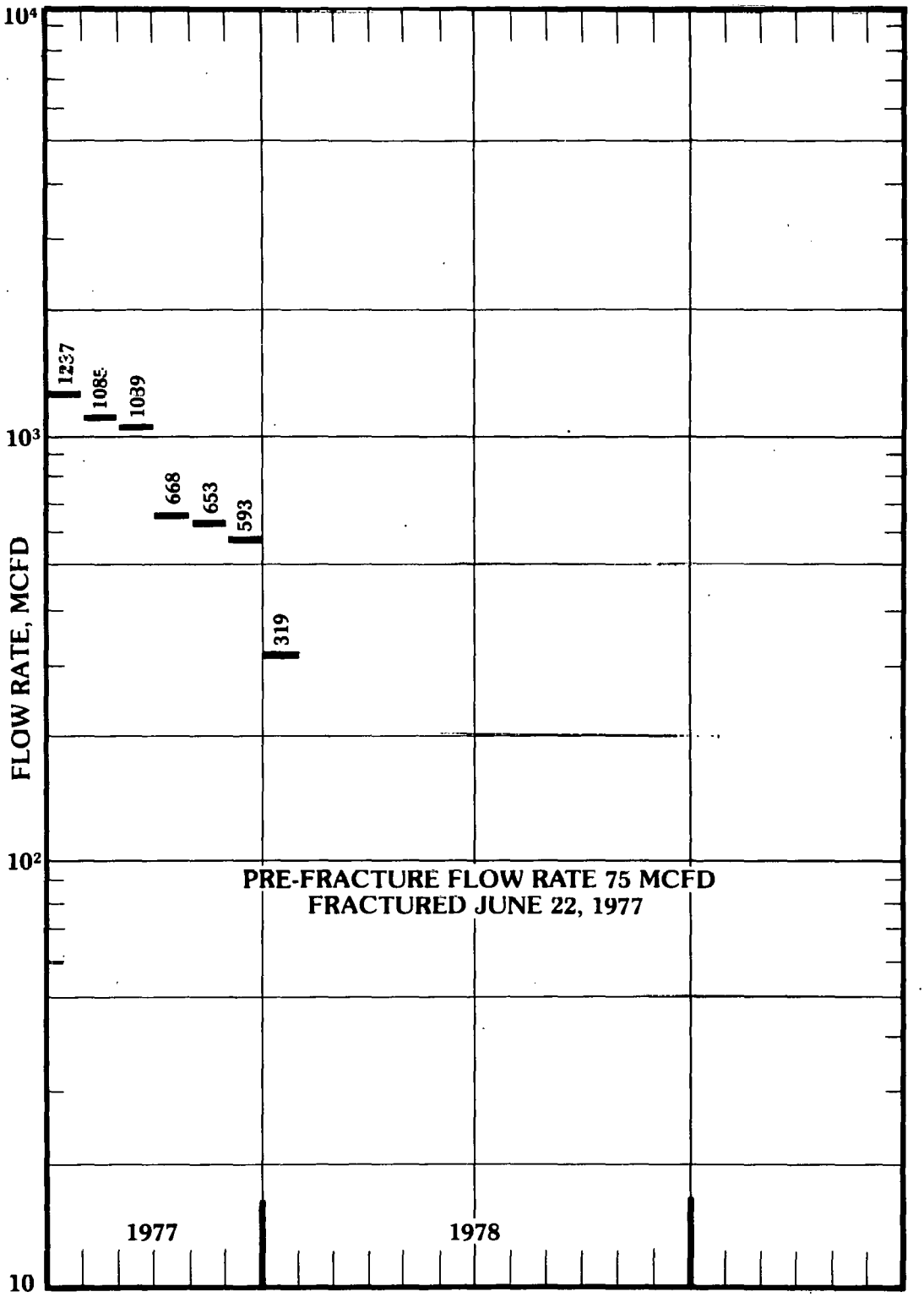


FIGURE 5-4 FLOW RATE PERFORMANCE OF NATURAL BUTTES NO. 20 WELL

