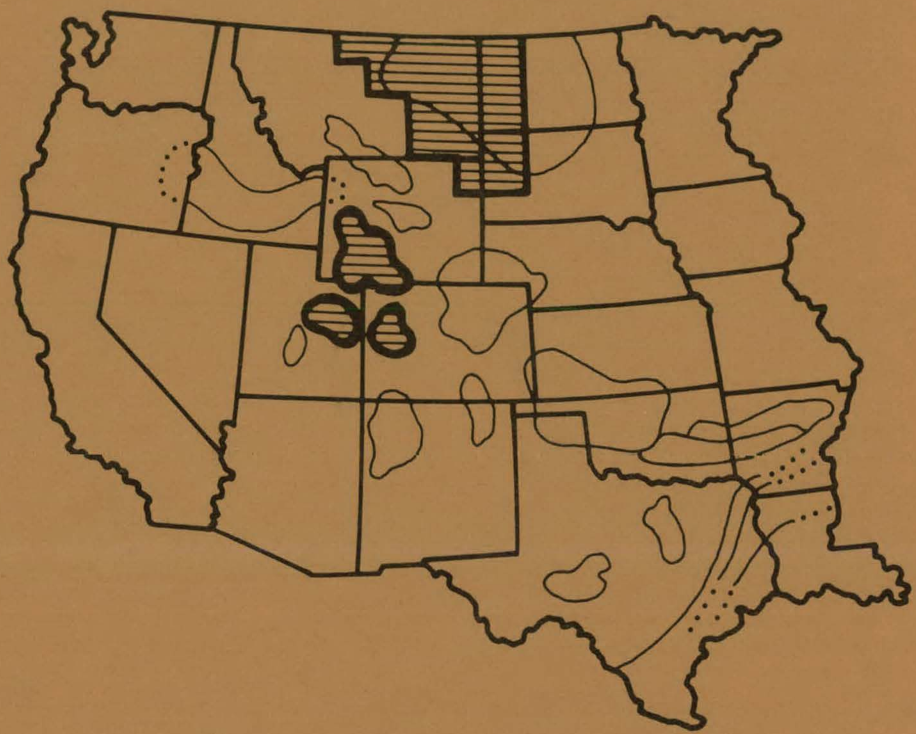
27 12/6/78 NTIS 24 to

MASTER

NVO/0655—112

Western Gas Sands Project Status Report



September 30, 1978

Prepared for
U.S. Department of Energy

Bartlesville Energy Technology Center
Charles H. Atkinson
Project Manager

Compiled by CER Corporation
Las Vegas, Nevada

Contract EY-76-C-08-0655

DISCLAIMER

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

NATIONAL TECHNICAL INFORMATION SERVICE PAPER COPY PRICES
EFFECTIVE JANUARY 1, 1976

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

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

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

CONTENTS

FIGURES

TABLES

1. SUMMARY

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

One of the largest massive Hydraulic Fracture (MHF) treatment to date was performed on Gas Producing Enterprises Well No. CIGE 2-29. C. H. Atkinson, Western Gas Sands Project (WGSP) Manager and D. C. Bleakly, CER Corporation were observers.

Oriented coring operations on the Mitchell Energy well, Muse-Duke No. 1 were observed by Atkinson and Bleakly near Mexia, Texas.

The third *Quarterly Basin Activities Report, July 31, 1978* has been completed and will be distributed. The *Log Program* and *Status Report - Financial Supplement, June 30, 1978* have been distributed. The *Status Report, July 31, 1978* has been completed and the *Fiscal Year 1979 Project Plan* is in review.

The Fourth Annual Department of Energy Symposium on Enhanced Oil and Gas Recovery and Improved Drilling Methods was held on August 29-31, 1978 in Tulsa, Oklahoma.

The USGS continued geological and geophysical studies in the four primary study areas. Low-level oblique photography of Tertiary and Cretaceous rocks exposed in the Rock Springs Uplift area was completed and core from the J. C. Paine well in Montana was sampled for petrographic analysis.

Bartlesville Energy Technology Center continued work on the improved pressure coring system and anticipates completion of the project by September 30, 1978. Preliminary work began on the *Parametric Analysis of MHF Test Data; An Engineering Study of Western Gas Sands*, by Intercomp.

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

The Mitchell Energy well, Muse Duke No. 1 has reached total depth and was logged on August 31, 1978. The DOE well test facility was moved from the RB-MHF 3 well in Colorado to Vernal, Utah for trailer modifications and checkout.

2. PROJECT MANAGEMENT

2.1 TECHNICAL MONITORING AND EVALUATION

C. H. Atkinson, DOE, and D. C. Bleakly, CER Corporation, were observers at the August 8, 1978 MHF treatment of Gas Producing Enterprises well CIGE 2-29. The treatment was one of the largest massive hydraulic frac jobs completed to date with a total of 722,000 gal of fluid and 1,965,000 lb of sand used over the 7,251-8,774 ft interval.

On August 21-24, Atkinson and Bleakly traveled to Mexia, Texas to observe oriented coring operations on the Mitchell Energy well, Muse-Duke No. 1. The objective formation was the Upper Jurassic Cotton Valley Lime, which will be treated with a MHF sometime in October.

L. T. Hodges, also of CER Corporation, studied the geology associated with the Mitchell Energy demonstration project. A review follows:

Stratigraphy

Cotton Valley Limestone, Cotton Valley Lime, and Haynesville Limestone are informal terms that have been replaced by the formal Gilmer Limestone Formation of Upper Jurassic age. The Gilmer Limestone is separated from the overlying Cotton Valley Group by a major unconformity and is not included in that group. The Gilmer Limestone overlies either the Buckner Formation or the Smackover Formation.

Figure 2-1 illustrates the position of the Gilmer Limestone relative to other Upper Jurassic Formations in the northeast Texas—northwest Louisiana—southwest Arkansas area. The Gilmer Limestone is stratigraphically equivalent to the Haynesville Formation which was devined as a predominantly red sandstone and shale unit, so that use of the term Haynesville Limestone should be discontinued.

The areal extent of the Gilmer Limestone is not well known. It is stratigraphically equivalent to and replaced by the Haynesville Formation near the Texas-Louisiana-Arkansas border. It grades into sandstone and shale of the Haynesville Formation towards the west, north, and northeast. Where the Gilmer Limestone lies directly on the Smackover, these units are difficult to separate. In this case the Louark Group is a satisfactory name.

Confusion about boundaries between the Cotton Valley Group and underlying units such as the Smackover Formation exists because they are difficult to distinguish in the subsurface, and in the past, some geologists placed part or all of the Smackover limestones in the Cotton

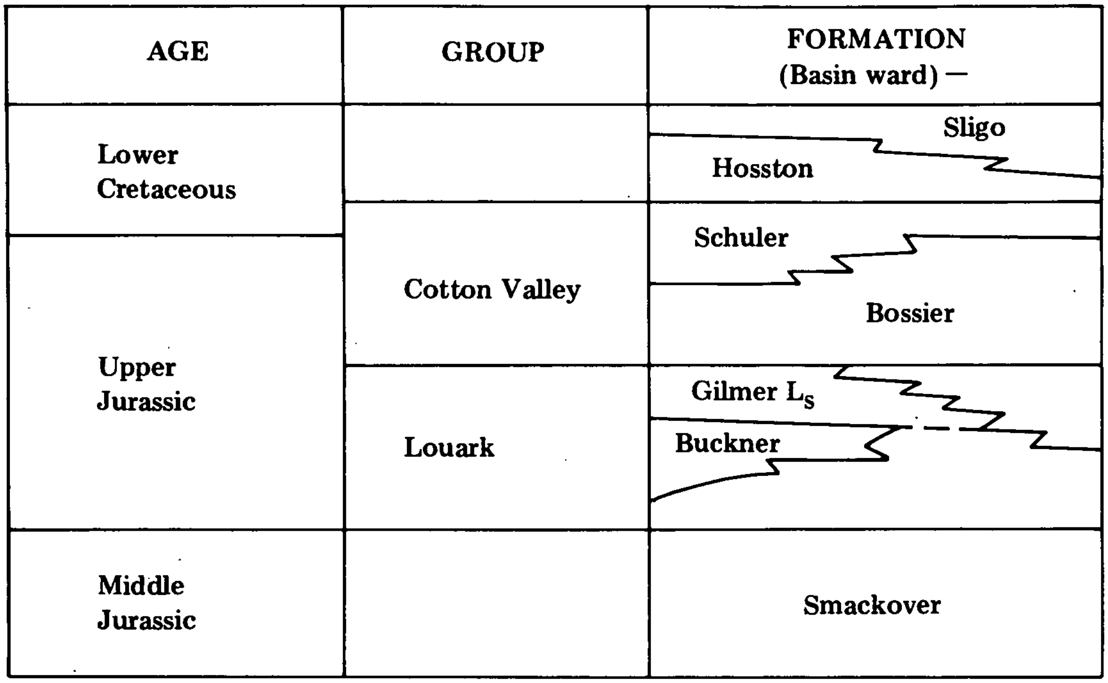


Figure 2-1 Stratigraphy and Extent of Cotton Valley Limestone

Valley Group. This may be the origin of the informal "Cotton Valley Lime." A schematic stratigraphic cross-section of the Cotton Valley Smackover is shown in Figure 2-2.

The Buckner Formation, where it underlies the Gilmer Limestone is usually recognized by its anhydrite and shaly facies, and this, then separates the Gilmer from underlying carbonate units.

The Gilmer Limestone does not outcrop, but is known only in the subsurface. The type well in Indiana Rock Gas Unit 2 of the Arkansas Louisiana Gas Company. It is located in the Gilmer Field, three miles east of Gilmer, Upshur County, Texas. The elevation of the well is 418 ft (KB). The top of the Gilmer Limestone is at 11,620 ft depth, and the base (top of the Smackover Formation) at 11,940 ft depth, giving a thickness of 320 ft at the type well.

A structure contour map for the pre-Cotton Valley Jurassic in northeastern Texas has been drawn. Depths to the (assumed) surface of the Gilmer Limestone or its Haynesville equivalent appear to range from about 4,000 ft to more than 12,000 ft. The surface dips to the southeast. In Limestone County, of interest because of Mitchell Energy's well, depths to the Gilmer Limestone range from less than 5,000 ft to over 12,000 ft.

Production

The Gilmer (Cotton Valley) Limestone of east Texas is thick, massive, oolitic, and finely crystalline. It rims part of the east Texas Basin and the Sabine uplift. The clean, porous,

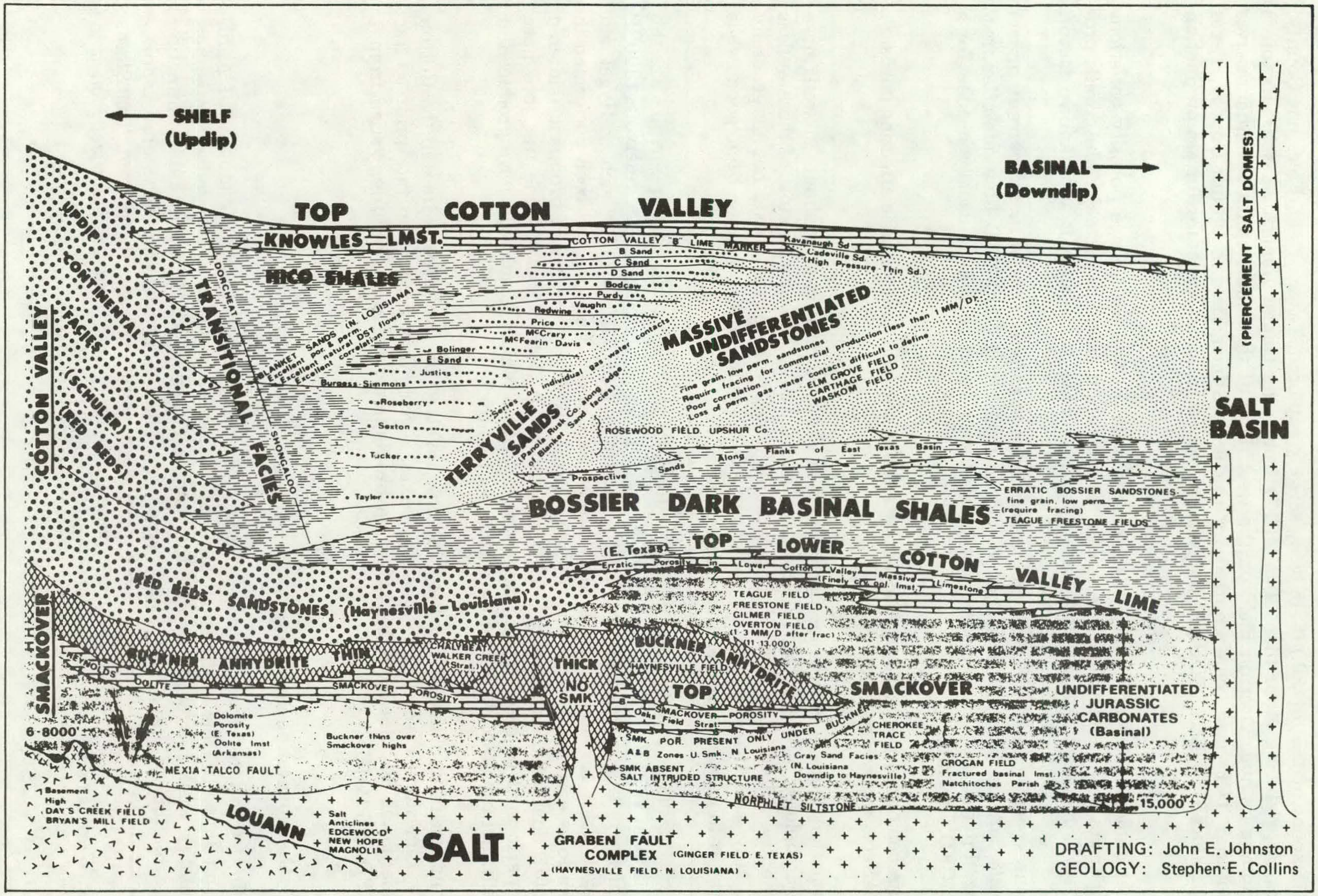


Figure 2-2 Schematic Stratigraphic Cross Section—Cotton Valley-Smackover (Jurassic) Ark-La-Tex Area (No Scale)

oolitic zones of the top 300 ft are being actively explored. Teague Field, Freestone County, Texas is producing more than 30 MMCFD from nine Gilmer Limestone wells. Exxon is developing its huge Overton Field on the west flank of the Sabine uplift. Potential reserves of up to 1 TCF have been reported for this area. Gilmer Field in Upshur County, Texas has produced 50 BCF. Stratigraphy is more important than structure for gas production here.

Gilmer Limestone reserves vary considerably from well to well, since porosity variations range from 4-17 percent and the results of fracturing are unpredictable. Most wells probably will recover in the 2-5 BCF range. Drainage area of the wells is an unknown factor.

Fractures significantly aid well productions. For example, wells with six percent or less porosity and permeability less than 0.4 md can sustain a 500 MCFD flow rate after fracturing. Internal fracturing or porosity greater than seven percent is usually needed for a 1 MMCFD flow rate.

Calcite cement in pore spaces is an important but unpredictable variable affecting porosity. This affects reserves and flow rates.

Information from a service company based in Dallas indicated that about 75 wells have been completed in the Cotton Valley Lime of east Texas, but data on most of these wells is proprietary. Stimulation by acidizing in the tight reservoirs of east Texas has not generally been very effective. Successfully acidized wells would probably have been good wells anyway with good damage removal treatment.

One of the major problems in using frac-fluid in east Texas carbonate reservoirs was the reduction in viscosity of the frac fluid because of high temperature in the reservoirs (300°F and higher). This was a problem until the introduction of frac fluids such as Hygel and Versagel. Prior to January 1976, only about two dozen frac jobs had been performed in the various carbonate reservoirs in east Texas. With an improved proppant (sintered bauxite), first used in January 1976, more than 50 Cotton Valley Lime frac jobs have been performed to date. More than a dozen Cotton Valley Lime wells have produced at a rate higher than 3 MMCFD for more than six months.

Information from a service company engineer involved on five massive fracs in the Cotton Valley Limestone in Freestone County, Texas, reveals that production rate prior to frac treatment was less than 100 MCFD while production rates after fracturing varied from 1 MMCFD to 5 MMCFD.

2.1.1 Documentation and Reports

The third *Quarterly Basin Activities Report, July 31, 1978* covering the months of April, May and June, 1978 is in the final stages of completion and is to be released in September. Preliminary work has begun on the fourth quarter report which will include information for the months of July, August and September. The *Log Progam* and the *Status Report - Financial Supplement June 30, 1978* have been completed and distributed. The *Status Report - July 31, 1978* has been completed and the *Fiscal Year 1979 Project Plan* is in review. Work is continuing on the WGSP Bibliography.

The following papers were presented by CER Corporation personnel at the Fourth Annual Department of Energy Symposium on Enhanced Oil and Gas Recovery and Improved Drilling Methods on August 29-31, 1978. Abstracts of other pertinent papers to the WGSP appear in Section 2.1.4 "Articles and Publications".

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

ABSTRACT

The Department of Energy (DOE) initiated the Western Gas Sands Project to develop resource information and pursue technological improvements in characterizing and stimulating the low-permeability reservoirs of the western United States. Previous studies have estimated natural gas resources of as much as 730 TCF in the largest four of twenty basins. Most of this potential source, however, is found in low-permeability of "tight" sand-shale sequences that cannot be exploited economically with current technology. The principle activities of the project are: resource assesment, laboratory research and development, and field research, development and demonstration. Resource assessment will include geological and geophysical studies to define the physical aspects of gas generation and entrapment, and to delineate the characteristics of the reservoir and source rocks. Laboratory research and development will concentrate on developing equipment and techniques to more accurately evaluate the resource. Rock and stimulation mechanics, fracture geometry, and simulated *in situ* measurements of reservoir characteristics will be emphasized. Simulation and modeling studies will provide new bases for analyses of production behavior and stimulation effectiveness. Field tests will aid in the development of techniques for formation evaluation, logging instrumentation and interpretation, production testing, and stimulation. Joint experiments between DOE and Industry will be utilized, ranging from limited, single-purpose "add-on" experiments in single wells to multiple-company "task force" participation in multi-well programs. The experiments will aid in tool and technique development, and will involve coring and logging in selected intervals, stimulation research, production testing and economic analysis.

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

ABSTRACT

The Gas Producing Enterprises/DOE MHF demonstrations in the Uinta Basin, Utah, constitute an important part of the FY 78 Western Gas Sands Project. Coring and logging of CIGE 21-15-10-22, a Mesaverde test in the Bitter Creek Field, has provided a multitude of formation evaluation data.

This paper analyzes log quality problems in the Mesaverde. Crossplot techniques are used to establish log validity, evaluate formation log parameters, and to provide methods for data normalization. Specific recommendations are made to improve the reliability of Mesaverde log evaluations.

H.E. Newman, III, R.L. Mann, and C.H. Atkinson (DOE)

Western Gas Sands Coring Program

ABSTRACT

Cretaceous low-permeability gas sands in the Rocky Mountain basins and adjoining regions represent significant amounts of potential natural gas resources. Coring select intervals of these sandstones, siltstones and shales is one of the primary steps in resource assessment and reservoir analysis. The Department of Energy will negotiate cooperative agreements or contracts with industry toward coring selected areas that have significant interest to the program.

The coring program will include both field work and subsequent laboratory evaluations. The field operation will include recovering, describing, packaging and shipping of the cores to the proper laboratories.

Routine core analysis will be done on most of the cores as well as special core analysis and tests on selected core samples. Normally the routine analysis will be performed by commercial laboratories and special core tests will be done by the government laboratories. The USGS will be responsible for archiving of all the core recovered in this program.

A comprehensive suite of geophysical well logs will also be run in order to compare logs with core data. The objective is to develop accurate log interpretations that can be used for formation evaluation without the need for cores. Wells will also be production tested to supplement core and log information.

2.1.2 Project Data Bank

CER Corporation has received numerous well logs and completion cards from Petroleum Information for wells drilled in the Piceance, Uinta, Greater Green River Basins, and Northern Great Plains Province. A library of articles pertaining to each basin has also been established. CER has access to an abstracting service and is receiving production information from the State of Utah on a monthly basis.

2.1.3 Calendar of Events

The following meetings and symposiums are of interest to the WGSP:

October 25-27
Second Annual Well Testing Symposium
Contact: W. J. Schwarz, Lawrence Berkeley Laboratory, Berkeley, CA 94720

October 30-31
SPE-AIME Production Technology Symposium
Contact: Bill Hart, Dowell, P. O. Box 640, Hobbs, NM 88240

November 5-9
Energy Technology Conference and Exhibition (Houston)
Contact: Energy Technology Conference and Exhibition, P. O. Box 59489, Dallas, TX 75229

November 6-8
Hydraulic Fracturing Symposium (Calgary)
Contact: Oil & Gas Consultants International Inc., Suite 1210, 3205 Boston, Tulsa, OK 74103

February 26-28
Sixth Energy Technology Conference
Contact: Martin Heavner, Energy Technology Conference, 4733 Bethesda Avenue, N. W. Washington, D. C. 20014

May 20-22
SPE-AIME Symposium on Low-Permeability Gas Reservoirs
Contact: SPE-AIME

2.1.4 Articles and Papers

The following papers relevant to the WGSP were presented at the Fourth Annual DOE Symposium, August 29, 30 and 31, 1978 in Tulsa, Oklahoma.

Demonstration of Massive Hydraulic Fracturing, Piceance Basin, Rio Blanco County, Colorado

J. L. Fitch and W. L. Medlin, Mobil Research and Development Corp.

Abstract—A thick sequence of gas-bearing sands and shales underlies the productive Wasatch Formation in Mobil's Piceance Creek Field. Demonstration that massive hydraulic fracturing will provide commercially attractive gas production rates from these sands is being attempted by Mobil with financial assistance from DOE. After the testing and fracturing work for the first two zones was completed, the well was cleaned out to total cased depth, and all open zones were put on production on January 18, 1978. The initial flow rate was 3.0 MMCFD. By February 16, the flow rate had declined to 1.5 MMCFD. Additional potentially productive zones in the interval 7,300 ft to 9,086 ft will be tested in 1978.

Continuity and Permeability Development in the Tight Gas Sands of the Eastern Uinta Basin, Utah

C. F. Knutson and C. R. Boardman, C.K. GeoEnergy Corporation

Abstract—Outcrop and subsurface studies of the tight gas sands of the Eastern Uinta Basin, Utah indicate that the gas-bearing elements are generally lenticular. Production curves for about 20 Eastern Uinta Basin wells were analyzed for radial or linear (lenticular performance. About 75 percent of the wells appear to produce from linear reservoirs; about 5 percent from radial reservoirs; and the remainder were indeterminate.

The Relation Between Facies and Low-Permeability Reservoirs in the Northern Great Plains

Dudley D. Rice and George W. Shurr, U. S. Geological Survey

Abstract—Major natural gas resources are entrapped in low-permeability (tight) reservoirs at depths less than 4,000 ft in the Northern Great Plains. Prospective reservoirs range in age from late Early Cretaceous to Late Cretaceous. To facilitate detailed examination, the potential reservoir section was divided into five intervals: (1) Muddy Sandstone and Mowry Shale, (2) Belle Fourche Shale and Greenhorn Formation, (3) Carlile Shale, (4) Niobrara and Telegraph Creek Formations and Eagle Sandstone, and (5) Claggett Shale and Judith River Formation. The most promising low-permeability reservoirs are developed in the shelf-sandstone, siltstone, and chalk facies because they are enveloped by thick sequences of shale which serve as both a seal and a source for gas.

Stimulation and Mineback Experiment Project—The Direct Observation of Hydraulic and Explosive Fracturing Tests

David A. Northrop, Norman R. Warpinski, Richard A. Schmidt, and Carl W. Smith, Sandia Laboratories

Abstract—Hydraulic and explosive fracturing experiments have been conducted adjacent to an existing tunnel complex at DOE'S Nevada Test Site and have been directly observed by subsequent mineback through the experimental area. Activities and accomplishments during the past year include: (1) Evaluation of a proppant distribution fracture experiment revealed a very complex fracture system; (2) An experiment was designed and conducted which examined the behavior of hydraulic fractures at an interface between an ashfall tuff and a welded tuff formation interface; and (3) In conjunction with a nuclear containment program, the residual stress effects around a contained explosive detonation have been studied.

Massive Hydraulic Fracture Mapping and Characterization Program

Carl L. Schuster, Sandia Laboratories

Abstract—Sandia Laboratories has continued the development and field testing of the surface electrical potential system. Several experiments have demonstrated the ability of this technique to determine fracture orientation and asymmetry. Applicability to deeper, smaller, multi-zone, and other types of fracturing is continuing to be evaluated.

Some Theoretical and Experimental Considerations of the Hydraulic Fracturing Process and Supporting Research

M. E. Hanson, G. D. Anderson, R. J. Shaffer, D. O. Emerson and H. C. Heard, Lawrence Livermore Laboratory

Abstract—A joint theoretical-experimental program is being pursued to analyze the hydraulic fracturing process to improve the design and analysis of this stimulation technique. Theoretical analyses with newly developed two-dimensional numerical models which include complete descriptions of the elastic continuum and porous flow fields have been applied to analyze the effects of pore pressure on the Mode 1 stress concentration factor. These analyses indicate that as the fluid migrates from the fracture into the surrounding medium, the stress concentration factor decreases. Other results indicate that for a fracture symmetrically located across an interface between two materials, the stress concentration factor is larger in the material with the higher Young's modulus, due to the presence of the other material.

Progress Report and Review of Natural Buttes Unit Massive Hydraulic Fracturing Project

R. G. Merrill, Gas Producing Enterprises, Inc.

Abstract—A Massive Hydraulic Fracturing program was initiated in the Natural Buttes Unit, a marginal gas field located in the Bitter Creek Field in the Uinta Basin of northeastern Utah. The program includes fracturing nine wells with different combinations of types and volumes of fluid, size and amount of sand and methods of placement to find the completion procedure which is the most effective in recovering gas from these low-permeability sands. The program also includes fracture orientation tests on various wells and coring, extensive electric logging, prefracture testing, etc. on one well. To date, one well has been cored with over 500 ft of recovery, and six wells have been fractured under the program.

Cyclic Dry Gas Injection Project, Dakota J. Sand, Wattenberg Field, Colorado

Howard R. Fredrickson, Colorado Interstate Gas Company

Abstract—Colorado Interstate Gas Company (CIG), in cooperation with the Department of Energy, is conducting a field test to determine if the productivity of wells completed in natural gas reservoirs of low-permeability can be improved by reducing the interstitial water saturation in the reservoir. Cyclic injection of dry natural gas is the method to be tried to accomplish the reduction of the water saturation. In addition to reducing the water saturation, cyclic injection of dry natural gas may improve the productivity through effects such as the dehydration of matrix clays and amelioration of surficial damage adjacent to the induced fractures.

