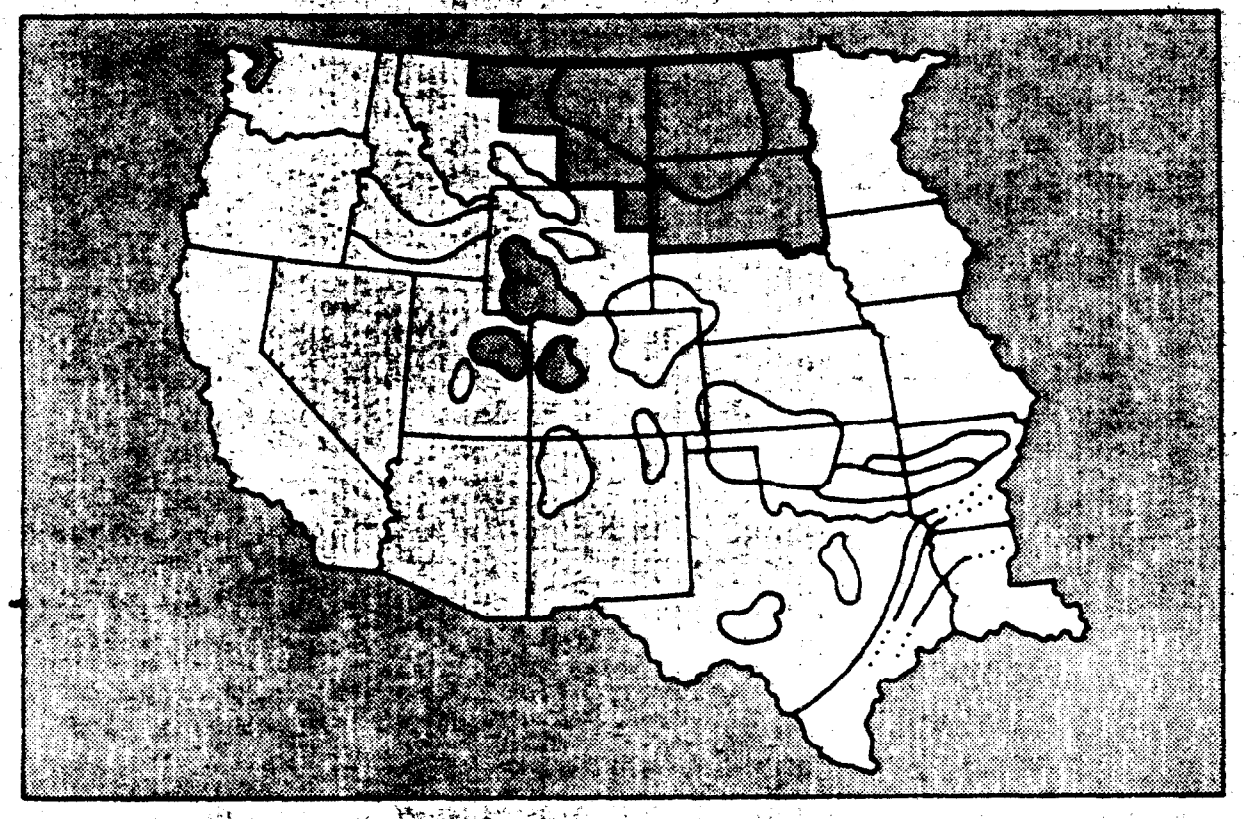
UGR File #216
October 1979
DOE/BC/10003-1
CER Corporation

DOE/BC/10003-1

Western Gas Sands Project Status Report



1 October 1979 - 31 October 1979

Prepared for
U.S. Department of Energy

Bartlesville Energy Technology Center
Charles H. Atkinson
Project Manager

Compiled by CER Corporation
Las Vegas, Nevada

Contract DE-AC08-79BC-10003

UGR File #216
October 1979
DOE/BC/10003-1
CER Corporation

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

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

NATIONAL TECHNICAL INFORMATION SERVICE
PAPER COPY PRICES EFFECTIVE JANUARY 1, 1979

Page Range	Domestic Price
001-025	$4.00
026-050	$4.50
051-075	$5.25
076-100	$6.00

UGR File #216
October 1979
DOE/BC/10003-1
CER Corporation

CONTENTS

Page

1. SUMMARY 1

2. PROJECT MANAGEMENT 3

   2.1 Technical Monitoring and Evaluation 3
   2.2 Technology Transfer 3

3. RESOURCE ASSESSMENT 7

   3.1 U.S. Geological Survey Activities 7
   3.2 Core Program 8
   3.3 Logging Program 14
   3.4 Survey of Basin Activities 14
   3.5 C K GeoEnergy Corporation 21
   3.6 Multi-Well Experiment 21

4. RESEARCH AND DEVELOPMENT BY ENERGY TECHNOLOGY CENTERS AND NATIONAL LABORATORIES 25

   4.1 Bartlesville Energy Technology Center 25
   4.2 Gas Research Institute 38
   4.3 Lawrence Livermore Laboratory 41
   4.4 Los Alamos Scientific Laboratory 48
   4.5 Sandia Laboratories 53

5. FIELD TESTS AND DEMONSTRATIONS 63

   5.1 Background 63
   5.2 CER Corporation 66
   5.3 Colorado Interstate Gas Company 68
   5.4 DOE Well Test Facility 71
   5.5 Gas Producing Enterprises, Inc. 75
   5.6 Mitchell Energy Corporation 80
   5.7 Mobil Research and Development Corporation 82
   5.8 Rio Blanco Natural Gas Company 84
   5.9 Sandia Laboratories—Mineback 86

FIGURES

		Page
Figure 3-1	Milestone Chart — USGS	9
Figure 3-2	Composite Plot of Formation Resistivity Index — Saturation Relationships	15
Figure 3-3	Greater Green River Basin Showing Wells of Interest and USGS Designated Core Areas	18
Figure 3-4	Northern Great Plains Province Showing Wells of Interest and USGS Designated Core Areas	19
Figure 3-5	Piceance Basin Showing Wells of Interest and USGS Designated Core Areas	20
Figure 3-6	Uinta Basin Showing Wells of Interest and USGS Designated Core Areas	22
Figure 3-7	Milestone Chart — Multi-Well Experiment	23
Figure 4-1	Pressure Build-up Curves for three Hypothetical Reservoirs Showing Effects of Slight Variances in Critical Parameters	34
Figure 4-2	Pressure Draw-down Curves for two Hypothetical Reservoirs	35
Figure 4-3	Pressure Build-up Curves	36
Figure 4-4	Milestone Chart — BETC	39
Figure 4-5	Normalized Mode I Stress intensity factor vs. normalized distance of the crack tip from the interface for five values of initial frictional stress along the interface	42
Figure 4-6	Normal strain and parallel strain to the left of the interface for crack tip position = 0.188	43
Figure 4-7	Normal strain, EPSX, and parallel strain to the right of the interface for crack tip position = 0.188	44
Figure 4-8	Geometry of Time Dependent Crack Problem	45

Page

Figure 4-9 Displacement of the point x=0.8c, y-0.1c in the y direction when the crack speed is three tenths of the dilatational wave speed. The elastic constants for material 1 are 30 GPa 45

Figure 4-10 Experimental Setup to Study Crack Growth 49

Figure 4-11 Milestone Chart — LLL 50

Figure 4-12 Cross Section of Design of Improved Downhole Nuclear Magnetic Resonance Tool 51

Figure 4-13 Signal Integration Time for Given S/N Ratios at Particular Depths 55

Figure 4-14 Milestone Chart — LASL 56

Figure 4-15 Milestone Chart — Sandia 60

Figure 5-1 Production and Injection Volumes and Associated Pressure of CIG Miller No. 1 and Sprague No. 1 Wells 69

Figure 5-2 Horner Plot for October 5 BHP Test, RBNG No. 397-19-1 Government Well 73

Figure 5-3 Flow Rate Performance of Natural Buttes No. 9 Well 76

Figure 5-4 Flow Rate Performance of Natural Buttes No. 14 Well 76

Figure 5-5 Flow Rate Performance of Natural Buttes No. 18 Well 77

Figure 5-6 Flow Rate Performance of Natural Buttes No. 19 Well 77

Figure 5-7 Flow Rate Performance of Natural Buttes No. 20 Well 78

Figure 5-8 Flow Rate Performance of Natural Buttes No. 22 Well 78

Figure 5-9 Schematic of Fracture Behavior in the Interface Test Series 88

Figure 5-10 Milestone Chart — Sandia Mineback 90

TABLES

		Page
Table 3-1	Identification and Description of Core Samples	13
Table 3-2	Acoustic Velocity Data	13
Table 3-3	Air-Brine Capillary Pressure Data	13
Table 3-4	Formation Factor and Resistivity Index Data	16
Table 3-5	Overburden Formation Factor Data	16
Table 3-6	Summary of Wells — Greater Green River Basin	18
Table 3-7	Summary of Wells — Northern Great Plains Province	19
Table 3-8	Summary of Wells — Piceance Basin	20
Table 3-9	Summary of Wells — Uinta Basin	22
Table 4-1	Coring Parameters, Equipment and Recovery, With and Without Low Invasion Fluid	26
Table 4-2	Gas Permeabilities Evaluated During Successive Stress Cycles	29
Table 4-3	Comparison of Permeabilities Evaluated With and Without Masking Tape Wrapped Around Core	30
Table 4-4	Summary of Performance Estimates for NMR Logging Tool	54
Table 4-5	Aspect Ratios Calculated from A(k)	59
Table 5-1	MHF Contract Location and Frac Data	64
Table 5-2	BHP Buildup Test Commencing October 5, RBNG No. 397-19-1 Government Well	72

1. SUMMARY

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

The USGS in Denver continued work toward resource assessment in the four primary study areas of the WGSP. Preparations continue for the coring of the Pacific Transmission Supply Company No. 3-10A Federal well in Sweetwater County, Wyoming, and coring and logging operations were completed at PTS No. 22-12 Federal well, Rio Blanco County, Colorado.

Projects of the National Laboratories and Energy Technology Centers progressed on schedule in October. Work on fracture conductivity, rock-fluid interaction and log evaluation and interpretation techniques continued at Bartlesville Energy Technology Center. The Gas Research Institute suspended work on the Rio Blanco Natural Gas Company No. 397-19-1 Government well but continued progress on their two other projects. Lawrence Livermore Laboratory continued experimental and theoretical work on hydraulic fracturing mechanics and analyses of well test data. Los Alamos Scientific Laboratory continued nuclear magnetic resonance studies. Analyses of the borehole seismic system and the borehole hydrophone system continued at Sandia Laboratories, as well as electromagnetic logging experimentation.

Alterations will be implemented at Colorado Interstate Gas Company Miller No. 1 and Sprague No. 1 wells to reduce interruptions and shutdowns. After completing the tests for the GRI/DOE funded Rio Blanco Natural Gas Company No. 397-19-1 Government well, the DOE Well Test Facility went into temporary storage. Gas Producing Enterprises, Inc., Natural Buttes Unit wells continued to flow to sales. As of October 12, the Mitchell Energy Corporation Muse-Duke No. 1 well was shut in. The hydraulic fracturing containment experiment and geochemistry and petrographic work continued for the Sandia-mineback program.

UGR File #216
October 1979
DOE/BC/10003-1
CER Corporation

2. PROJECT MANAGEMENT

2.1 TECHNICAL MONITORING AND EVALUATION

C. H. Atkinson (DOE) and R. L. Mann (CER Corporation) participated in a Federal Energy Regulatory Commission (FERC) meeting in Denver on October 4 with personnel from BETC, USGS, Lewin & Associates and Rio Blanco Natural Gas Company. The purpose of the meeting was to draft DOE's recommendations to FERC for definition and price incentives for gas production from tight western gas reservoirs.

Dresser-Magcobar met with C. H. Atkinson (DOE), R. L. Mann and other CER staff on October 16 to discuss drilling fluids for the multi-well experiment.

C. H. Atkinson (DOE) and R. L. Mann (CER Corporation) met with D. Northrop and M. Becktell (Sandia Laboratories) in Las Vegas on October 17 regarding Sandia's planning function in the multi-well experiment.

R. L. Mann (CER Corporation) contacted a landman in Grand Junction, Colorado, on October 29 to assist in locating an appropriate site for the multi-well experiment.

A meeting of the Multi-well Advisory Committee was held on October 31 in Denver. Participating in the meeting were C. H. Atkinson (DOE/BETC-NV), H. Carroll, D. C. Ward (DOE/BETC), A. Hunt (DOE/METC), R. L. Mann, G. C. Kukal, J. C. Schillo (CER Corporation), D. A. Northrop, C. L. Schuster (Sandia Laboratories), R. W. Veatch, Jr. (Amoco Production Company), C. Young (Science Applications, Inc.), R. J. Saucier (Shell Development Company), J. L. Fitch (Mobil R&D Corporation), and C. E. Cooke (Exxon Production Research Company). The meeting included tentative drilling, coring and logging plans of the multi-well experiment, the tentative schedules for Phase I as well as discussions of Phase II. (Refer to Section 3.7 for more details about the planning of the multi-well experiment).

2.2 TECHNOLOGY TRANSFER

2.2.1 Documentation Reports

The WGSP Financial Supplement for October, 1979, has been distributed. The draft of the DOE Morgantown Semi-Annual Report of Unconventional Gas Recovery Program (period ending September 30, 1979) is in the final stages. The WGSP Third Quarterly Basin Activities Report, 1979, has been distributed. Comments on the draft of the WGSP Project Plan, FY 1980, have been incorporated and final printing is planned. The DOE Well Test Facility Operations Manual and a report on the WGSP Logging Program have been updated. Work has commenced on the WGSP Greater Green River Basin Review and data is being compiled for similar reports on the Piceance and Uinta Basins.

2.2.2 Project Data Bank

The following maps have been added to the WGSP project data bank.

"Wildcat well penetration map showing wells drilled into and through potentially gas-bearing, low-permeability Upper Cretaceous and Tertiary Reservoirs, Sand Wash Basin, Colorado," T. Tyler, USGS, 1979;

"Energy Resources Map of Colorado," by D. A. Myers, J. A. Sharps (USGS), D. K. Murray, D. C. Jones, and R. H. Pearl (Colorado Geological Survey, 1977);

"Energy Resources Map of Utah," USGS, Utah Geological Survey, 1977;

"Oil and Gas Discoveries Map of Rocky Mountain Region," Petroleum Information, March 1976;

"Northeastern Utah, Oil and Gas Well Location Map, Petroleum Information;

"Northwestern Colorado, Oil and Gas Well Location, Map," Petroleum Information, 1959; and

"Preliminary Chart Showing Electric Log Correlation Section F-F′ of Some Upper Cretaceous and Tertiary Rocks, East Flank Rock Springs Uplift, Wyoming," Open File Report, T. Tyler, USGS, 1979.

Updating continued on the WGSP Bibliography.

2.2.3 Articles and Publications

The following articles and publications relate to the WGSP and are included in the bibliography. Abstracts are included, when available.

Mapping Deep Hydraulic Fractures with Surface Tilt Instrumentation
by M. D. Wood and G. R. Holzhausen

The FRAC-MAP™ method of determining the spatial geometry of hydraulically induced fractures has been applied in a variety of sites in treatments ranging up to 8,000 feet in depth and with injected volumes up to 1 million gallons of fluid and 1 million pounds of proppant. The technique isolates the exceedingly small deformation fields (nano-radians at microhertz frequencies) generated at the surface by commercial hydraulic-fracture treatments from prevalent broadband high-amplitude noise. The residual signals are then analyzed to determine fracture azimuths for deep, massive hydraulic fractures.

The method is commercially feasible because it is mobile, deployable in inexpensive near-surface boreholes, and does not interfere with treatment procedures at the wellhead. It has been successfully used to map fractures in low-permeability oil and gas zones at depths of 8,000 feet. Accuracies of fracture azimuth within five degrees have been achieved for many wells with an independent means of determining azimuth.