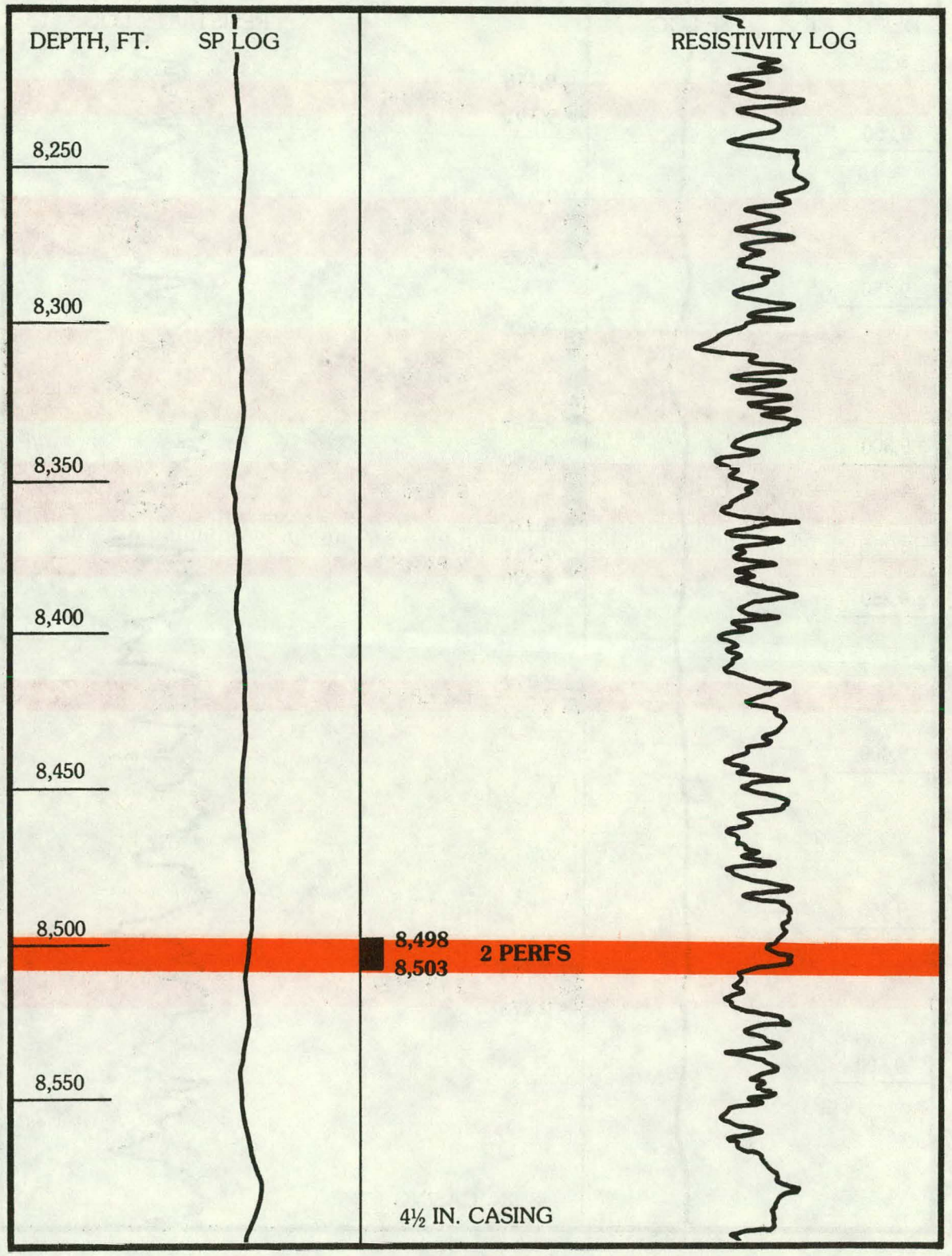


FIGURE 5-5 NATURAL BUTTES NO. 20 WELL SHOWING SANDS FRACTURED

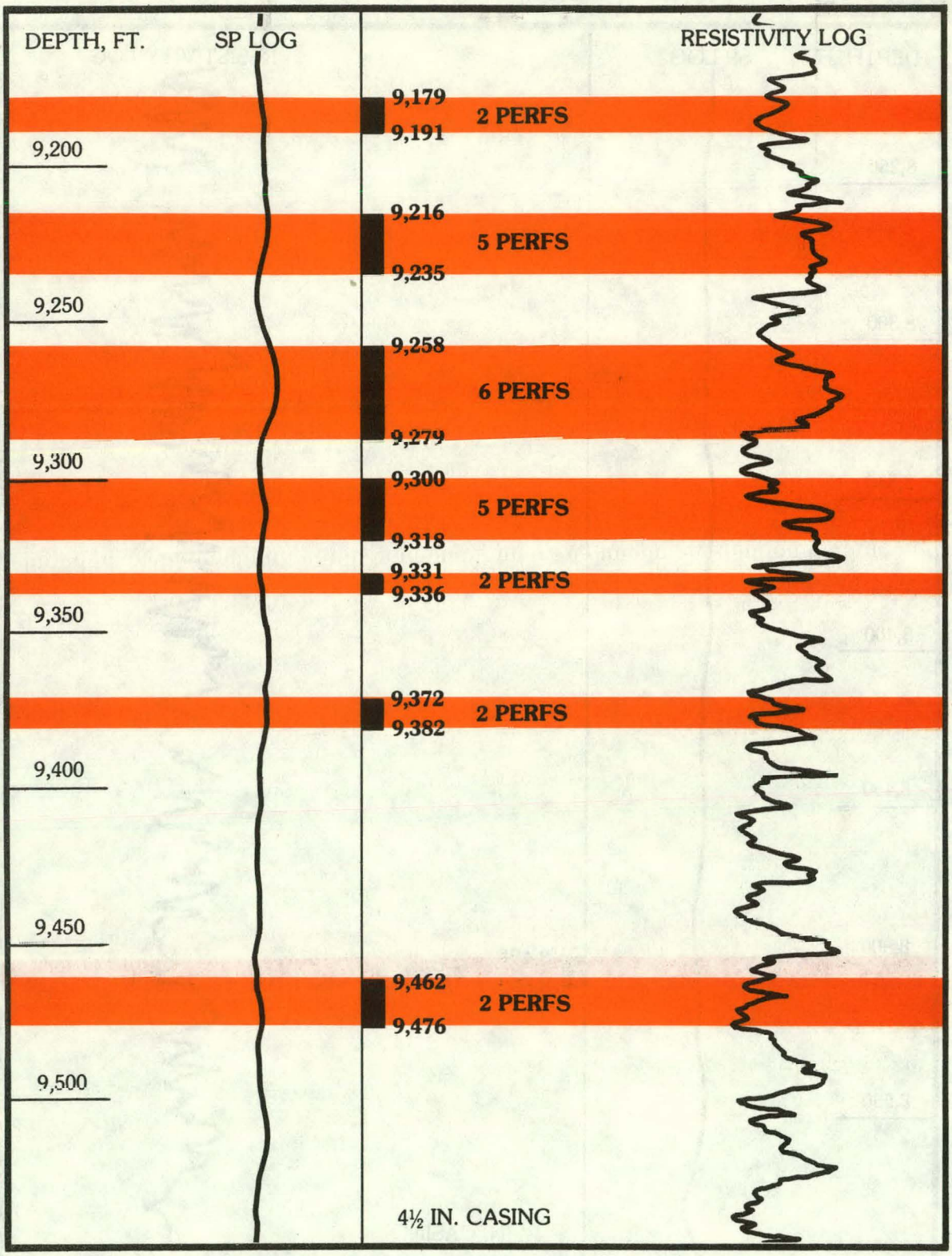


FIGURE 5-5 CONTINUED

PICEANCE CREEK FIELD, COLORADO, MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