Fourth Frac Treatment, Well Federal 498-4-1 Rio Blanco County, Colorado, A Progress Report

Anis A. Ishteiwy, H. K. van Poollen and Associates, Inc.

Abstract—A moderate volume fracturing treatment was performed on a 600-gross-foot section of the Mesaverde/Fort Union in Rio Blanco Natural Gas Company Well Federal No. 498-4-1. The treatment was designed to stimulate a multiple sand sequence at a minimum cost. The gross interval contains four separate sands with log-calculated net thickness, porosities, and water saturations of 30 to 60 feet, 8.5 to 11.5 percent, and 48 to 55 percent, respectively. After performing extensive remedial cementing and perforating, each individual zone was isolated and selectively broken down with acid, nitrogen and ball sealers. Commingled post-breakdown gas flow tested 100 to 130 MCFD.

Acoustic Methods for Detecting Water Filled Fractures Using Commercial Logging Tools

J. N. Albright, Los Alamos Scientific Laboratory

Abstract—The Los Alamos Scientific Laboratory, in cooperation with Dresser Atlas, has conducted single- and dual-well acoustic measurements to detect fractures in the artificial geothermal reservoirs at the Fenton Hill, New Mexico Experimental site. The measurements were made using modified Dresser Atlas logging tools. Signals traversed distances of from 48 to 150 ft between two wells. Signals intersecting hydraulic fractures in the reservoir under both hydrostatic and pressurized conditions were simultaneously detected in both wells. Upon reservoir pressurization, signals along many ray paths were severely alternated throughout their entire coda. The signals were procedded to obtain Full-Wave Acoustic, Power, and Normalized Equi-Power logs. Analysis of these logs identified the effective top of a region of hydraulically activated fractures and fractures intersecting the injection well behind casing.

An Improved Pressure Coring System for Fluid Content Measurements Sand 78-0679A

Alan L. McFall, Sandia Laboratories

Abstract—An improved tool for obtaining cores under near *in situ* conditions for accurate fluid content measurements will be described. Its use will apply toward the determination of the saturations of tight gas sands and unfractured shales. In addition, oil reservoirs, both new and those in secondary or tertiary recovery stages, will benefit.

The following papers and publications are of interest to the WGSP. Abstracts, when available are included.

Investigation of Acoustic Boundary Waves and Interference Patterns as Techniques for Detecting Fractures

E. A. Koerperich, Member SPE-AIME, Shell Development Company

Abstract—Acoustic wave-form amplitudes (compressional, shear, and later arrivals) and patterns of reflected and mode converted waves recorded on an axially oriented acoustic logging tool have been found to be unreliable indicators of *in situ* fractures in Altamont Field, Utah. Acoustic wave forms from two cored wells at Altamont were recorded on analog tape. The wave forms were played back, processed, and analyzed in the laboratory. Various acoustic events were compared in fractured vs unfractured rock through the cored intervals. Naturally occurring earth fractures were delineated and distinguished from drilling-induced fractures by observing crystal growth on the core fracture planes.

The Optimization of Well Spacing and Fracture Length in Low-Permeability Gas Reservoirs

S. A. Holditch, J. W. Jennings, S. H. Neuse, Texas A&M University; R. E. Wyman, Canadian Hunter Exploration, Ltd. (SPE 7496)

Abstract—Describes a modeling procedure for determining the most economic well spacing and fracture length in low-permeability gas reservoirs that requires minimum computing time and storage. The model combines fracture-length calculations, reservoir performance predictions, and present-value economic analyses for a given set of reservoir conditions. Presents findings, including the roles of variables such as formation gas permeability, other formation factors, and costs in determining optimum development plans.

Interpretation Guidelines for Post Fracturing Temperature Logs

R. C. Smith, T. A. Dobkins, M. B. Smith, P. D. Pattillo, Amoco Production Company (SPE 7559)

Abstract—Compares postfracture temperature logs with results of finite-element computer modeling of heat conduction around fractured and unfractured wellbores. Case histories of fractured-well temperature logs agree with model logs. Derives guidelines for qualitative interpretation of down-hole temperature behavior from comparing shapes of actual with predicted postfracture temperature curves. Discusses temperature anomalies resulting from changes in lithology and from fracturing fluid entering the formation. Describes modeling procedures and log indications of fracture height, radial temperature effects, and fracture azimuth.

Factors Affecting Water Blocking and Gas Flow from Hydraulically Fractured Gas Wells

S. A. Holditch, Texas A&M University (SPE 7561)

Abstract—Describes a computer simulation project conducted to study the combined effects of formation and relative-permeability damage on performance of hydraulically fractured gas wells. Reports using a two-dimensional, two-phase, fully implicit, finite-difference reservoir simulator to study effects of injected water and reservoir and fracture parameters on liquid removal. Discusses the roles of capillary pressure effects, water mobility, pressure drawdown, reservoir permeability damage, and other factors affecting gas productivity.

The Effects of Various Proppants and Proppant Mixtures on Fracture Permeability

R. R. McDaniel, J. A. Doak, B-J Hughes, Inc. (SPE 7573)

Abstract—Reports results of a study measuring fracture permeability vs closure stress of various proppants and proppant mixtures. Emphasizes mixtures of costly high-strength proppants and more economical fracturing sand. Presents computer analysis designed to help formulate guidelines for choosing the optimum productive fracture permeability and most economic proppant for use at different well depths.

3. RESOURCE ASSESSMENT

The USGS is performing the majority of the geologic studies involved in resource assessment. In support of this work additional activity, primarily in the area of field tests and core analysis is provided by participants in the Western Gas Sands Project.

3.1 U. S. GEOLOGICAL SURVEY ACTIVITIES

3.1.1 Greater Green River Basin

Low-level oblique photography of Tertiary and Cretaceous rocks exposed in the Rock Springs Uplift area was completed at a flight altitude from 200 to 500 ft. Very strong natural jointing was noted in many sandstones. The dominant joint patterns seem to be northwest and northeast. Several lineaments seen on USGS LANDSAT photos were checked out and appear to be lines of vegetation (sage brush) apparently controlled by concealed fractures or faults.

Cross section B-B′ has been completed and is being reviewed. The manuscript is a north-south electric-log section along the east flank of the Rock Springs Uplift.

Field work in the Hoback Basin which is part of northern Green River Basin has been completed.

The USGS received approval to sample the Koch Exploration No. 1 Adobe Town Unit wildcat in Section 20, T15N, R97W, Sweetwater County, Wyoming. This wildcat is a projected 17,500 ft Mesaverde test near the structural bottom of the Washakie Basin and will be the deepest test in the Basin.

3.1.2 Piceance Basin - Uinta Basin

The results from studies of reservoirs within Mesaverde rocks at Southman Canyon gas field were abstracted.

An abstract was prepared from the results of an analysis of mineralogical and sedimentological factors influencing diagenesis in some reservoir rocks of the Green River Formation. Similar gas-bearing rocks occur as tongues in the so-called "Wasatch" beds of the southeast part of the Uinta Basin.

The preparation of engineering and rock stratigraphic cross-sections in parts of the southern Piceance Basin was continued. When complete, the charts will be released as U. S. Geological Survey open-file reports.

3.1.3 Northern Great Plains Province

Core from the J. C. Paine well in Montana was sampled for petrographic analysis, and research on improved coring techniques through shaly sequences was conducted.

3.1.4 Schedule Status

Figure 3-1 is a milestone chart depicting the status of USGS projects through August, 1978.

3.2 CORE PROGRAM

CER personnel contacted many operators active in the USGS recommended core areas about the possible acquisition of core from their proposed wells. At months end no agreements were reached with operators to participate in the DOE core program. Difficulties in obtaining industry cooperation can be attributed in part to the following reasons:

- Private companies often work on a strict time schedule, which does not allow for a core operation.
- The data generated from coring a well for the WGSP is necessarily public information. Private industry often wants this information kept proprietary.
- There is always a certain amount of paper work associated with any governmental interaction which to some operators can be overwhelming.
- The WGSP needs core from wells in wildcat locations. Since these areas are untested, drilling problems inherent with high pressure, etc. may arise which tends to render the company adverse to a coring operation.
- Lastly, many companies do not want close interaction with a governmental agency for a variety of reasons.

Table 3-1 is the core analysis report on the Joseph J. C. Paine well, Midlands Federal 1-0296. Core samples have been sent to BETC, LASL, Texas A&M University, and USGS. Currently, work is proceeding on correlation of the core data with the log data and a final report on this work will be published in January, 1979.

3.3 LOGGING PROGRAM

The WGSP Logging Program "draft for comment" was distributed to the interested participants of the WGSP with a request for comments. The comments are expected by October 2, 1978 and a Logging Program meeting is tentatively planned for the week of October 23. Tentative meeting participants include:

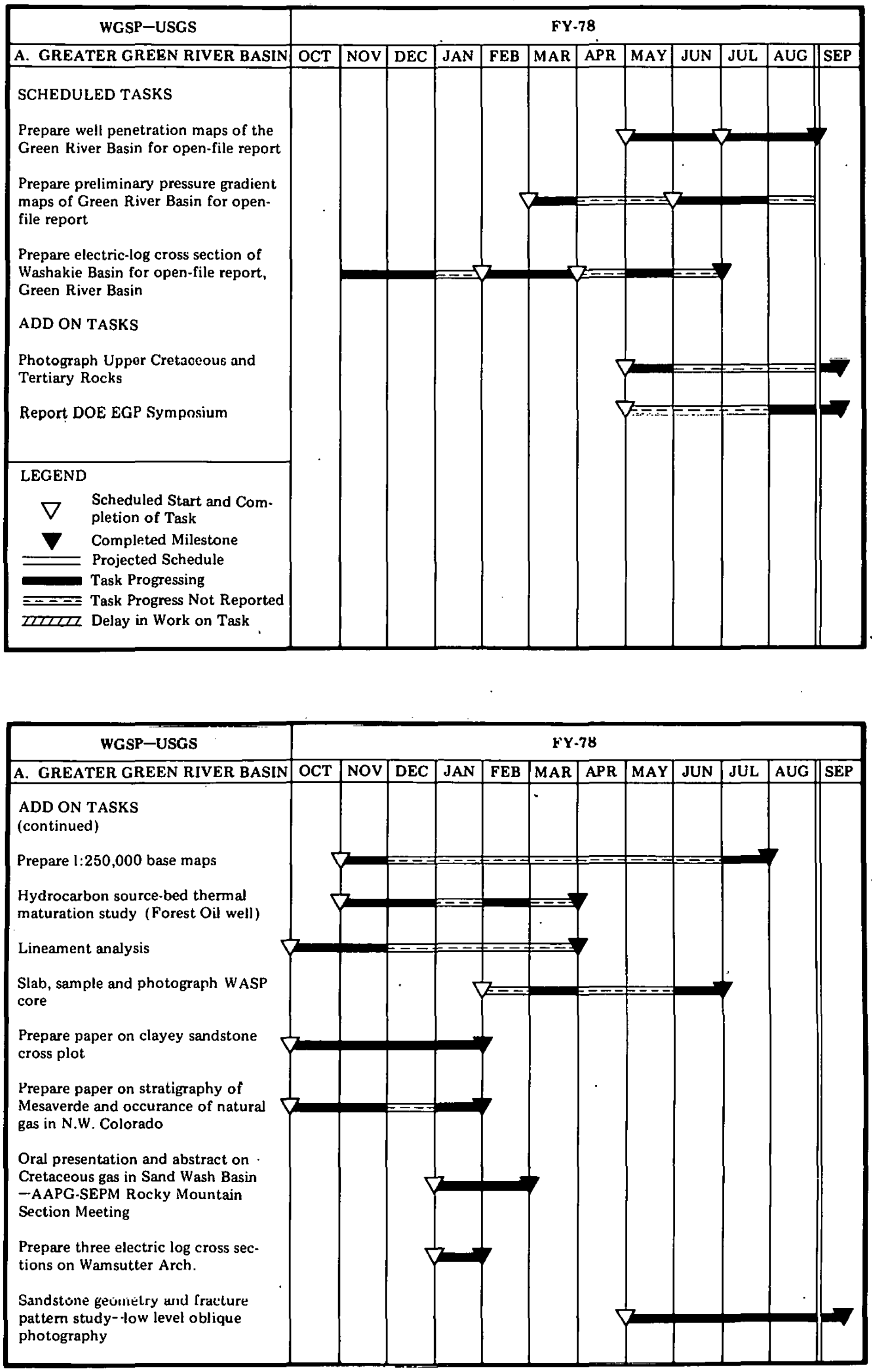
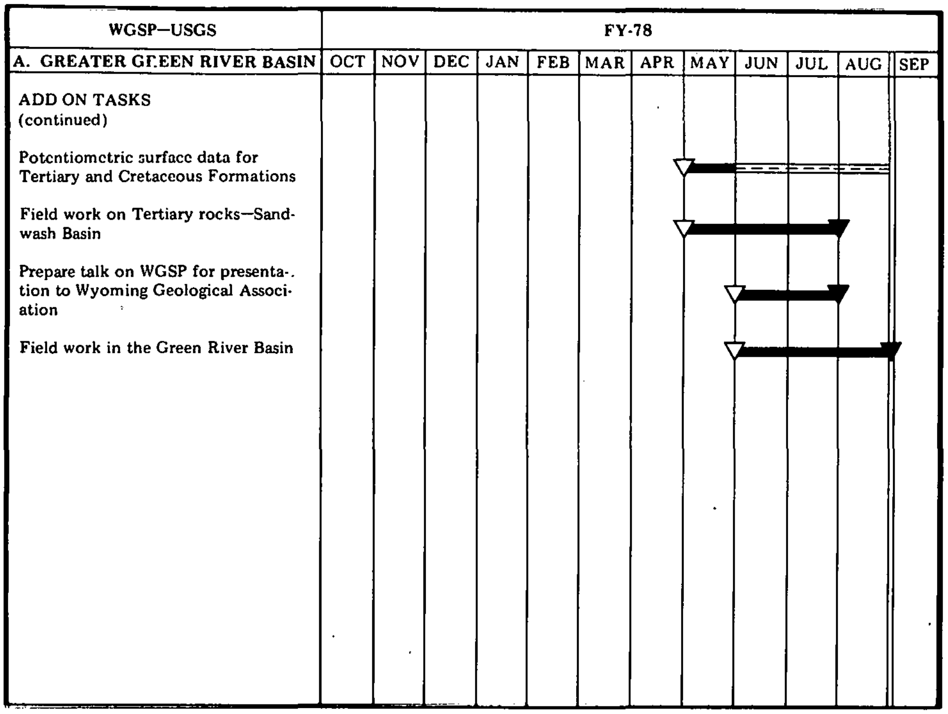


Figure 3-1 Milestone Chart—USGS



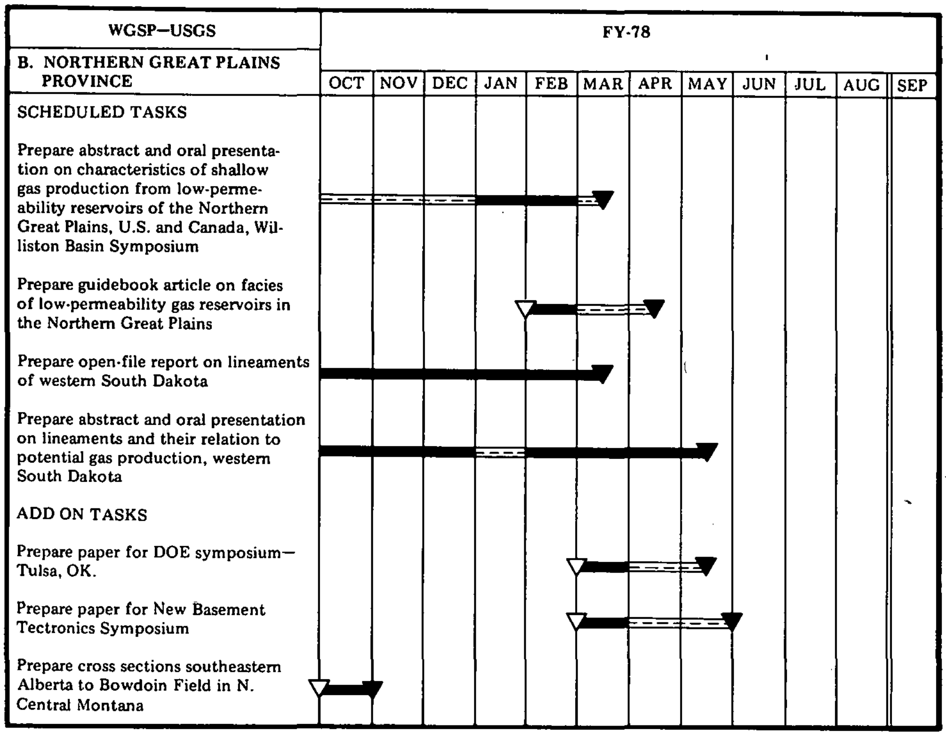
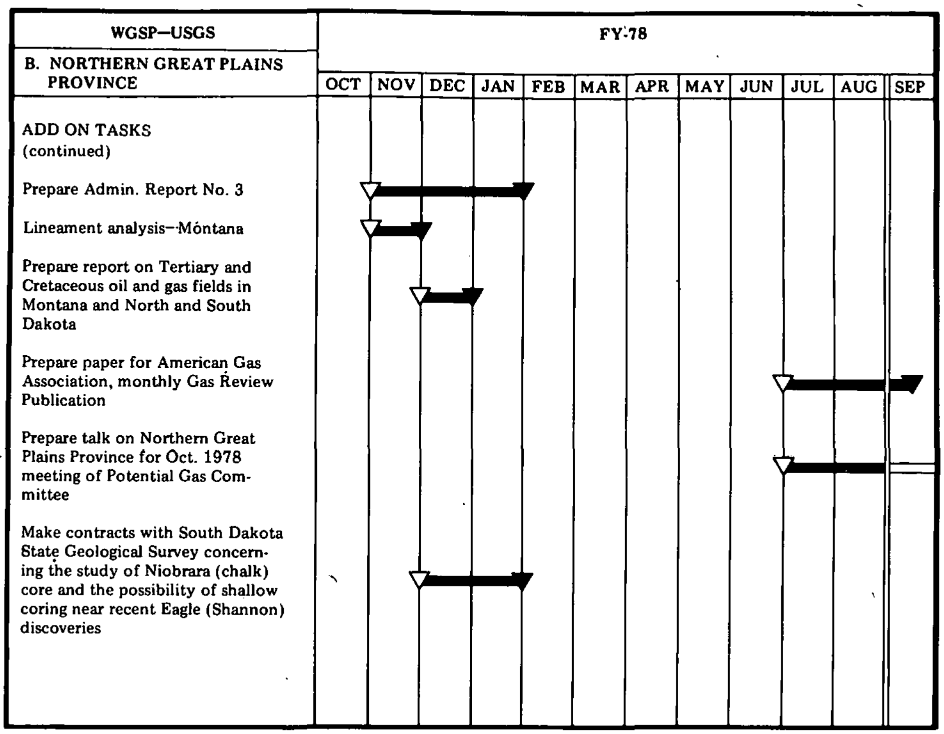


Figure 3-1 Continued



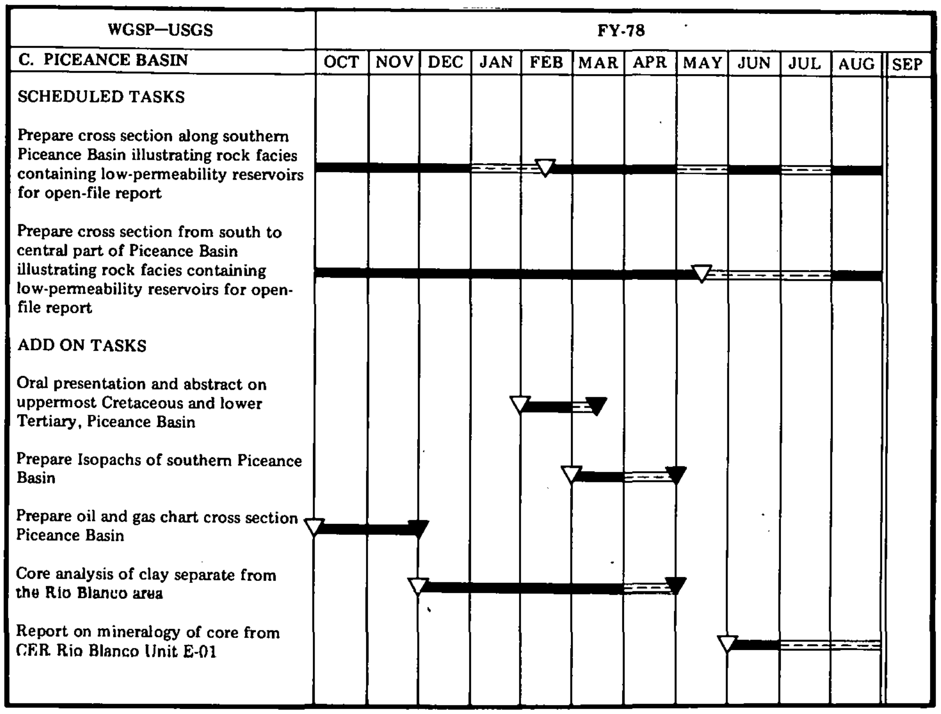
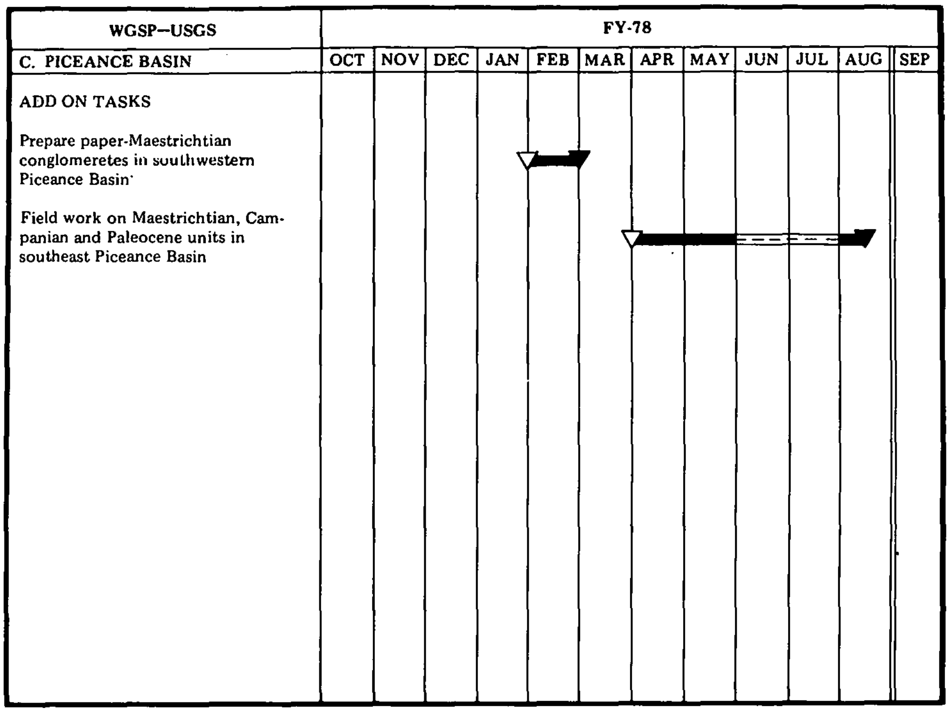


Figure 3-1 Continued



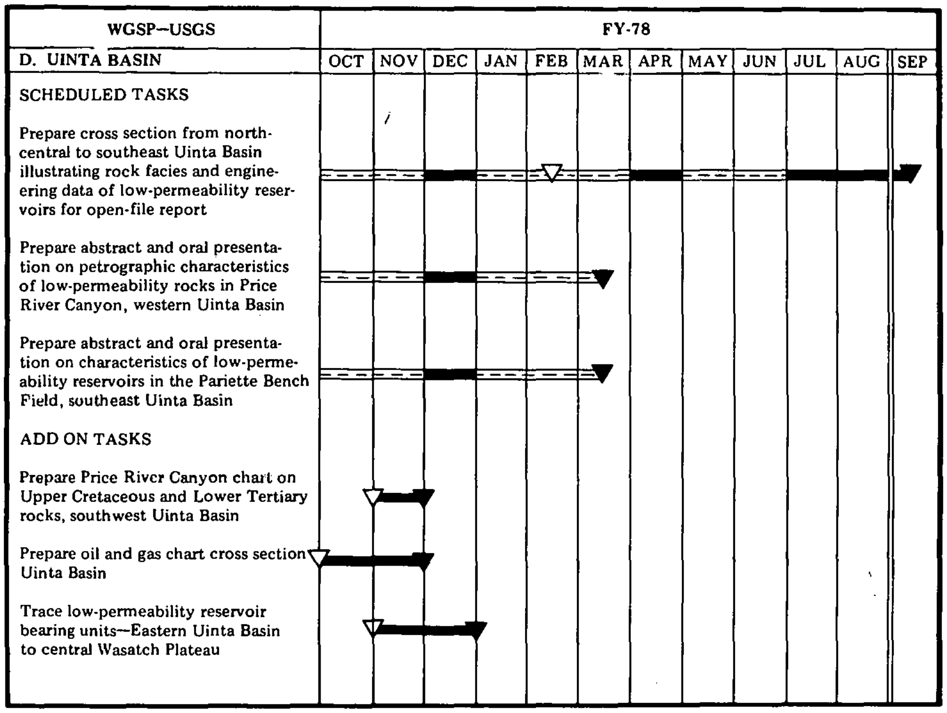
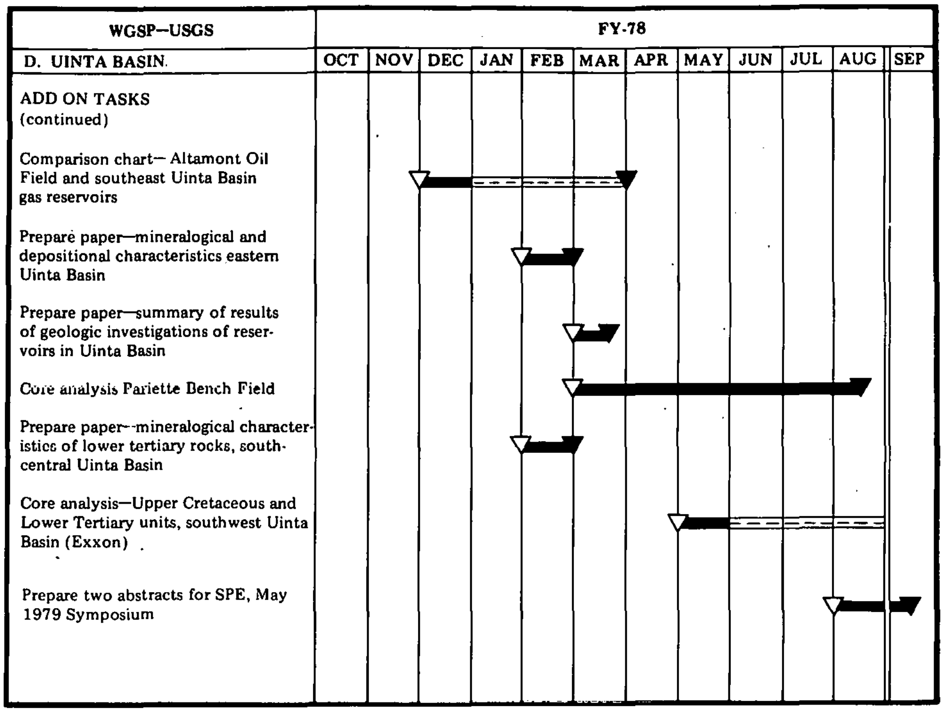