Pressure Transient Analysis of Tight Western Gas Sands — Pre- and Post-Fracturing
by J. H. Kennedy and J. E. McElhiney
Intercomp

In the last several years the Department of Energy, together with various industrial participants, has funded a series of massive hydraulic fracturing (MHF) experiments in the Upper Cretaceous formations of the Rocky Mountain gas provinces. The purpose of these large stimulation treatments is to enhance the productivity of these low permeability reservoir systems so that commercial economics will become a reality. The initial stage of this study encompasses the pressure transient analysis of various tests run in several different MHF projects. Some of the preliminary results for the Mobil PCU F31-13G well located in the Piceance Creek Gas Field, located in Rio Blanco County, Colorado, are reported here. These results are fraught with a variety of difficulties; these problems are discussed and recommendations for improvements in future pressure testing programs associated with MHF programs are made.

Preliminary Results of Organic Maturation, Temperature, and Pressure Studies in the Pacific Creek Area, Sublette County, Wyoming
by B. E. Law, C. W. Spencer, and N. H. Bostick
U. S. Geological Survey

Preliminary investigations of a sequence of Upper Cretaceous and Lower Tertiary rocks in the Pacific Creek area of the northeastern Green River Basin show that studies of organic maturation, subsurface temperature, and formation pressure may help define prospective gas-saturated intervals and delineate areas of maximum gas resource potential.

At about 11,600 ft (3,500 m) near the base of the Upper Cretaceous Lance Formation, the top of significantly high overpressuring has been identified. Drillstem test data indicate that the pressure gradient is as high as 0.84 psi/ft (19.0 KPa/m). The development of overpressuring may involve several processes; however, interpretation of the available information indicates that the active generation of large amounts of wet gas is one of the more important processes.

A vertical profile of organic maturation, determined by vitrinite reflectance and color alteration of organic material, shows that the top of overpressuring and beginning phase of wet-gas generation occurs within, but well below the top of, the "oil window." The present minimum temperature at the top of overpressuring is at least 190°F (88°C). This temperature was determined from uncorrected bottom-hole temperatures recorded during logging of wells drilled in the area. The preservation of abnormally high pressures is probably due to presently active generation of gas in a thick interval of discontinuous, very low-permeability shales, siltstones and sandstones.

3. RESOURCE ASSESSMENT

3.1 U.S. GEOLOGICAL SURVEY ACTIVITIES

3.1.1 Uinta-Piceance Basins

Field work continued in the Uinta and Piceance Basins.

Upper Cretaceous core from Exxon drill holes in the Uinta Basin was described and sampled.

Revision continued of a report prior to USGS Open-file release: "Preliminary results of mineralogic and diagenetic studies of low-permeability sandstones of Late Cretaceous age, Piceance Creek Basin, Colorado," prepared by P. Hansley and R. C. Johnson.

3.1.2 Greater Green River Basin

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

Three cross sections from the Sand Wash Basin by L. Kiteley and D. Carr are in review.

T. F. Tyler published a cross section entitled "Preliminary chart showing electric log correlation, section F-F′ of some Upper Cretaceous and Tertiary rocks, East Flank Rock Springs Uplift, Wyoming," as USGS Open-File Report 79-1573. He also published "Wildcat well penetration map showing wells drilled into and through potentially gas-bearing, low-permeability Upper Cretaceous and Tertiary reservoirs, Sand Wash Basin, Colorado," as USGS Open-File Report 79-1437.

Several project personnel attended Rocky Mountain Section/Society of Economic Mineralogists and Paleontologists Field Conference in Rock Springs Uplift. B. E. Law was field conference chairman.

C. W. Spencer presented a talk on Tight Gas Sands Research to the Rocky Mountain Association of Geologists.

3.1.3 Northern Great Plains Province

The following abstracts were submitted for the National AAPG-SEPM Meeting in Denver, June 1980:

> "Geometry of sandstone bodies in Shannon-equivalent sandstones in the northern Black Hills, Montana and South Dakota," by G. W. Shurr.

"Diagenesis in shallow conventional and low-permeability biogenic methane reservoirs of the Eagle Sandstone, Montana," by D. L. Gautier.

"Development of biogenic gas from shallow, low-permeability reservoirs — examples from southeastern Alberta and Bowdoin Dome area, north-central Montana," by D. D. Rice and D. L. Gautier.

"Upper Cretaceous Mosby Sandstone, Central Montana — an example of thin, widespread storm-generated sandstone cycles," by D. D. Rice.

Work continued on the resource appraisal of low-permeability, gas-bearing reservoirs of the Northern Great Plains for the National Petroleum Council.

A regional cross section is being prepared from Suffield Block in southeastern Alberta to Bowdoin Dome area, north-central Montana.

Petrographic examination has been performed on Milk River reservoirs in southeastern Alberta.

A draft was finished on conditions required for the generation and accumulation of biogenic gas.

3.1.4 Schedule Status

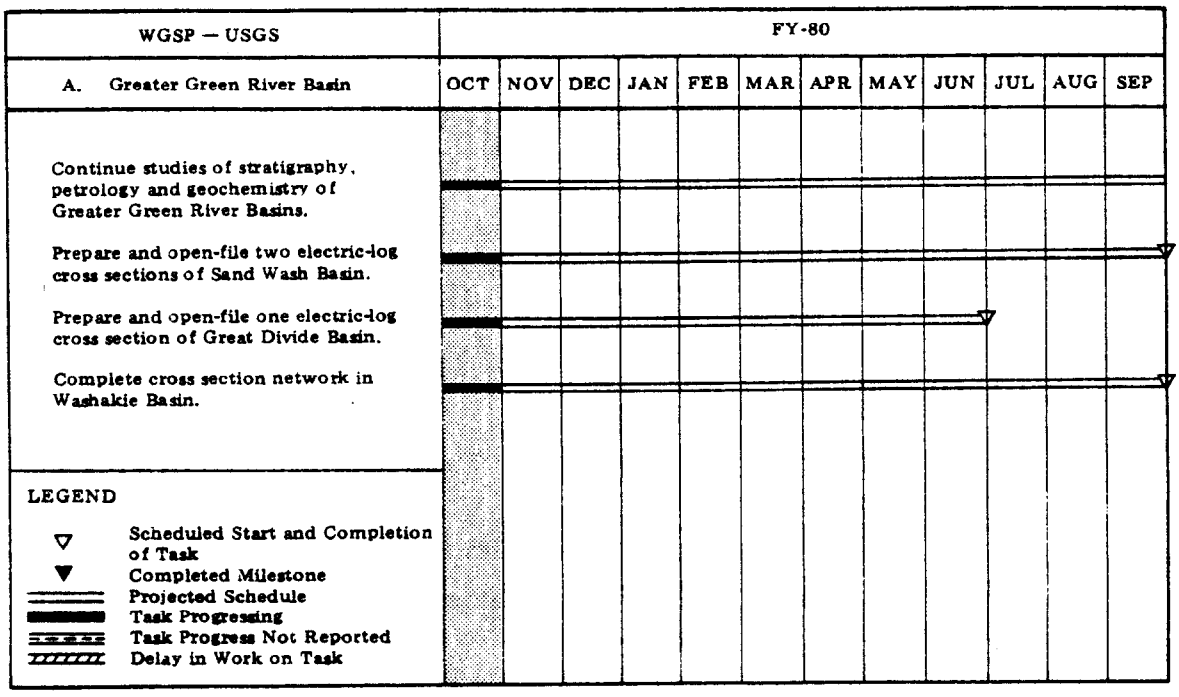
Figure 3-1 is a milestone chart depicting the status of all USGS projects within the WGSP.

3.2 CORE PROGRAM

In the Greater Green River Basin, Tenneco Oil contacted CER about the possibility of jointly coring their well in the Sand Wash Sub-basin, Moffat County, Colorado. This possibility depends on the outcome of a current Tenneco well being tested in the same area (T10N, R93W), which should spud in early 1980. The rocks of interest (from the Lewis, Almond and Ericson Formations) are of similar age to those in Wyoming. Preparations continued for the coring of Pacific Transmission Supply Company No. 3-10A wildcat well, Sweetwater County, Wyoming. The objectives include coring about 240 ft of the Almond Formation. Rainbow Resources contacted CER about coring their proposed 13,500 ft Mesaverde test in Sweetwater County. Forest Oil declined proposed coring of No. 1 Jonah Gulch, Sublette County, Wyoming.

There was little activity in the Northern Great Plains Province in October. The coring of a Midlands (Kansas-Nebraska) well in Phillips County, Montana, originally set for this fall, was delayed until spring, 1980.

Preparations continued for the coring of Mapco RBU No. 11-17F, Sec. 17, T10S, R20E, Uintah County, Utah. The well was spudded on October 18 and coring is expected in early November.



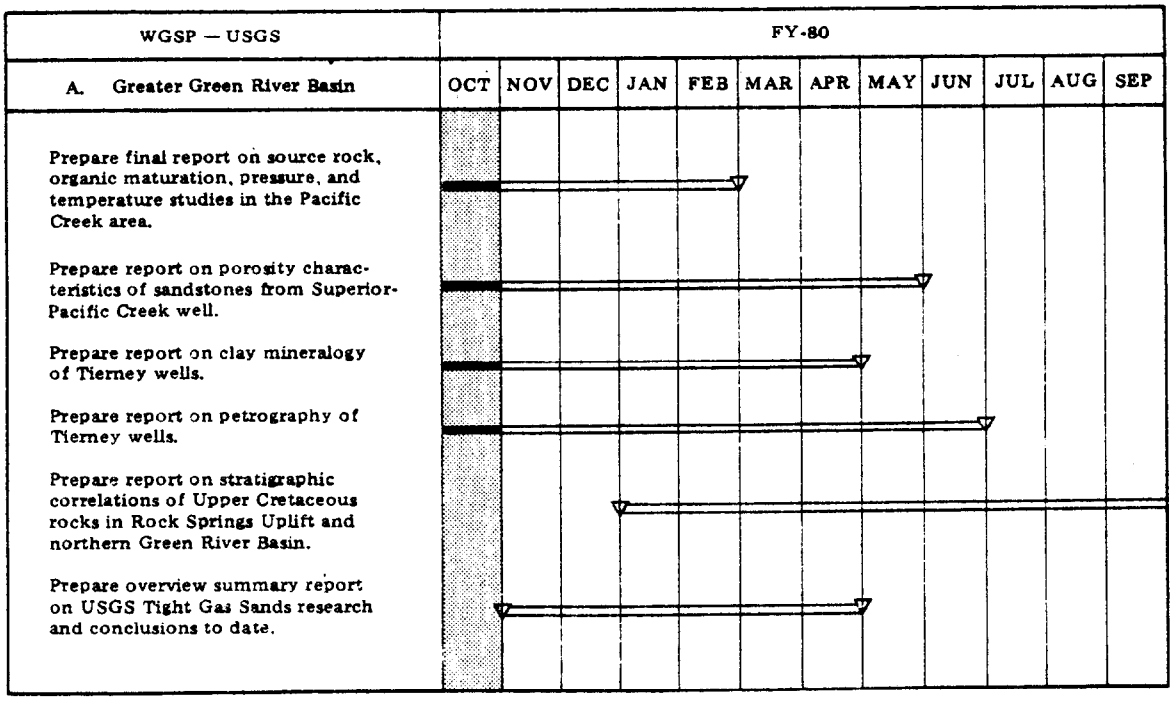
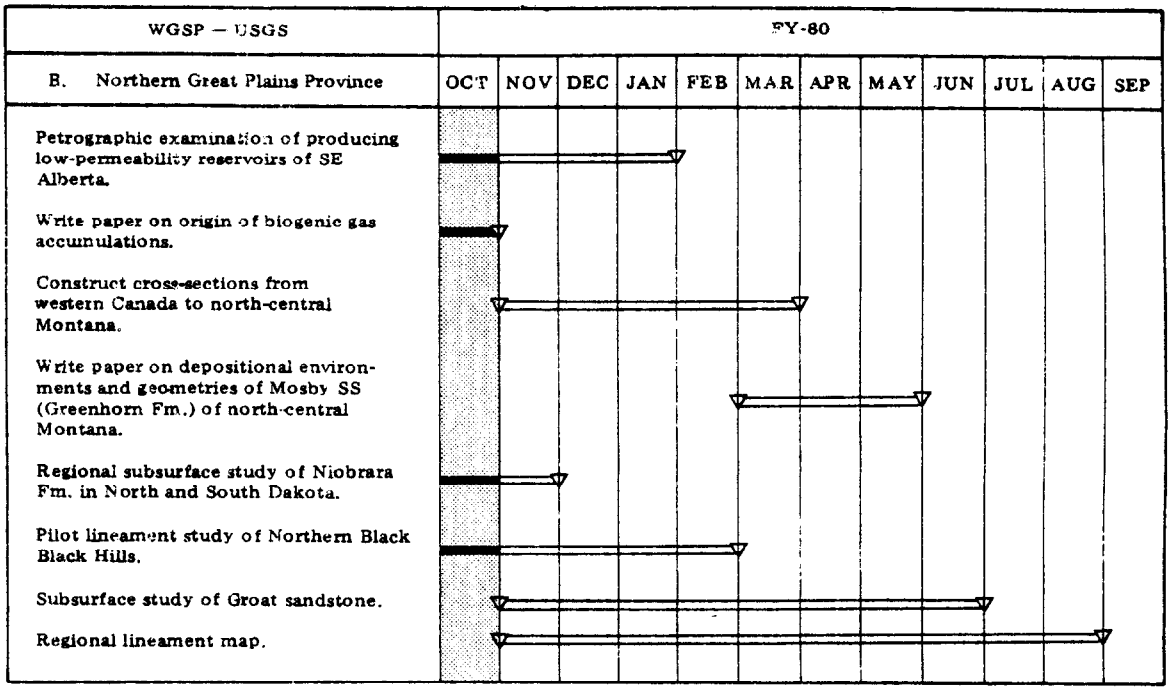