EY-76-6-08-0678

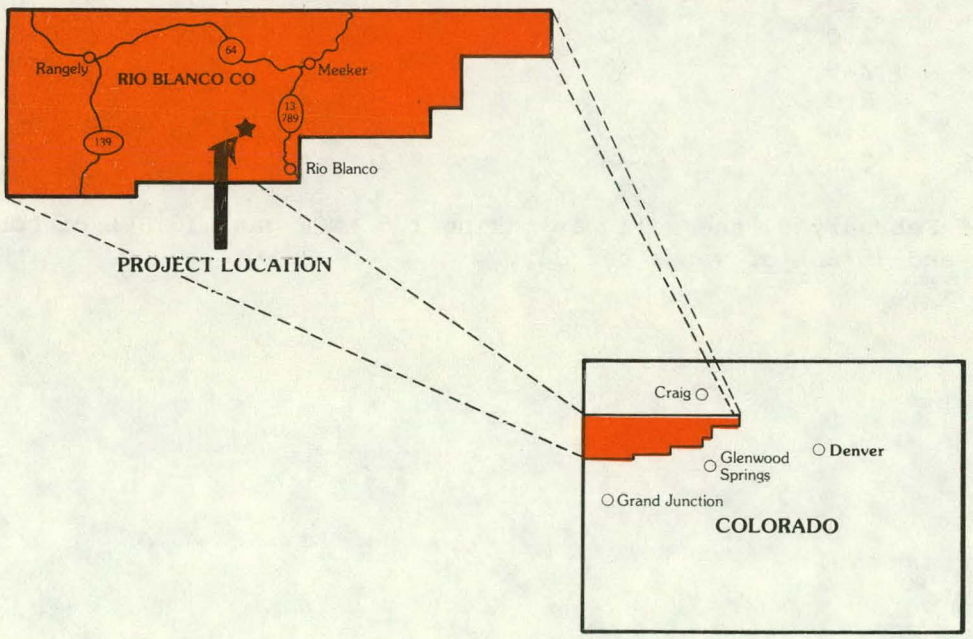
Mobil Research and Development Corporation
Dallas, Texas

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

The Mobil well F-31-13G remained shut in from December 18 until January 17 while awaiting connection to the pipeline. The well was opened briefly to flow on January 17, then shut in to correct difficulties with the separator. Flow data beginning January 18 are given in the table below. Choke size was 1 in. on January 19 and 3/4 in. for the remainder of the period.

Date	Gas MMCFD	Condensate BPD	Water BPD	C.P. psi	T.P. psi
1/19	3.0	28	400	1200	450
1/21	2.4	10	260	1125	430
1/22	2.3	27	250	1120	376
1/23	2.2	33	150	1080	378
1/24	2.0	20	200	1023	370
1/25	2.0	20	180	1010	375
1/26	2.0	20	170	1010	370
1/27	2.0	20	150	1160	372
1/28	2.0	20	142	1160	372
1/31	2.0	--	140	--	--

As of February 9, the well was making 1.5 MMCF gas, 16 BBL of condensate and 75 BBL of water per day.