Figure 3-1 Continued



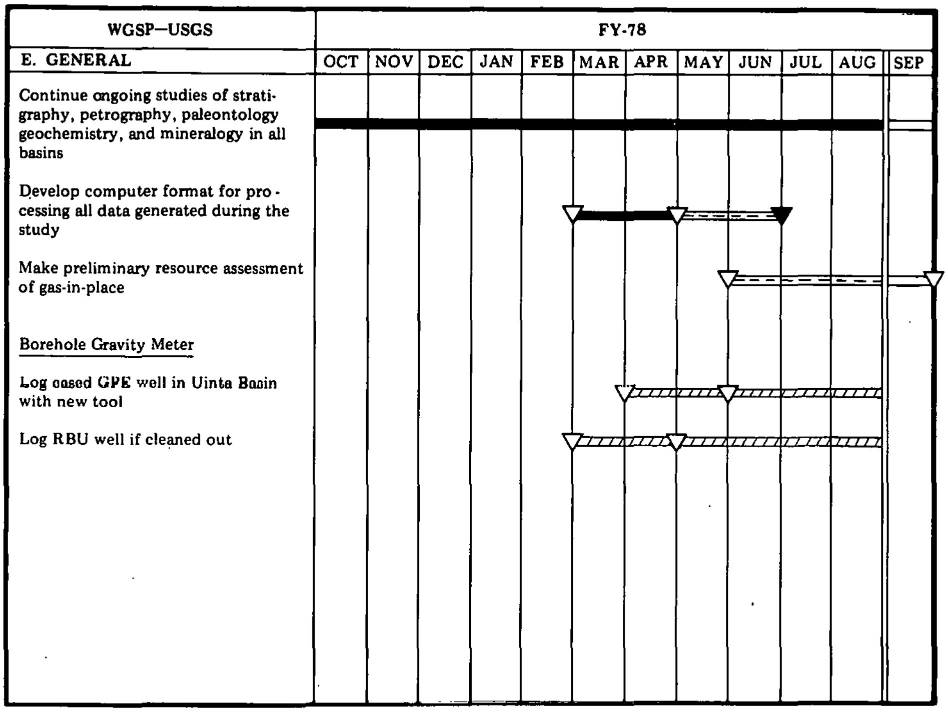


Figure 3-1 Continued

Table 3-1 Conventional Core Analysis

JOSEPH J. C. PAINE		DATE : 7-25-78
MIDLANDS FEDERAL 1-0296	DRLG. FLUID : WATER BASE MUD	FILE NO. : RP-4-4714-H
WILDCAT	LOCATION : LOT 6, SEC 2, T29N, R36E	ANALYSTS : BOWEN
VALLEY COUNTY	STATE : MONTANA	ELEVATION : 2382 GR

SAMPLE NO.	DEPTH	PERM. TO HORZ.	POR. FLD.	FLUID OIL	SATS. WATER	GR. DNS.	DESCRIPTION
EAGLE FORMATION							
	550- 554						LOST RECOVERY
1	554- 555	1.60	22.0	0.0	81.5	2.73	SD, GY VFG V/SLTY
2	555- 556	5.50	21.8	0.0	91.9	2.74	SD, GY VFG V/SLTY
3	556- 557	0.55	19.2	0.0	90.8	2.71	SD, GY VFG V/SLTY
4	557- 558	1.00	23.7	0.0	82.9	2.69	SD, GY VFG V/SLTY
5	558- 559	28.00	24.6	0.0	86.3	2.72	SD, GY VFG V/SLTY
6	559- 560	24.00	23.0	0.0	85.8	2.70	SD, GY VFG V/SLTY
7	560- 561	2.30	22.7	0.0	87.2	2.70	SD, GY VFG V/SLTY
8	561- 562	5.60	21.2	0.0	85.3	2.70	SD, GY VFG V/SLTY
9	562- 563	0.83	23.2	0.0	80.9	2.67	SD, GY VFG V/SLTY
10	563- 564	7.50	21.4	0.4	77.7	2.72	SLT, GY VFG TR/SD TR/PYR
11	564- 565	1.10	21.8	0.0	74.6	2.70	SD, GY VFG V/SLTY
12	565- 566	0.47	21.3	0.0	86.5	2.70	SD, GY VFG V/SLTY
13	566- 567	2.70	21.6	0.0	84.2	2.71	SD, GY VFG V/SLTY
14	567- 568	2.90	17.4	0.0	86.4	2.70	SD, GY VFG V/SLTY
15	568- 569	52.00	23.1	0.0	86.4	2.74	SLT, GY VFG CLYEY
16	569- 570	63.00	21.8	0.8	83.5	2.73	SLT, GY VFG CLYEY
	570- 575						DRILLED
	575- 577						NON SAMPLED INTERVAL
17	577- 578	7.70	20.5	0.4	76.0	2.71	SD, GY VFG SLTY
	578- 579						NON SAMPLED INTERVAL
	579- 604						LOST RECOVERY
	604- 835						DRILLED
18	835- 836	0.01	5.9	0.0	88.4	2.74	SD, GY FG V/CALC
19	836- 837	87.00	28.0	0.0	77.0	2.70	SD, GY VFG V/CALC
20	837- 838	58.00	28.9	0.0	77.2	2.68	SD, GY FG SLTY
21	838- 839	99.00	25.3	0.0	70.5	2.70	SD, GY FG SL/SLTY
22	839- 840	46.00	29.8	0.0	67.9	2.69	SD, GY FG SL/SLTY
23	840- 841	0.58	27.9	0.0	69.0	2.71	SD, GY FG SL/SLTY
	841- 843						PRESERVED SAMPLE-NO ANALYSIS
24	843- 844	22.00	26.5	0.0	79.1	2.71	SD, GY FG SLTY
25	844- 845	39.00	24.2	0.0	75.8	2.71	SD, GY FG SLTY
26	845- 846	15.00	19.5	0.0	64.3	2.70	SD, GY FG SLTY
27	846- 847	10.00	24.2	0.0	69.9	2.70	SD, GY FG SLTY
28	847- 848	19.00	22.4	0.0	68.7	2.70	SD, GY FG SLTY
	848- 850						PRESERVED SAMPLE-NO ANALYSIS
29	850- 851	25.00	23.2	0.0	75.9	2.70	SD, GY FG SLTY
30	851- 852	0.29	24.2	0.0	82.4	2.70	SD, GY FG SLTY
31	852- 853	23.00	29.6	0.0	77.3	2.70	SD, GY FG SLTY
32	853- 854	52.00	23.2	0.0	80.2	2.74	SD, GY FG SLTY
33	854- 855	70.00	25.6	0.0	76.2	2.71	SD, GY FG SLTY
34	855- 856	17.00	25.6	0.0	76.4	2.70	SD, GY FG SLTY
35	856- 857	84.00	21.9	0.0	64.8	2.74	SD, GY FG SLTY

NOTE: AIR (MD) VERTICAL not reported due lack of data
VF = Verticle Fracture

Table 3-1 Continued

SAMPLE NO.	DEPTH	PERM. TO HORZ.	POR. FLD.	FLUID OIL	SATS. WATER	GR. DNS.	DESCRIPTION
36	857- 858	61.00	26.1	0.0	83.9	2.70	SD, GY FG SLTY
37	858- 859	40.00	24.0	0.0	87.5	2.71	SD, GY FG SLTY
38	859- 860	23.00	24.0	0.0	85.2	2.70	SD, GY FG SLTY
39	860- 861	4.30	22.4	0.0	87.4	2.71	SD, GY FG SLTY
40	861- 862	2.50	21.9	0.0	84.7	2.73	SD, GY FG SLTY
41	862- 863	65.00	21.7	0.0	86.1	2.71	SD, GY FG SLTY
42	863- 864	25.00	22.9	0.0	81.1	2.71	SD, GY FG SLTY
43	864- 865	37.00	22.7	0.0	82.8	2.71	SD, GY FG SLTY
44	865- 866	26.00	23.9	0.0	78.8	2.71	SD, GY FG SLTY
45	866- 867	22.00	24.8	0.0	84.3	2.71	SD, GY FG SLTY
46	867- 868	3.30	15.2	0.0	78.0	2.70	SD, GY FG V/SLTY
47	868- 869	16.00	20.3	0.0	79.4	2.71	SD, GY FG V/SLTY
48	869- 870	23.00	20.7	0.0	80.3	2.71	SD, GY FG V/SLTY
49	870- 871	1.20	16.2	0.0	78.4	2.70	SD, GY FG V/SLTY
50	871- 872	1.00	20.9	0.0	79.6	2.70	SD, GY FG V/SLTY
51	872- 873	3.90	19.9	0.0	83.6	2.70	SD, GY FG V/SLTY
52	873- 874	4.00	20.2	0.0	82.1	2.72	SD, GY FG V/SLTY
53	874- 875	4.20	22.5	0.0	85.2	2.71	SD, GY FG V/SLTY
54	875- 876	15.00	18.6	0.0	78.4	2.70	SD, GY FG V/SLTY
55	876- 877	4.40	22.0	0.0	75.1	2.72	SLT, GY FG TR/SD TR/SHELL FRAG
56	877- 878	44.00	16.0	0.0	72.7	2.75	SD, GY VFG V/SLTY
	878- 880						PRESERVED SAMPLE-NO ANALYSIS
57	880- 881	3.10	18.7	0.0	84.5	2.72	SD, GY VFG V/SLTY
58	881- 882	2.60	21.7	0.0	78.6	2.70	SD, GY VFG V/SLTY
59	882- 883	10.00	21.0	0.0	77.3	2.66	SLT, GY VFG
60	883- 884	3.10	21.6	0.0	83.0	2.69	SLT, GY VFG
61	884- 885	1.10	20.2	0.5	88.8	2.73	SLT, GY VFG
62	885- 886	1.10	21.4	0.0	83.7	2.70	SLT, GY VFG
63	886- 887	1.10	19.8	0.0	85.4	2.65	SLT, GY VFG TR/SD LAM
64	887- 888	2.10	21.8	0.0	86.0	2.66	SLT, GY VFG CALC
65	888- 889	3.10	17.8	0.0	90.2	2.67	SLT, GY VFG CALC
66	889- 890	7.30	18.7	0.0	09.1	2.65	SH, DK GY VFG CALC
67	890- 891	3.60	18.9	0.0	84.3	2.62	SH, DK GY VFG TR/SD
	801-1350						DRILLED
BOWDOIN FORMATION							
	1350-1351						NON SAMPLED INTERVAL
68	1351-1352	12.00	20.0	0.0	93.9	2.71	SLT, GY FG CALC
	1352-1354						NON SAMPLED INTERVAL
69	1354-1355	6.80	20.4	0.0	90.7	2.66	SD, GY VFG CLY/FLD
70	1355-1356	0.65	19.3	0.0	94.4	2.73	SLT, GY VFG CALC TR/FOS
71	1356-1357	3.60	22.2	0.8	88.5	2.64	SLT, GY VFG V/SLTY
	1357-1359						NON SAMPLED INTERVAL
72	1359-1360	1.60	18.5	8.1	83.1	2.68	SD, GY VFG V/SLTY CALC
	1360-1364						NON SAMPLED INTERVAL
73	1364-1365	15.00	16.8	3.9	90.4	2.67	SLT, GY VFG V/CALC
	1365-1369						NON SAMPLED INTERVAL
74	1369-1370	24.00	20.3	17.9	75.1	2.70	SLT, GY VFG V/CALC
	1370-1374						NON SAMPLED INTERVAL
75	1374-1375	69.00	20.6	14.6	76.5	2.71	SLT, GY VFG V/CALC
76	1375-1376	1.70	21.1	9.0	79.0	2.68	SH, GY VFG SL/SLTY

Table 3-1 Continued

SAMPLE NO.	DEPTH	PERM. TO HORZ.	POR. FLD.	FLUID OIL	SATS. WATER	GR. DNS.	DESCRIPTION
77	1376-1377	4.70	20.4	12.7	78.2	2.70	SD, GY FG V/SLTY
78	1377-1378	11.00	22.7	11.0	77.1	2.70	SLT, GY VFG TR/GY SD LAM
79	1378-1379	5.70	18.4	6.0	79.8	2.71	SD, GY VFG SH/LAM
80	1379-1380	27.00	25.7	4.0	75.5	2.68	SLT, GY FG CALC
81	1380-1381	0.30	23.4	4.5	81.9	2.70	SD, GY FG SH/LAM
82	1381-1382	0.79	23.8	4.6	79.1	2.68	SD, GY FG SH/LAM
83	1382-1383	6.40	22.8	4.7	77.6	2.72	SD, GY FG SH/LAM
84	1383-1384	2.30	24.4	4.4	77.5	2.69	SD, GY FG SH/LAM
85	1385-1386	1.20	23.6	4.6	79.0	2.69	SD, GY VFG SLTY
86	1386-1387	1.10	20.2	7.1	87.4	2.68	SLTST, GY VFG SH/LAM SD/LAM
87	1387-1388	2.00	20.3	7.2	91.3	2.78	SD, GY VFG
88	1388-1389	4.60	22.5	6.4	81.5	2.78	SD, GY VFG SLT/LAM
89	1389-1390	2.00	22.2	4.9	82.4	2.66	SLTST, GY VFG SD/LAM
90	1390-1391	3.00	23.7	2.7	83.7	2.66	SD, GY VFG SLTY
	1391-1396						NON SAMPLED INTERVAL
91	1396-1397	1.60	21.6	8.9	79.8	2.66	SLTST, GY VFG
92	1397-1398	1.20	22.7	8.4	83.4	2.67	SLTST, GY VFG
93	1398-1399	6.70	24.5	7.7	75.2	2.64	SLTST, GY VFG
94	1399-1400	2.00	18.9	7.7	78.6	2.65	SLTST, GY VFG SDY
95	1400-1401	2.80	20.8	9.0	75.0	2.65	SLTST, GY VFG SD/LAM
96	1401-1402	3.10	18.7	10.2	76.1	2.70	SLTST, GY VFG
97	1402-1403	0.90	18.5	10.3	76.3	2.60	SLTST, GY VFG
98	1403-1404	0.95	20.0	9.7	72.1	2.65	SLTST, GY VFG SD/LAM
99	1404-1405	8.30	18.4	8.0	80.0	2.76	SLTST, GY VFG
100	1405-1406	6.50	20.5	9.3	76.4	2.69	SLTST, GY VFG
101	1406-1407	9.20	22.2	8.4	70.8	2.68	SLTST, GY VFG
102	1407-1408	2.00	19.9	9.6	76.2	2.66	SLTST, GY VFG
103	1408-1409	8.00	19.8	9.7	72.0	2.68	SLTST, GY VFG
104	1409-1410	0.90	19.2	10.0	80.3	2.67	SLTST, GY VFG
105	1410-1411	1.70	21.4	8.9	74.2	2.65	SLTST, GY VFG
106	1411-1412	1.60	19.4	9.8	76.8	2.70	SLTST, GY VFG
107	1412-1413	0.35	17.6	8.3	70.5	2.66	SLTST, GY VFG
108	1413-1414	2.60	17.9	8.2	75.7	2.62	SD, GY VFG SHY
109	1414-1415	2.70	16.9	8.9	75.5	2.65	SD, GY VFG SHY
	1415-1416						NON SAMPLED INTERVAL
110	1416-1417	0.55	16.1	8.2	60.8	2.65	SD, GY VFG TR/CLY
	1417-1419						NON SAMPLED INTERVAL
111	1419-1420	4.00	14.0	10.8	61.8	2.67	SLTST, GY VFG SD/LAM
	1420-1424						NON SAMPLED INTERVAL
112	1424-1425	0.53	11.3	6.0	79.4	2.65	SLTST, GY VFG
	1425-1429						NON SAMPLED INTERVAL
113	1429-1430	6.90	23.1	2.6	65.7	2.65	SD, GY VFG SHY
	1430-1434						NON SAMPLED INTERVAL
114	1434-1435	0.39	16.8	1.1	82.7	2.66	SD, GY VFG SHY
	1435-1437						NON SAMPLED INTERVAL
115	1437-1438	1.50	17.7	1.1	87.4	2.68	SLTST, GY VFG
	1438-1439						NON SAMPLED INTERVAL
116	1439-1440	3.20	20.7	0.9	83.3	2.69	SD, GY VFG
	1440-1444						NON SAMPLED INTERVAL
117	1444-1445	2.60	17.9	1.0	90.0	2.68	SD, GY VFG TR/MICA
	1445-1448						NON SAMPLED INTERVAL
118	1448-1449	1.9	19.3	1.0	89.8	2.61	SLTST, GY VFG SHY TR/MICA

Table 3-1 Continued

SAMPLE NO.	DEPTH	PERM. TO HORZ.	POR. FLD.	FLUID OIL	SATS. WATER	GR. DNS.	DESCRIPTION
119	1449-1450	0.66	18.7	0.5	87.7	2.62	SLTST, GY VFG SHY
120	1450-1451	1.00	13.7	0.0	63.0	2.57	SLTST, GY VFG SHY
121	1451-1452	0.13	4.9	0.0	24.9	2.56	SLTST, GY VFG SHY
	1452-1470						LOST RECOVERY
	1470-1605						DRILLED
122	1605-1606	0.30	19.9	5.6	82.8	2.63	SLTST, GY VFG SHY
123	1606-1607	1.20	19.8	1.0	89.6	2.66	SD, GY VFG SHY
	1607-1630						NON SAMPLED INTERVAL
124	1630-1631	5.80	22.6	20.6	71.4	2.66	SD, GY VFG SHY
125	1631-1632	7.60	20.9	24.6	70.3	2.60	SD, GY VFG SHY
126	1632-1633	3.50	19.7	13.1	82.4	2.59	SD, GY VFG SHY
127	1633-1634	2.10	21.7	20.2	72.5	2.59	SD, GY VFG SHY
128	1634-1635	2.50	21.7	24.9	69.7	2.60	SD, GY VFG SHY TR/MICA
GREENHORN FORMATION							
129	1635-1636	1.20	22.7	20.3	70.4	2.56	SLTST, GY VFG SD/LAM SLCALC
130	1636-1637	0.25	6.6	24.6	55.4	2.55	SLTST, GY VFG SD/LAM SLCALC
131	1637-1638	1.00	18.0	32.8	61.5	2.59	SLTST, GY VFG SD/LAM SLCALC
132	1638-1639	0.36	20.3	32.2	60.9	2.59	SLTST, GY VFG SD/LAM SLCALC
133	1639-1640	0.26	14.6	14.0	74.7	2.56	SLTST, GY VFG SD/LAM SLCALC
134	1640-1641	2.60	20.4	23.0	69.0	2.58	SLTST, GY VFG SD/LAM SLCALC
135	1641-1642	0.52	19.1	23.4	68.2	2.55	SD, GY VFG SHY CALC
136	1642-1643	1.40	22.7	22.7	64.8	2.56	SH, GY VFG SD/LAM
137	1643-1644	0.25	18.7	31.4	64.7	2.53	SLTST, GY VFG SD/LAM
138	1644-1645	0.25	16.1	23.8	71.4	2.57	SLTST, GY VFG SD/LAM CALC
139	1645-1646	1.00	17.2	20.1	71.6	2.56	SLTST, GY VFG SD/LAM CALC
140	1646-1647	3.70	21.7	27.9	67.2	2.56	SLTST, GY VFG SD/LAM CALC
141	1647-1648	0.37	21.1	26.2	70.0	2.53	SLTST, GY VFG SD/LAM CALC
142	1648-1649	0.45	20.3	24.5	70.0	2.58	SLTST, GY VFG SD/LAM CALC
143	1649-1650	1.90	17.2	34.3	59.9	2.56	SH, GY VFG
144	1650-1651	2.60	20.3	29.4	64.4	2.55	SH, GY VFG
145	1651-1652	0.81	7.3	39.0	44.5	2.54	SLTST, GY VFG TR/MICA CALC SDY
146	1652-1653	0.37	15.2	35.2	56.4	2.55	SLTST, GY VFG MICA SDY CALC SHY
147	1653-1654	1.10	22.1	33.1	61.2	2.56	SLTST, GY VFG TR/MICA CALC SHY
148	1654-1655	0.61	16.5	34.3	57.1	2.58	SLTST, GY VFG TR/MICA CALC SHY
149	1655-1656	0.48	17.6	37.0	55.0	2.57	SH, GY VFG
150	1656-1657	0.76	24.2	24.8	66.1	2.60	SH, GY VFG
151	1657-1658	0.28	5.2	2.0	47.3	2.60	SH, GY VFG
	1658-1659						NON SAMPLED INTERVAL
152	1659-1660	4.50	16.9	15.3	72.2	2.66	SH, GY VFG
	1660-1661						NON SAMPLED INTERVAL
153	1661-1662	2.40	21.1	15.8	70.2	2.59	SH, GY VFG TR/MICA
	1662-1663						NON SAMPLED INTERVAL
154	1663-1664	0.31	18.0	12.7	75.1	2.55	SH, GY VFG TR/MICA
	1664-1667						NON SAMPLED INTERVAL
155	1667-1668	0.43	19.1	13.6	75.5	2.54	SH, GY VFG TR/MICA
	1668-1671						NON SAMPLED INTERVAL
156	1671-1672	0.73	22.3	14.7	71.9	2.59	SH, GY VFG TR/MICA
	1672-1675						NON SAMPLED INTERVAL
157	1675-1676	0.37	20.4	12.5	74.9	2.60	SH, GY VFG TR/MICA
	1676-1679						NON SAMPLED INTERVAL

Table 3-1 Continued

SAMPLE NO.	DEPTH	PERM. TO HORZ.	POR. FLD.	FLUID OIL	SATS. WATER	GR. DNS.	DESCRIPTION
158	1679-1680	1.50	22.3	16.3	68.5	2.63	SH, GY VFG TR/MICA
	1680-1683						NON SAMPLED INTERVAL
159	1683-1684	1.40	25.2	21.7	52.6	2.60	SH, GY VFG CALC TR/MICA
	1684-1687						NON SAMPLED INTERVAL
160	1687-1688	0.10	16.7	32.7	63.3	2.60	SH, GY VFG CALC TR/MICA
	1688-1691						NON SAMPLED INTERVAL
161	1691-1692	0.44	17.8	14.4	74.1	2.61	SH, GY VFG SL/CALC TR/MICA
	1692-1693						NON SAMPLED INTERVAL
162	1693-1694	0.93	16.0	11.9	70.4	2.62	SH, DK GY MG SL/CALC SLTY
	1694-1695						NON SAMPLED INTERVAL
163	1695-1696	0.96	12.6	11.6	63.9	2.64	SH, DK GY MG SL/CALC SLTY
	1696-1699						NON SAMPLED INTERVAL
164	1699-1700	0.38	24.2	6.0	75.2	2.63	SH, DK GY MG SL/CALC SLTY
	1700-1709						NON SAMPLED INTERVAL
165	1709-1710	0.44	20.9	6.8	68.4	2.58	SH, DK GY MG CALC SLTY
	1710-1714						NON SAMPLED INTERVAL
166	1714-1715	0.27	12.9	15.1	63.4	2.60	SH, DK GY MG CALC SLTY
	1715-1719						NON SAMPLED INTERVAL
167	1719-1720	0.21	18.5	7.0	80.7	2.55	SH, DK GY MG CALC SLTY
	1720-1722						NON SAMPLED INTERVAL

H. B. Carroll	U. S. Department of Energy/BETC
R. D. Clarke	U. S. Department of Energy/NV
A. B. Crawley	U. S. Department of Energy/HQ
Nick Vanderborgh	Los Alamos Scientific Laboratories
M. E. Hanson	Lawrence Livermore Laboratory
H. M. Stoller	Sandia Laboratories
C. W. Spencer	U. S. Geological Survey
J. L. Fitch	Mobil Research & Development Corporation
G. C. Kukal	CER Corporation
R. L. Mann	CER Corporation
C. H. Atkinson	U. S. Department of Energy/BETC -NV
Dave Pollard	Intercomp

3.4 SURVEY OF BASIN ACTIVITIES

Drilling and testing activities in the four primary study areas are monitored as part of assessing the resource and to identify possible core sites for the WGSP Coring Program. Figures 3-2 through 3-5 show recent wells with significance to the WGSP and to the core program. Background information on the core areas is given in the *WGSP Quarterly Basin Activities Report, April 1, 1978, NVO/0655-05.*

3.4.1 Greater Green River Basin

During August, 39 wells were staked in horizons of interest to the WGSP; a 50 percent increase. Approximately two-thirds of the wells were located in the eastern half of the basin and were concentrated around core area A (Figure 3-2). The major objectives were the commercial Almond and Ericson Formations of the Mesaverde Group.

The Frontier Formation was the major objective in the western part of the Basin. Operators with Frontier tests were Amoco Production, Marathon Oil, Pacific Transmission Supply, Belco Petroleum (with two Mesaverde and two Frontier tests), and Davis Oil (with an unnamed 10,800 ft test).

Twelve wells went on stream during the month, and produced about 20,000 MCFD of gas. Producing horizons were the Frontier (approximately 8,200 MCFD), the Mesaverde Group (approximately 8,200 MCFD), the Lewis (2,500 MCFD) and the Tertiary (960 MCFD).

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

3.4.2 Northern Great Plains Province

Seventy-four new wells of interest to the WGSP were staked in August. By the end of the month 8 of these wells were completed D&A (6 development and 2 wildcat wells), 11 were drilled to total depth and two were drilling ahead. Just less than half of the new wells were wildcats and were concentrated in Montana's shallow gas districts in Toole, Hill, Blaine and Phillips Counties.