Figure 3-1 Milestone Chart — USGS



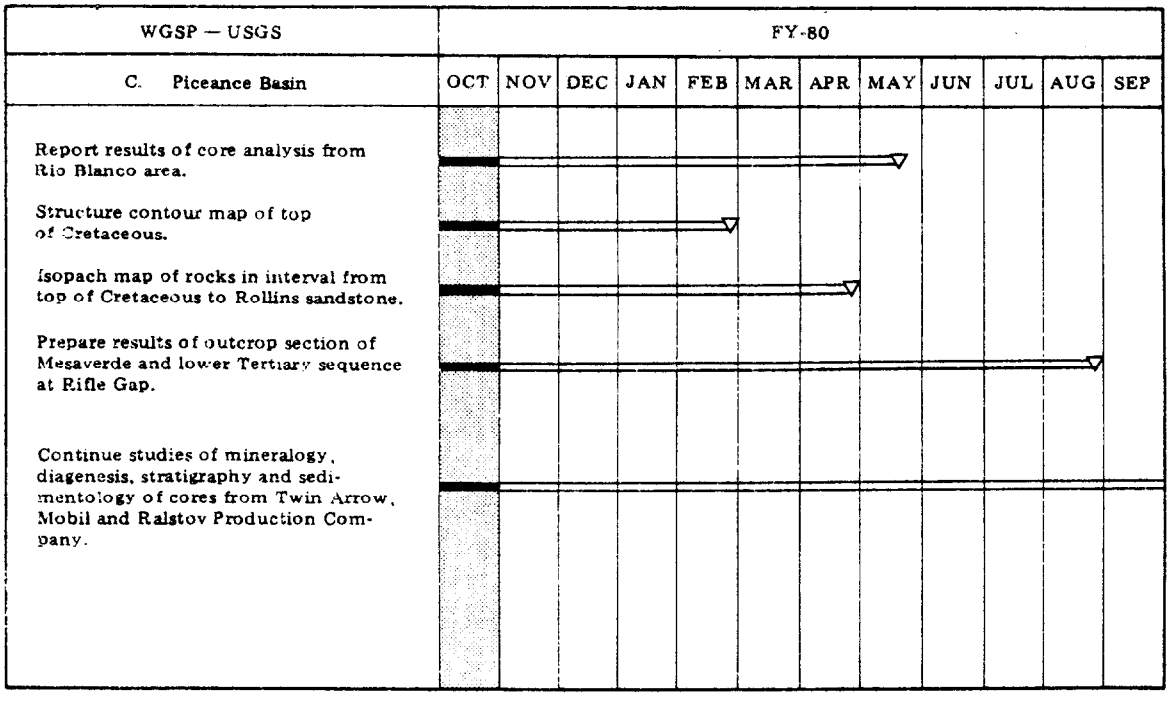


Figure 3-1 Continued

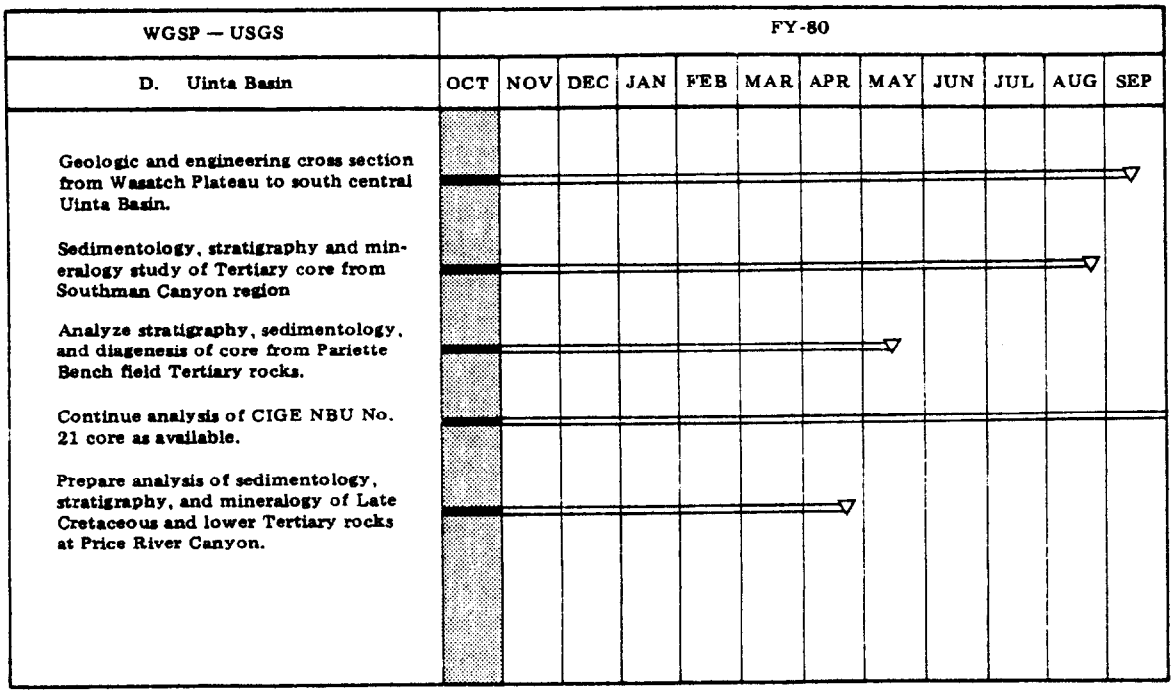


Figure 3-1 Continued

In the Piceance Basin, coring operations were completed at the Pacific Transmission Supply Company No. 22-12 Federal well, Sec. 12, T1N, R99W, Rio Blanco County, Colorado. Coring of the Mancos B began on October 1 and ended October 3, with 118.3 ft of core recovered from 120 ft cut (depth 11,669 ft to 11,789 ft). The Mancos B is a fairly consistent deltaic sand-shale sequence. Individual sand and shale lenses are closely interspersed and one to two inches thick. The laminar bedding is somewhat contorted and both sands and shales are micaceous and slightly calcareous. The sandstone is generally fine-grained and tight. Background gas recorded by the mud logger during earlier coring operations at the Mesaverde level (6,500 ft) registered two units, yet at the Mancos B level 750 to 1,000 units were recorded.

A 16-ft field laboratory trailer for use in the Coring Program was obtained by CER Corporation for DOE and is tailored to suit field operations in core handling, description, preparation, packaging and storage. It is fully equipped, has an on-board electric generator and is weatherized for winter use in the northern Rocky Mountains.

Core Laboratories, Inc. performed special core analyses on selected samples of core from Pacific Transmission Supply Company No 24-19 Federal well, Sublette County, Wyoming. These tests included acoustic velocity measurements (compression and shear) on one sample, point capillary pressure tests on two plugs, formation resistivity factor measurements at various overburden pressures, and formation resistivity index measurements. The plugs used are described and identified in Table 3-1.

Three full-diameter cores from 5,199 ft, 5,305 ft and 5,307 ft were submitted for the analyses. The full-diameter segment specified for compression and shear acoustic velocity measurements was reduced from 4-in. to 3-in. in order to fit the available equipment. One core plug, 1-1/2 in. in diameter, was obtained from each of the remaining two segments. The two plugs, identified as nos. 1 and 2, were voided of hydrocarbons with alternate injections of toluene and acetone, leached of salt with methyl alcohol, and then dried. Air permeabilities and Boyle's law porosities were determined on the cleaned and dried plugs. The full-diameter segment was submerged under a brine containing 15,000 ppm total dissolved solids and evacuated a short time to remove any gas saturation which may have been present. The two plugs were also evacuated and pressure saturated with a brine containing 15,000 ppm total dissolved solids.

The full-diameter segment was mounted in a triaxial type core holder and a brine containing 15,000 ppm total dissolved solids was dynamically displaced through the core using back-pressure in order to ensure that the sample was fully saturated. Direct measurements of transit times were performed at increasing overburden pressures which ranged from 1,600 psi to 3,200 psi. Both compression and shear measurements were performed. These data are presented in Table 3-2. (The value for shear velocity is not consistent with that normally noted for sandstone.)

With the exception of a final high-speed centrifuge point, eight-point capillary pressure tests were performed on the two brine-saturated plugs utilizing a porous-plate cell and an air-brine system. The results of these tests are presented in Table 3-3.

Table 3-1 Identification and Description of Core Samples

Sample Number	Depth, ft	Lithological Description
1	5,199	Ss, gry, fn gr, calc, well indurated
2	5,305	Ss, gry, fn gr, calc, well indurated
3	5,307	Ss, gry, fn gr, calc, well indurated

Table 3-2 Acoustic Velocity Data

Sample Number: 3

Porosity, percent: 11.3

Effective Overburden Pressure, psi	Transit Time, micro-seconds/ft Compression	Shear
1,600	77.15	245.2
2,000	75.75	240.2
2,400	74.41	235.7
2,800	73.30	231.3
3,200	72.52	229.0

Table 3-3 Air-Brine Capillary Pressure Data

			Pressure, psi:	1	2	4	8	15	35	200	484*
Sample Number	Permeability, md	Porosity, percent	Brine Saturation, Percent Pore Space								
1	1.10	13.4		100	100	100	100	94.1	68.6	61.5	46.4
2	0.60	11.3		100	100	100	100	96.2	77.6	69.9	54.1

* Equivalent Pressure from centrifuge (Air-Brine System).

Prior to performing the capillary pressure tests, the electrical resistivities of the brine and the two brine-saturated plugs were measured. These measurements were repeated over a period of several days until the electrical resistivities stabilized, indicating that ionic equilibrium within the plugs had been attained. Each plug was desaturated during the capillary pressure tests, and the electrical resistivities were measured at each equilibrium saturation attained. These data are listed in Table 3-4. Using Archie's equation, a cementation exponent "m" of 1.70 was calculated. The formation resistivity index-saturation relationships yield calculated saturation exponents "n" of 1.71 and 1.57. A composite plot of the formation resistivity index-saturation relationships is presented in Figure 3-2 yielding a composite saturation exponent of 1.64.

The two plugs, used for the capillary pressure and electrical resistivity measurements, were leached of salt with methyl alcohol and then dried. Air permeabilities and Boyle's law porosities were again determined on each plug, which was then evacuated and saturated with a brine containing 15,000 ppm total dissolved solids. The formation resistivity factor for each plug was measured in the same manner as already discussed using no overburden pressure and under several overburden pressures ranging from 200 psi to 2,800 psi (See Table 3-5). The cementation exponent "m" at 0 psi effective overburden pressure is 1.70. The cementation exponent increased to 1.84 at an effective overburden pressure of 200 psi and to 1.90 at an effective overburden pressure of 2,800 psi. An examination of the formation resistivity factor measurements reveals that the cementation exponent "m" follows a normal trend of increasing formation resistivity factor with increasing effective overburden pressure.

3.3 LOGGING PROGRAM

G. C. Kukal (CER Corporation) assisted in logging operations at the Pacific Transmission Supply Company "Barcus Creek" No. 22-12 Federal well, Sec. 12, T1N, R99W, Rio Blanco County, Colorado. Before logging, a circulated mud sample was caught on October 17. The general mud type was low solids non-dispersed. Additives included sodium bichromate and ammonium nitrate. From October 17 to October 19, the well was logged as follows: Dual Induction Log - Laterolog 8/SP/GR, Formation Density Log/Compensated Neutron/Caliper/GR, Dual Laterolog/SFL/Caliper/SP, BHC Sonic/GR/Caliper, and Variable Density Log - Sonic Amplitude. The Natural Gamma Spectroscopy Tool was not available for this well.

On October 22, 1979, Schlumberger ran its Natural Gamma Spectroscopy Log through casing on the PTS "Beamers Bluff" No. 24-19 Federal well, Sublette County, Wyoming. Log interval was 5,531 - 4,400 ft in the Mesaverde horizon.

3.4 SURVEY OF BASIN ACTIVITIES

3.4.1 Greater Green River Basin

During October, 11 development wells were reported as producers, as well as 2 wildcat wells. Two development and 4 wildcat wells were reported D&A. Locations were abandoned in the case of 10 development and 7 wildcat wells.

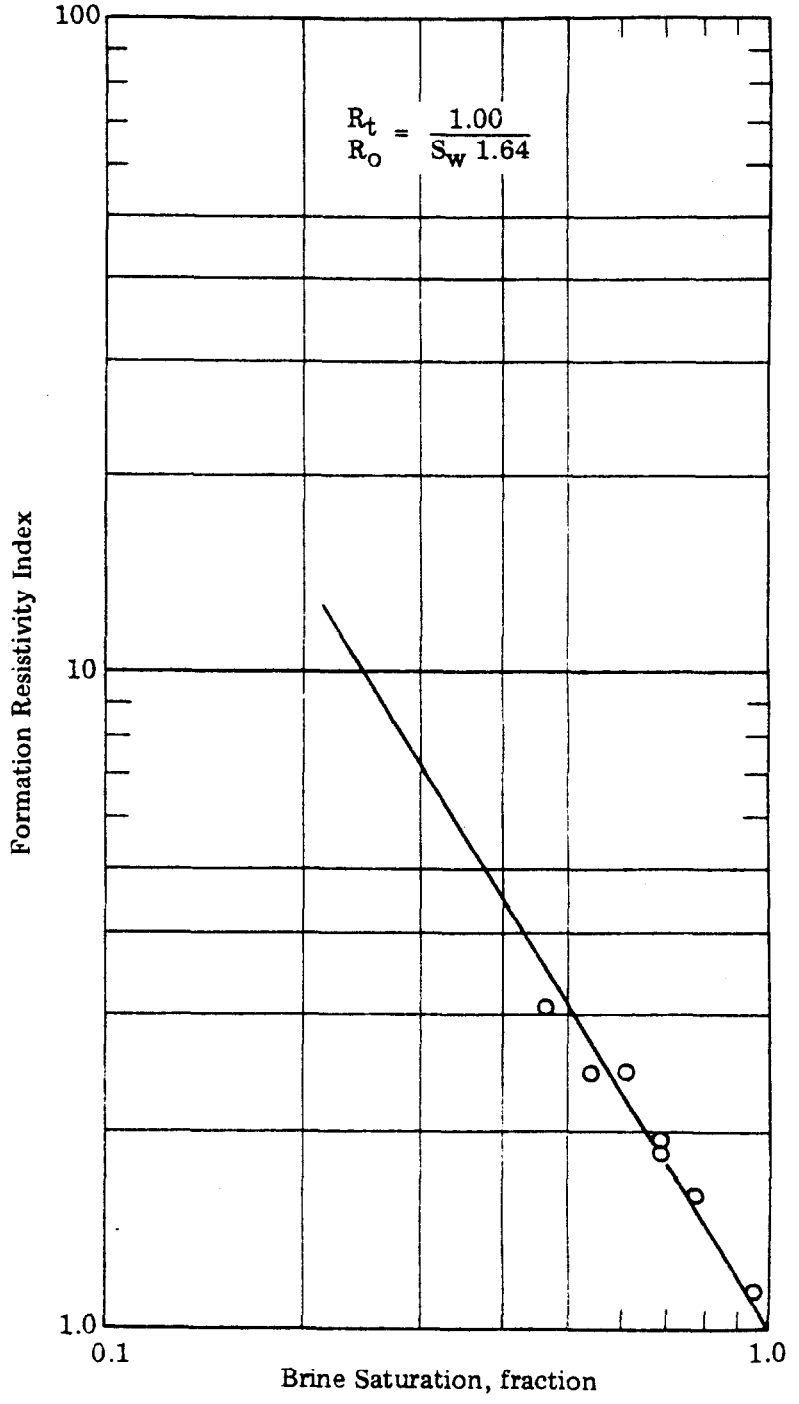


Figure 3-2 Composite Plot of Formation Resistivity Index-Saturation Relationships

Table 3-4 Formation Factor and Resistivity Index Data

Resistivity of Saturating Brine, ohm-meters: 0.3838 @ 73.0°F

Sample Number	Air Permeability, md	Porosity, percent	Formation Factor	Brine Saturation, Percent Pore Space	Resistivity Index
1	1.10	13.4	32.9	100.0	1.00
				94.1	1.14
				68.6	1.92
				61.5	2.46
				46.4	3.08
2	0.60	11.3	37.6	100.0	1.00
				96.2	1.13
				77.6	1.59
				69.9	1.84
				54.1	2.41

Table 3-5 Overburden Formation Factor Data

Saturant: Simulated Formation Brine

Resistivity of Saturant, ohm-meters: 0.3249 @ 76.5°F.

Sample Number	Depth, ft	Permeability, md	Porosity, percent	Effective Overburden Pressure, psi					
				0.0	200	1,000	4,000	6,000	10,000
				Formation Resistivity Factor					
1	5,199	1.00	13.4	33.0	41.8	44.5	46.8	47.3	48.2
2	5,305	0.54	11.3	39.0	50.5	54.1	57.1	57.7	58.6

From the 13 reported producers, the potential flow was a total of 13,312 MCFD of new gas. The contributing horizons included the Almond, undifferentiated Mesaverde, Wasatch, Frontier, 2nd Frontier, Ericson, Lewis and Ft. Union, with the Frontier contributing the most potential gas (2,583 MCFD).

Eighteen new wells were reported during October: 14 development and 4 wildcat.

Wells of interest are summarized in Table 3-6, and Figure 3-3 shows the locations of the wells and designated core areas.

3.4.2 Northern Great Plains Province

Thirty-two development wells were reported as producers this month and 3 were reported D&A. Two wildcat wells were producing and 9 were D&A by month's end. One wildcat location was abandoned.

From the 34 producing wells, 14,797 MCFD of potential flow of new gas was reported. (2 IPFs were not available from P.I. Report). The largest producing horizon was Phillips (5,131 MCFD). Other horizons included the Eagle, Shannon, Bowdoin, Greenhorn, Bow Island and 2nd Bow Island.

By month's end, 37 new development and 10 new wildcat wells were reported.

Wells of interest are summarized in Table 3-7 and shown in Figure 3-4.

3.4.3 Piceance Basin

Ten development and 2 wildcat wells were reported producing by the month's end. One development and one wildcat well were D&A.