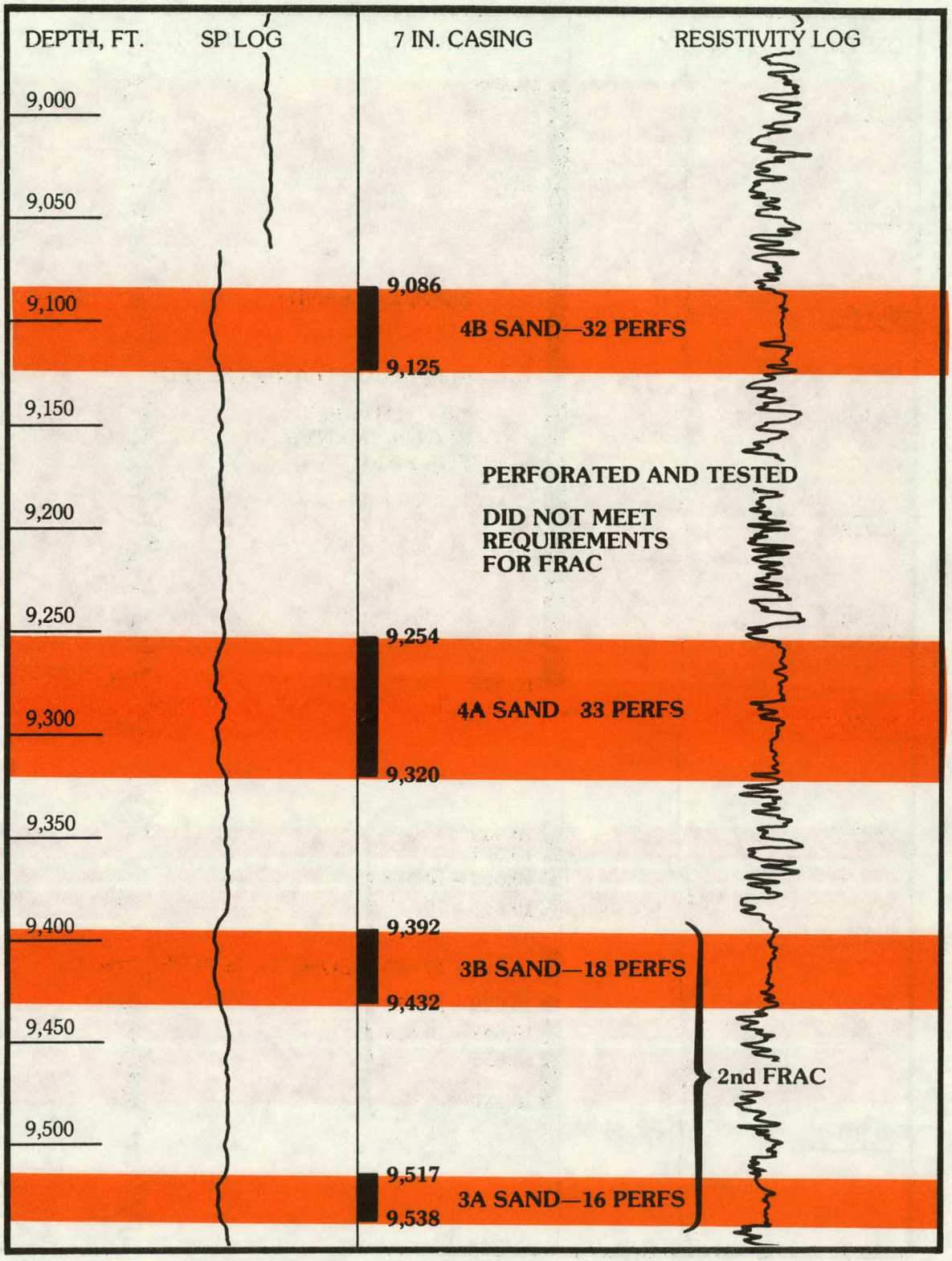


FIGURE 5-6 MOBIL F-31-13G WELL SHOWING SANDS FRACTURED

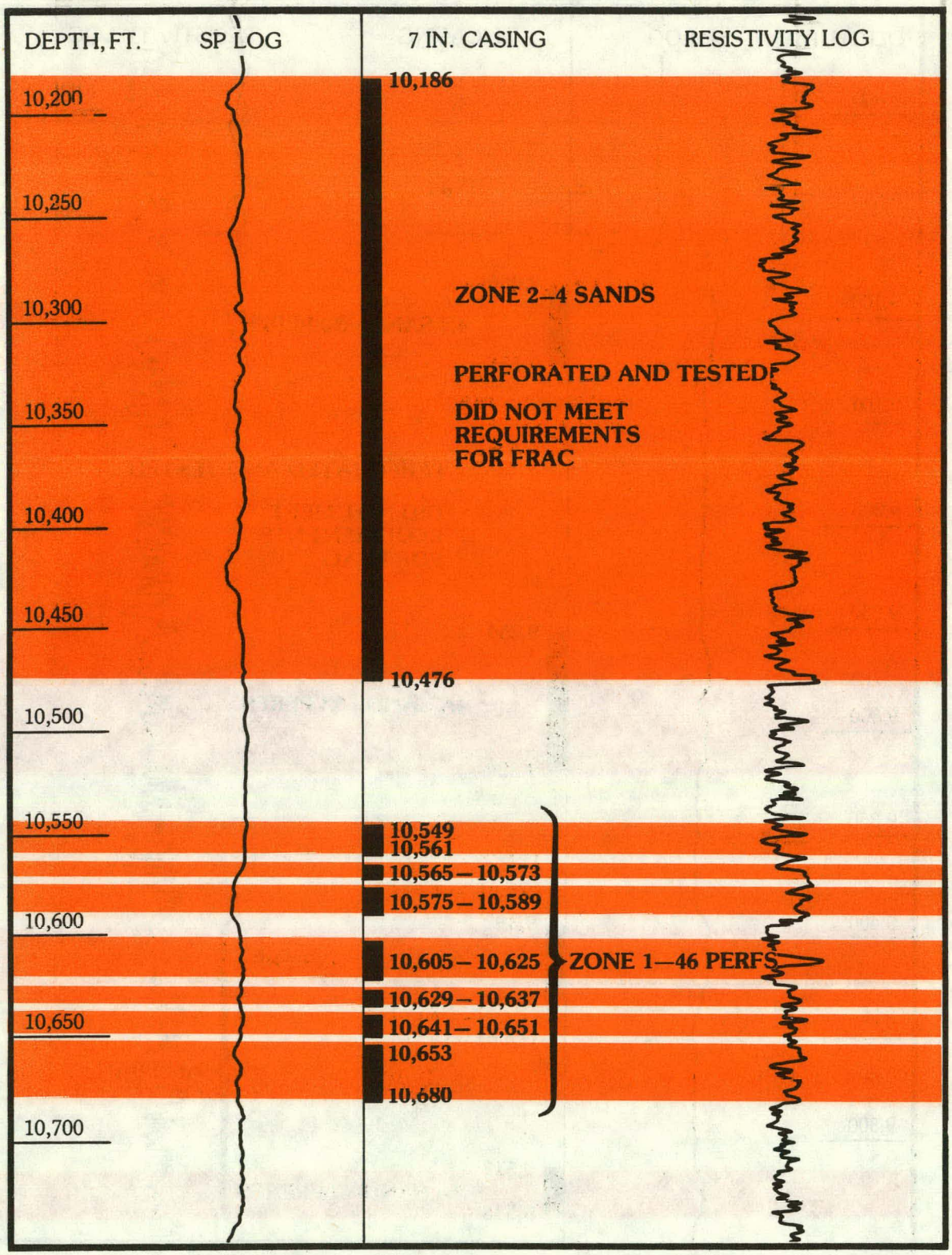


FIGURE 5-6 CONTINUED

RIO BLANCO COUNTY, COLORADO MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

EY-76-C-08-0677

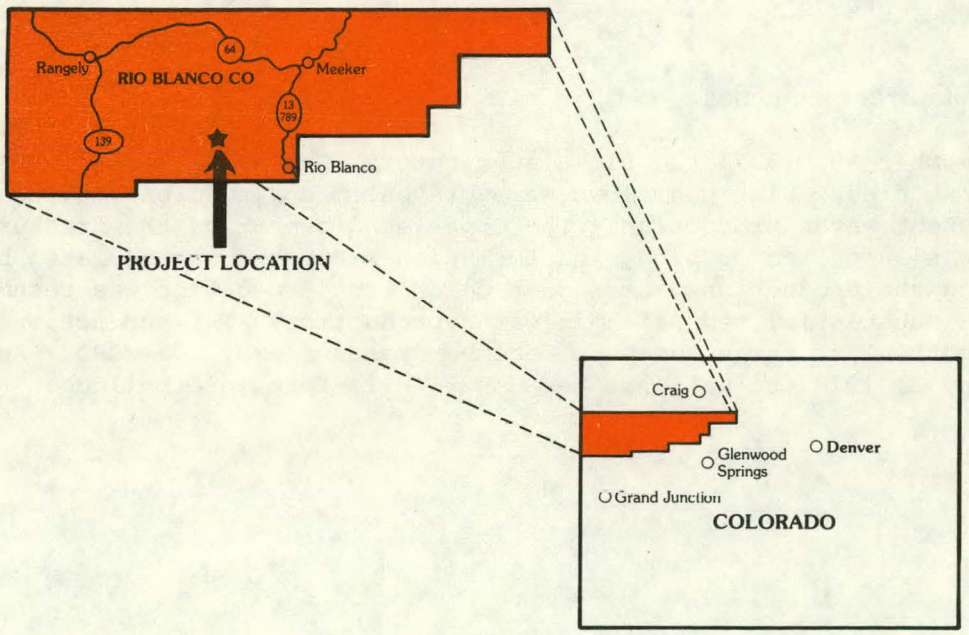
Rio Blanco Natural Gas Company
Denver, Colorado

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. Atkinson, Bartlesville Energy Research Center

OBJECTIVE

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



5.6 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

On November 30, 1977, the Rio Blanco Natural Gas Well, Federal 498-4-1 was fractured. High gas flows were prevented during clean-up due to persistent water production. 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. The production rate during the last three weeks in December was a steady 285 MCFD. As of January 2, 1978 the well has been shut-in for pressure buildup.