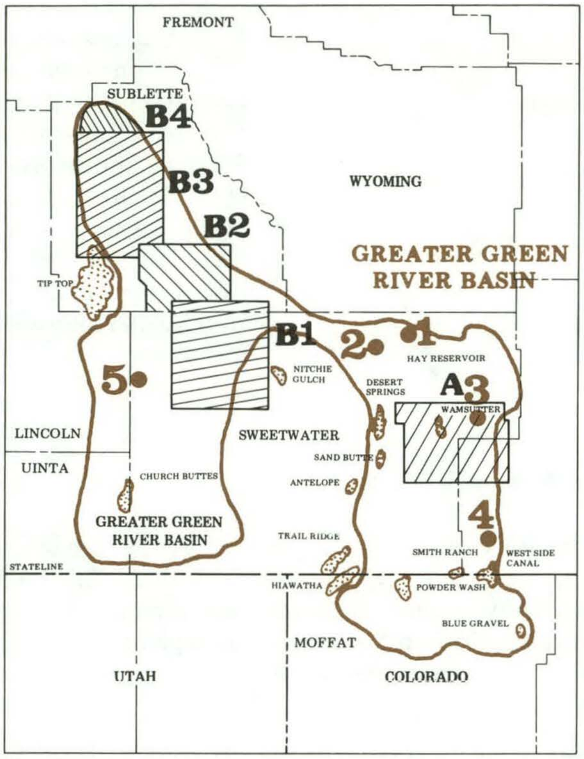


Figure 3-2 Greater Green River Basin Showing Wells of Interest and USGS Designated Core Areas (refer to Table 3-2)

Table 3-2 Summary of Wells—Greater Green River Basin

OPERATOR	WELL NAME	MAP INDEX NO.[1]	LOCATION Sec/T/R	HORIZON[2]	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Davis Oil	1 Picket Lake Unit	1	24/26N/97W Wildcat Field Sweetwater Cty, Wyoming	Mesaverde (14,000 ft)			Drilling- 8,323 ft	
Woods Petroleum	1 Lost Valley Unit	2	17/25N/98W Wildcat Field Sweetwater Cty, Wyoming	Baxter (14,180 ft)			Located	
Davis Oil	1 Eva-Federal	3	2/21N/92W Wildcat Field Sweetwater Cty, Wyoming	Ericson (12,500 ft)			Located	
Sinclair Oil	23-1 Hamilton-Federal	4	23/15N/92S BlueGap Field Carbon Cty,	Mesaverde (6,801-7,624 ft)	9,450 PB 8,650	192,000 gal emul 437,000 lb sand	Comp.	5,100
Energetics Inc.	32-33 Ferguson-Federal	5	33/26N/110W Unnamed Field Sweetwater Cty, Wyoming	Frontier (10,461-10,481 ft)	11,555 PB 10,675	acidized-1,000 gal 75,000 gal emul 135,000 lb sand	Comp.	344

[1] Refer to Figure 3-2 "Greater Green River Basin Showing Wells of Interest and USGS Designated Core Areas"

[2] Horizon - projected depth or producing interval

Thirty-two wells were staked during July, and as of August 31, five of these wells were completed D&A (3 wildcats, 2 development wells), seven reached total depth and three were drilling ahead.

Thirty-three wells were completed in addition to those newly staked and completed during this reporting period. Approximately 12,550 MCFD of gas was produced from the following intervals: Eagle (2,000 MCFD), "natural" Eagle (6,905 MCFD), Bowdoin (14,000 MCFD), commingled Bowdoin/Greenhorn (368 MCFD), commingled Bowdoin/Phillips (284 MCFD) Second White Specks (95 MCFD) and Bow Island (1,500 MCFD).

Recent wells of interest ot the WGSP are listed in Table 3-3 and located on Figure 3-3.

3.4.3 Piceance Basin

Twenty-two wells were staked in horizons of interest to the WGSP and 30 percent of these wells were wildcats. The primary objective was the Mancos at 2,100 ft to 3,250 ft. The Wasatch, Mesaverde and Mancos "B" intervals were also tested.

New locations were concentrated along the western boundary of the Piceance Basin in the following fields: Evacuation Creek, North Douglas Creek, Trail Canyon, Cathedral and Lower Horse Draw.

Houston Oil and Minerals staked four wildcat (9,700 - 10,600 ft) Weber tests close to a WGSP coring area. CER Corporation has contacted this company about the possibility of including one of these wells in the WGSP Coring Program; no agreement has yet been made.

Nine wells of significance to the WGSP were completed during August. Four were wildcat wells, which were 50 percent successful, and five were development wells with 60 percent success. The completed wells added 4,933 MCFD of gas from the following horizons: Wasatch (1,901 MCFD), Mancos (IPF not available), commingled Cameo/Cozzette/Corcoran (460 MCFD), commingled Morapos/Mancos (481 MCFD) and Mancos "B" (2,091 MCFD).

Recent wells of interest are summarized in Table 3-4 and located on Figure 3-4.

3.4.4 Uinta Basin

There were 36 new wells staked in the Uinta Basin during August. This compares with 13 staked in July, a 64 percent increase. More than half of the wells staked this month were wildcats. Belco Petroleum was most active, with 14 new locations all scheduled to test the Wasatch (6,000 - 8,700 ft) in the Natural Buttes Field. CIG Exploration, Gas Producing Enterprises and Enserch Exploration also staked wells in this area.

Production from completed wells was 2,142 MCFD from the Wasatch, Dakota and Green River.

Recent wells of interest to the WGSP are summarized in Table 3-5 and are located on Figure 3-5.

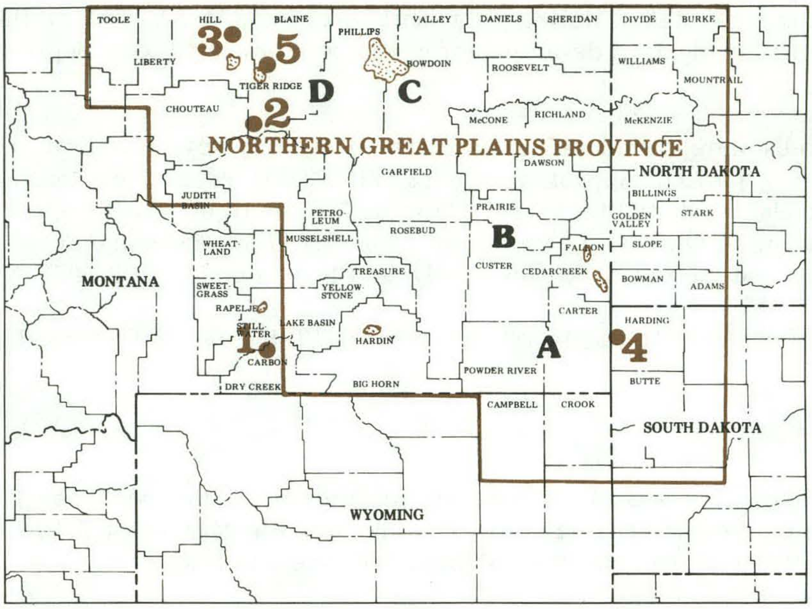


Figure 3-3 Northern Great Plains Province Showing Wells of Interest and USGS Designated Core Areas A, B, C and D

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

OPERATOR	WELL NAME	MAP INDEX NO.[1]	LOCATION Sec/T/R	HORIZON[2]	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Energy Reserves Group	1L Anderson	1	12/4S/21E Wildcat Field Carbon Cty, Montana	Morrison	4,660		Comp.	D&A
Fuel Resources Development	J-13-24-17-N M-20200	2	13/24N/12E Wildcat Field Blaine Cty, Montana	Eagle (1,430 ft)			Located	
Xeno Inc.	11-16 SE Saddle	3	16/35N/14E Wildcat Field Hill County, Montana	Greenhorn (2,600 ft)			Located	
Marmik Oil	1-26 State	4	26/19N/1E Wildcat Field Harding Cty, South Dakota	Shannon (1,500 ft)			Located	
Tricentrol United States	16-9 States	5	16/32N/18E Unnamed Field Blaine Cty, Montana	Eagle (1,107-1,113 ft)	1,430 PB 1,185	Sand-water fracture (no size rpt)	Comp.	2,000

[1] Refer to Figure 3-3 "Northern Great Plains Province Showing Wells of Interest and USGS Designated Core Areas - A, B, C, and D"

[2] Horizon - projected depth or producing interval

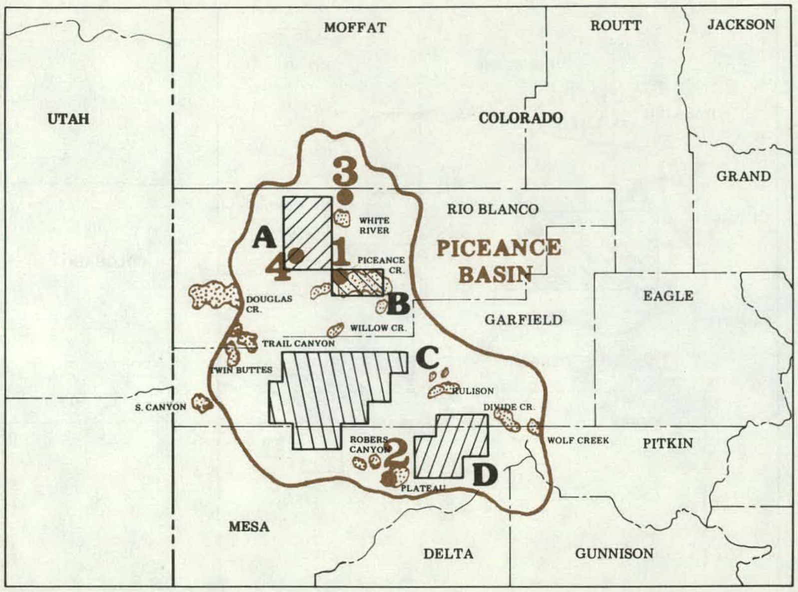


Figure 3-4 Piceance Basin Showing Wells of Interest and USGS Designated Core Areas

Table 3-4 Summary of Wells—Piceance Basin

OPERATOR	WELL NAME	MAP INDEX NO.[1]	LOCATION Sec/T/R	HORIZON[2]	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
William Moss Properties	7-8-2-97 Federal	1	8/25R97W Piceance Creek Field Rio Blanco Cty, Colorado	Wasatch (6,200 ft)			Located	
Adolph Coors Company	2-19 Fetters et al	2	19/10S/96W Plateau Field Mesa County, Colorado	Mesaverde (3,300 ft)			Located	
General Crude Oil Company	15-29 Colorow Gulf Federal	3	29/3N/97W Wildcat Field Rio Blanco Cty, Colorado	Weber (12,400 ft)			Drilling-10,910 ft	
David M. Munson	30-1-99 Cities Service	4	30/1S/99W Unnamed Field Rio Blanco Cty, Colorado	Mancos B (9,007 - 9,311 ft)	9,610	378,000 gal of 2% KCl gelled water, 145 tons CO_2, 150,000 lb 100 mesh sand, 170,000 lb 20/40 sand	Comp.	2,091

[1] Refer to Figure 3-4 "Piceance Basin Showing Wells of Interest and USGS Designated Core Areas"

[2] Horizon - projected depth or producing interval

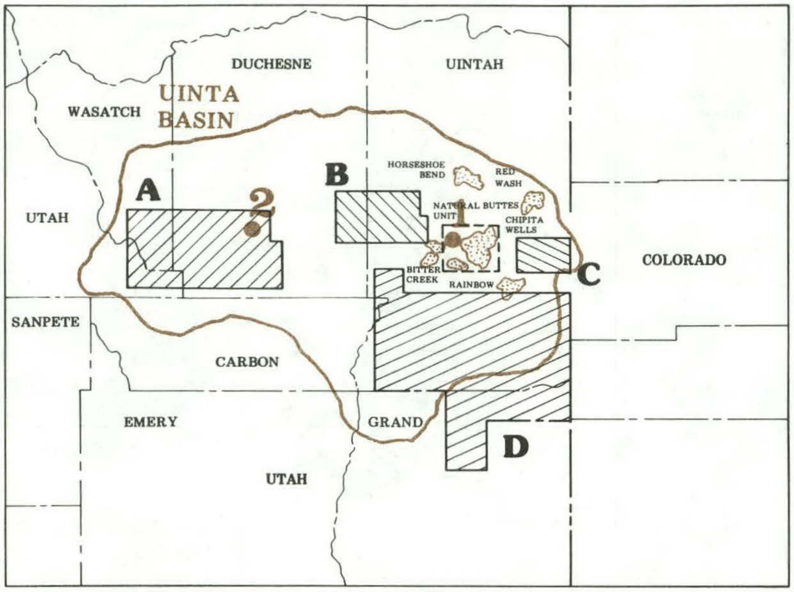


Figure 3-5 Uinta Basin Showing Wells of Interest and USGS Designated Core Areas

Table 3-5 Summary of Wells—Uinta Basin

OPERATOR	WELL NAME	MAP INDEX NO.[1]	LOCATION Sec/T/R	HORIZON[2]	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Belco Petroleum	542 B Natural Buttes Unit	1	2/9S/21E Natural Buttes Field Uintah Cty, Utah	Wasatch (8,700 ft)			Located	
W. A. Moncrief	10-1 Reimann	2	10/4S/6W Wildcat Field Duchesne Cty, Utah	Unnamed Test			Located	

[1] Refer to Figure 3-5 "Uinta Basin Showing Wells of Interest and USGS Designated Core Areas"

[2] Horizon - projected depth or producing interval

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

4.1 BARTLESVILLE ENERGY TECHNOLOGY CENTER

4.1.1 Improved Pressure Coring System

4.1.1.1 Core Retriever Design

Design work is on schedule, and approximately 165 machine shop drawings defining the entire core retriever system will be delivered to Sandia before September 30, 1978.

4.1.1.2 Coring Fluid Selection

The second test of the water-base mud, utilizing a lost circulation material additive called "Sanheal," has been completed. The results were similar to the first evaluation. No measureable invasion was observed when the Berea sandstone was held at an over-balance pressure of 500 psi for five hours. The particles suspended in the mud appear to very rapidly block the pore space presented at the fluid-rock interface. There has been no tendency for the water phase of the mud to separate and invade the sandstone. Apparent viscosity is approximately 100 cp. This mud appears to be an excellent candidate for the low-invasion fluid that is required in the presently designed pressure coring system.

This water-base mud freezes quite readily at dry ice temperatures, and two approaches to frozen core removal are being considered. In the first approach, laboratory tests have shown that cores of two foot length can be readily removed in an undamaged state by flash heating the tube and pushing the core out. This procedure is now being evaluated on ten foot cores. To facilitate core removal, the inside of the test barrel is being impregnated with a fluorocarbon material. Although this material is only 0.003 in. thick, it has superior lubrication and abrasion resistance properties.

The second approach investigates the prospect of making the mud non-freezing. Solutions of calcium chloride and ethylene glycol are being mixed with the Sanheal to produce a non-freezing and yet, non-invading fluid.

4.1.1.3 Bit Design

The computer programming for machining the full bit body is under way and will be completed by September 30. This programming is extensive and involves the control of a five axis milling machine to fabricate the entire bit body, including the threads.

The pilot bit was completely redesigned during August. It now has a much thinner wall thickness and will require about 25 percent less rock removal than the previous design. This will reduce the possibility of bit overheating. Construction of these bits has begun, and the first will be available for testing by October 15 and all bits completed by November 30.

An NQ size core bit utilizing stratapax cutters that have been diffusion bonded to the matrix has been completed and will be tested in September. The HQ core bits have been machined and are ready for attachment of the cutters. A brazed cutter version will be tested in September, while a diffusion bonded bit will not be ready until October.

4.1.1.4 Other Related Activities

A presentation of the progress on *The Improved Pressure Coring System* was given at the Fourth Annual DOE Symposium on Enhanced Oil and Gas Recovery and Improved Drilling Methods, held in Tulsa on August 31.*

4.1.2 Interface Conductivity Effects on Electric Logging

Resistivity of KCl solutions used for conductivity experiments were calculated from Schlumberger log interpretation charts to check resistivity values measured at experimental temperatures.

Table 4-1 Calculated and Measured Resistivity

% KCl Solution	Temperature	Calculated Resistivity (ohm-meters)	Measured Resistivity (ohm-meters)
2.0	70°C	0.1570	0.1620
	80°C	0.1410	0.1430
3.5	70°C	0.0950	0.0960
	80°C	0.0850	0.0870
5.0	70°C	0.0695	0.0696
	80°C	0.0625	0.0629
7.0	70°C	0.0505	0.0511
	80°C	0.0460	0.0462
8.5	70°C	0.0420	0.0430
	80°C	0.0370	0.0390

*The abstract of this report appears in Section 2.2.4 "Articles and Papers."

These measured values were used to calculate formation factors for the following core plugs (Mesaverde Group, Hayward No. 25-95 Austral Oil Well).

Table 4-2 Formation Factors for Test Plugs

Core	Resistivity ohm-meter (intercept)	Porosity	Permeability (μd)	Formation factor
7,300 ft	28.7	0.144	67	114
7,530 ft	55.0	0.072	44	295
7,553 ft	74.6	0.092	78	226

The formation factors were calculated from linear regression curves of the data and the equation

$$F = \frac{C_w}{C_o - C_i}$$

C_i = Intercept

C_o = Observed conductivity

4.1.3 Mapping and Contouring Formation Water Resistivity (R_w)

No progress reported.

4.1.4 Rock-Fluid Interactions

An analysis of the particles contained in the liquids used to perform the MHF experiment in GPE CIGE No. 2 well was completed. The total number of particles per unit volume along with the mean and mode of the particles in the frac-water, the gelled water, and those washed off the frac sand are listed in Table 4-3. The gelled water was "broken" by the time it was received in the Bartlesville Laboratory. The Green River water contains a significant number of particles per ml, approximately 133,000 per ml, in the size range of 1.54 microns to 6.15 microns with the majority of them around 3 microns in size. Fines, washed off from the sand proppant, add to the number in the slightly smaller size mode.

The gelled frac-fluids were received in two different sample bottles and appeared to be "broken" or thermally decomposed before arrival. The frac-fluid contains 334,908 to 709,828 particles per ml in the range of 1.54 to 35.2 microns in diameter. A typical analysis of the frac-fluid is shown in Figure 4-1.

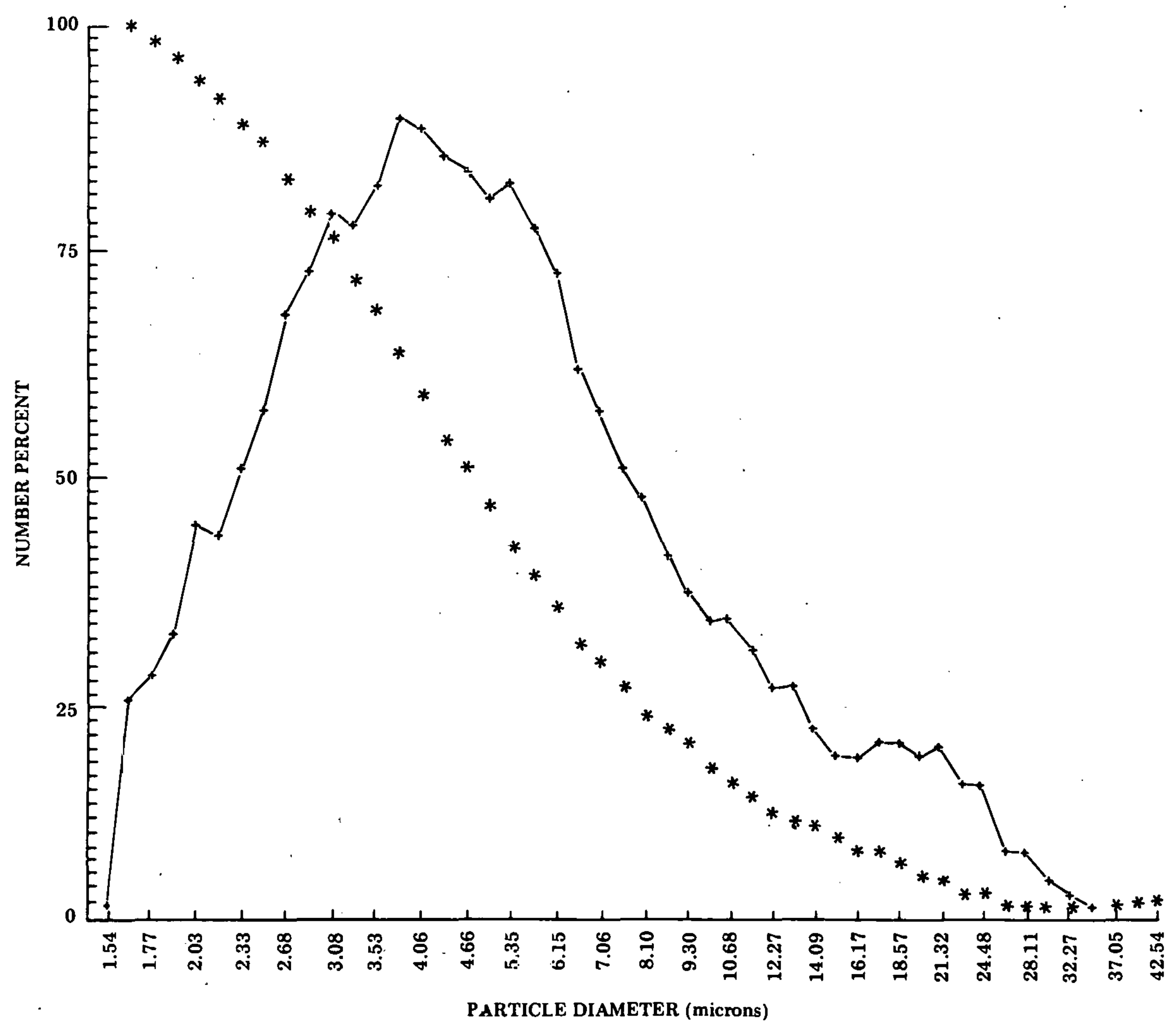


Figure 4-1 Particle Size Distribution of Frac-Fluid

The fines in both the Green River water and sand proppants are relatively large when compared to the pore throats in the formation. The particles contained in the frac-fluid are massive in comparison.

Table 4-3 Particle Analysis of Liquids Used to Perform MHF of GPE Well CIGE No. 2, Uintah County, Utah

Total Cnts per Ml.	Mean (microns)	Mode (microns)	Range (microns)
	Green River Water		
126,856	2.74	2.74	1.54- 5.60
138,324	2.94	3.08	1.54- 6.15
	Fines decanted off 20-40 mesh sand (41% sand water)		
134,474	2.87	2.81	1.54- 6.60
	Fines decanted off 40-60 mesh sand (40% sand water)		
112,034	2.39	1.81	1.54- 5.35
	Frac-Fluid (sample bottle C)		
335,258	5.11	3.79	1.54-35.20
334,908	5.23	3.97	1.54-32.30
	Frac-fluid (sample bottle D)		
709,828	3.62	2.87	1.54-20.40
681,548	3.62	2.87	1.54-21.30

4.1.5 Reservoir Simulation Studies

4.1.5.1 Parametric Analysis of MHF Test Data; An Engineering Study of Western Gas Sands—Intercomp, Inc.

A meeting was held in Nevada on July 13 and 14 to discuss the project and the data requirements for this project. The data on four wells was obtained from CER Corporation, Las Vegas, Nevada. The data are from wells that have been fractured under various government contracts. Data have been received for:

- Mobil's F31-13G well in the Piceance Creek Unit, Colorado
- Rio Blanco Natural Gas Company's (RBNG) Federal 498-4-1, Rio Blanco County, Colorado
- Gas Producing Enterprises, Inc., CIGE No. 21-15-10-22, Uintah County, Utah (Natural Buttes No. 21)
- CER's RB-MHF-3, Rio Blanco County, Colorado

After preliminary evaluation of these data, the Mobil F31-13G well was chosen as a starting point. As of the last reporting period, Mobil had tested seven zones and had performed four frac jobs. The well tests were analyzed by the normal methods and show a short period of wellbore storage. The type curves show some strange behavior after the first wellbore storage period had ended. Several of the plots showed a straight line with a 0.20 slope on a log m(p) (real gas potential) vs. log (Δ t) (shut-in time) plot (see Figure 4-2).

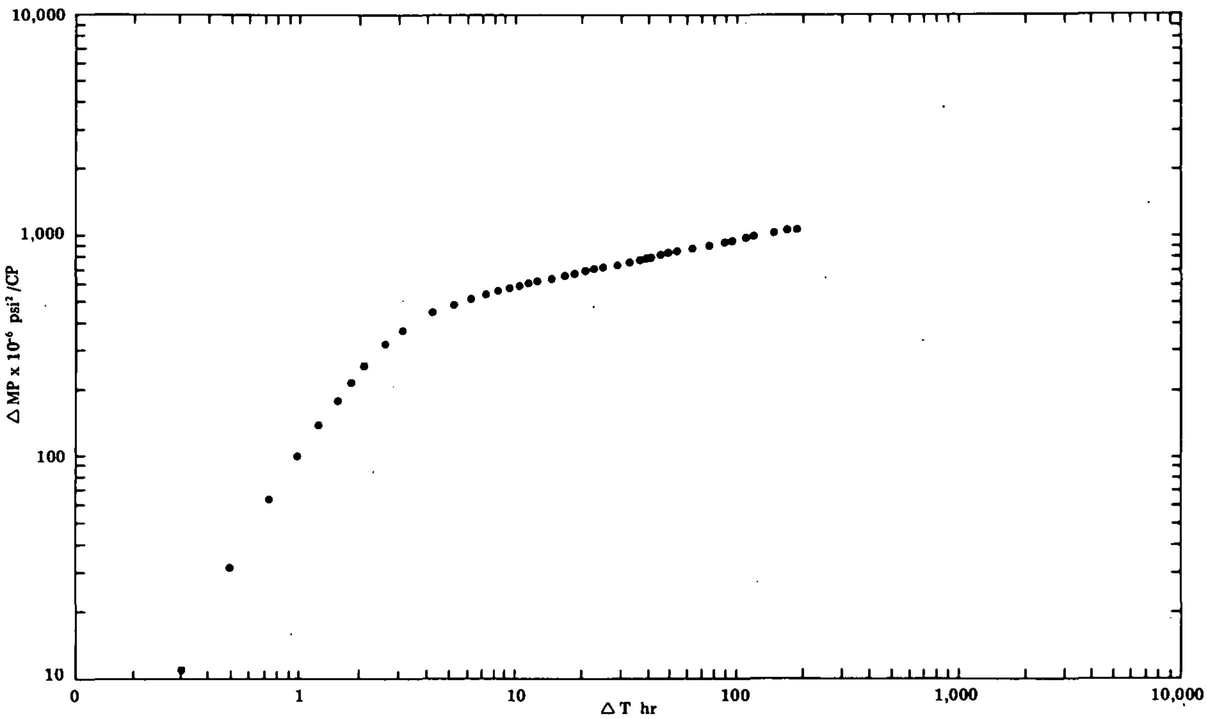


Figure 4-2 Type Curve for Mobil F31-13G Pre Frac No. 1, Zone 1

Zone 1 of the Mobil well, 10,549 - 10,680 ft, was chosen for dry gas simulation. Some water production was noted during production, but it appeared to be fairly constant. The pre-frac test results were compared to the simulated results. The permeability thickness term calculated from the buildup curves is low by an order of magnitude. The type curve plot shows a slope of 0.2 after the initial storage period. Several runs were made with several zones open to the wellbore. The zones were given different permeabilities where $k_1 = 10k_2$ and kh = 1.1. In no case was the simulated behavior similar to the observed behavior.