From the 12 reported producers, there was a potential flow of 5,083 MCFD of new gas. Producing horizons included the Mesaverde, Rollins, Corcoran, Cozzette, Mancos, Mancos B and the Wasatch, which yielded the most gas for the month (1,278 MCFD).

Sixteen new development and 4 new wildcat wells were reported during the month.

Wells of interest are summarized in Table 3-8, and Figure 3-5 shows the locations of the wells and designated core areas.

3.4.4 Uinta Basin

Activity in the four areas of primary interest to the WGSP was slowest this month in the Uinta Basin. Five development wells were reported producers and 9 wildcat wells were reported D&A. One Wasatch producer was listed completed as a shut in gas well.

Producing horizons included the Wasatch, Mesaverde and Green River for a reported potential 3,209 MCFD of new gas.

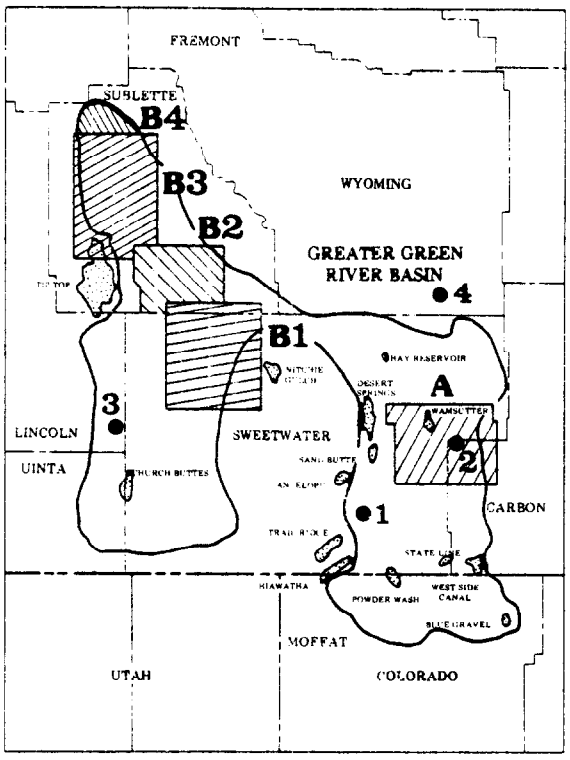


Figure 3-3 Greater Green River Basin Showing Wells of Interest and USGS Designated Core Areas (refer to Table 3-6)

Table 3-6 Summary of Wells — Greater Green River Basin

OPERATOR	WELL NAME	MAP INDEX NO.[1]	LOCATION Sec/T/R	HORIZON[2] ft	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Smokey Oil	3-18 Bluewater Federal	1	cne 18/15N/99W Unnamed Field Sweetwater Cnty, WY	Lewis (12,074-12,087) Ericson (13,338-13,376)	13,900 PB: 13,440	Fract twice w/total of 107,840 gal gel 128,000 lb sand	Wildcat discovery, no cores or tests, commingled production. Comp. 8-23-79. (Lewis-Ericson Discovery-New Field)	
Amoco Production	1 Champlin 261 Amoco-C	2	csw 3/18N/93W Standard Draw Field Carbon Cnty, WY	Almond (8,770-8,858)	9,342	338,772 gal water, 657,312 lb sand	Development well comp. 7-17-79, no cores or tests. Located in Core Area A.	1,811
Wexpro Company	10-1 Mountain Fuel-Fee	3	nwnw 10/19N/112W Bruff Field Lincoln Cnty, WY	Frontier (11,272-11,306)	11,400		Development well, comp. 9-11-79.	2,298
Burton-Hawks	33-1 Lost Creek-Federal	4	nesw 33/27N/93W Lost Creek Field Fremont Cnty, WY	Wasatch (1,430-1,438)	2,975 PB: 1,470		Development well, comp. 7-30-79.	156

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

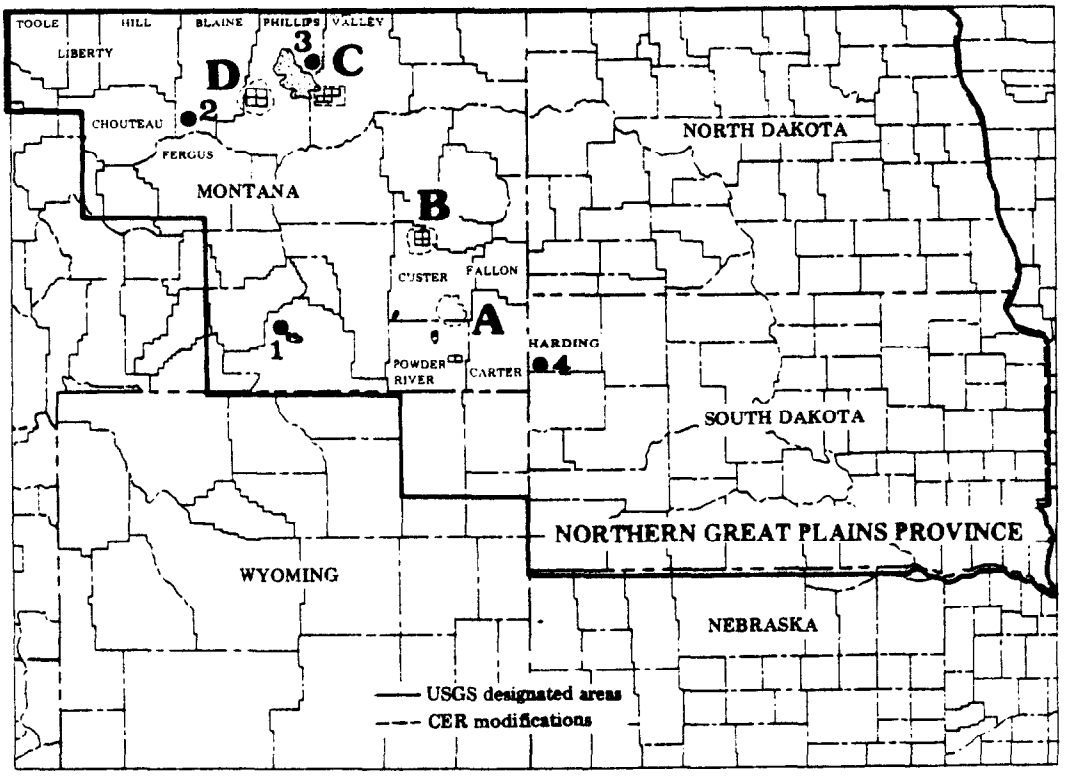


Figure 3-4 Northern Great Plains Province Showing Wells of Interest and USGS Designated Core Areas (refer to Table 3-7)

Table 3-7 Summary of Wells — Northern Great Plains Province

OPERATOR	WELL NAME	MAP INDEX NO.[1]	LOCATION Sec/T/R	HORIZON[2] ft	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Amarala Petroleum	1 Challender	1	sesw 22/1N/32E Wildcat Field Bighorn Cnty, MT	Muddy (2,700)	2,498		Wildcat, comp. 2-7-79, D&A.	
Wise Oil	2-30 O'Connel	2	nwne 30/26N/19E Unnamed Field Blaine Cnty, MT	Eagle (2,199-2,122)	2,365 PB: 2,189		Wildcat discovery, comp. 11-15-76 as SIGW. No cores. (Eagle Discovery-New Field)	N/A
Falcon-Colorado Exploration	1-26 Yeska	3	swsw 26/33N/34E Swanson Creek Field Phillips Cnty, MT	Phillips (1,043-1,056)	1,220	15,000 gal gel, 40,000 lb sand Acidized w/250 gal	Development well, comp. 8-26-79. No cores or tests. Operator had 6 additional wells completed the same week in the same locale.	481
Jerry McCutchin	1-5 Harrison-State	4	senw 5/16N/2E West Short Pine Hills Field Harding Cnty, SD	Shannon (1,867-1,918)	1,950		Wildcat outpost extension, comp. 6-20-79. No cores.	2,000

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

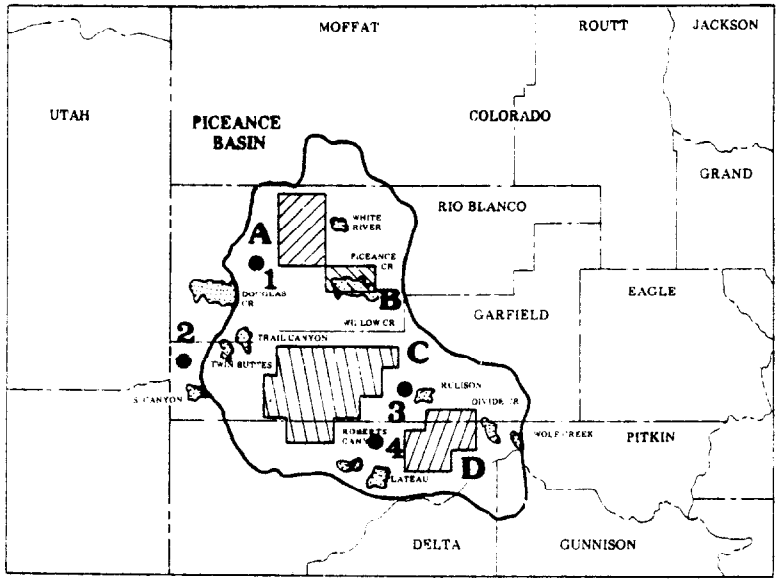


Figure 3-5 Piceance Basin Showing Wells of Interest and USGS Designated Core Areas (refer to Table 3-8)

Table 3-8 Summary of Wells — Piceance Basin

OPERATOR	WELL NAME	MAP INDEX NO.[1]	LOCATION Sec/T/R	HORIZON[2] ft	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Adolph Coors	1-19 USA-PC	1	swne 19/1S/100W Wildcat Field Rio Blanco Cnty, CO	Mancos (5,500)			Wildcat well, reported 10-2-79.	
Coseka Resources	16-6-5-103 Gentry	2	nene 6/5S/103W Unnamed Field Garfield Cnty, CO	Mancos (3,191-3,709)	3,795 PB: 3,755	44,646 gal emul, 145,300 lb sand	Wildcat discovery, comp. 9-13-79. (Mancos-Discovery-New Field)	127
Northwest Exploration	2 Clough	3	sesw 21/6S/94W Rulison Field Garfield Cnty, CO	Mesaverde	8,600	Acidized	Wildcat outpost, comp. 6-6-79. (Mesaverde Extension-Rulison Field)	450
Chandler & Associates	5-31 Shire Gulch-Federal	4	swnw 31/9S/96W Shire Gulch Field Mesa Cnty, CO	Rollins (2,782-2,788) Corcoran (3,204-3,210)	3,657 PB: 3,470	Fract twice w/total 106,050 gal water, 267,000 lb sand	Development well, comp. 9-12-79, no cores or tests. Commingled production.	325

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

Fourteen development and 2 wildcat wells were staked during the month.

Wells of interest are summarized in Table 3-9, and Figure 3-6 shows the location of the wells and designated core areas.

3.5 C K GEOENERGY CORPORATION

3.5.1 Development of Techniques for Optimizing Selection of Western Tight Gas Sands

Field work in the Green River Basin and the reconnaissance work in the Wind River Basin for the Wyoming sand continuity background study were completed. The interim report on the Green River Basin should be drafted prior to the end of the year.

C K GeoEnergy has been in contact with Sandia Laboratories concerning the project on the use of seismic data in the evaluation of lenticular sands. Copies of the 1 in. = 40 in. scale work maps of the Westwater canyon area of Utah were supplied to Sandia.

3.5.2 Reservoir Characteristics in Uinta Basin Gas Wells

All field measurements have been completed and the final report is being prepared. A meeting will be held on November 30, 1979, at C K GeoEnergy office to discuss the report results. Four National Petroleum Council Tight Gas Committee members will attend in order to discuss their work and obtain C K GeoEnergy's advice in setting up new courses of action.

3.6 MULTI-WELL EXPERIMENT

Experiment objectives are to obtain a comprehensive geologic characterization of certain low permeability reservoirs in the western United States and to evaluate state-of-the-art and developing technologies for the recovery of gas from these reservoirs.

A meeting of the industry advisory group and key DOE, national laboratory, and contractor personnel was held in Denver, Colorado, on October 31, 1979. The meeting included discussions on site selection, the drill program, the logging program, core collection and *in situ* stress measurements. Site acquisition has been delayed as the originally proposed site was not available. The delay precludes any site activity prior to winter, so drilling of the first well will occur in a May-June, 1980 time-frame.

A detailed Phase 1 planning meeting was scheduled for the end of November, 1979, but was later changed to January 15, 1980. The planning will utilize network analysis techniques which have proven successful in similar high technology, high risk energy-related programs at Sandia. A key feature is that the project plan will be created and agreed to by the participants.

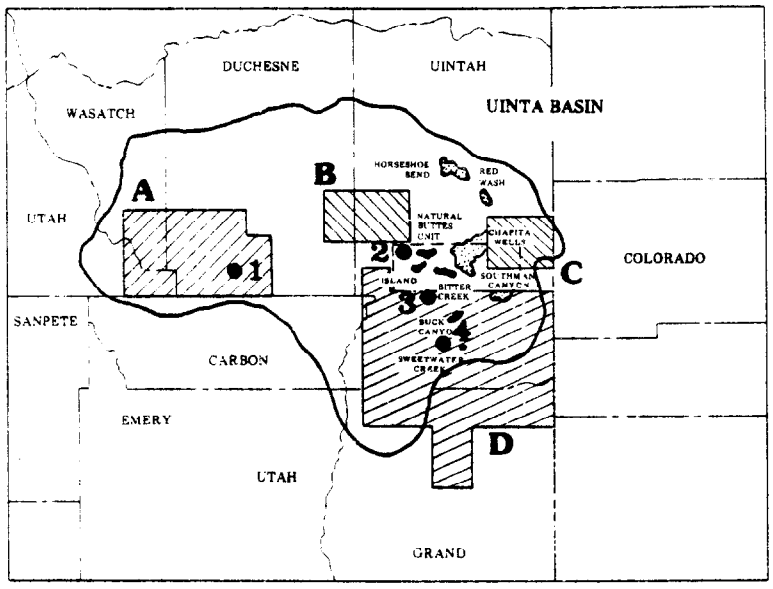


Figure 3-6 Uinta Basin Showing Wells of Interest and USGS Designated Core Areas (refer to Table 3-9)

Table 3-9 Summary of Wells — Uinta Basin

OPERATOR	WELL NAME	MAP INDEX NO.[1]	LOCATION Sec/T/R	HORIZON[2] ft	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Burton-Hawks	27-1 Sowers Canyon-Federal	1	sene 27/6S/6W Wildcat Field Duchesne Cnty, UT	Wasatch (3,900)	4,144		Wildcat, comp. 8-6-79, D&A. No cores or tests. Located in Core Area A.	
Gas Producing Enterprises	7 Natural Buttes Unit	2	nene 23/9S/20E Natural Buttes Field Uinta Cnty, UT	Green River (3,015-3,516)	8,297 PB: 3,900	Acidized w/10,000 gal	Development well, comp. 6-14-78. No cores or tests. OWWO, previous prod. zone Wasatch.	50
Cotton Petroleum	1 Love Unit	3	csw 11/11S/21E Wildcat Field Uintah Cnty, UT	Mesaverde (8,000)			Wildcat well, reported 9-26-79. Located in Core Area D.	
Coseka Resources	2X-16-14-22 Pine Springs Unit	4	swse 16/14S/22E Sweetwater Creek Field Uintah Cnty, UT	Morrison (9,693)			Wildcat deeper pool, reported 9-26-79. Located in Core Area D.	

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

A "strawman" core acquisition and analysis program was prepared and sent to prospective participants for their review and comments. Specific suggestions for core handling and the idea of slow-, middle-, and fast-track analyses for different information were presented.

Figure 3-7 is a milestone chart depicting progress of the multi-well experiment program.