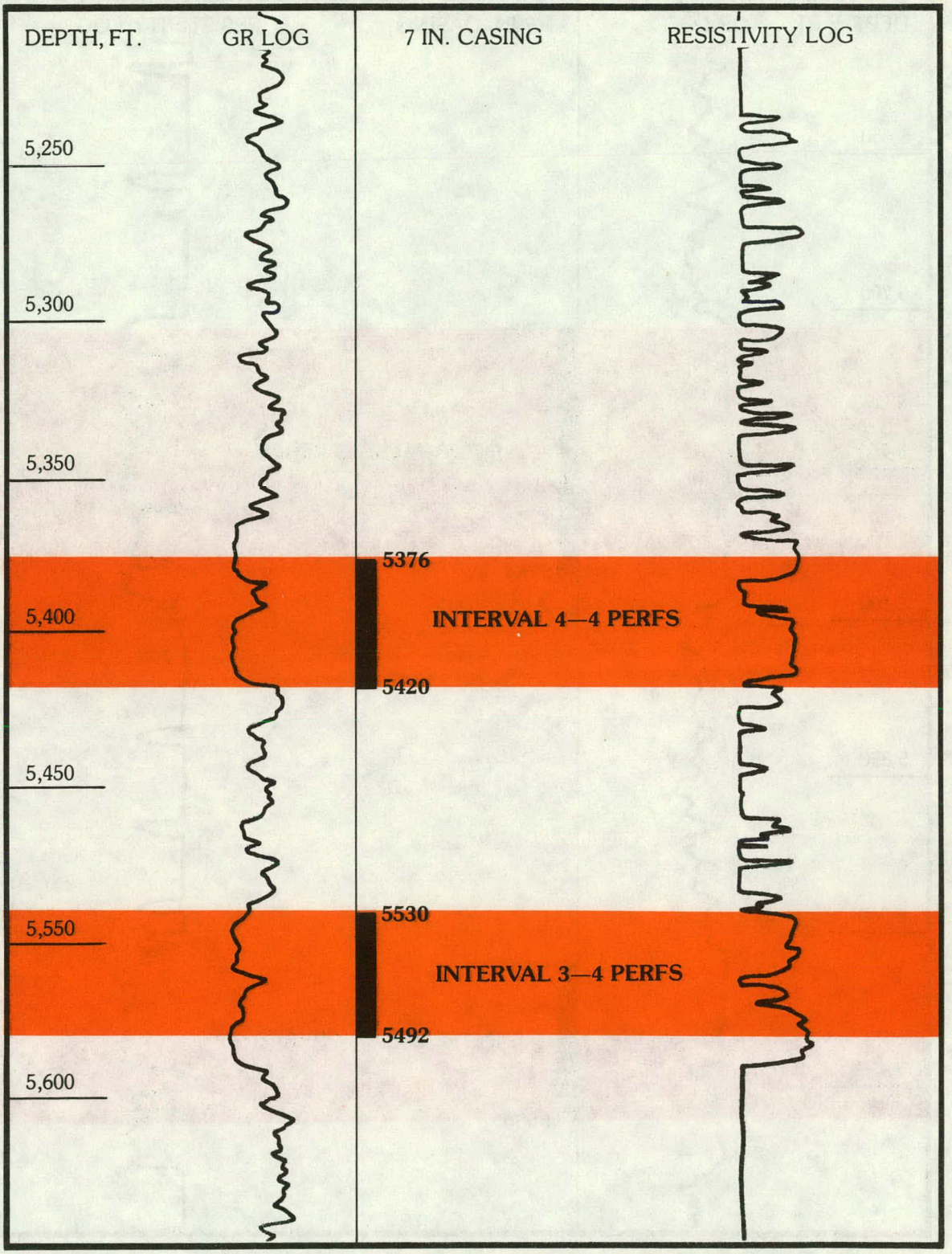


FIGURE 5-7 RIO BLANCO NATURAL GAS FEDERAL 498-4-1 