The post-frac period was also simulated using a 50-foot fracture and a kh of 1.1. This was an attempt to see what effect an artificial fracture would have on the buildup of a well. The kh value of 1.1 was obtained from buildup analysis and from simulated results from Lawrence Livermore Laboratories (NVO/0655-106). The kh appeared to be low as the well did not produce the required rate prior to shut-in. The fracture length was not as long as that used by LLL. The simulated type curve showed similar behavior to that observed but an analysis of the simulated buildup plot gave a kh lower than input. This was due to the superimposed buildup rates, as the sand face flow rate continued after the well was shut-in at the surface.

An attempt was made to determine what effect a linear analysis would have on the results when storage was taken into account. A. F. Van Everdingen, *The Skin Effect and Its Influence on the Productive Capacity of a Well,* Petroleum Engineer, October, 1953, shows a dimensionless pressure function for after flow when the rate can be approximated by:

(1) $q_{sf} = q(1 - e^{-Bt_D})$

q_{sf} = sand face flow rate;

q = rate prior to shut-in;

B = empirical constant;

t_D = dimensionless time.

The dimensionless pressure is given as:

(2) $\overline{P}(t_D) + S \frac{1}{-2} e^{-Bt_D} (-\ln B - 2\gamma + \ln 4 + Ei(Bt) + 2S)$

$\overline{P}(t_D)$ = dimensionless pressure with storage;

$P(t_D)$ = dimensionless pressure without storage;

S = skin;

γ = 0.5772

At long times, e^{-Bt_D} becomes small and the solution is the same as without the correction term. By applying this formula, Figure 4-3 is produced for conditions approximating the pre-frac case. The dots represented data computed from Equation (2) and the line is the non after flow equation. This figure shows that for these tight reservoirs, the effect of after flow on the slope must be considered.

4.1.5.2 Future Work

Data analysis will continue. A reason for the 0.2 slope on the type curve will be examined. A leak from the tubing to the casing may be causing a departure from normal. The other wells will be analyzed to determine some of the important variables.

4.1.6 Petrophysics

Tapes containing digital well log data have been received on the following wells:

- CIGE No. 21-15-10-22
- Rio Blanco Natural Gas Federal 498-4-1

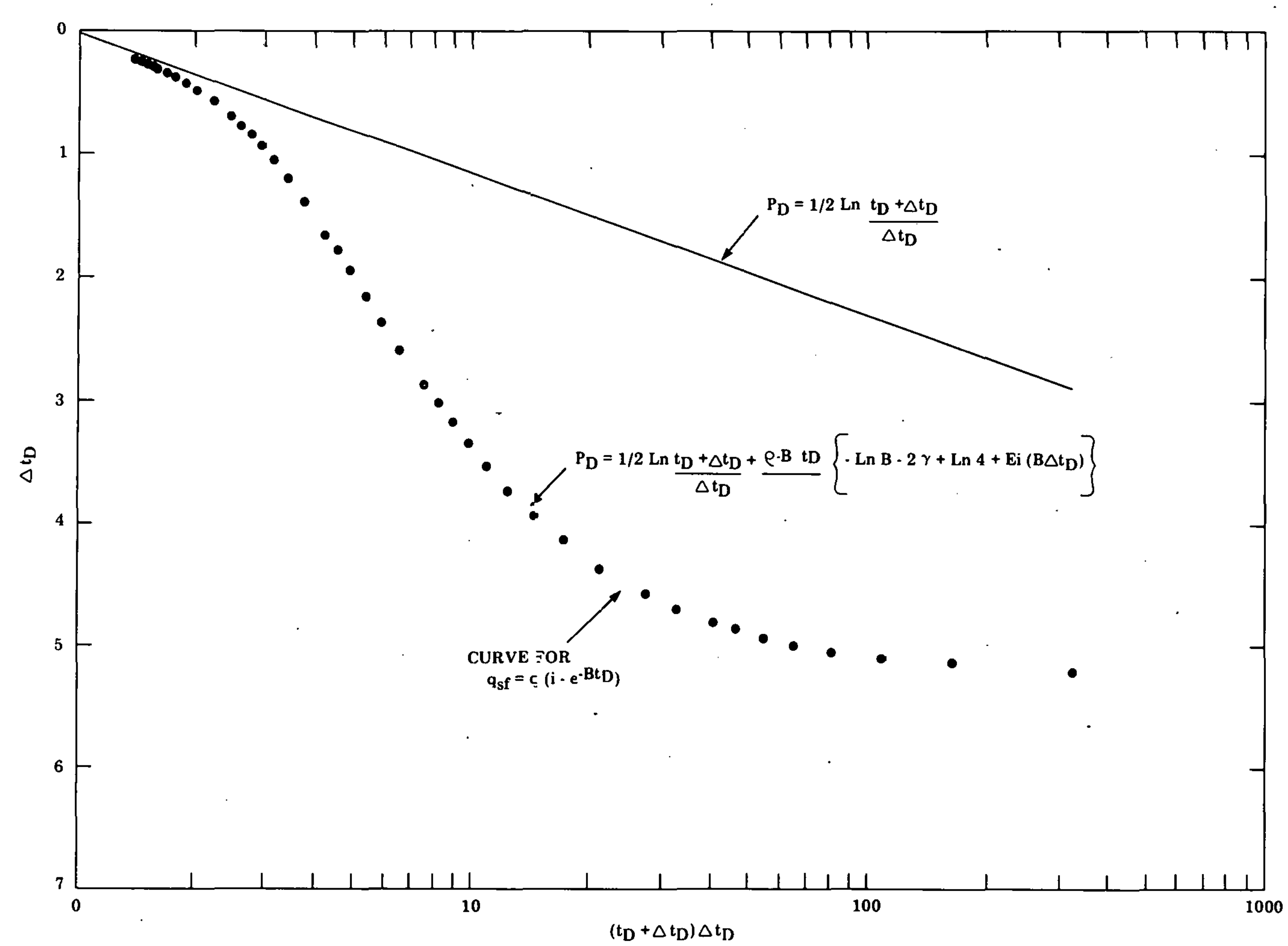


Figure 4-3 Dimensionless Pressure For Storage and No Storage Cases (No Skin) Build-Up

- Mobil Piceance Creek F31-13G
- CER RB-MHF-3

These data have been edited and prepared for analysis.

4.1.7 Schedule Status

Figure 4-4 is a milestone chart depicting the status of BETC projects through August 31, 1978.

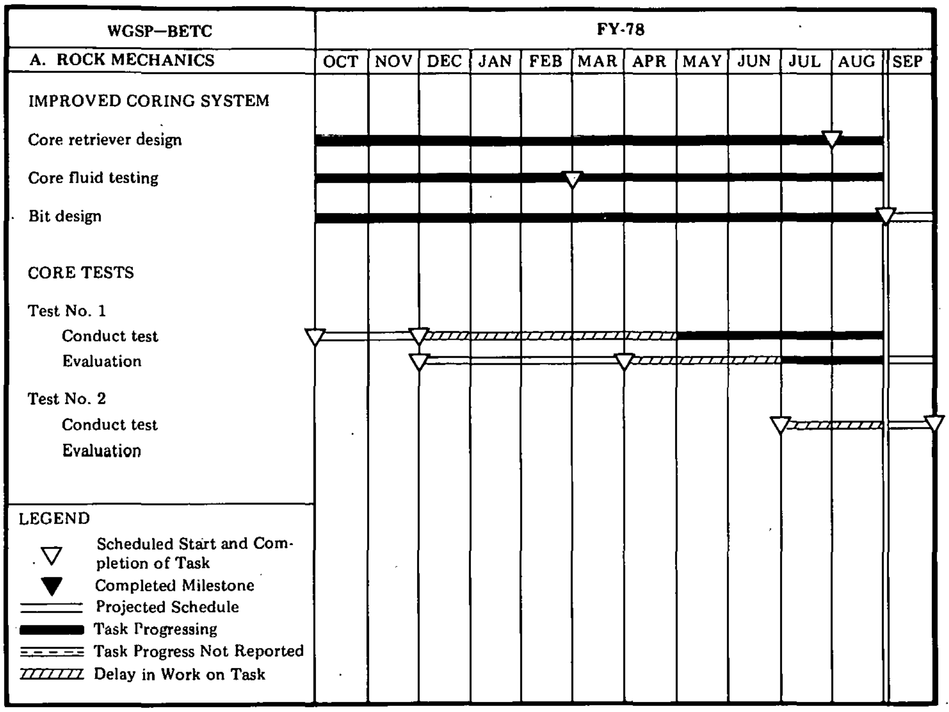
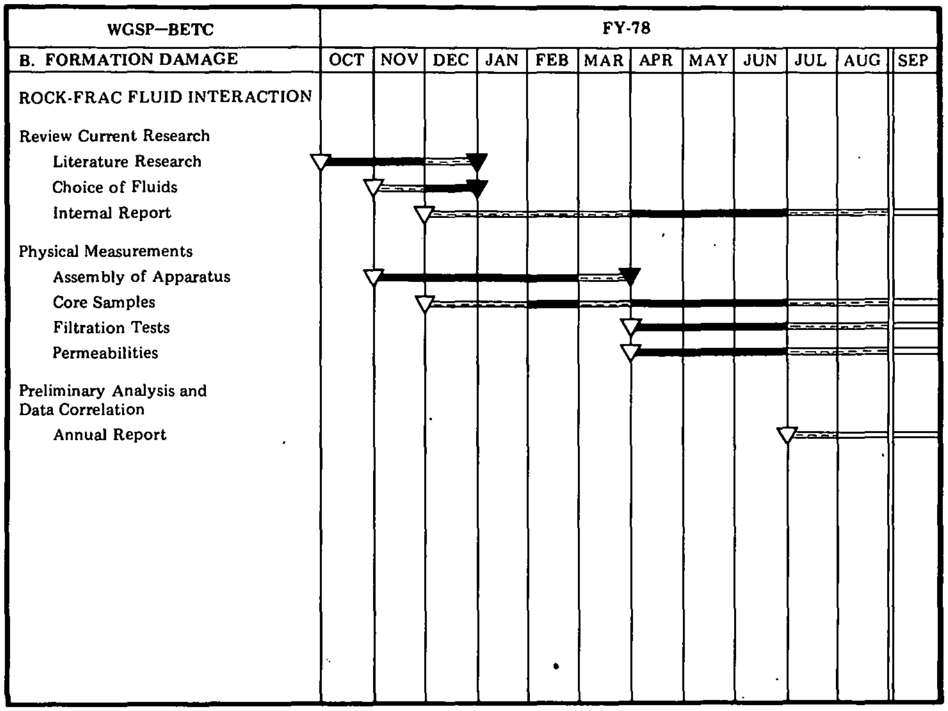


Figure 4-4 Milestone Chart—BETC



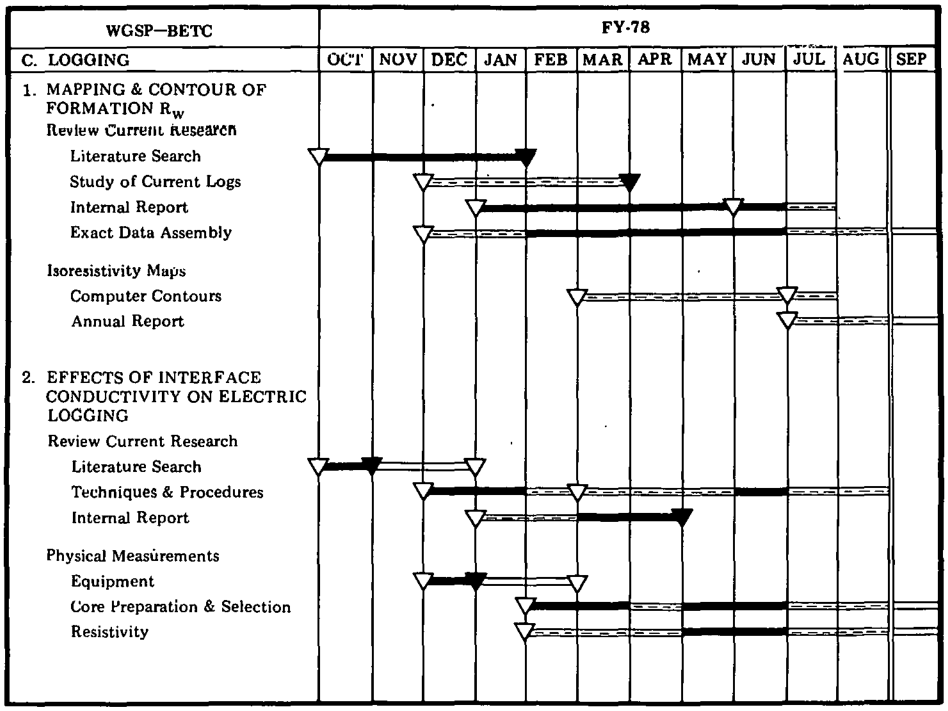
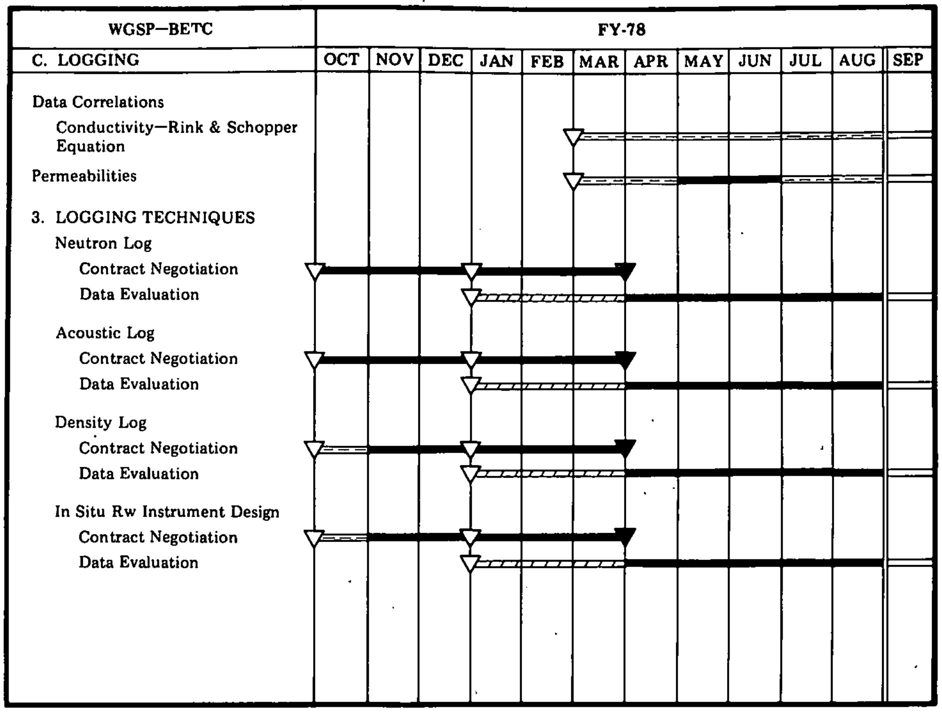


Figure 4-4 Continued



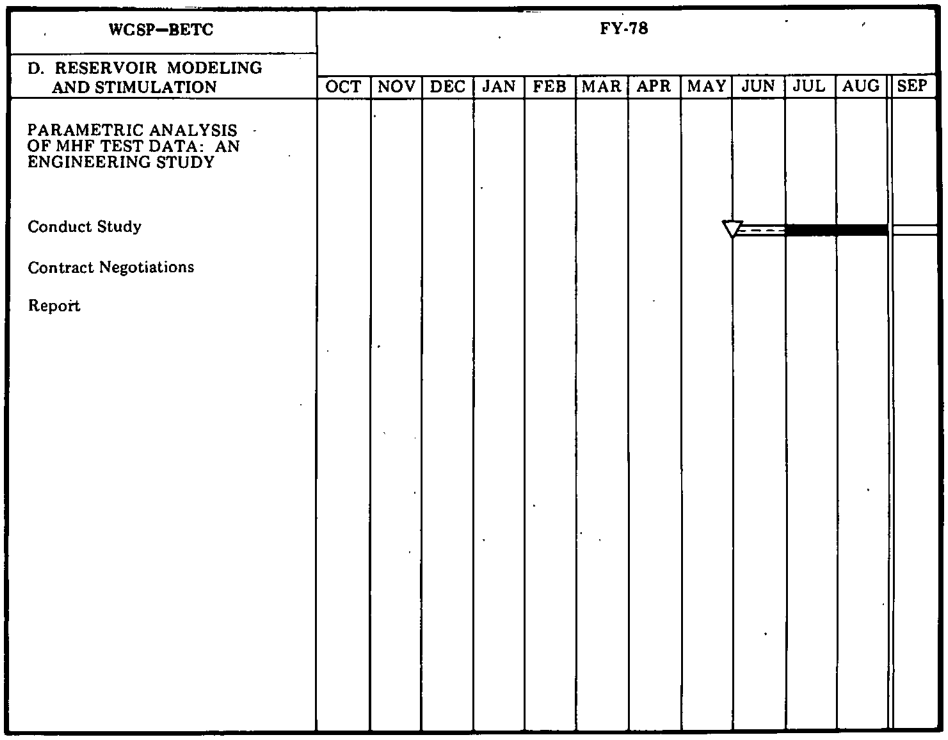


Figure 4-4 Continued

4.2 LAWRENCE LIVERMORE LABORATORY

4.2.1 Theoretical and Experimental Model Development and Application

Analysis of the changes in shear stress across a well bonded interface due to the presence of a hydraulically inflated fracture near the interface is proceeding. These analyses are being performed to understand how a hydraulic fracture modifies the stress field near an interface and the results will be used to guide the further development of the theoretical models to include friction across these interfaces.

Other calculations have been performed to determine the elastic stress and strain variations caused by embedded layers of finite extent (lenses). Although it is obvious that some "plastic" relaxation occurred, these calculations in the elastic limit may provide some insight in how the stress-strain field can vary due to the lenses. In these analyses the lenses were typified by elastic constants (E_2, ν_2) which differ from those of the surrounding medium (E_1, ν_1), where E and ν are the Young's modulus and Poisson's ratio, respectively. At present LLL is analyzing simple triple lens geometries with the assumption that the lenses are homogeneous and isotropic. Additionally, plastic deformation is not included.

Poisson's ratio was set at 0.35 for both materials and for each lens configuration a calculation was made for E_1 = 0.2 Mbar and E_2 = 0.1 Mbar. The Young's modulii were then reversed and the calculation repeated. A sample of the results is shown as contours of the largest principal stress on Figures 4-5 through 4-7. The top of the plots represent the ground surface and the medium is subjected to vertical compression. In all the contour plots the ends of the lens show strong changes in the largest principal stress. When the lenses are stiffer than the surrounding medium (top plot in each figure) a fracture external to the immediate area of the lens would tend to be repelled. When the medium is stiffer than the lens, (bottom plots in the figures) a fracture in the medium near the end of the lens would tend to be attracted toward the lens.

4.2.2 Experimental Program

During the month of August a new supply of Nugget sandstone blocks was fabricated for use in experiments to study crack initiation and growth across a bonded interface between limestone and sandstone. These experiments will resume in September. In late August, one experiment was performed in which a crack was generated in a large Nugget sandstone cylinder. The purpose of this experiment was to see if a crack could be initiated and slowly grown. The cylinder was 12 in. in length and 11 in. in diameter. An injection hole was drilled along the axis of the cylinder to near the center of the cylinder. A steel injection tube was epoxied into the injection hole in the standard manner. The fluid pressure was increased at a constant rate over a four minute time period at which time it reached a value of 6,200 psi and fracture occurred. The crack reached the exterior surface but the block remained intact. The interior surface of the crack has not yet been examined.

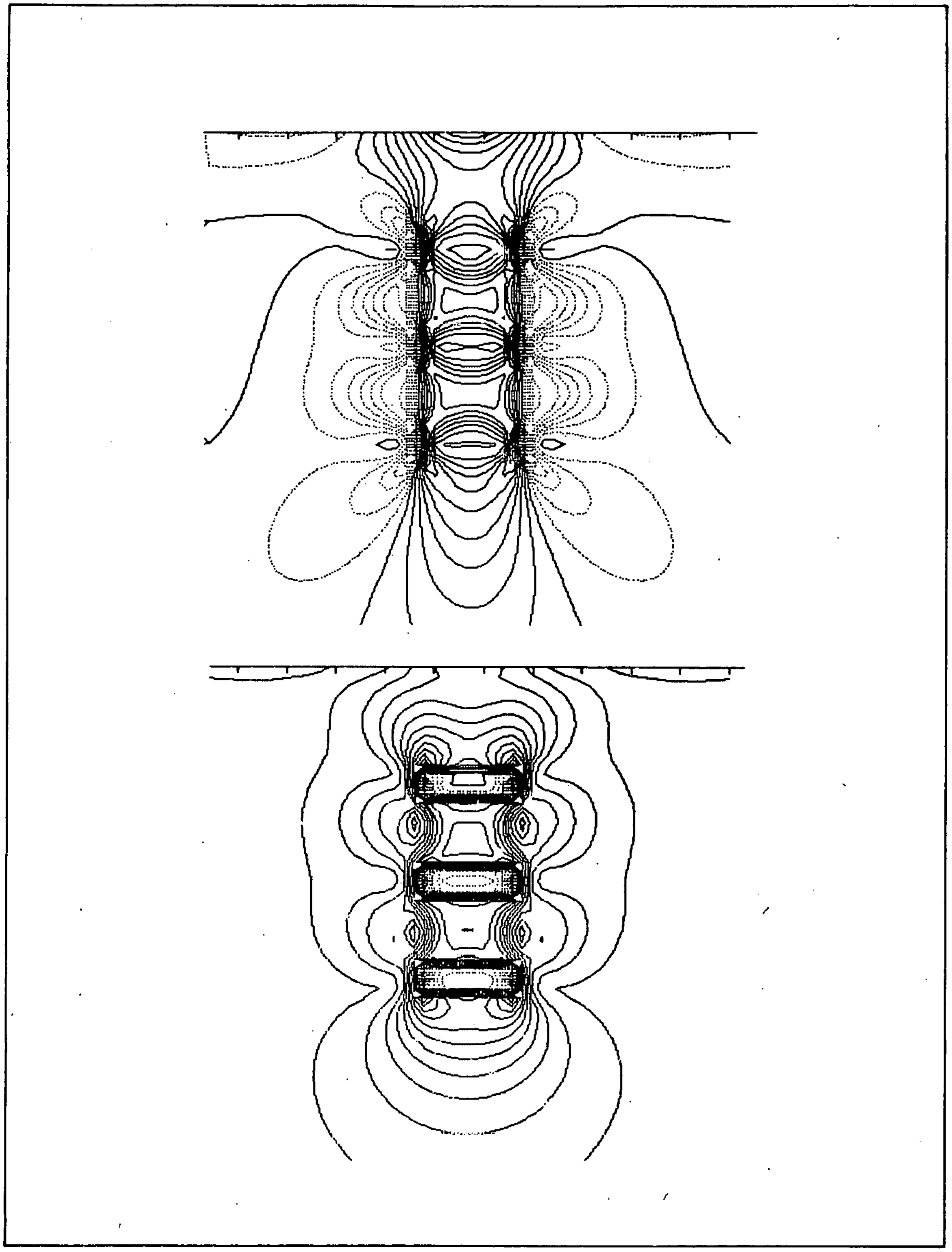


Figure 4-5 Contours of Greatest Principal Stress for Three Vertically Arranged Layers. Top: $E_1 = .1$, $E_2 = .2$ where the subscript 2 refers to the layers. Bottom: $E_1 = .2$, $E_2 = .1$.