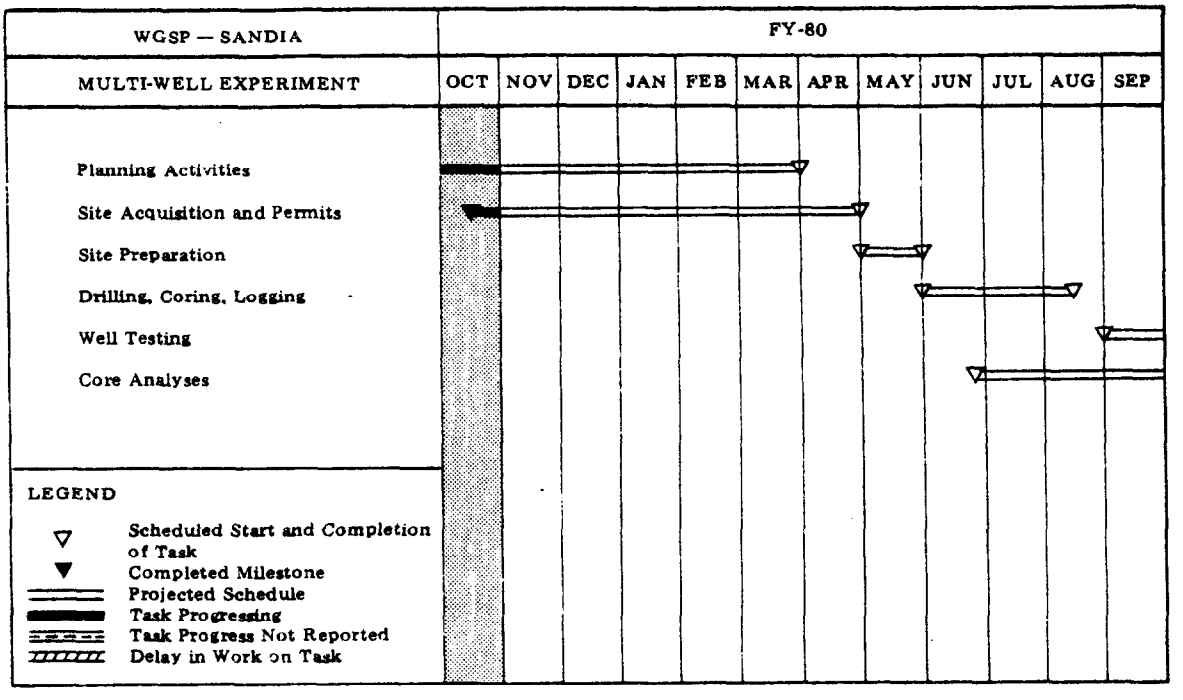


Figure 3-7 Milestone Chart — Multi-well Experiment

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

4.1 BARTLESVILLE ENERGY TECHNOLOGY CENTER

4.1.1 Improved Pressure Coring System — Sandia Laboratories, et al.

4.1.1.1 Core Retriever Design and Test

Lining the inner core barrel with polystyrene to reduce jamming has been tested but no improvement was observed. The diamond compax core bit and low invasion fluid system has reduced jamming and further testing of plastic linings will be deferred.

The lower swivel redesign has been completed and parts are being fabricated to field test the new improved bearing configuration.

Transducers and a digital readout have been ordered for the plug-in pressure readout improvement program and should be available in mid-December. A series of laboratory tests to simulate field environment survivability will be started before hardware fabrication.

4.1.1.2 Core Fluid Tests

The low invasion fluid was used in cutting 22 cores for Texas Pacific Oil Company and Gruy Federal, Inc. on the Bennett Ranch near Denver City, Texas, during September and October. This series is now being analyzed by Core Laboratories and results should be available in December. A tabulation of the coring parameters, equipment and recovery is shown in Table 4-1 for the first twelve cores, which will be used to evaluate field effectiveness of the low invasion fluid and the diamond compax core bits in controlling washing and invasion in pressure coring operations.

4.1.1.3 Bit Design and Fabrication

A one-piece diamond compax core bit design has been completed based on cutter elements diffusion bonded to steel studs. This bit is designed for use with low invasion coring fluid and utilizes a built-in dam to reduce core washing and invasion. The design is compatible with Exxon pressure core barrel attachments and core catchers. Cutter placement is based on the Sandia Laboratories diamond compax cutter placement computer program.

Table 4-1 Coring Parameters, Equipment and Recovery, With and Without Low Invasion Fluid

Run No.	Bit No.	RPM	Weight (x 1,000 lb)	Depth (ft) In	Depth (ft) Out	Strokes (GPM)	Barrel Pressure	Low Invasion Gel (LIG)	Drilling Rate ft/hr
1	CS106[1]	80	5-6	5,175	5,181	39(174)	2,750	w/ LIG[3]	1.92
2	CS103[2]	80	5-6	5,181	5,190	39(174)	2,550	w/o LIG[4]	5.93
3	CS106	80	8	5,190	5,198	39(174)	0	w/ LIG	2.04
4	diamond[5]	60-72	8	5,198	5,207	32(143)	0	w/o LIG	1.95
5	Shell SP[6]	70	6	5,207	5,216	32(143)	2,600	w/ LIG	3.46
6	Shell SP	70	6	5,216	5,224	32(143)	1,600	w/ LIG	1.74
7	diamond	70	8	5,224	5,233	32(143)	2,800	w/o LIG	1.96
8	CS103	80	9	5,233	5,242	32(143)	3,600	w/o LIG	5.93
9	CS106	80	9	5,242	5,250	32(143)	0	w/ LIG	2.56
10	diamond	75	9	5,250	5,259	32(143)	1,600	w/o LIG	2.22
11	CS103	80	9	5,259	5,267	32(143)	0	w/ LIG	6.23
12	CS103	80	9	5,267	5,273	32(143)	3,300	w/ LIG	4.09

[1] Stratapax (R) bit with recess
[2] Stratapax (R) bit without recess
[3] with low invasion fluid
[4] without low invasion fluid
[5] Standard diamond bit
[6] Shell Stratapax (R) bit

A two-piece diamond compax core bit design is being drafted based on the one-piece design. The two-piece design has a pilot bit profile for minimum rock removal by the pilot bit cutters and maximum low invasion fluid flow for chip removal and cutter cooling.

The two-piece core bit will be ready for laboratory testing in late January, 1980.

4.1.1.4 Polycrystalline Diamond Core Bit Tests

The single-piece bit which was tested in the laboratory (Terra Tek Drilling Research Laboratory) and twice in the field has been used on two subsequent wells to drill 41 cores. Good bit life was demonstrated by these tests.

The core bit was modified to use only stud mounted cutters in the core drilling tests, which are shown in Table 4-1. Penetration rates were reduced by this redesign, so further modification is planned to regain lost penetration capability. Gage trimmers were added to the bit body and they reduced the torquing present in the original design to an acceptable level.

4.1.2 Interface Conductivity Effects on Electric Logging

Experiments to determine the effect of overburden pressures on the electrical conductivity of saturated cores are in progress. Initial results indicate relatively large increases in observed core resistance as a function of increasing confining pressure, which ranged from 0 to 600 psig. Resultant resistance changes show the same trend as single-phase permeability for tight sands, i.e., a strong decrease in permeability as a function of low confining pressure.

The cation exchange capacity (CEC) of core samples from four WGSP wells was determined and compared with the radioactive potassium content (potassium gamma log, γK). A preliminary interpretation of the samples showed that a linear relation existed between the CEC and γK for three of the four wells. Three wells exhibited the same slope (600 p curies/meq) but with different intercepts. Data from the fourth well was more scattered and had a slope of about 1/6 that of the others. Invasion by drilling fluids might account for varying slopes or scattered data, but should not alter the intercept.

Several of these samples were analyzed for clay type and amount, using average CEC values. There was some expected scatter, but the correlation was reasonably good. The degree of correlation will be determined after the remainder of the cores are analyzed.

4.1.3 In Situ Permeability

4.1.3.1 Measurement of Formation Characteristics for Western Tight Sands — Institute of Gas Technology

Core from the Mobil PCU F31-13G well, Piceance Basin (9,957 ft depth), was subjected to a number of stress cycles to determine if the measurement of gas permeabilities at low confining pressures is accompanied by blow-by along the surface of the core exposed to the rubber sleeve. Each cycle consisted of sequential confining pressure of 120 psi, 3,000

psi, and 120 psi. Table 4-2 lists the permeability values evaluated from these measurements. Five stress cycles were required before the permeability values reached nearly constant values at increasing and decreasing confining pressures, respectively. To eliminate gas slip effects, the mean pore pressure was maintained between 34.2 and 35.1 psi (corresponding to a differential pressure from 39.1 to 40.7 psi). After the permeability values had reached steady conditions, the plug was removed, wrapped in masking tape and replaced in the core holder, and the permeability values were again measured as a function of net confining pressures up to 500 psi. Higher net confining pressures were not applied to avoid intrusion of the adhesive into the pore spaces. The measured permeabilities, shown in Table 4-3, are compared with the values obtained during the last stress cycle without the masking tape. There is no significant difference in permeability values measured with or without the masking tape.

These tests were conducted to verify the accuracy of high pore pressure measurements made earlier.[1] The results indicate that while permeability may well be strongly dependent on net confining pressure at low net confining pressures, there is no significant annular slip between the core and the rubber sleeve used to confine the core.

4.1.3.2 Permeability of Interbedding Material of Tight Western Gas Sands — Lawrence Livermore Laboratories

The permeability measurement sub-system is nearly complete, with work on the pressure generation sub-system continuing. Both systems are expected to be completed, joined and mostly debugged by mid-December. All electronic units for the test control and data acquisition are expected to be completed, debugged and hooked up to the pressure/permeability systems by the same time. Testing of samples should be underway by early January, 1980.

4.1.4 Advanced Logging Techniques and Interpretation

4.1.4.1 Dielectric Constant Measurements for Formation Evaluation

The design of the special purpose network analyzer for dielectric constant measurements has been completed and the parts have been ordered. This unit will be connected to the HP9825 desktop controller. An interface is being designed to connect the special purpose network analyzer directly to the HP9825 HPIB data bus. A backup interface using an available HP3495A Scanner or an HP6940B Multiprogrammer may also be used.

A system was designed and components were ordered to provide automatic frequency scanning for the dielectric constant lab analysis. This function will also be controlled by the HP9825 controller.

---

[1] Byrnes, A. P., et al, "Effect of Pressure and Water Saturation on Permeability of Western Tight Sandstones." Paper presented at the Fifth Annual DOE Symposium on Enhanced Oil and Gas Recovery and Improved Drilling Technology, Tulsa, Oklahoma, August 22-24, 1979.

Table 4-2 Gas Permeabilities Evaluated During Successive Stress Cycles

Mobil PCU F31-13G Well
Core No. 9957

Net Confining Pressure (P_c, psi)	Cycle No.	Permeability (md) P_c Increasing	Permeability (md) P_c Decreasing
120	1	0.160	0.065
	2		0.070
	3		0.048
	4		0.058
	5		0.060
	6		0.061
	7		0.062
	8		0.064
	9		0.063
200	1	0.096	—
	9		0.058
500	1	0.050	0.043
	2	0.045	0.043
	3	0.050	0.031
	7		0.032
	8	0.041	0.035
	9	0.042	0.033
1,000	1	0.032	0.024
	2	0.031	0.032
	3	0.034	0.020
	4	0.026	0.019
	5	0.025	0.019
	6	0.024	0.019
	7	0.026	0.0195
	8	0.026	0.021
	9	0.027	0.022
2,000	1	0.017	0.015
	2	0.018	0.014
	3	0.020	0.014
	4	0.015	0.013
	5	0.014	0.011
	6	0.013	0.011
	7	0.014	0.011
	8	0.014	0.012
	9	0.014	0.012
3,000	1	0.012	
	2	0.012	
	3	0.011	
	4	0.010	
	5	0.0088	
	6	0.0089	
	7	0.009	
	8	0.010	
	9	0.0094	

Table 4-3 Comparison of Permeabilities Evaluated With and Without Masking Tape Wrapped Around Core

Mobil PCU F31-13G Well
Core No. 9957

Net Confining Pressure (psi)	Permeability of Core Without Masking Tape (md)	Permeability of Core Wrapped in Masking Tape (md)
120	0.063	0.0624
200	0.058	0.0560
500*	0.042*	0.0440

* Since the confining pressure was increased only up to 500 psi with masking tape, the permeability value quoted for the core without masking tape is from the increasing portion of the stress cycle.

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

Laboratory measurements of porosities continued using whole cores from the CIGE NBU No. 21 well. Since porosity will be determined by saturation with kerosene, plugs from two samples were cut to compare saturation times.

In order to find the best method of utilizing logs to determine porosity, logs from NBU No. 21, of which core data is available from several intervals, have been digitized and analyzed. Presently, the density log requires special matrix density values be used to obtain agreement between the log-derived porosity and the porosity obtained in the laboratory by direct measurement. From this analysis, techniques can be developed for utilizing each log independently to determine the porosity of subsurface reservoirs.

4.1.5 Reservoir Simulator Studies

Parametric Analysis of MHF Test Data and Engineering Studies of Western Gas Sands — Intercomp

The pressure transient performance of a fractured gas well can be correlated with three dimensionless parameters. These are dimensionless pressure, P_{wD}, dimensionless time t_{Dxf}, and the dimensionless fracture flow capacity, $k_{fD}w_{fD}$. The dimensionless pressure for a gas well is defined by the equation:

$$P_{wD} = \frac{k_g h[m(P_i) - m(P_{wf})]}{1{,}424_q T} \qquad (1)$$

where:

k_g	=	effective gas permeability, md
h	=	net gas pay thickness, ft
q	=	production rate, MCFD
T	=	reservoir temperature, °R
$m(P_{wf})$	=	flowing real gas pseudo pressure, psia^2/cp
$m(P_i)$	=	static real gas pseudo pressure, psia^2/cp

Dimensionless time is defined by:

$$t_{Dxf} = \frac{0.0002637\ k_g t}{\phi(\mu c_t)_i x_f^2} \qquad (2)$$

where:

t	=	time, hr
ϕ	=	porosity, decimal fraction
μ_i	=	viscosity at initial reservoir pressure, cp
$(c_t)_i$	=	compressibility at initial reservoir pressure, psi^{-1}
x_f	=	fractured half length, ft

The dimensionless fracture flow capacity can be defined as:

$$k_{fD}w_{fD} = \frac{w\,k_f}{\pi x_f k} \tag{3}$$

where:

w	=	fracture width, ft
k_f	=	fracture permeability, md

The pressure transient performance of a fractured gas well can be predicted if the reservoir and fracture parameters defining the dimensionless variables are known. Usually the reservoir and fracture parameters are evaluated from the measured transient pressure behavior of the well by using various analytical techniques (e.g., Horner analysis[2] and type curve matching[2]) or computer matching of the test data. Transient pressure data from completed fractured wells in extremely low permeability reservoirs often cannot be analyzed using analytical techniques, but only by matching the test data with a computer program designed to simulate the well's performance. This is usually a trial and error procedure in which the assumed values of the reservoir and fracture parameters are used to calculate the well's pressure response. If the calculated pressures do not match the measured pressures, new parameters are used in the program. The procedure is repeated until a computer match with the test data is obtained. The uniqueness of the match is questionable since many parameters are needed to define the dimensionless variables.

Certain reservoir parameters are assumed to be known from log analysis, fluid analysis, static pressure surveys and core analysis. These are:

- net gas pay thickness,
- porosity,
- initial reservoir pressure,
- reservoir temperature,
- gas viscosity, and
- reservoir compressibility.

---

[2] Earlougher, R. C., Jr., "Advances in Well Test Analysis," Monograph Series, Society of Petroleum Engineers of AIME, Dallas (1977) 5.