WELL SHOWING SANDS FRACTURED

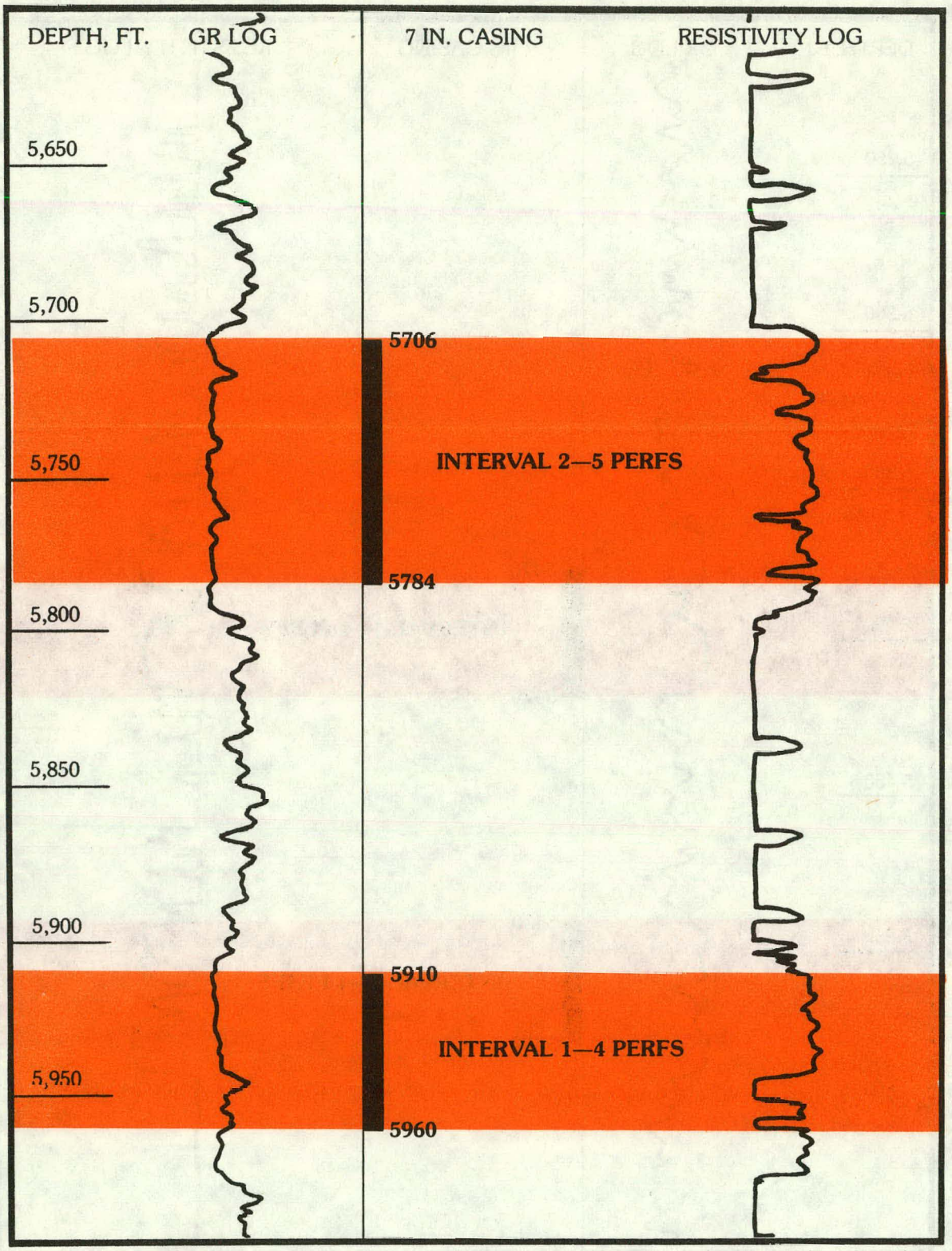


FIGURE 5-7 CONTINUED