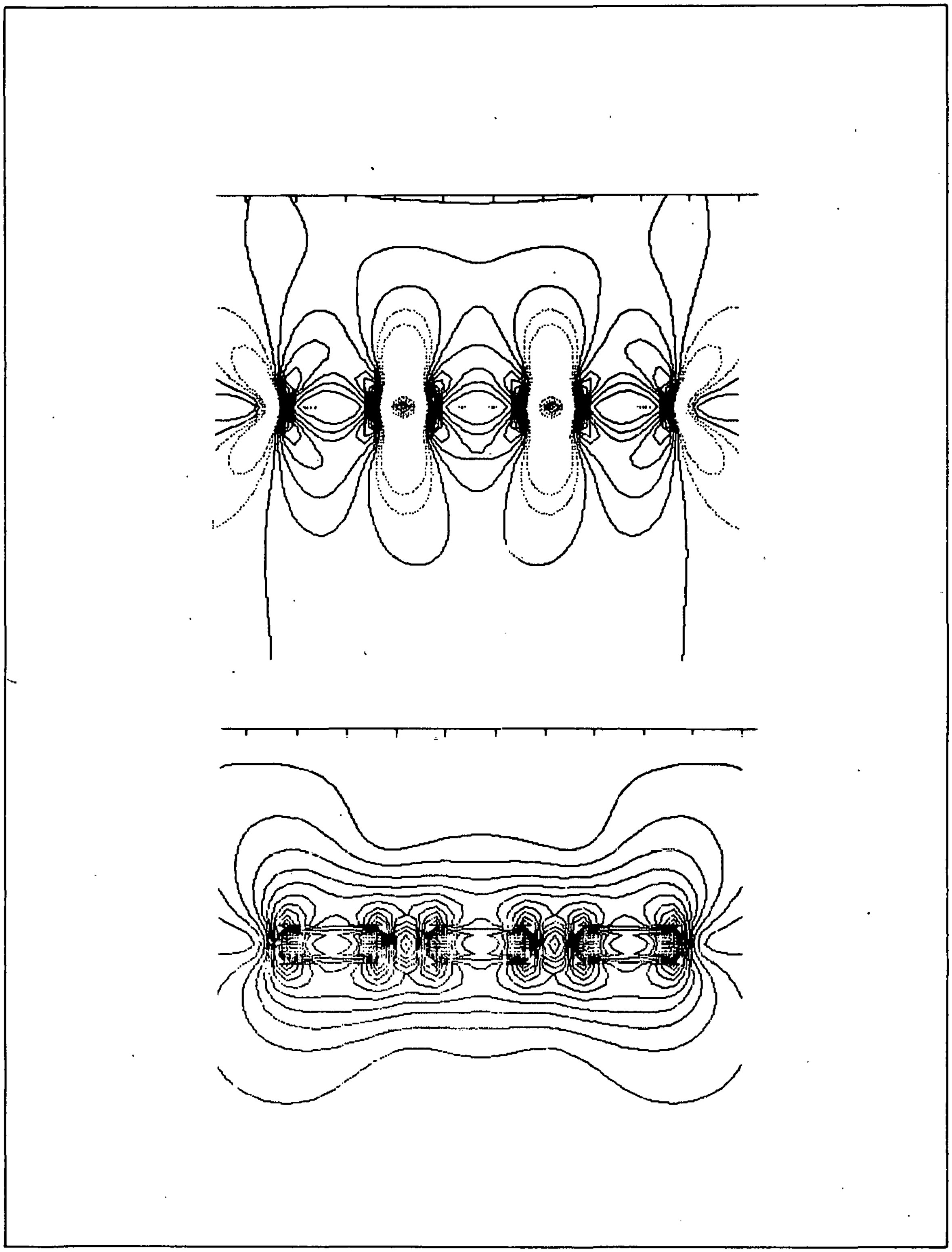


Figure 4-6 *Contours of Greatest Principal Stress for Three Staggered Layers.*
Top: $E_1 = .1, E_2 = .2.$
Bottom: $E_1 = .2, E_2 = .1.$

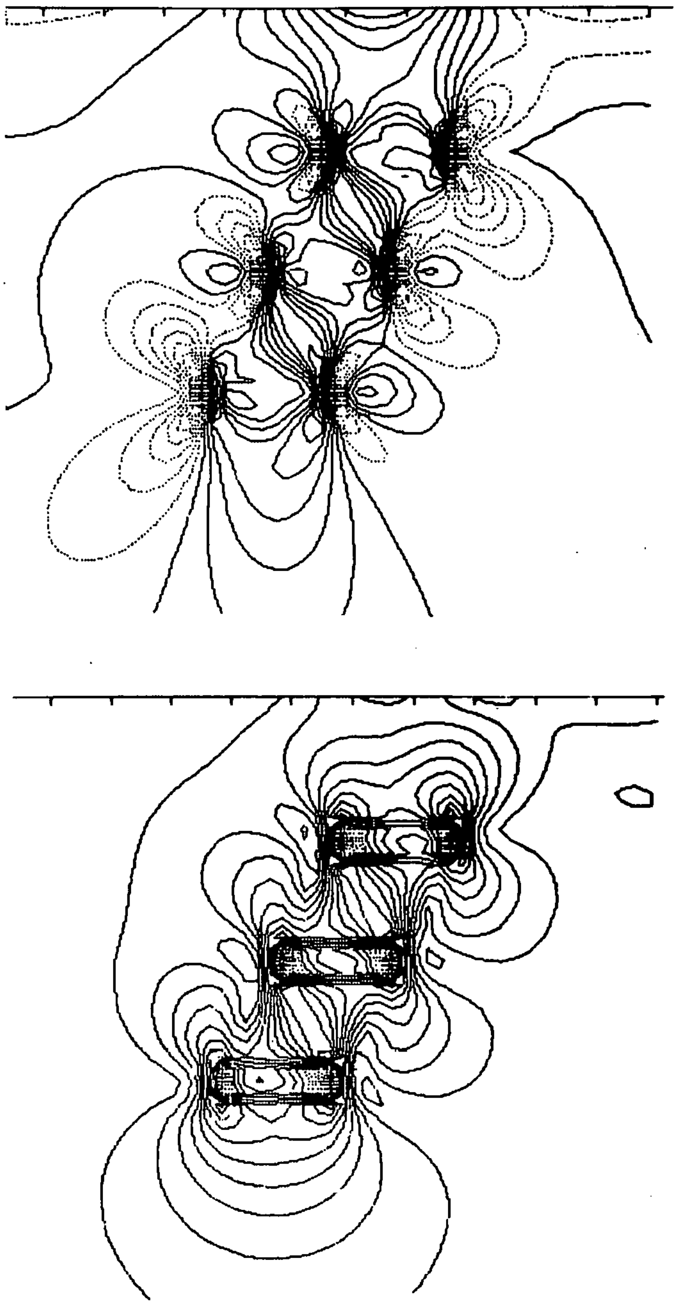


Figure 4-7 Contours of Greatest Principal Stress for Three Horizontally Arranged Layers.
Top: $E_1 = .1, E_2 = .2$.
Bottom: $E_1 = .2, E_2 = .1$.

4.2.3 Logging Program

The LLL dry hole sonic tool was tested in a hole at the Nevada Test Site. Except for some problems with one receiver, the tool performed mechanically as expected. The transmitter and receiver crystals and the reaction pistons were cycled into the borehole numerous times at various locations and there was no tendency for the tool to become lodged in the aperature of the hydraulic pistons.

During these tests an anamolous electrical signal was noticed. Since the field tests, these anomolous signals have been identified as a flexural mode in the transmitter module. They have been eliminated by filtering and a simulated borehole test was performed in the laboratory to verify that the signals were eliminated. A test on an aluminum plate showed that the bar wave velocity of 5 km/sec can be measured accurately. The system is ready for field use when holes become available.

4.2.4 Environmental Assessment

The following is an updated list of the environmental assessments which are being prepared for the Enhanced Gas Recovery program in the WGSP.

Mitchell Energy Corporation, MHF, Limestone County, Texas

In June, LLL was informed that Mitchell Energy would be drilling a deep well (11,650 ft) in the Cotton Valley Lime Formation (a tight blanket sand) of east Texas which would be stimulated using a large water frac. The actual fracture treatment will occur in late September or early October, 1978. Since certification from the state of Texas agencies was not immediately available, a preliminary environmental assessment was filed September 1, 1978 pending the receipt of additional information. Once the needed information is received, the final assessment will be completed.

Colorado Interstate Gas, Wattenberg Field, Colorado

Colorado Interstate Gas Company contracted with DOE to perform a dry gas injection experiment in the Wattenberg Field, outside of Denver, Colorado. The experiment would involve the use of two previously drilled wells. Work began on this project late last year. CIG is currently in the process of purchasing the necessary right-of-way and selecting a compressor for use at the site. The environmental assessment is partially completed but has been suspended until the technical information on compressor characteristics and emissions has been received.

4.2.5 Other Activities

During the month, representatives of LLL visted C. W. Spencer of the USGS, Denver, to learn the status and findings of the USGS Western Tight Gas Sands Reservoir and Resource Characterization Program. Additionally, the Laboratory attended the Fourth Annual DOE Symposium on Enhanced Oil and Gas Recovery and Improved Drilling Methods and presented a paper, *Theoretical and Experimental Research on Hydraulic Fracturing.**

*The abstract of this report appears in Section 2.1.4 "Articles and Papers."

4.2.6 Schedule Status

Figure 4-8 is a milestone chart showing the progress of LLL projects as of August, 1978.

4.3 SANDIA LABORATORIES

4.3.1 Hydraulic Fracture Characterization

To facilitate Sandia's understanding of state-of-the-art nuclear magnetic resonance (NMR) oil field applications and to pursue joint Sandia-industrial cooperation, T. L. Dobecki and J. G. Castle of Sandia visited with the staff of Chevron Oil Field Resesearch Labs on August 3-4, 1978, as guests of Dr. Aytekin Timur, head of borehole geophysics.

Numerous empirical studies relating the laboratory NMR response of various elastic and carbonate reservoirs have been published by Timur and others. Of particular importance to the WGSP is the expected application of such studies to shaly, low-permeability, gas sands. The minimal data on low-permeability formations shown by Chevron indicate that rapid (approximately 1 msec) phenomena need to be measured via NMR to adequately describe the desired petrophysical parameters (pore size distribution, permeability, residual oil saturation). Current downhole nuclear magnetism log (NML) tools have a 12 msec dead time associated with their operation. This means that currently available logs are incapable of providing required data for the typical low-permeability gas sand. Chevron has had success, however, making measurements on-site using core samples or chip samples and portable laboratory instruments.

To be able to use such on-site measurements quantitatively, it is necessary to extend the existing empirical studies of NMR formation evaluation to include the low-permeability gas sands of the WGSP. Chevron and Sandia are entering into a cooperative program to measure the petrophysical characteristics of these gas sands as well as their NMR behavior to establish empirical relationships which will be needed. Sandia is in the process of obtaining representative core samples already obtained in the Uinta Basin. These will be analyzed at Chevron to determine:

- If correlations between NMR response and formation parameters are evident,
- The consistency of such correlations for different reservoirs in the same field, and
- The resolution required to make quantitative evaluations in the field using available samples.

The Surface Electrical Potential System (SEPS) has been undergoing extensive redesign and rework in the last several months. An internal solid state timer has been added to the current injection pulses to improve pulse repeatability.

The calibration of the SEPS has been upgraded by the addition of a digitally programmable voltage source. This voltage source is input to the 24 potential measurement boxes (PMB's) at the beginning of each pulse-stake data set. The computed gain of each of the 24 data channels is used to correct the data amplitude at that point in time before data storage.

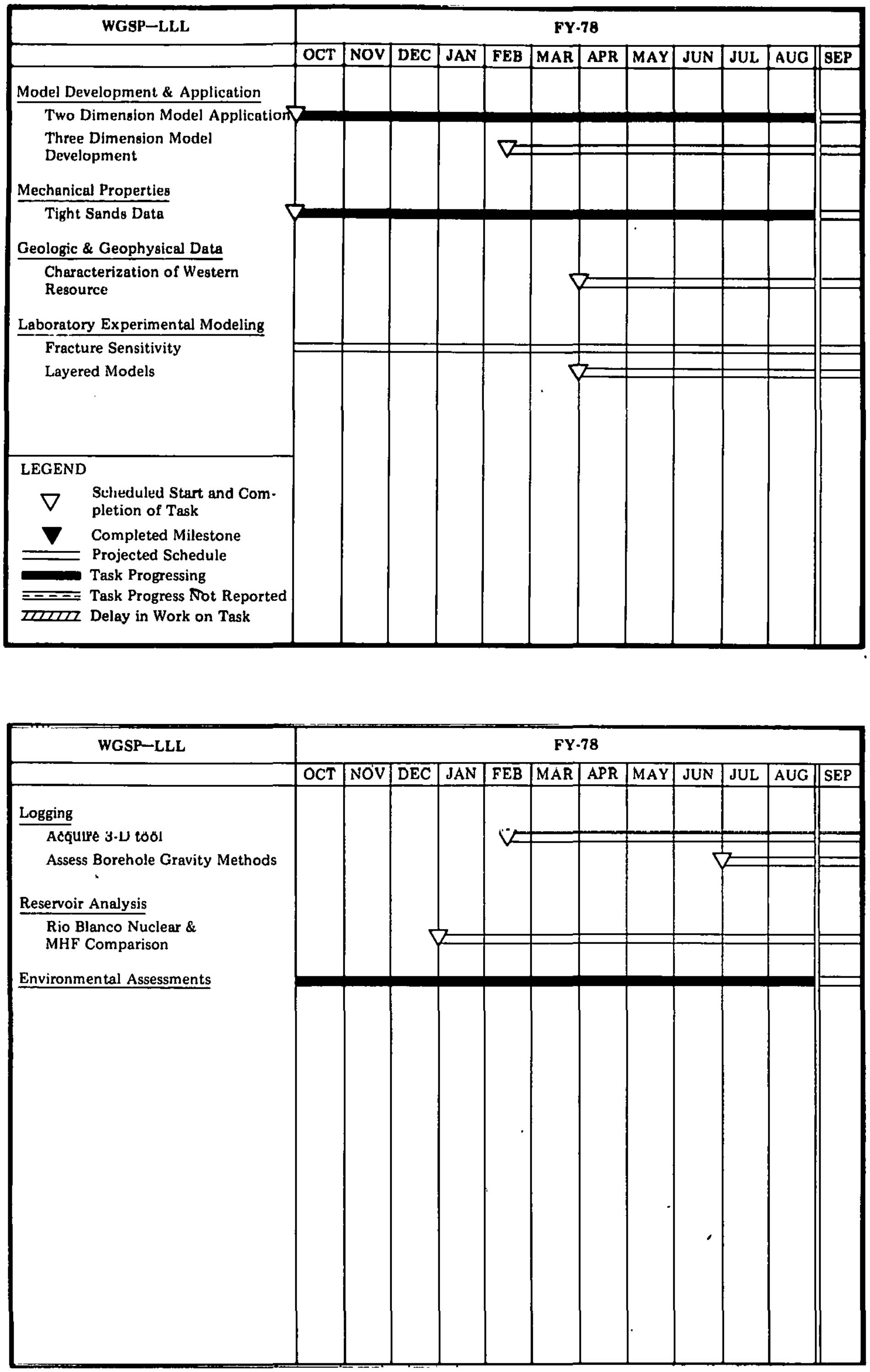


Figure 4-8 Milestone Chart—LLL

A 1 HZ bandpass filter has been added to each PMB in front of the isolation amplifier to eliminate stake-to-reference current flow via the isolation amplifier input impedance. A 4 pole, linear phase active lowpass filter has been added to each PMB prior to the subcarrier VCO to attenuate that portion of the telluric spectrum above 1 HZ, the pulser operating center frequency. The methods of subcarrier VCO mixing has been changed to increase subcarrier amplitude.

4.3.2 Other Program Related Activities

- R. A. Schmidt and C. L. Schuster accompanied Mike Sorrels, Teledyne-Geotech, to the Nevada Test Site on August 1, 1978. Mr. Sorrells has been investigating the nature of seismic signals generated by hydraulic fractures and wanted to view the fractures and their interaction with the geologic formations in the mineback tests.

- R. A. Schmidt presented a 1½ hour invited paper at the Gordon Conference which was held August 7-11, 1978, in Tilton, New Hampshire. The paper was entitled *Crack Propagation and Fracture in Rocks* and dealt with fracture measurements made in laboratory investigations and with the hydraulic fracture experiments being performed at NTS.

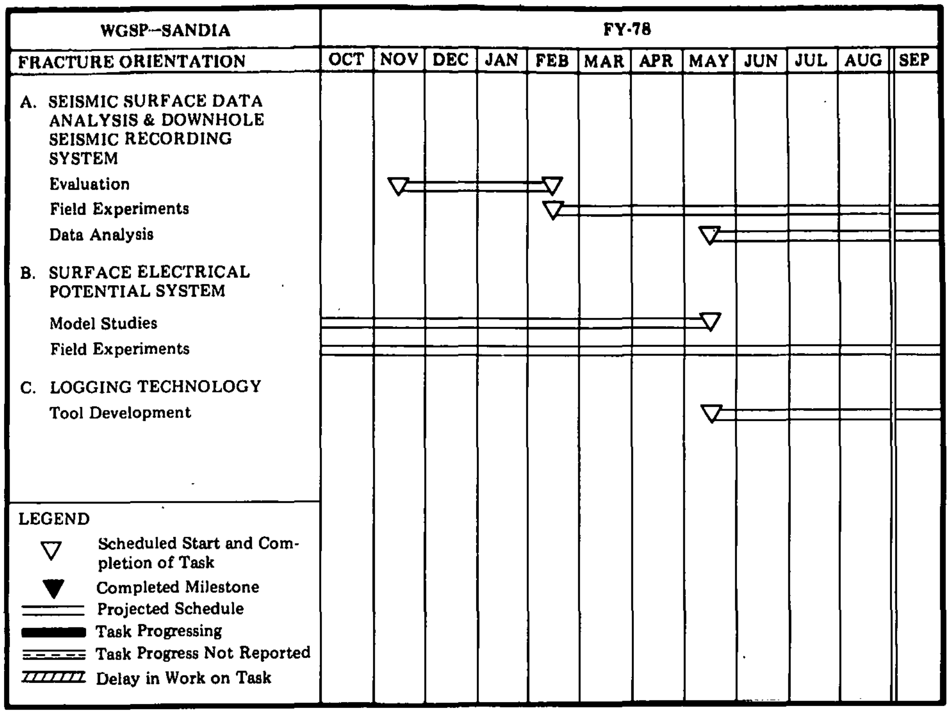
- D. A. Northrop, R. A. Schmidt, N. R. Warpinski, and other Sandia personnel briefed Robert Huggins, Ralph Veatch and Mike Smith, Amoco Production Company, during their visit to G-tunnel, Nevada Test Site, on August 22, 1978. These people have been closely involved with the project and this first-hand look stimulated an excellent exchange of observations and ideas for future experiments.

4.3.3 Schedule Status

A milestone chart, depicting status of Sandia projects appears in Figure 4-9. Project tasks are scheduled through August 31, 1978.

4.4 M. D. WOOD, INC., TILTMETER

No information available.



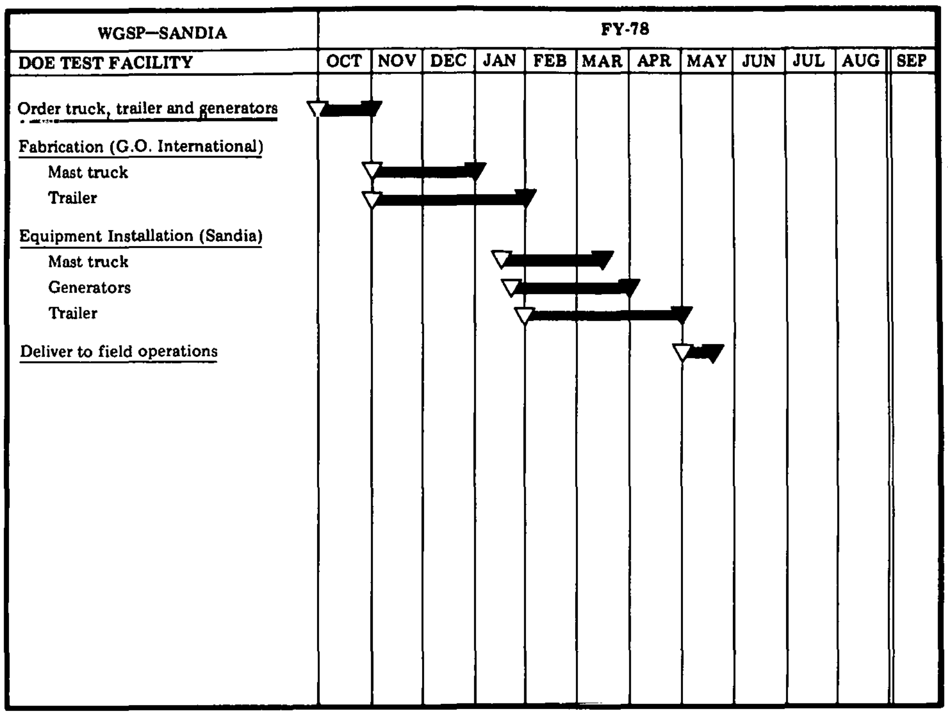


Figure 4-9 Milestone Chart—Sandia

5. FIELD TESTS AND DEMONSTRATIONS

5.1 BACKGROUND

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

- A dry gas injection experiment in the Wattenberg Field, Colorado, by Colorado Interstate Gas Company,
- MHF demonstrations by Gas Producing Enterprises in the Uinta Basin, Utah,
- MHF treatment of the Cotton Valley Limestone Formation in Limestone County, Texas, by Mitchell Energy Corporation,
- MHF demonstrations in the Piceance Basin, Colorado, by Mobil Research and Development Corporation and Rio Blanco Natural Gas Company,
- A mineback testing program by Sandia Laboratories, and
- The utilization of a DOE well testing facility by CER Corporation to evaluate the productive potential of all types of wells.

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

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

Table 5-1 MHF Contract Locations and Frac Data

COMPANY, BASIN	LOCATION T / R / Sec	WELL	INTERVAL FRACTURED Feet	FRAC. DATE	FRAC. TREATMENT Lbs of Sand	FLUID INJECTED 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 Gel H 0
CONSORTIUM MANAGED BY CER CORPORATION Piceance, Mesaverde	3S, 98W, S11 Rio Blanco Co. Colorado	RB-MHF-3	8,048- 8,078 7,760- 7,864 5,925- 6,016 5,851- 5,869	10-23-74 5- 2-75 5- 4-76 11- 3-76	400,000 880,000 815,000 448,000	117 Gel 285 Gel 400 Gel 228 Gel
GAS PRODUCING ENTERPRISES, INC. Uinta, Wasatch and Mesaverde	10S, 22E, S10 Uintah County Utah	Natural Buttes No. 18	6,490- 8,952	9-22-76	1,480,000	745 Gel
	10S, 21E, S21 Uintah County Utah	Natural Buttes No. 19	8,909- 9,664 7,224- 8,676	9-21-76 9-28-76	424,000 784,000	280 Gel 364 Gel
	9S, 21E, S22 Uintah County Utah	Natural Buttes No. 14	6,646- 8,004	3-15-77	1,093,000	544 Gel
	9S, 21E, S28 Uintah County Utah	Natural Buttes No. 20	8,498- 9,476	6-22-77	826,000	322 Gel
	10S, 22E, S18 Uintah County Utah	Natural Buttes No. 22	6,858- 8,550	11-21-77	1,091,000	479 Gel
	9S, 21E, S19 Uintah County Utah	Natural Buttes No. 9	5,661- 8,934	3-27-78	554,000	349 Gel
	10S, 21E, S29 Uintah County Utah	Natural Buttes No. 2	7,251- 8,774	8- 8-78	1,965,000	722 Gel
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 9,432- 9,538 8,163- 8,650	6-22-77 8-24-77 7- 6-78	580,000 600,000 680,000	316 Gel 260 Gel 288 Gel
PACIFIC TRANSMISSION Uinta, Mesaverde	8S, 23E, S25 Uintah County	Federal 23-25	NO FRACS PERFORMED			
RIO BLANCO NATL. GAS Piceance, Mesaverde	4S, 98W, S4 Rio Blanco Co. Colorado	Federal 498-4-1	6,150- 6,312 5,376- 5,960	10-22-76 11-30-77	766,000 243,000+ 22,500 Beads	276 Gel 164 Gel
WESTCO Uinta, Mesaverde	10S, 19E, S34 Uintah County	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

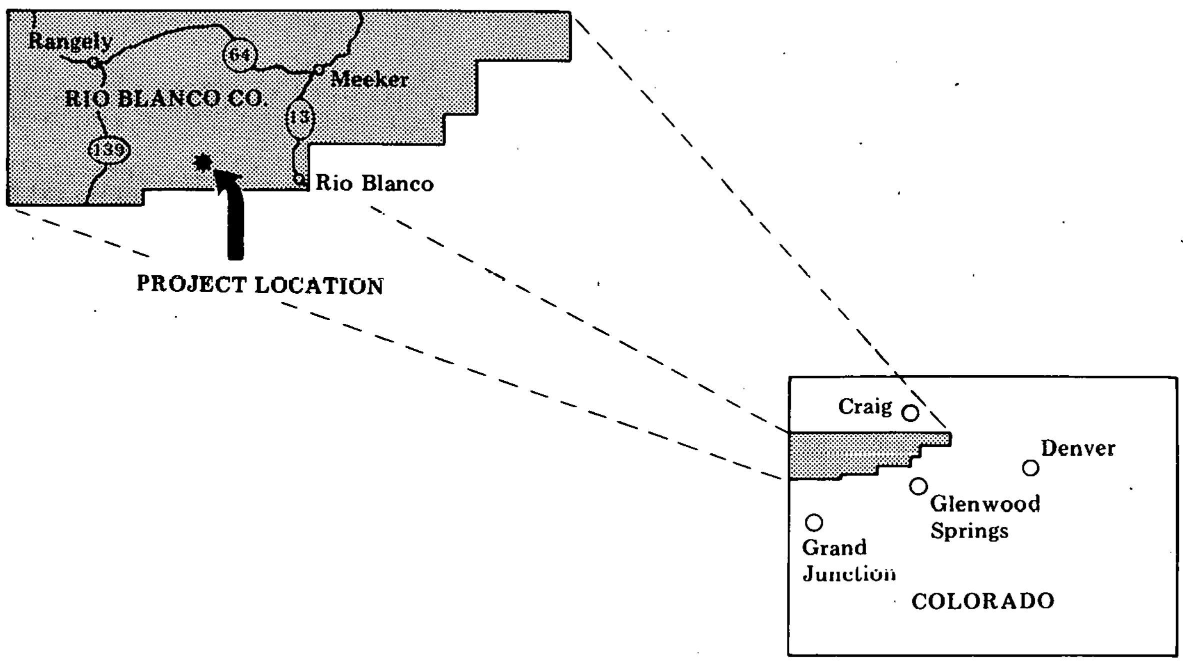
CER Corporation
Las Vegas, Nevada

Status: Awaiting Advisory Committee Decision

Interagency Agreement Date:	June 19, 1974	
Anticipated Completion Date:	December 31, 1978	
Project Cost (estimated):	DOE	$1,975,000
	Industry	1,630,000
	Total	$3,605,000
Principal Investigator:	G. R. Luetkehans	
Technical Advisor for DOE:	C. H. Atkinson	

OBJECTIVE

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



5.2 CER CORPORATION

5.2.1 Summary of Past Activities

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

5.2.2 Current Status

Field activities on RB-MHF 3 well have been suspended. Negotiations have taken place with an outside party to complete the commingling of the fractured gas zones and to perform additional tests in return for the well and subsequent gas production. Legal documents are being prepared for distribution to the project participants for their concurrance.

WATTENBERG FIELD | EY-77-C-08-1514

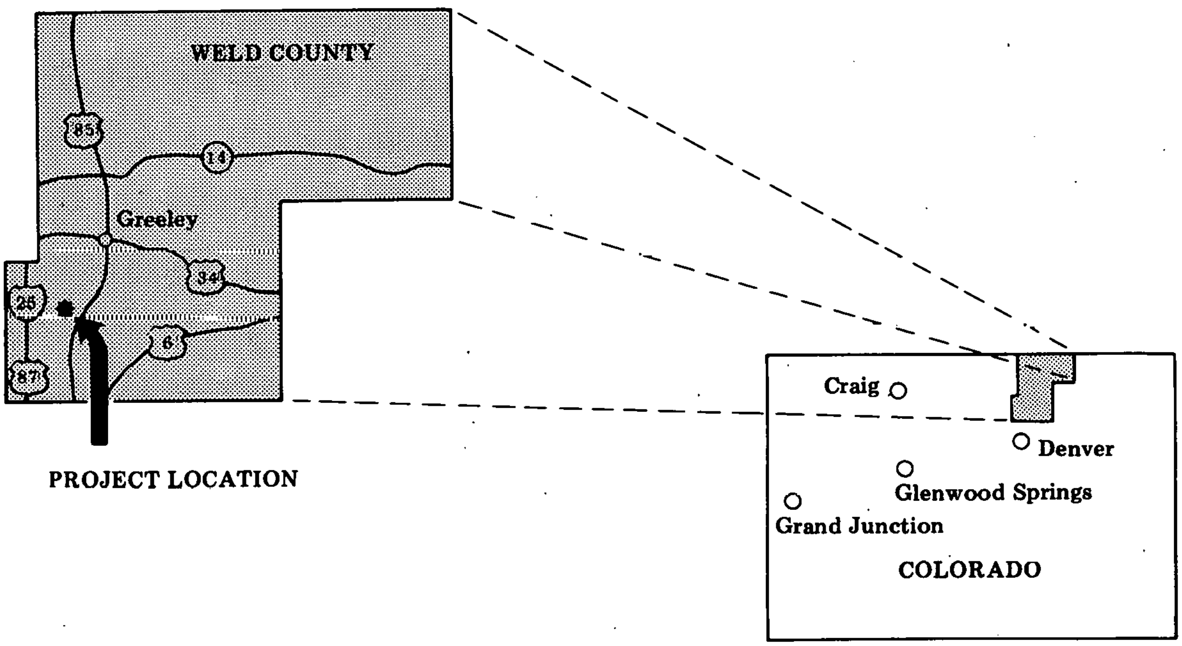
Colorado Interstate Gas Company
Colorado Springs, Colorado

Status: Active

Contract Date:	September 1, 1977	
Anticipated Completion Date:	March 1, 1981	
Total Project Cost (estimated):	DOE	$ 75,000
	CIG	99,000
	Total	$174,000
Principal Investigator:	Howard Fredrickson	
Technical Project Officer for DOE:	C. H. Atkinson	

OBJECTIVE

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



5.3 COLORADO INTERSTATE GAS COMPANY

5.3.1 Scope of Work

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

5.3.2 Current Status

A special compressor has been ordered with delivery expected in December, 1978. One additional month is required for completion of site preparation and BHP buildup, and the first cyclic injection-withdrawal is expected to begin around February 1, 1979.