These parameters are held constant and the computer matching technique is used to evaluate fracture half length, effective gas permeability and fracture flow capacity. The dimensionless pressure versus the dimensionless time curve for the well is defined once these three parameters are known from the pressure match. The solution can be examined by looking at Equations 1, 2, and 3. For a given value of the dimensionless time (t_{Dx_f}), the only unknowns in Equation 2 are the gas permeability and the fracture half length. These variables appear as the ratio k_g/x_f^2. Any values of k_g and x_f will satisfy the equality as long as the ratio remains constant. Gas permeability is the only unknown in Equation 1 if h, $m(P_i)$, and T are known. This fixes k_g through the pressure match. It also sets x_f due to Equation 2. With k_g and x_f set, wk_f is also set through Equation 3.

Several computer runs were made to test the assumptions above and the results are shown in Figures 4-1 through 4-3.

Figure 4-1 shows pressure buildup curves for three sets of k_g, x_f and h. Porosity, reservoir pressure, fluid properties, and reservoir temperature were held constant. The base case is for a reservoir with a k_g of 0.2 md, x_f of 357 ft and h of 22.5 ft. The pressure buildup behavior of the well is shown by the circles. The squares show the buildup behavior calculated for the gas permeability equal to 0.1 md, with x_f and h remaining constant. There is considerable separation between these data and the base data and would not be considered a match. The third case represented by the triangles in Figure 4-1 again assumes k_g to be 0.1 md but assumes h to be 45 ft. This causes k_gh to be the same as in the base case. This case sets x_f at 253 ft, which makes k_g/x_f^2 equal to that of the base case. With these data, the pressure buildup curve is an exact duplicate of that for the base case and would be considered a match.

Figure 4-2 shows pressure drawdown data for two sets of x_f, h, and k_g. The k_gh is half constant for the two cases. The base case is represented by the circles and has a fracture half length of 357 ft. The fracture half length for the case represented by the squares is 802 ft. The two curves coincide at late times but are quite different at early times. Figure 4-3 shows data for a pressure buildup test following the pressure drawdown test. The late time data coincide, as in Figure 4-2 and early time data are displaced.

It appears that a unique match to pressure transient test data from a fractured gas well is obtained if the net gas pay, reservoir porosity, reservoir pressure, reservoir temperature, and gas properties are known.

4.1.6 Rock-Fluid Interaction

4.1.6.1 Gel Fracture Fluid Characterization

An important mechanism for formation permeability loss following hydraulic fracturing is from pore plugging by the gels in the fracturing fluid. Although these gels are supposed to break down and be produced back to the wellbore after fracturing, a significant fraction remains within the formation. To understand the nature of the plugging and to correct it, the molecular weight distribution of the polymer gel extruded into the formation needs to be determined.

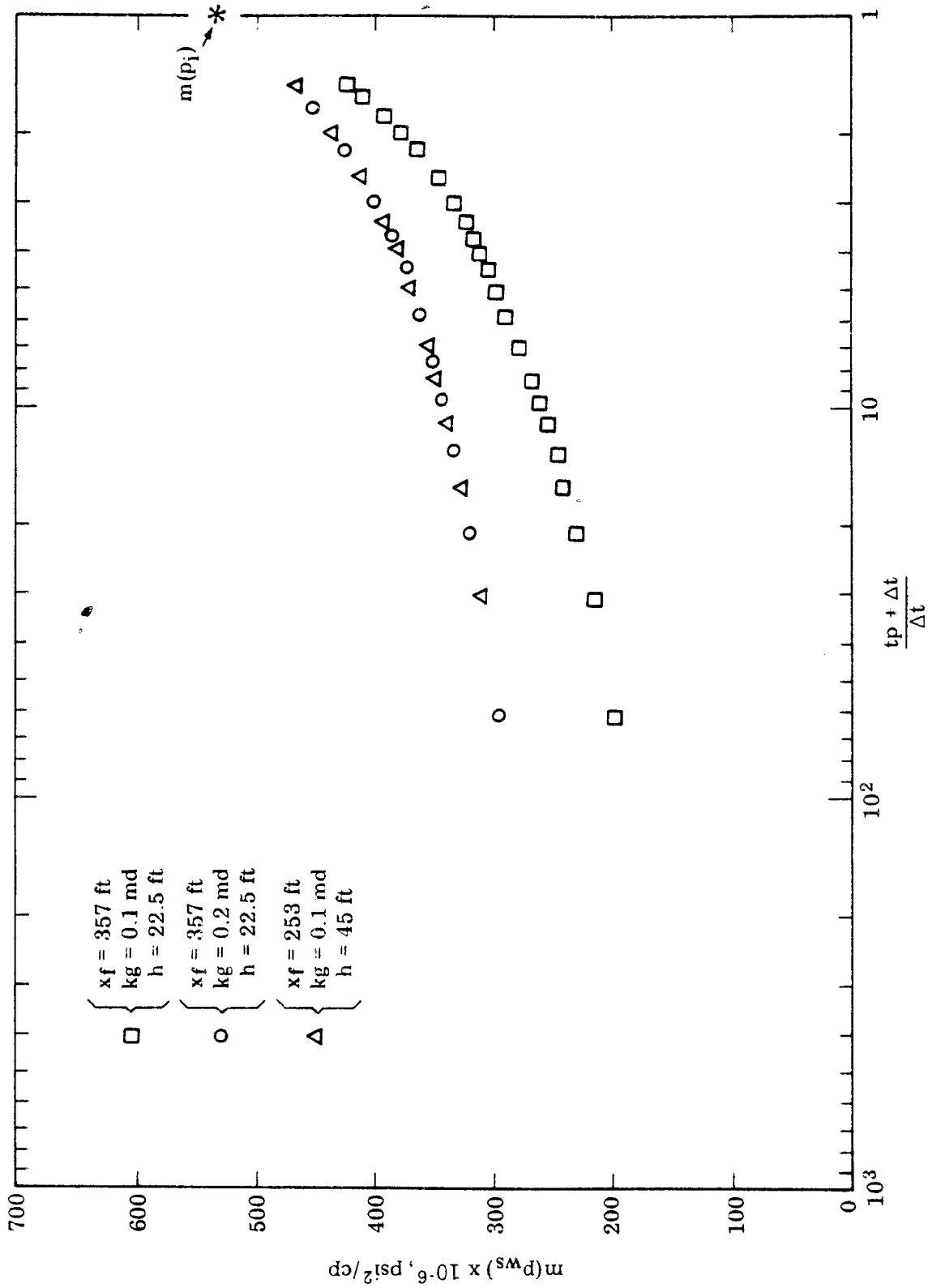


Figure 4-1 Pressure Build-up Curves for three Hypothetical Reservoirs Showing Effects of Slight Variances in Critical Parameters

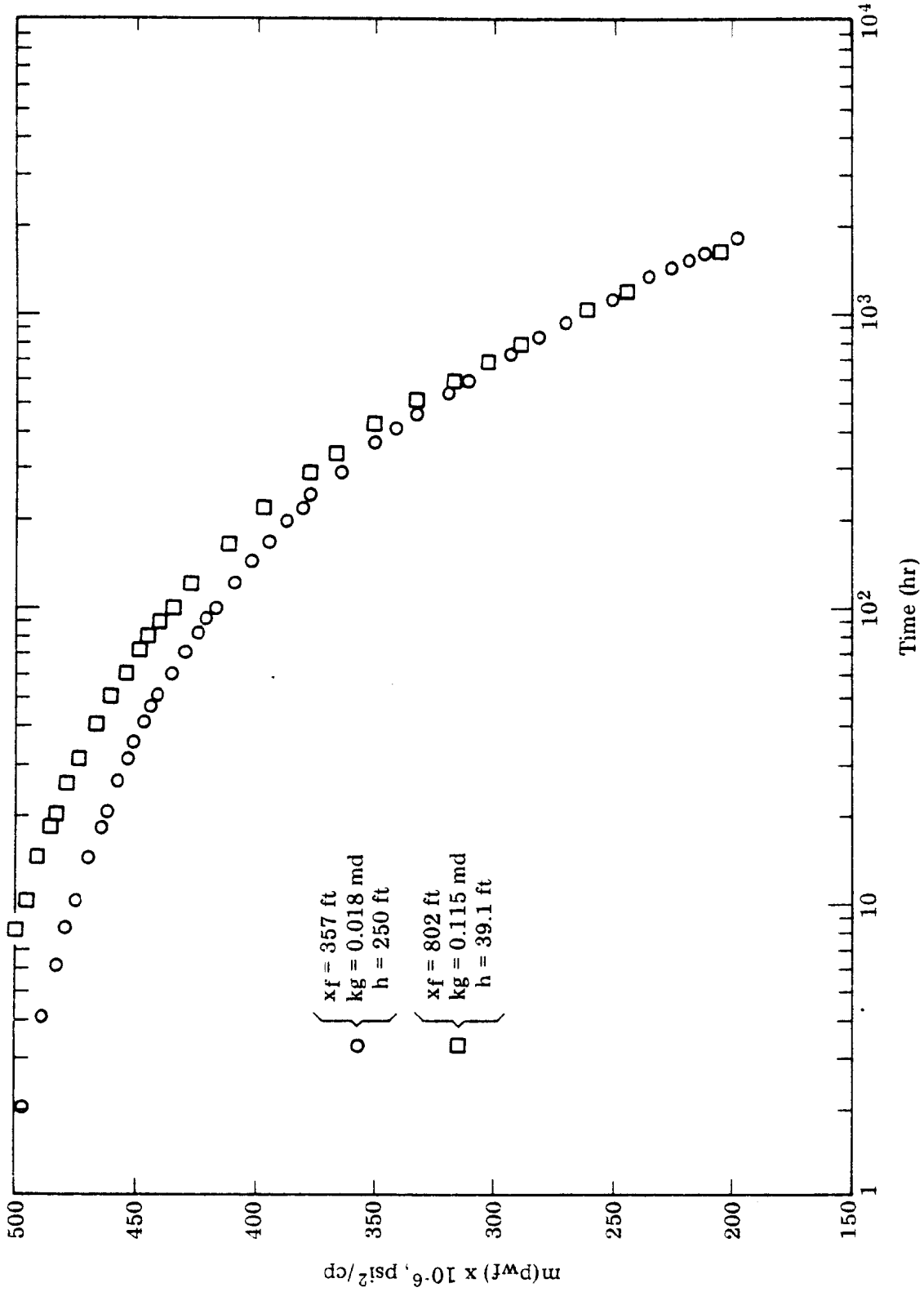


Figure 4-2 Pressure Draw-down Curves for two Hypothetical Reservoirs

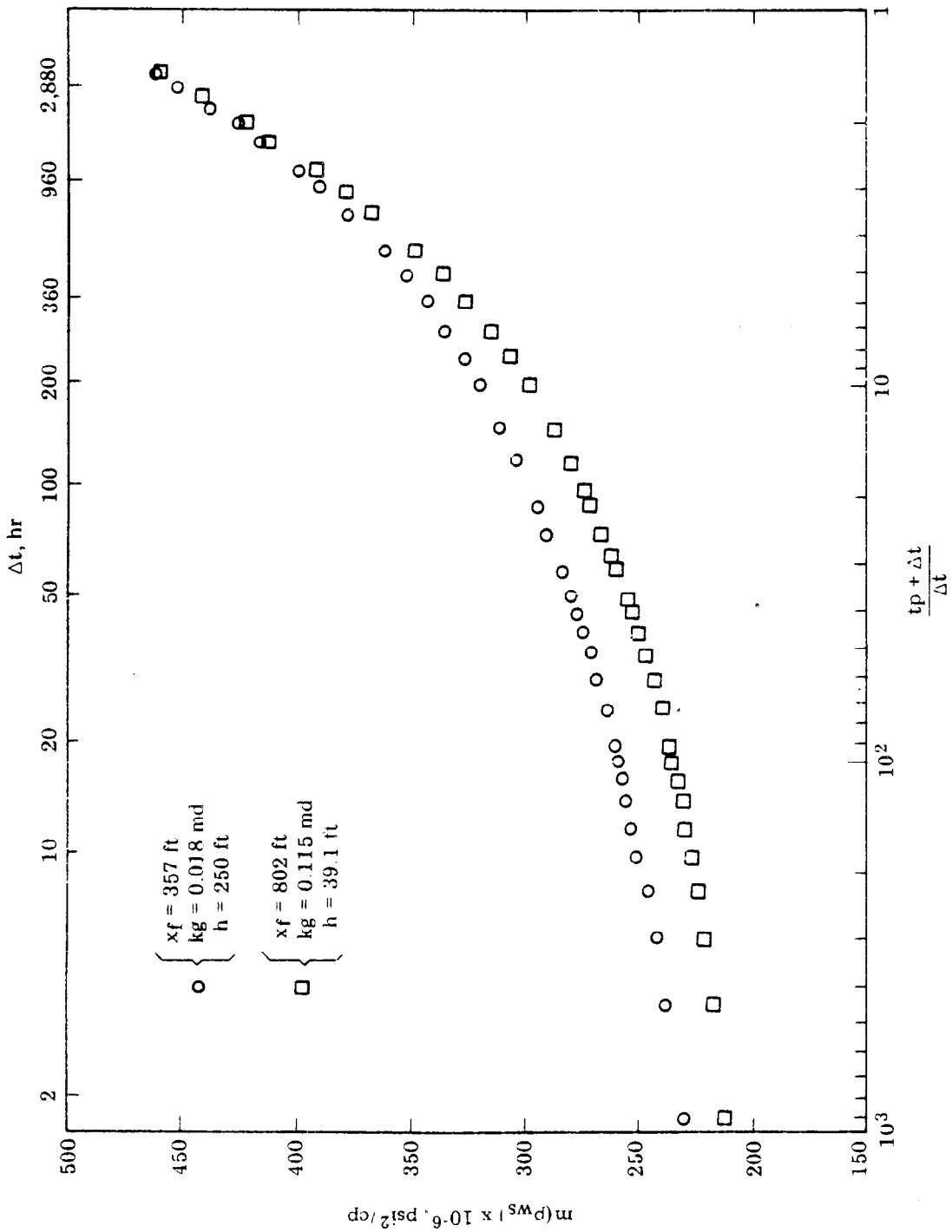


Figure 4-3 Pressure Build-up Curves following Draw-down Tests shown in Figure 4-2

A 40 lb (0.048 wt percent) low residue guar gel was eluted onto a Bio-Gel P2 column. Neither the broken nor unbroken gel showed any decomposition products of low molecular weight (less than 1,000). The estimated detection limit for dextrose or sucrose was 4 μg, corresponding to about 10 percent decomposition into this product for the sample size. The only difference between the broken and unbroken gel was the smaller bandwidth (40 percent narrower) of the high molecular weight peak for the broken gel. This could have been due to viscosity effects rather than actual molecular weight differentiation.

When the decomposed gel was run on a Water Associates μ - Bondegel E-1000 column (molecular weight separation range: 50,000 to 2,000,000), there was evidence of significant degradation. The detection limit for the column was estimated to be 0.1μg for the lower molecular weight species. Analysis of this data is not complete. However, based on the sensitivity of the column to dextrose, the broken gel contained 1.8μg of low molecular weight material (less than 50,000), or about 3.8 percent decomposition into these lighter fractions. A more sensitive column will be needed to examine the low molecular weight species.

4.1.6.2 Feasibility of Fabricating Light Weight Proppants for Application in Gas and Oil Well Stimulation — Terra Tek

Requirements for a new light weight proppant have been determined and are as follows:

- density less than or equal to 2 gm/cm^3;
- ability to withstand pressures to 20,000 psi at brine temperatures to 400°F, whether placed as a partial monolayer or as a multilayer in hard formations;
- chemically inert in brine at 400°F;
- average Krumbein roundness of 0.8 or higher; and
- grain size distribution of the present 20/40 sand.

Three proppant designs will be given detailed consideration:

- porous ceramic,
- hollow ceramic, and
- composite bead, with an inner core of light weight material and outer layer of ceramic.

The primary constraint in selection was the availability of suitable material which could sustain the high load in the corrosive, high temperature environment. Potential ceramic candidates are sintered bauxite, SIALON, and SiC. Polymides are candidate light weight materials.