DOE WELL TEST FACILITY — EY-76-C-08-0623

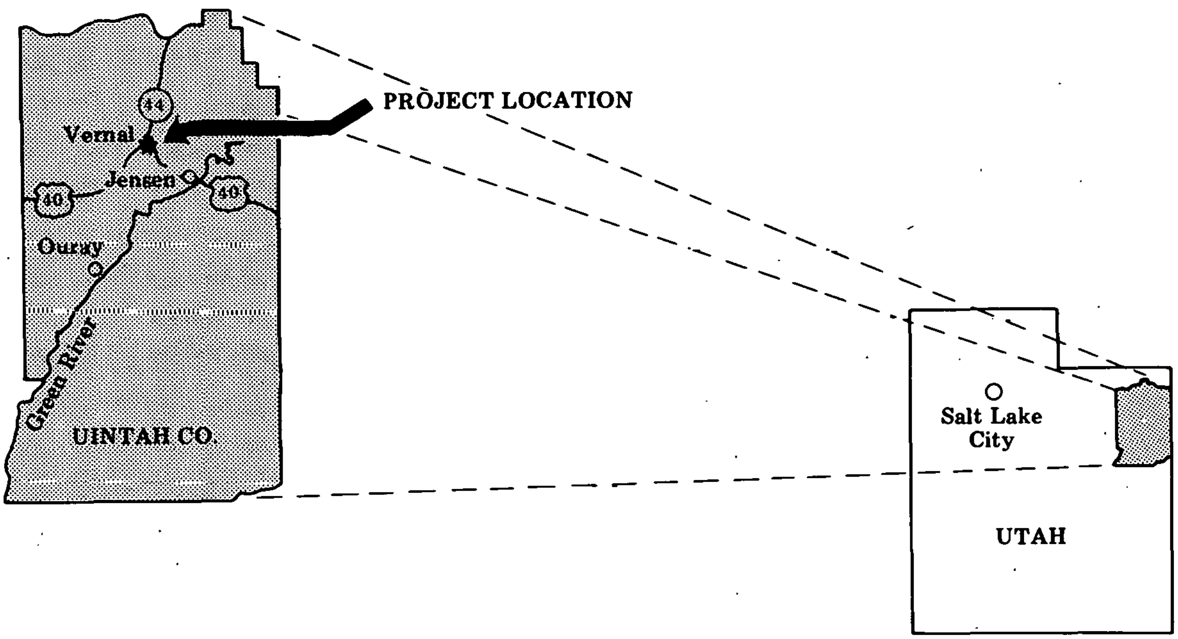
CER Corporation
Las Vegas, Nevada

Status: Equipment checkout and test proceeding

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

OBJECTIVE

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



5.4 DOE WELL TEST FACILITY

5.4.1 Background

A modification to CER's DOE Contract EY-76-C-08-0655 provides for the operation of the well test facility at various locations selected by DOE. The facility is comprised of a 10 ft x 50 ft trailer, a two-ton truck equipped with a hydraulically controlled telescoping 50 ft mast, and two trailer-mounted 30 kw and 90 kw electric generators.

5.4.2 Current Status

On August 24, 1978, the DOE Well Test Facility was moved from the RB-MHF 3 well in Colorado to Vernal, Utah. The mast truck and two generators were stored in the GSA yard while the instrument trailer had polyurethane insulation applied to the underside of the floor and protective sheet metal and protective enclosures added to the electric motors and hydraulic systems.

The fabrication of the cable system was completed and the cable storage reel, splice and junction boxes, cable runs and connectors were tested.

The following additional equipment has been received:

- Differential pressure transducer
- Pressure transducer
- Temperature transducer
- Water turbine meter and totalizing recorder
- GO International pressure and temperature data processor
- Orifice meter run
- Carle gas chromatograph

The computer data acquisition program was run continuously for 48 hours and gathered accurate output data every hour without interruption.

Future plans call for the DOE well test facility to be installed at the GPE NBU 21 well south of Vernal, Utah.

5.4.3 Schedule Status

Figure 5-1 is a milestone chart depicting the progress mode on the DOE Well Test Facility as of August 31, 1978.

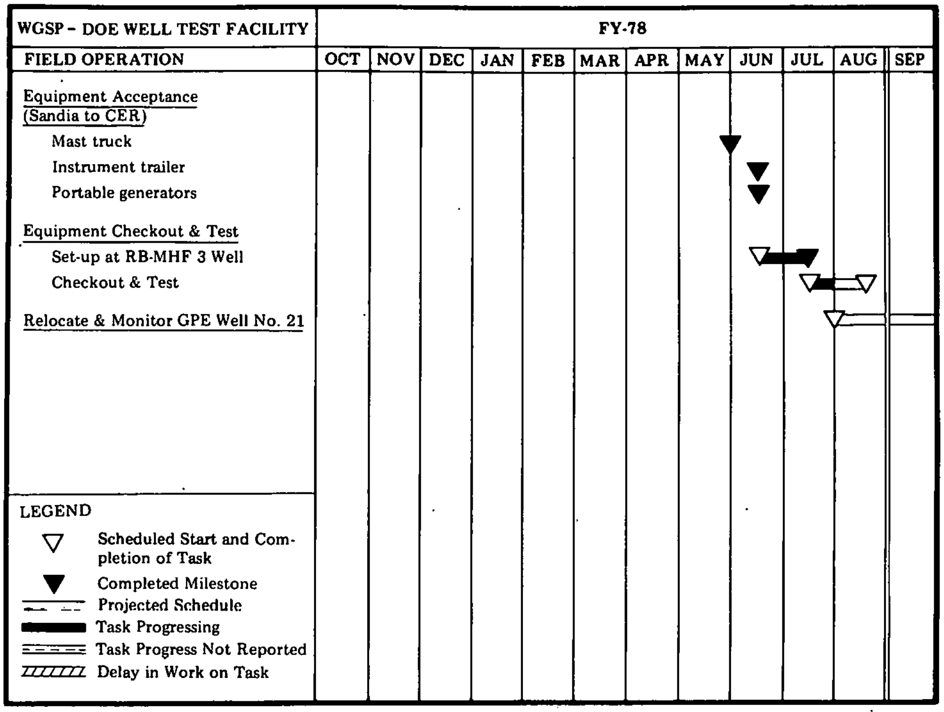


Figure 5-1 Milestone Chart—DOE Well Test Facility

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

EY-76-C-08-0681

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

Status: Active

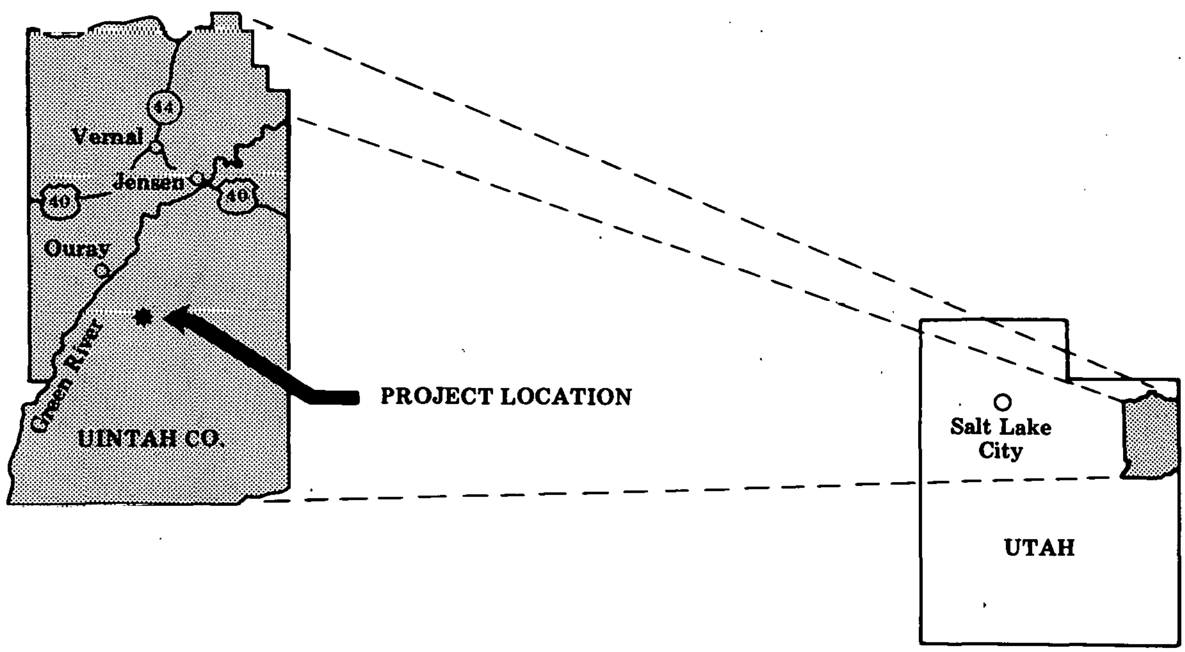
Contract Date: July 1, 1976
Anticipated Completion: September 30, 1979

Total Project Cost (estimated):		
	DOE	$2,827,000
	Industry (prior costs)	1,881,000
	Industry (new costs)	3,051,000
	Total	$7,759,000

Principal Investigator: W. E. Spencer
Technical Project Officer for DOE: C. H. Atkinson

OBJECTIVE

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



5.5 GAS PRODUCING ENTERPRISES, INC.

5.5.1 Summary of Past Activities

Gas Producing Enterprises was awarded DOE Contract EY-76-C-08-0681 in July 1976. Originally, two old wells, Natural Buttes Unit Wells 14 and 18, and four new wells, 19, 20, 21, and 22 were to receive MHF treatments. Three contract modifications have been entered into, adding one old well, Natural Buttes Unit No. 9, two new wells, 23 and CIGE 2-29-10-21, and increasing the scope of work for Natural Buttes Unit Well No. 21. In addition, the contract has been extended with the new completion date set at September 30, 1979.

5.5.2 Current Status

On August 8, 1978, one of the largest MHF treatments to date was performed on GPE's well CIGE 2. Previously, a smaller fracture treatment had been carried out on the Castlegate sand in this well (9,237 - 9,535 ft), but the zone produced water and was plugged back. The second stage of the frac in the well involved a limited entry technique in the Neslen and Lower Farrer sands of the Mesaverde Group. The interval 7,251 to 8,774 ft was perforated with 24 shots. Fluid was pumped at 7,200 psi at an average rate of 70 gal per minute down 4½ in. casing. 722,000 gal of fluid and 1,965,000 lb of sand were utilized. Radioactive sand was added at a constant rate throughout the treatment to aid gamma ray detection of the fracture zone.

Following treatment, the well was shut in until August 9. The well was opened to the pit with a flowing casing pressure of 550 lbs on a 18/64 in. choke. By the morning of August 20, the well was dead and plugged with sand.

By the end of August, CIGE 2 had been worked over and was again flowing a mixture of gas and water to the pit. At month end it was not possible to determine the success of the MHF treatment.

During the month, Natural Buttes Unit No. 9, 14, 20 and 22 were produced for 31 days. Natural Buttes Unit No. 18 was produced for 10 days and No. 19 was shut in due to field proration. Specific production data on these wells appears in Figures 5-2 through 5-7.

Natural Buttes Unit No. 21 is presently flowing to the pit after being perforated at 8,201, 8,202, 8,203, 8,204, and 8,205 ft on August 25, 1978. The perforations were broken down with 2,500 gal of 2 percent KCl water. If the well produces only water, then a plug will be set and perforations at 7,741, 7,742, 7,743 and 7,744 ft will be tested. Natural Buttes Unit No. 23 is shut in and waiting on completion. During September, the well will be prepared for MHF treatment early in October.

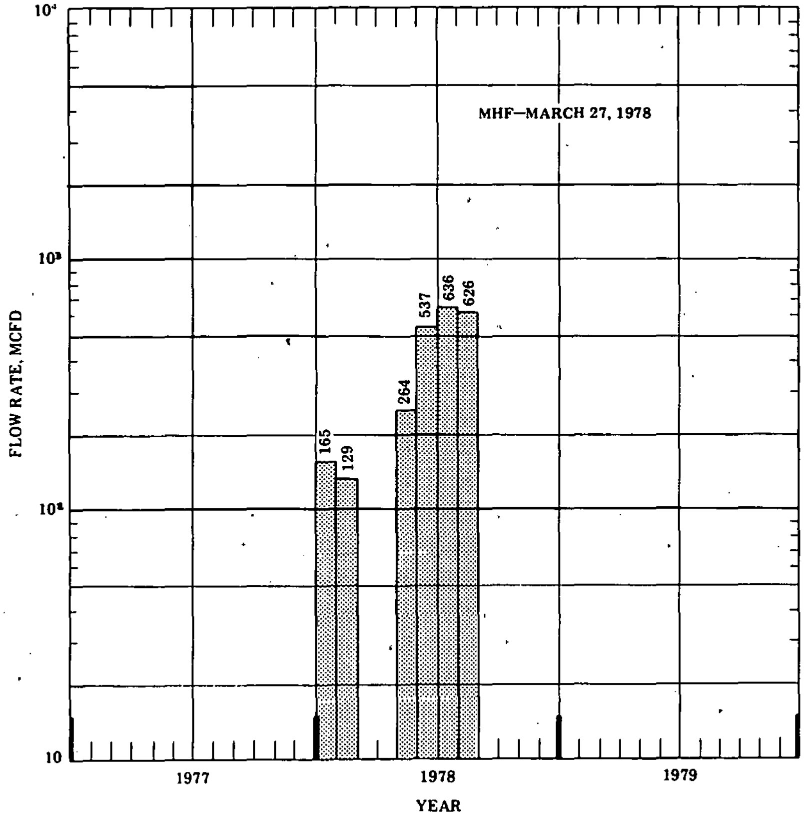


Figure 5-2
Flow Rate Performance of Natural Buttes No. 9 Well

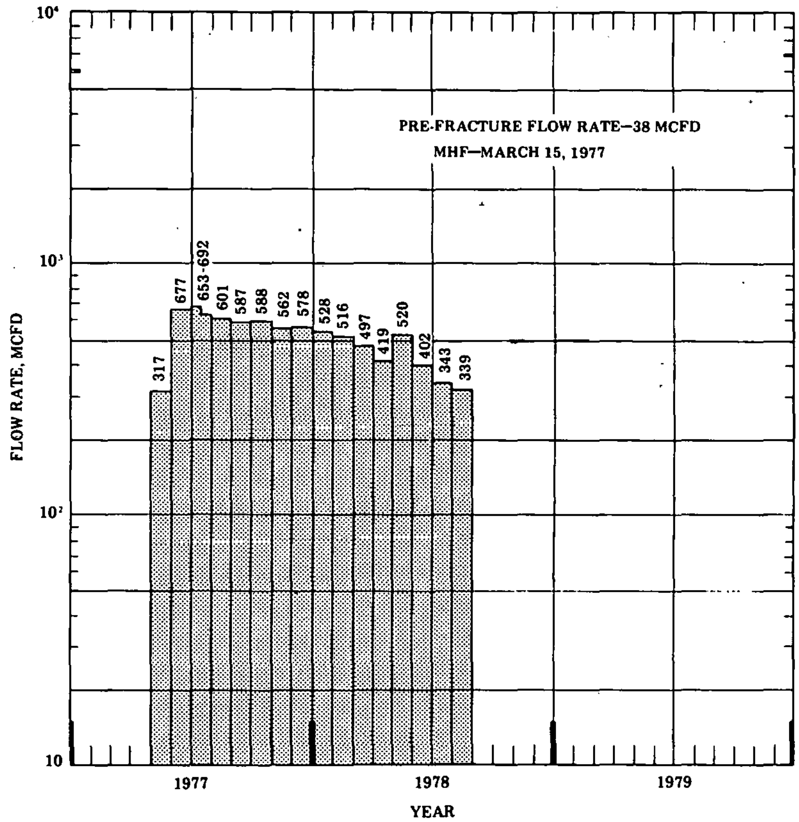
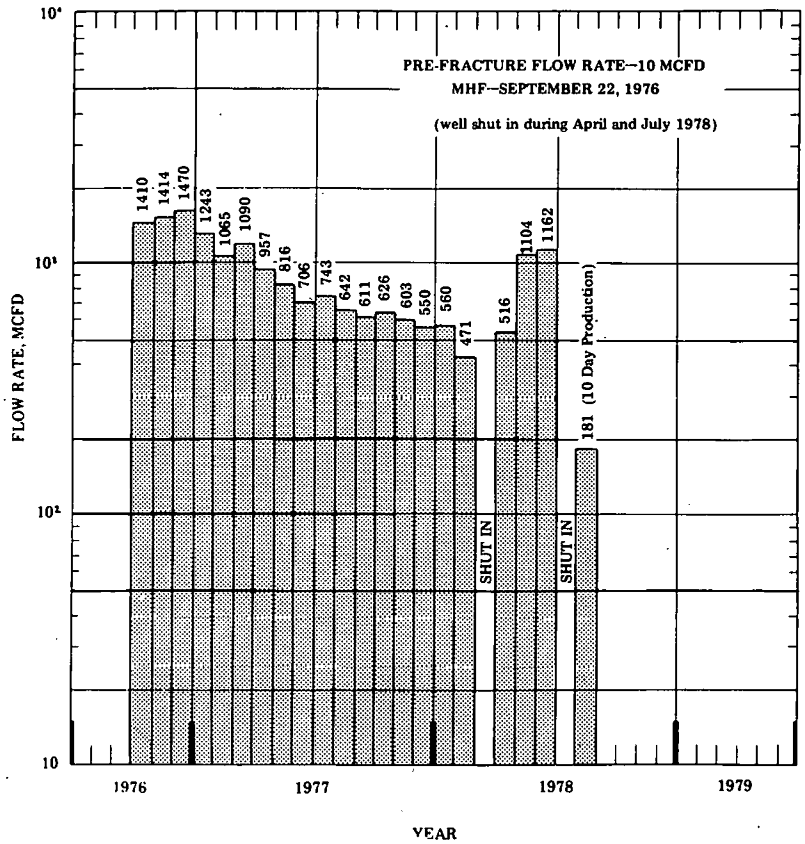


Figure 5-3
Flow Rate Performance of Natural Buttes No. 14 Well

Figure 5-4
Flow Rate Performance of Natural Buttes No. 18 Well



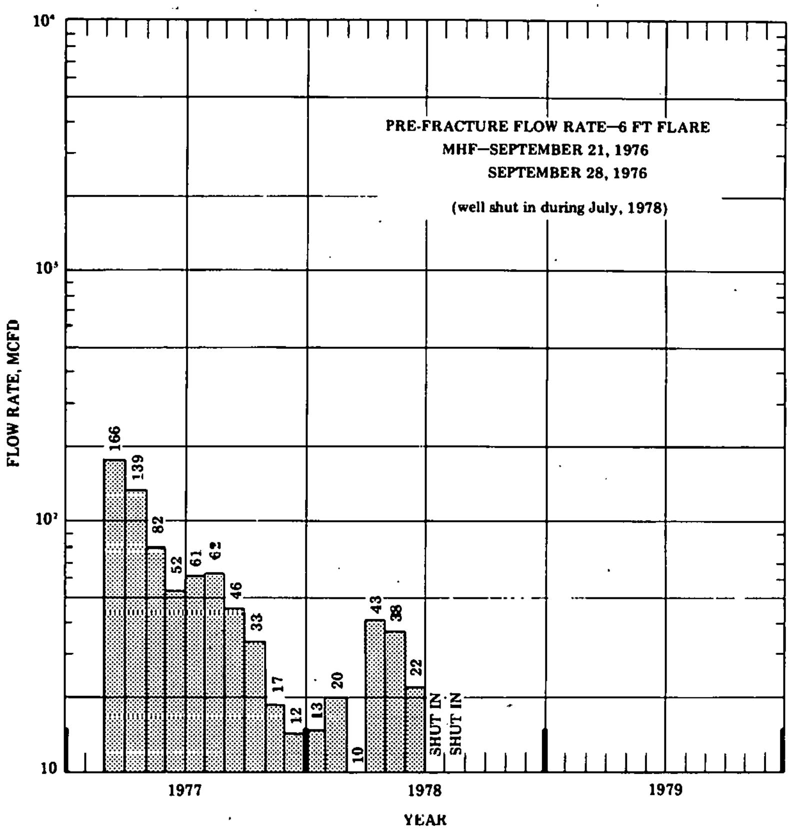


Figure 5-5
Flow Rate Performance of Natural Buttes No. 19 Well

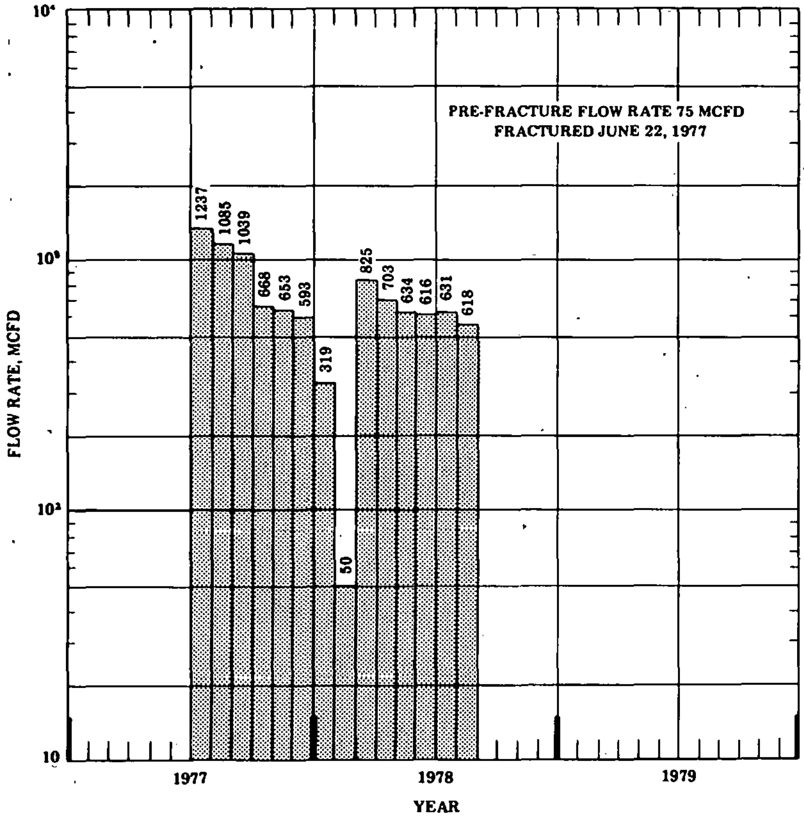


Figure 5-6

Flow Rate Performance of Natural Buttes No. 20 Well

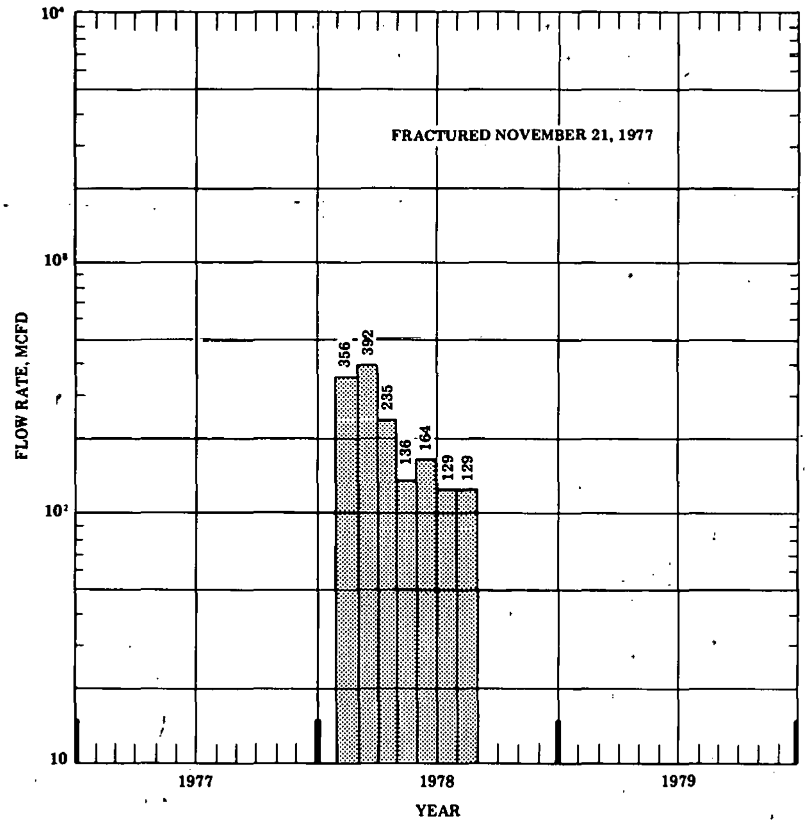


Figure 5-7

Flow Rate Performance of Natural Buttes No. 22 Well

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

EF-78-C-08-1547

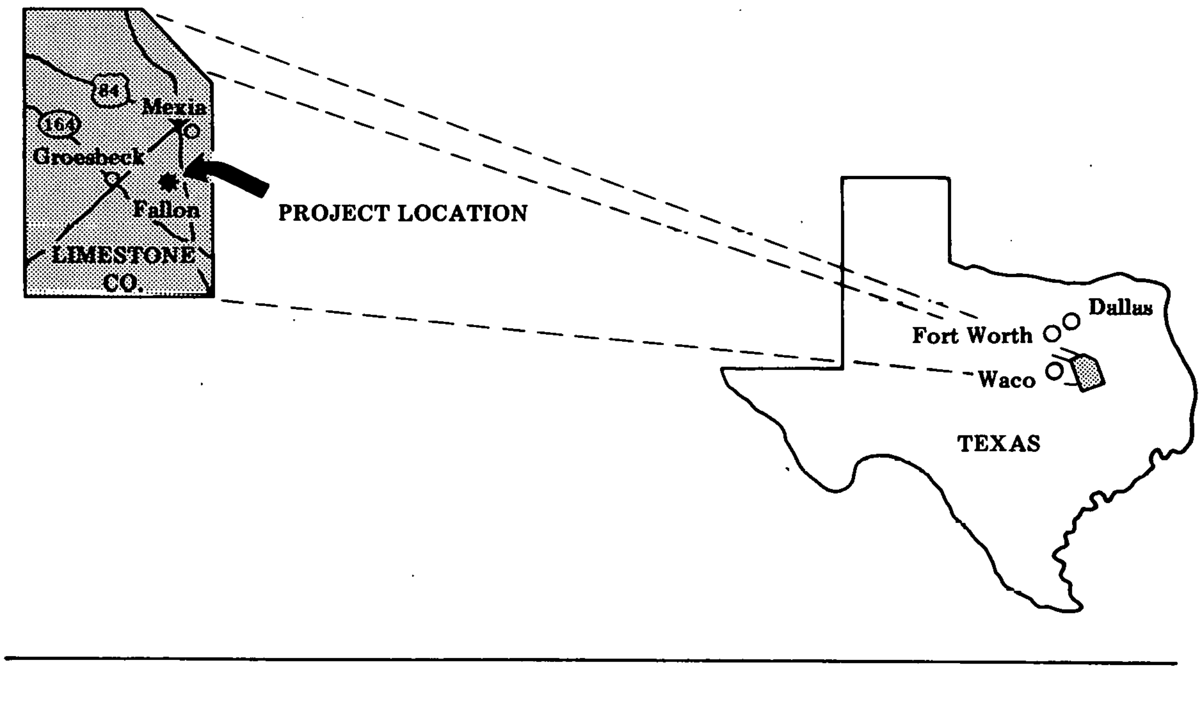
Mitchell Energy Corporation
Houston, Texas

Status: Active

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

OBJECTIVE

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



5.6 MITCHELL ENERGY CORPORATION

5.6.1 Scope of Work

DOE Contract EF-78-C-08-1547 was signed with Mitchell Energy Corporation in March 1978. The scope of work includes drilling, coring, logging and testing a new well, Muse-Duke No. 1, treating with MHF and evaluating results.