Design work has been initiated for the proppant requirements listed. Existing data on glass bead proppants will be used to check the analysis. This work is expected to continue through January 1980.

4.1.7 Schedule Status

Figure 4-4 is a milestone chart depicting BETC WGSP progress.

4.2 GAS RESEARCH INSTITUTE

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

4.2.1 Hydraulic Fracturing and Testing of Rio Blanco Natural Gas Company No. 397-19-1 Government Well

Pre-fracture testing was completed at the Rio Blanco Natural Gas Company No. 397-19-1 Government well, an Upper Mesaverde completion in the Piceance Basin, Colorado. The DOE mobile well test facility was used for all testing on this well. (See Section 5.4) The proposed fracture was to be gelled brine and high strength, sintered bauxite proppant to test the ability of the proppant to prevent fracture closure by crushing and embedment. This phenomenon has been indicated in previous wells fractured in the area.

Extensive testing and analysis of the well indicated insufficient natural flow capacity of the reservoir to effect a meaningful fracture stimulation experiment. Consequently, plans have been suspended for further GRI-sponsored work on the well.

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

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

The proposed site for the field experiment has been finalized. Well log data near the site have been obtained and assimilated, approval was obtained from the Bureau of Land Management, and requisite bonds were posted.

Problems with crew availability have delayed seismic field operations as well as topographic surveying. Work on the seismic modeling program progressed with a site visit to Bryson Canyon by Sandia Laboratories personnel. With the cooperation of C K GeoEnergy, a basic geometric model of channel size, primarily height and width as well as frequency in various members of the Mesaverde Group, has been established.

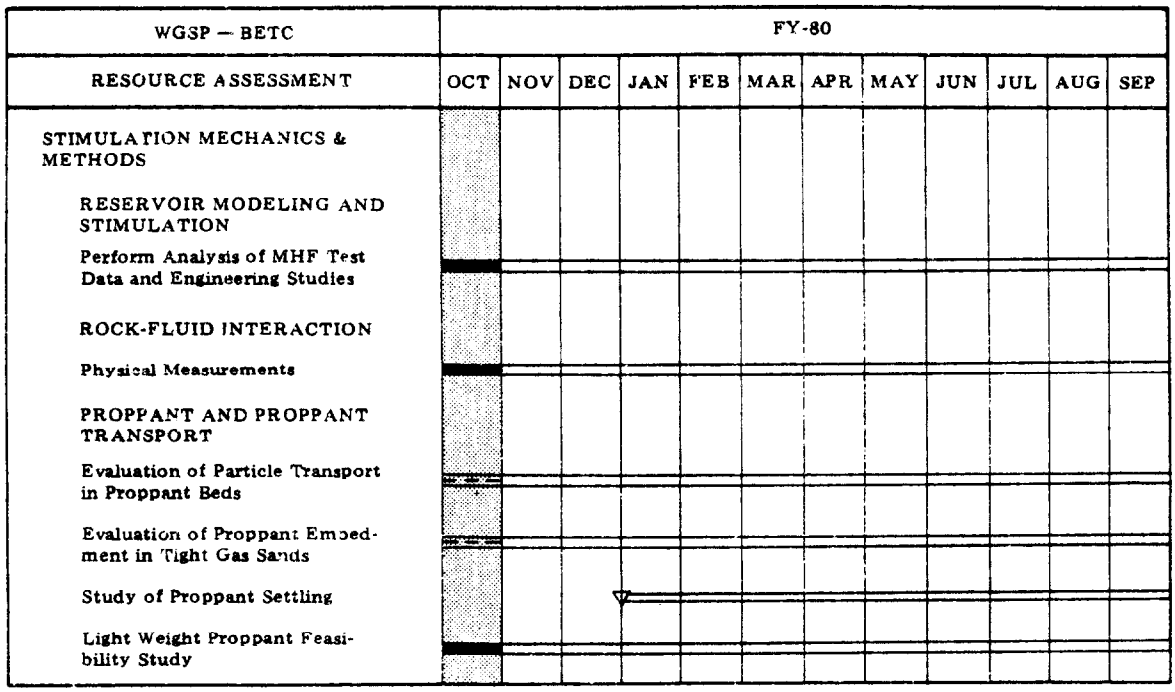
WGSP — BETC	FY-80											
RESOURCE ASSESSMENT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
FORMATION EVALUATION												
IMPROVED PRESSURE CORING SYSTEM												
Core Retriever Design & Test												
Core Fluid Testing												
Bit Design & Fabrication												
Bit Tests												

LEGEND

- ▽ Scheduled Start and Completion of Task
- ▼ Completed Milestone
- Projected Schedule
- Task Progressing
- Task Progress Not Reported
- Delay in Work on Task

WGSP — BETC	FY-80											
RESOURCE ASSESSMENT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
IN SITU PERMEABILITY												
Measurement of Formation Characteristics												
Permeability of Interbedding Material Measurement												
Development of Standardized Core Analysis												
ADVANCED LOGGING TECHNIQUES AND INTERPRETATION												
Measurement of Interface Conductivity Effects on Electric Logging												
Dielectric Constant Measurements												
Study of Sonic, Neutron and Density Logging of Low Permeability Gas Sands												

Figure 4-4 Milestone Chart — BETC



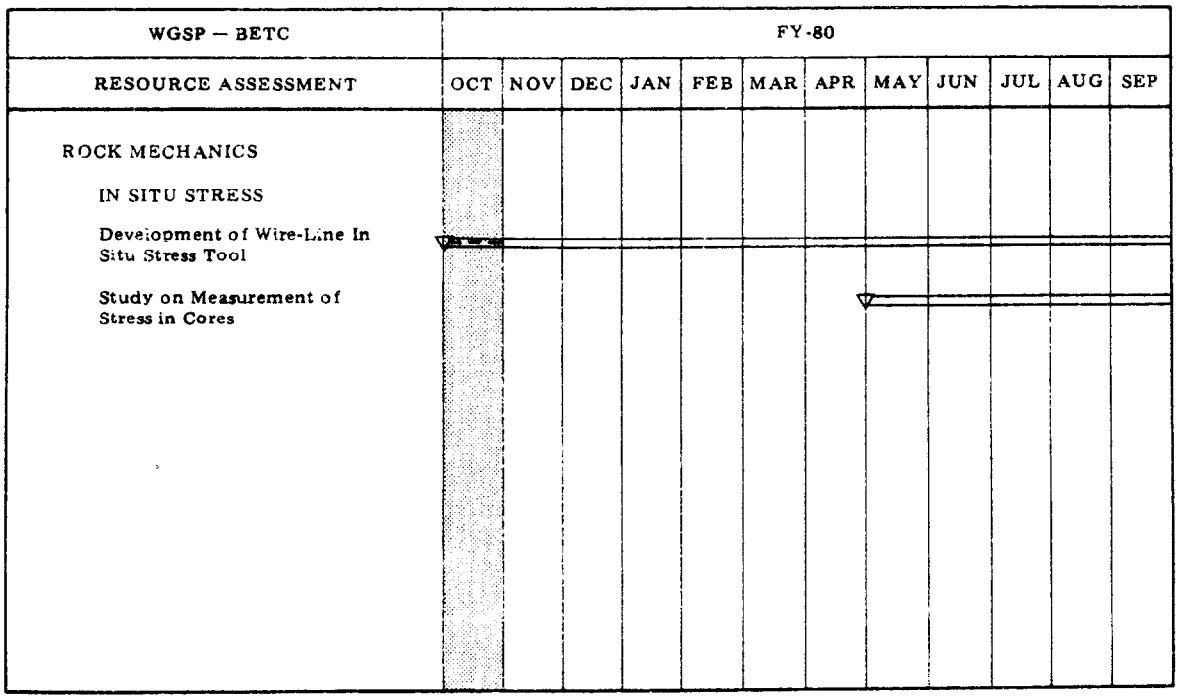


Figure 4-4 Continued

4.2.3 Coring and Logging of Pacific Transmission Supply Company No. 22-12 Federal Well

Coring of the Mancos B (funded by GRI) commenced October 1, 1979. No problems were encountered and the operation took six days to complete. A total of 120 ft of 4 in. core was cut from 11,669 to 11,789 ft, with recovery totalling 118.3 ft, or 99 percent. Portions of the core were shipped to Lawrence Livermore Laboratory, Los Alamos Scientific Laboratory and Bartlesville Energy Technology Center for analysis, with the bulk sent to Core Laboratories, Inc. in Casper, Wyoming. Upon completion of conventional analysis by Core Lab, the samples will be shipped to the USGS in Denver for geologic and mineralogic analysis and archiving.

Logging operations on the No. 22-12 Federal took place October 17-19, 1979. In addition to the basic suite of logs run by the operator, CER Corporation prescribed two additional geophysical well logs and special data processing.

4.3 LAWRENCE LIVERMORE LABORATORY

4.3.1 Theoretical Analysis

4.3.1.1 Crack Growth Near Frictional Interfaces

Mechanisms which impede fracture propagation in a reservoir and thereby strongly influence the geometry of created fractures have been of primary interest.

Analyses of the geometry of the fracture and interfaces continued. Changes in the Mode I stress intensity factor as the fracture approaches the interface are shown in Figure 4-5. Changes in the normalized Mode I stress intensity factor have been plotted for five values of $\gamma = \tau_f/p_c$, where τ_f is the initial frictional stress and p_c is the pressure in the crack, assumed to be constant along the axis of the crack. The fracture tip distance from the interface, δ, has been normalized with respect to the fracture length.

As reported in the September Status Report, Figure 4-5 shows that for fracture tip distances greater than $\delta = 1$, the effect of the interface on the fractures is negligible. However, for distances of δ less than 1, the stress intensity factor increases dramatically. This indicates that frictional slip will cause the fracture to be drawn toward the interface. Increasing frictional stress along the interface delays slip until the fracture is closer to the interface. However, for higher values of interface friction, the stress intensity factor increases at a higher rate once slip along the interface has occurred.

Figures 4-6 and 4-7 display changes in the strain on both sides and along the interface for the five values of γ in the coordinate system defined by the interface and the crack. The ordinate is parallel to the frictional interface and the abscissa is parallel to the crack. The strain values are portrayed as a function of η where $\eta = y/2c$ where c is the crack half length, with $\eta = 0$ on a line extended from the crack axis. The values of the strain are portrayed for the crack tip at $\delta = 0.188$. Figure 4-6 shows the strains just to the left and parallel to the interface while Figure 4-7 displays the values to the right of the interface. The effects of changes in friction can be seen by comparison of the strain in the y-direction. The strain has been modified significantly due to frictional slippage. The x components of strain also

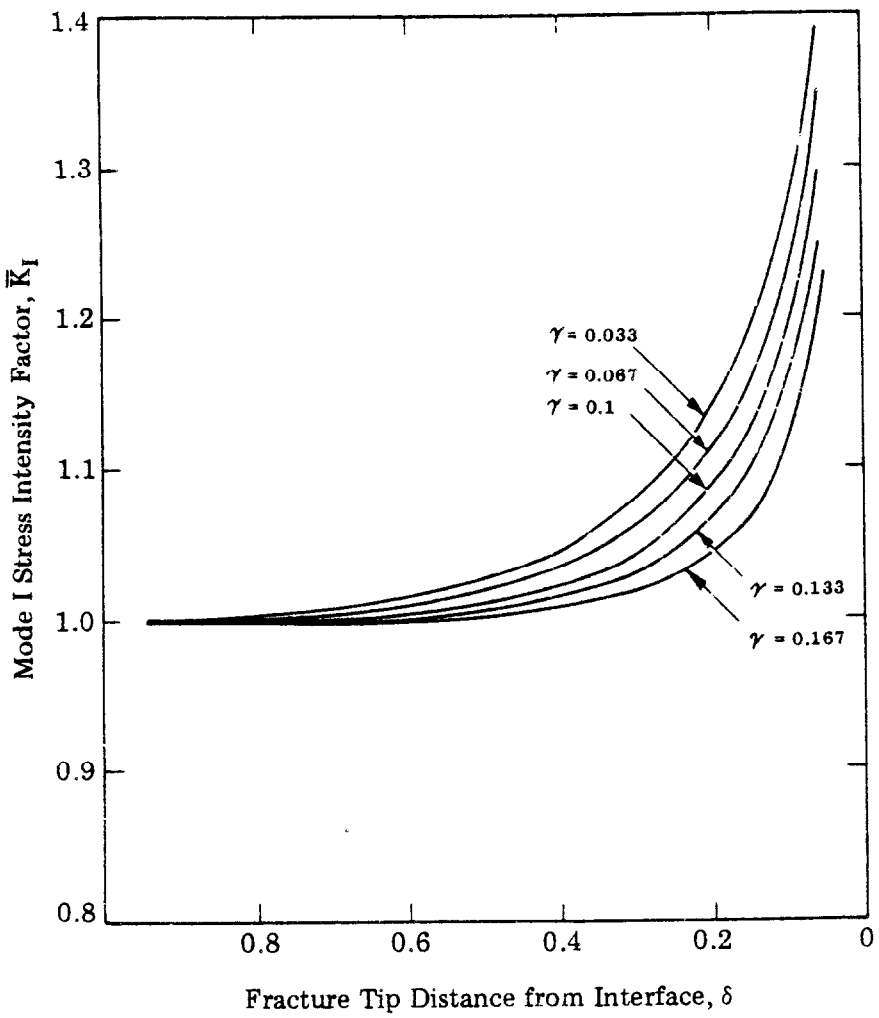


Figure 4-5 Normalized Mode I Stress intensity factor vs. normalized distance of the crack tip from the interface for five values of initial frictional stress along the interface

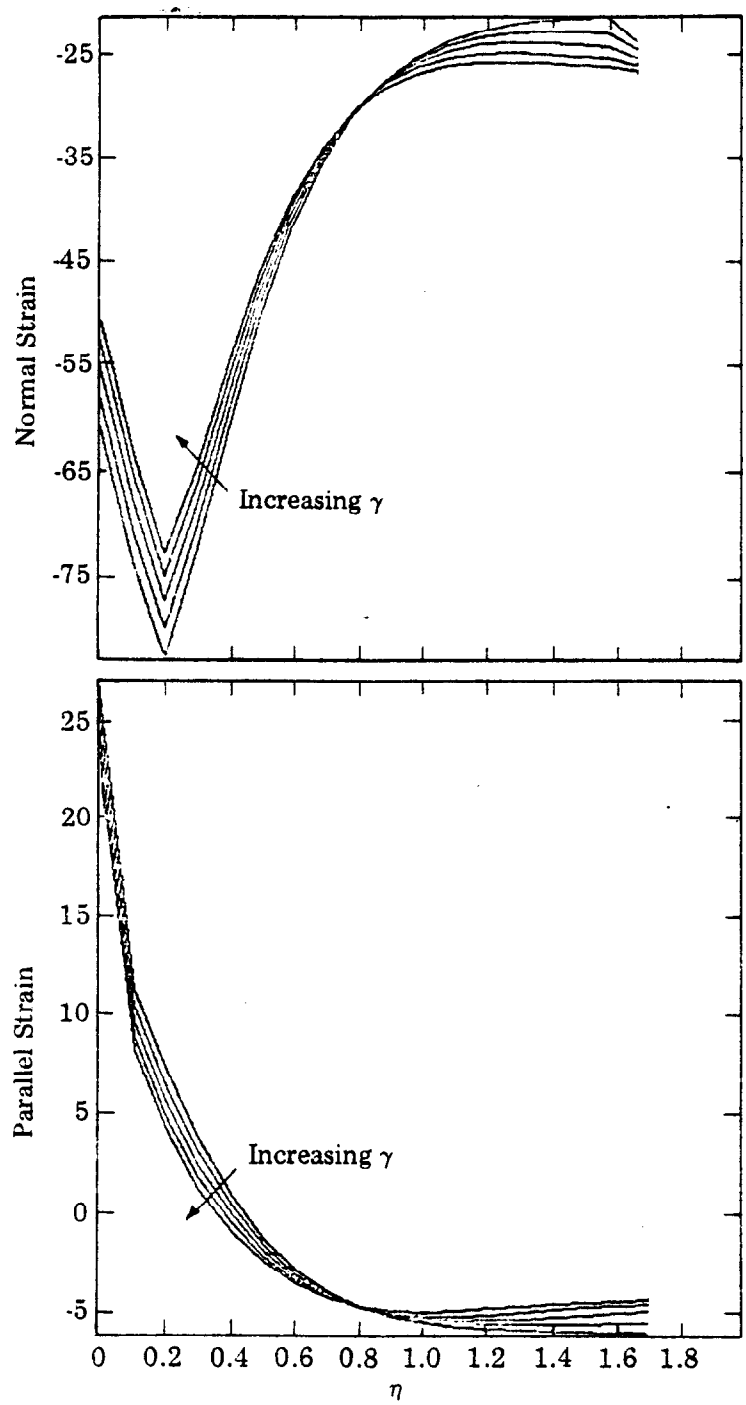


Figure 4-6 Normal strain and parallel strain to the left of the interface for crack tip position = 0.188