5.6.2 Current Status

The Mitchell Energy Corporation Muse-Duke No. 1 reached total depth of 11,633 ft and the well was logged on August 31, 1978. Also, a total of 447 ft of core was cut which included 95 ft of the overlying Bossier shale, 210 ft of the objective Cotton Valley lime and 142 ft of the underlying Buckner.

The Cotton Valley Lime was topped at 11,220 ft. Most of the core was recovered and good orientation was obtained for approximately 70 percent of the core. Core Lab now has the core for routine analysis.

One *in situ* formation breakdown test was attempted at 11,556 ft by Terra Tek with straddle packers. Unfortunately the bottom packer failed at 3,000 psi, 1,000 psi under its rating, and before the breakdown of the formation was achieved. The remaining tests were abandoned and 5½ in. production casing was cemented to 11,633 ft. Preliminary production tests will begin as soon as the drilling rig is replaced with a workover unit.

PICEANCE CREEK FIELD, COLORADO, MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

EY-76-C-08-0678

Mobil Research and Development Corporation
Dallas, Texas

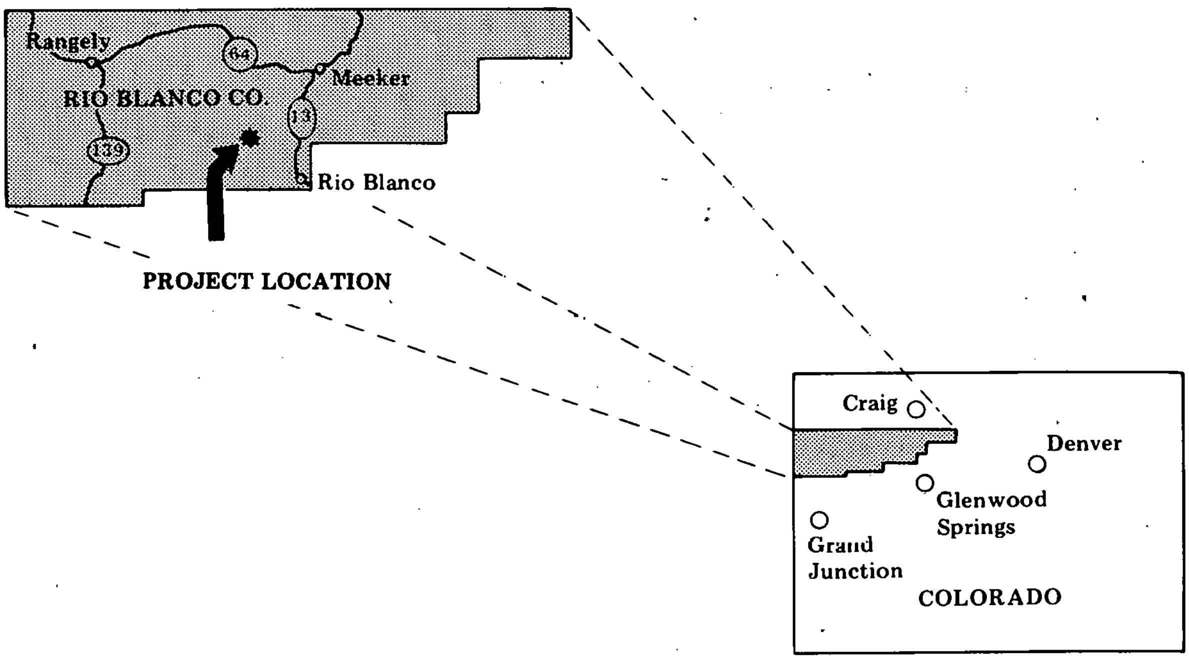
Status: Active

Contract Date:	July 1, 1976	
Anticipated Completion:	December 31, 1978	
Total Project Cost (estimated):	DOE	$2,510,000
	Contractor (prior costs)	2,376,485
	Contractor (new costs)	1,590,515
	Total	$6,477,000

Principal Investigator: John L. Fitch
Technical Project Officer for DOE: C. H. Atkinson

OBJECTIVE

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



5.7 MOBIL RESEARCH AND DEVELOPMENT CORPORATION

5.7.1 Summary of Past Activities

Mobil was awarded DOE Contract EY-76-C-08-0678 in July 1976, to perform up to six MHF treatments in a new well in Rio Blanco County, Colorado. The well was drilled by Signal Drilling Company under a separate DOE Contract EY-77-C-08-1504. Two treatments were performed in 1977, one in June on zone 1 and the second in August on zone 3. Zones 2 and 4 did not meet frac requirements and were abandoned. Zones 1 and 3 were commingled and produced to sales during the winter. The third MHF treatment was performed in May, 1978 on Zone 5. Increases in fracture propagating pressure continue to hamper efforts to obtain long, narrow fractures. Analysis of treating records from the well, and from other Piceance Basin wells shows that the basic pressure increase is not due to ineffective proppant transport. The treating pressure record indicates that the basic upward slope of the treating pressure/time is established prior to sand arrival at the perforations. Although some breaks occur in the treating pressure, the basic upward trend persists until the combination of increasing crack width and fluid leak-off (with increasing pressure) culminates in a screen-out. No quantitative explanation is at hand at this time.

5.6.2 Current Status

Remedial cementing of Zone 8 was accomplished during the period August 4-17. The casing was perforated at 7,818 - 7,820 ft with 8 shots. Circulation to the surface was attempted but failed. After perforating at 7,650 - 7,652 ft with 8 shots, circulation across the zone was established. The zone was cemented with 150 sacks. Circulation was lost during cementing. The bond log shows good bonding to at least 7,670 ft.

Zone 8 was perforated on August 19 in the intervals 7,704 - 7,736 and 7,776 - 7,796 ft with 27 hyperjet charges (nominal 0.4 in.; one hole /2 ft) carried in a 4 in. centralized gun. After perforating, the zone was broken down with 138 BBL of 2 percent KCl water at 10-12 BPM; ISIP 750 psi. Ball-off was achieved. After breakdown, the well flowed a little water for 2 hours and died. After a few hours, the well began flowing gas and water. Observed flow data are:

Date	Gas, MCF/day	Water, BBL/day
8/20	Est. 500+	—
8/21	575	—
8/22	575	552
8/23	443	480

Noise/temperature logs show most of the fluid is coming from the lower zone.

Two distinct slopes are present on the Horner plot, as in some previous zones. The final slope gives kh approximately 0.5 md-ft; kh from the intermediate slope is greater than 1 md-ft. Extrapolation of the buildup data to "infinite time" gives reservoir pressure about 2,800 psi. Although this value is uncertain due to short buildup time, it is consistent with the well's flow behavior and with estimated reservoir pressure in zone 7, i.e, some 500 psi below hydrostatic pressure.

5.7.3 Future Activities

The frac plan calls for 600,000 lb of 20/40 sand carried at 15 bpm in 230,000 gal of gel containing 5% condensate.

Note: The well was fractured on September 7. A severe testing pressure increase was experienced. Static surface pressure increased from 1,200 to 3,400 psi while pumping 120,000 gal and 218,000 lb of sand. The treatment was terminated by a screen-out. As of September 12, continuous flow had not been achieved.

RIO BLANCO COUNTY, COLORADO MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

EY-76-C-08-0677

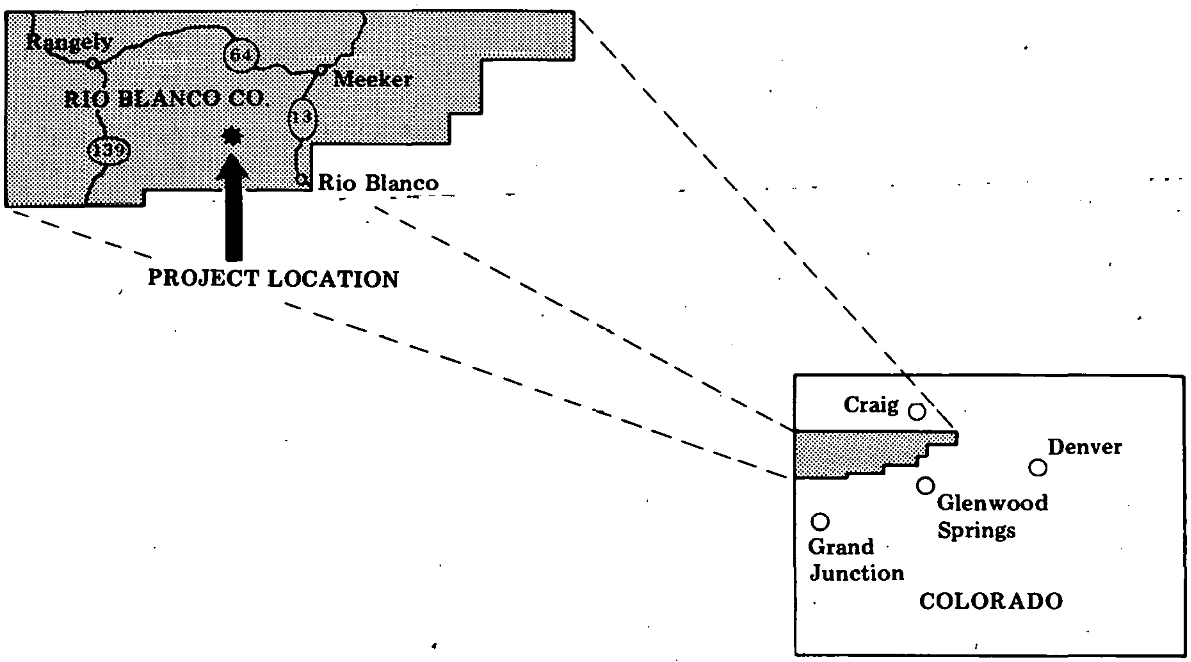
Rio Blanco Natural Gas Company
Denver, Colorado

Status: Active

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

OBJECTIVE

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



5.8 RIO BLANCO NATURAL GAS COMPANY

5.8.1 Summary of Past Activities

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

5.8.2 Current Status

Gas flow continued to be restricted due to persistant cyclical water production. The present production rate is 200 MCFD plus water with the well being flowed for further clean up.

NEVADA TEST SITE
NYE COUNTY, NEVADA
MINEBACK TESTING

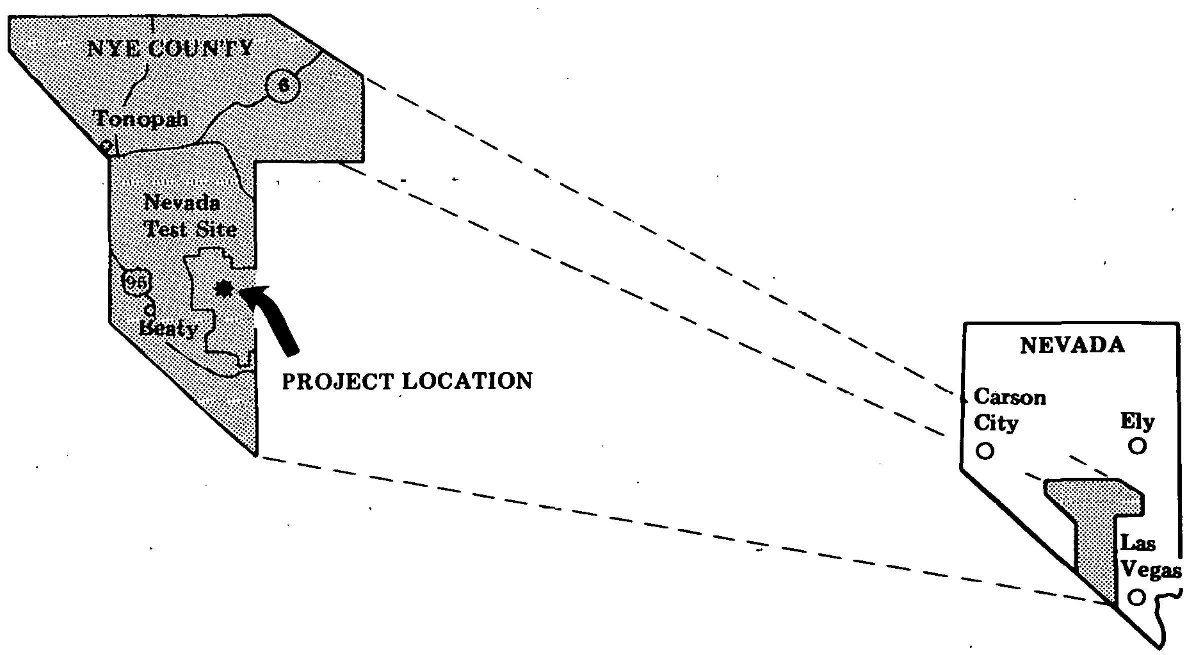
Sandia Laboratories
Albuquerque, New Mexico

Status: Active

Principal Investigator: D. A. Northrop

OBJECTIVE

To develop an understanding of the fracturing process for stimulation and thereby improve the production of natural gas from low-permeability reservoirs. This will be accomplished by conducting controlled fracture experiments which are accessible by mine-back for direct observation and evaluation.



5.9 SANDIA LABORATORIES—MINEBACK

5.9.1 Summary of Past Activities

The mineback of the Hole No. 6 interface experiment fractures was completed and the entire length of these fractures along the interface was mined back.

An alcove was excavated at the far end of the mineback to allow drilling of exploratory coreholes to locate the extent of the fractures, and for *in situ* stress measurements via small volume hydraulic fracturing.

It is noteworthy that the lower fracture propagated into the higher modulus welded tuff wherever there was contact, demonstrating that the formation interface was an ineffective boundary. Also the total length of the fracture at the interface was only 25 percent of the expected length. Further delineation of the fracture geometry will be determined by coring. Sites for material property samples were selected and will be obtained during August, 1978.

5.9.2 Current Status

The examination and analysis of the Hole No. 6 Formation Interface Fracture Experiment continued. This experiment is a mineback of two grout filled fractures propagated above and below a geologic interface consisting of a hard, welded, volcanic tuff overlying a softer ashfall tuff. The lower zone (ashfall tuff) was treated with 5,000 gal of green grout, followed by 4,000 gal of black grout and the upper fracture (welded tuff zone) was propagated with 5,000 gal of blue grout; both fractures were designed to 50 x 600 ft.

The entire length of the fracture at the interface was previously mined back. It was found that the lower fracture broke through the interface even though the modulus of the welded tuff is an order of magnitude greater than the modulus of the ashfall tuff. Although the lower fracture is observed to be a well defined, single fracture in the ashfall tuff, it exhibits abundant branching, stranding and filling of natural fractures in the welded tuff. Therefore the fracture is actually very complex. The upper fracture, initiated in the plane of the lower fracture, is often found side by side with the lower fracture, but only a small fraction of the blue grout is found.

After the mineback was terminated, an exploratory coring program was initiated to define the extent of the fractures. Shown in the plan view (Figure 5-8) and in the longitudinal view (Figure 5-9), two holes were cored into the welded tuff (EV6 No. 4 was cored at +45° and EV6 No. 5 at + 53°) and numerous fractures were intersected by both holes at the indicated locations. These fractures were mostly filled with green grout, indicating that the lower fracture had propagated well up into the welded tuff. Also in the welded tuff, the fracture exhibited a severe amount of branching.

Both the mineback and the coring suggest that this multiple fracture pattern is characteristic of fracture propagation in the hard, welded tuff. Subsequent exploratory holes will be cored (1) downward and away from Hole No. 6 to delineate the horizontal extent of the fracture below the interface and (2) higher up toward the interface at the top of the welded tuff.

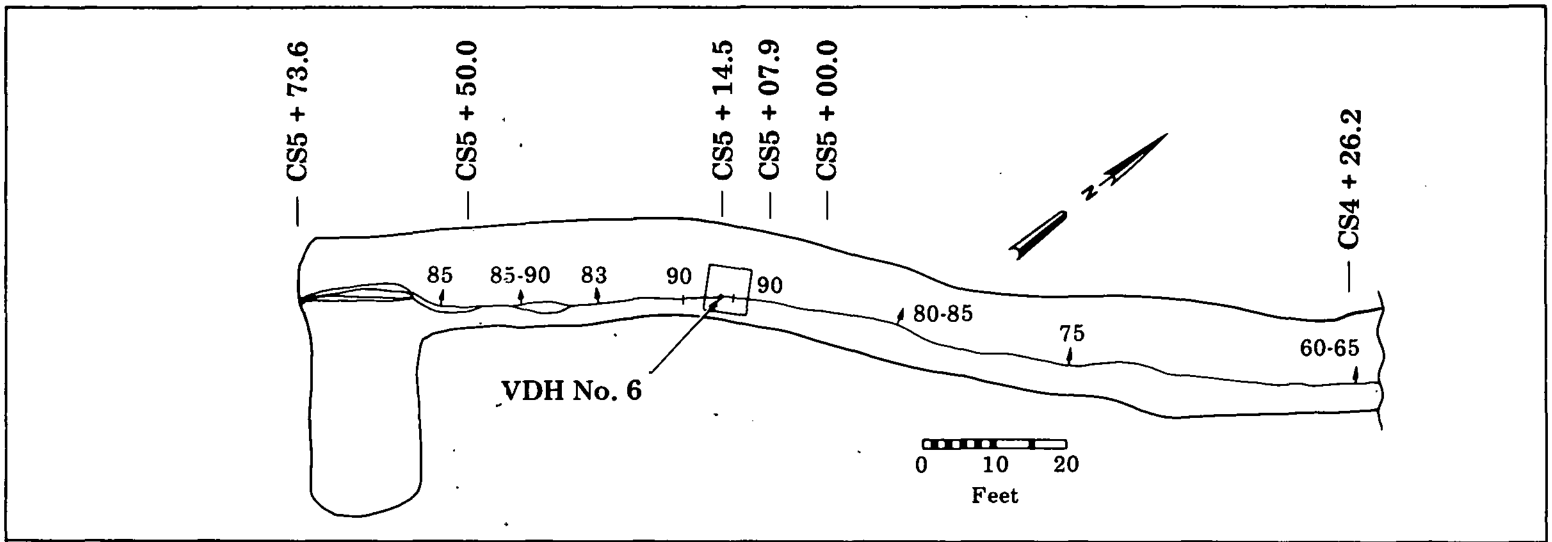


Figure 5-8 Plan View

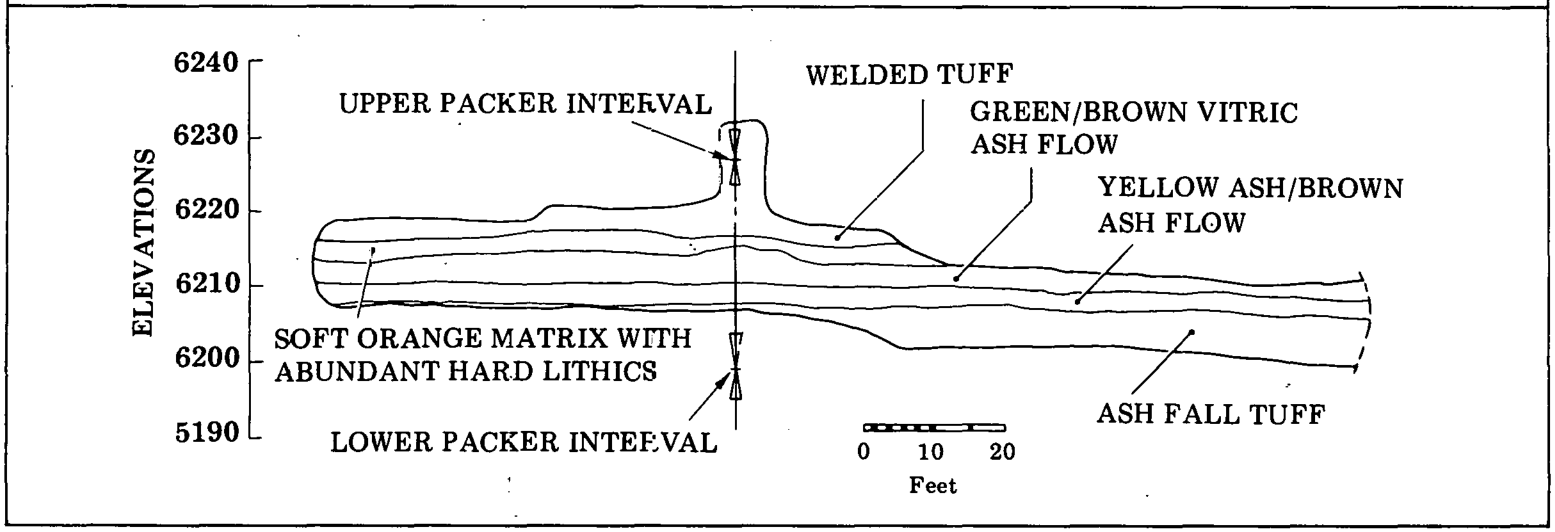


Figure 5-9 Longitudinal View

Since the main thrust of the Hole No. 6 experiment is hydraulic fracture containment by a material interface, a direct quantitative characterization of that problem is necessary. A thorough examination of existing analyses and experiments has revealed a deficiency that rests in the treatment of the interface as a discontinuous change of material properties, while in fact, the property changes are typically gradual on the scale of interest. Work on the more realistic "smeared interface" problem, where properties change in a smooth manner, has proceeded from three directions and a fourth is being considered.

- Analytical (closed form) calculations for stresses and stress intensities of a crack approaching a smeared interface were initiated by letting a contract to Southwest Research Institute with Tom Cook as principal investigator. Dr. Cook was the first to solve the problem of a crack approaching a discrete interface and will employ similar transform techniques for the smeared interface problem.

- Numerical (computer code) calculations are being performed on essentially the same problem with specific calculations for the Hole No. 6 experiment. Some difficulties were encountered in applying the CHILES code because the crack surface could not be pressure loaded properly. Instead, work has progressed using the APES code, which has recently been modified to run on the Sandia computers and seems well suited to the hydraulic fracture containment problem.

- Material characterization of the Hole No. 6 experiment region is needed as input to the two items mentioned above. Four-inch and six-inch cores are being taken from the formations and transition zones near the borehole by Holmes and Narver, Inc. After all necessary cores have been obtained, a contract will be let for direct pull tensile and fracture toughness tests.

- An experimental investigation on samples with a smeared interface is necessary to test the fracture criterion developed in the first two items above. Initial discussion with Professor A. Ingraffea of Cornell University indicates that well-controlled experiments using various mixes of high strength concrete are possible and details of a possible investigation are being worked out.

5.9.3 Schedule Status

Figure 5-10 is a milestone chart of the status of Sandia's Mineback Program as of August 31, 1978.

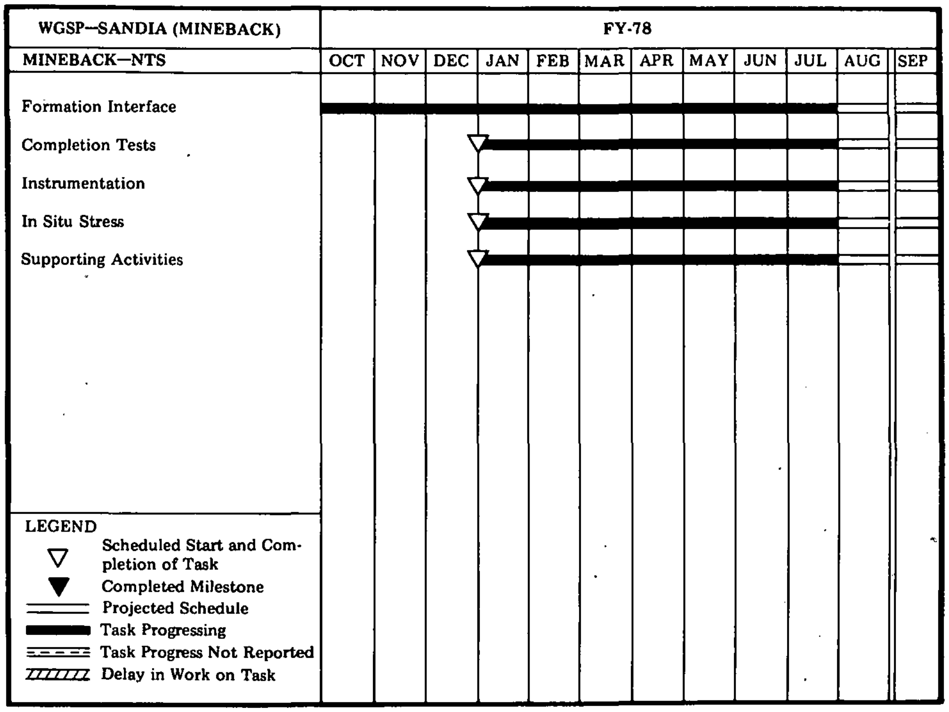


Figure 5-10 Milestone Chart—Sandia (Mineback)