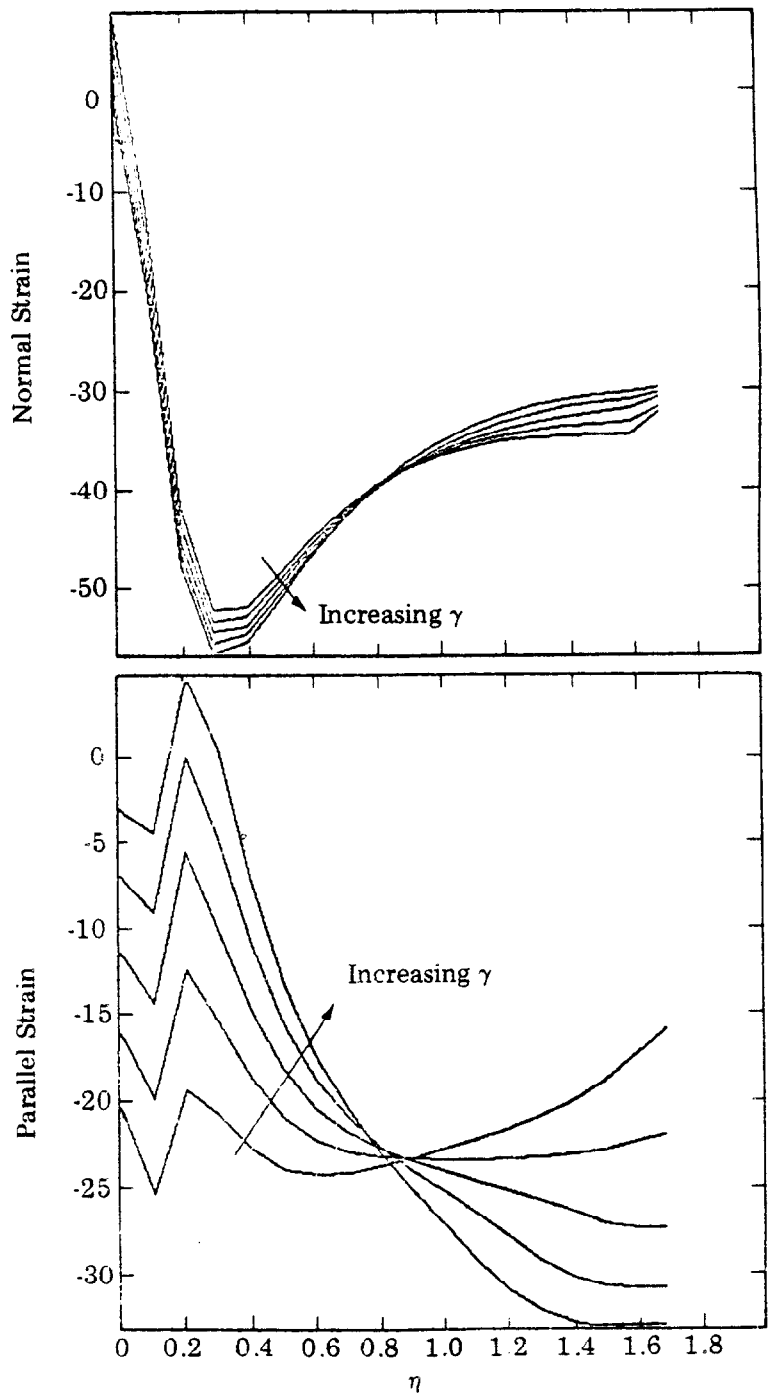


Figure 4-7 Normal strain, EPSX, and parallel strain to the right of the interface for crack tip position = 0.188

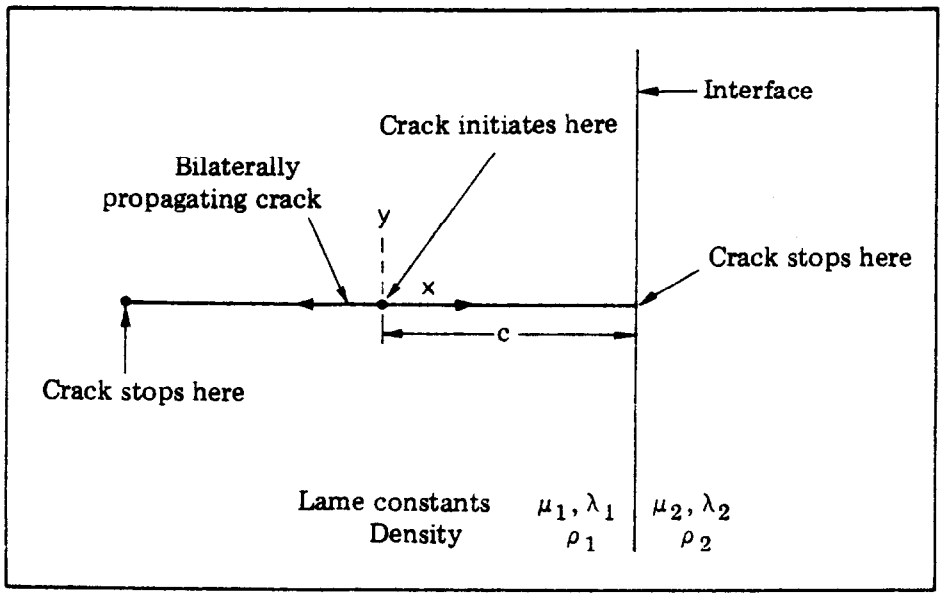


Figure 4-8 Geometry of Time Dependent Crack Problem

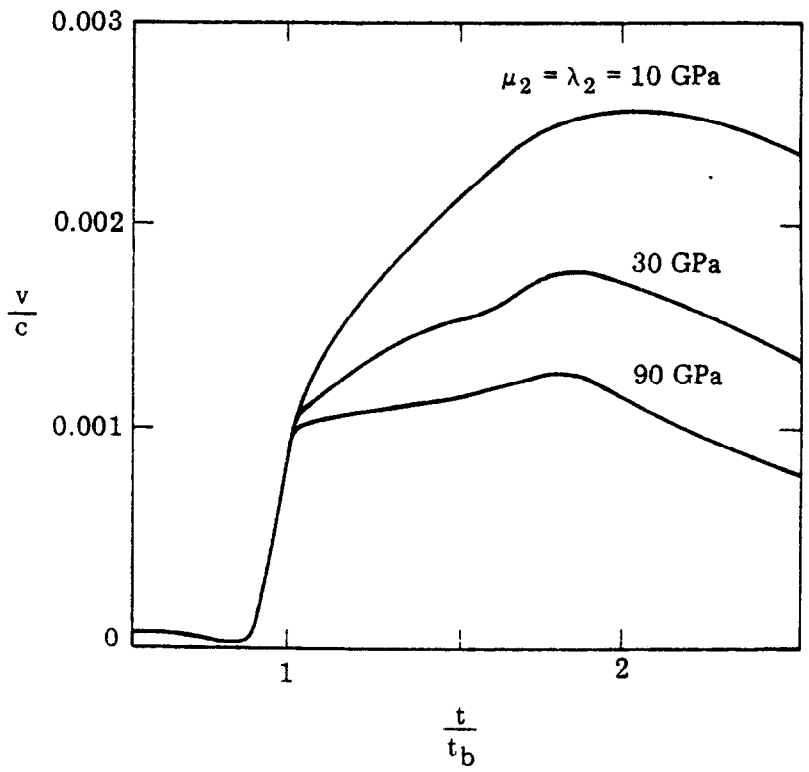


Figure 4-9 Displacement of the point x=0.8c, y-0.1c in the y direction when the crack speed is three tenths of the dilatational wave speed. The elastic constants for material 1 are 30 GPa

display an important aspect of the fracturing process. The existence of a crack in an elastic medium alters both components of strain significantly. It is manifested in the parallel strain near the tip of the crack by a suction-like or pulling tendency. Material directly ahead of the crack tip is drawn or pulled toward the tip. This alters the frictional stress along the interface since frictional stress is a linear function of normal stress. Hence, as the fracture tip nears the interface, it tends to reduce the normal stress across the interface, thereby decreasing the frictional stress. This phenomenon contributes to the rapid increase in the Mode I stress intensity factor as the fracture approaches the interface.

4.3.1.2 Dynamic Crack Growth

Analysis continued in October on a bilateral crack that propagated at half the dilational wave speed until the tip reached an interface and crack propagation ceased. (See Figure 4-8).

To determine the effects of crack velocity on the overshoot characteristics, the crack velocity was decreased to .3 C_p, where C_p is the dilatational wave speed, and the calculations, as given in the September report, were repeated. Results are shown in Figure 4-9. Displacement in the y-direction, v, is nondimensionalized with the final crack half length, c. Although it was found that the maximum displacements were essentially of the same magnitude as in the previous case, the time scale was shifted. Maximum displacement occurred at about 2 t_b when the crack speed was 0.3 C_p. Since the magnitudes of the maximum displacements are about the same, it is expected that the likelihood of fracture penetration through the interface would not be strongly dependent on crack velocity.

4.3.1.3 Fluid Flow-Crack Growth Interaction

Equations needed to describe the interaction between crack growth and the fluid motion inside a hydraulically driven fracture were formulated and will be dependent on numerical considerations. Therefore, related work was begun to determine if reasonable numerical techniques exist in the literature.

Initial work will be 2-dimensional, coupling an analytic solution for crack displacement to a numerical code that will calculate the pressure distribution on the crack face due to fluid motion.

Displacement for a crack of length 2c, subject to an internal pressure distribution P_oP_1 (x), can be written as[3]

$$u_y(x,0) = b \int_{x/c}^{1} \frac{t\, q_1(t)\, dt}{t^2 - x^2/c^2}$$

---

[3] Sneddon, I. N., and M. Lowengrub, "Crack Problems in the Classical Theory of Elasticity," John Wiley & Sons, Inc., (1969).

where

$$b = \frac{2\ (1-\eta^2)\ P_o c}{E}$$

$$q_1(t) = \frac{2}{\pi} \int_0^t \frac{P_1\ (u)\ du}{t^2 - u^2}$$

u_y = displacements of crack face

E = Young's modulus

η = Poisson's ratio

c = half crack length

A means to integrate this solution numerically has been developed and will be tested in the near future.

For the fluid motion, the incompressible form of the Navier-Stokes equations will initially be used. Isothermal flow will be assumed in order to neglect an energy equation, at present. With these assumptions the necessary equations are[4]

$$\frac{\partial u_i}{\partial x_i} = 0$$

$$\rho \frac{Du_i}{D_t} = \rho g_i - \frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_i} \left[\mu \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right]$$

where u_i = velocities, ρ = density.

If the viscosity, μ, is constant, the last term reduces to $V^2 \bar{v}$. The calculation will involve the iterative solution of $u_y(x,0)$ and P for each time step.

---

[4] White, Frank M., "Viscous Fluid Flow," McGraw-Hill Book Co., (1974).

One possible means to solve the Navier-Stokes equations is to write them in terms of a potential function. A code from Los Alamos[5], which uses the SMAC (Simplified MAC) method, has been acquired and is being run. This will be used to gain experience in one possible way of proceeding numerically, in addition to some physical effects.

4.3.2 Experimental Program

Experimentation on crack growth across unbonded interfaces continued in October (See Figure 4-10). If two perpendicular cracks, C_1 and C_2, are separated by 1 in. in a 4-in. wide block experiment, a hydraulically driven crack will not grow as readily in the region between the two cracks as it will in the lower block. However, when the separation of C_1 and C_2 is increased to 2 inches, the hydraulically driven crack more readily crosses the interface and penetrates the region between the two cracks C_1 and C_2. In these experiments, the applied load W is such that the normal stress across the interface exceeds the average threshold stress by about 25 percent for crack growth across the interface without C_1 and C_2.

4.3.3 Rock Mechanics Measurements

Pressure-volume measurements (confining pressure up to 1.2 GPa) continued during October on Mesaverde shale and Rio Blanco sandstone samples. Jacketing of Mesaverde sandstone from Wyoming for failure envelope measurements was completed. Work was begun on plumbing the high pressure system for simultaneous ultrasonic velocity measurements in multiple directions up to a pressure of 1.0 GPa.

4.3.4 Geology and Geophysics

Work continued on the compilation of stratigraphy and structure of upper Cretaceous shorelines and the major fault zones. A preliminary review of data on the evaluation and stress history of some western gas sands was prepared.

4.3.5 Schedule Status

Figure 4-11 is a milestone chart depicting LLL's WGSP status.

4.4 LOS ALAMOS SCIENTIFIC LABORATORY

4.4.1 Nuclear Magnetic Resonance Studies

Figure 4-12 is a cross section of a tool design under consideration, with a plot of the magnetic field strength within the homogeneous "resonance" region and the NMR resonant frequency as a function of radial distance from the borehole centerline and depth into the

---

[5] "The SMAC Method: A Numerical Technique for Calculating Incompressible Fluid Flows." Los Alamos Scientific Laboratory, Los Alamos, NM, LA-4370, (1970).

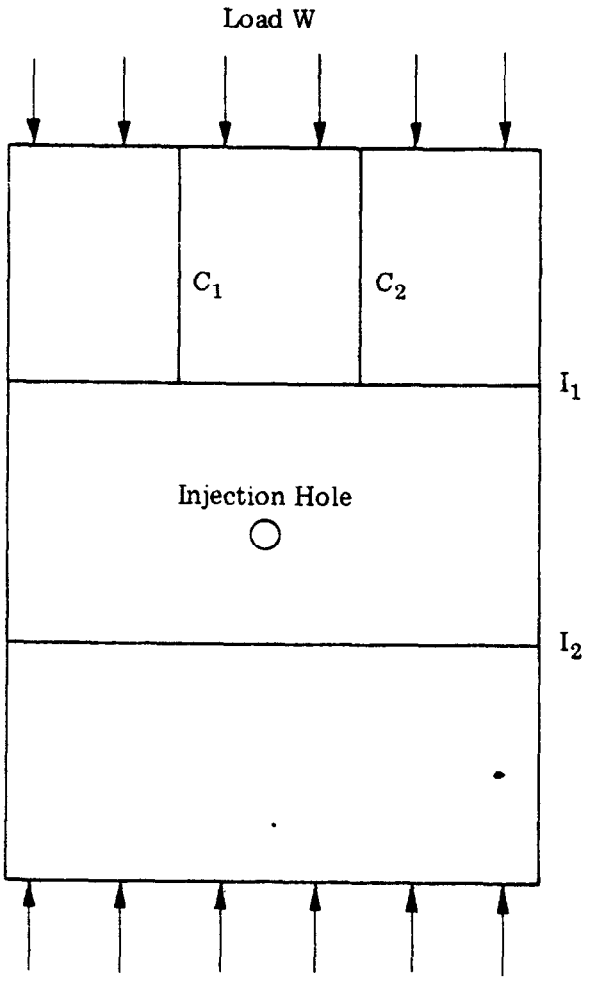
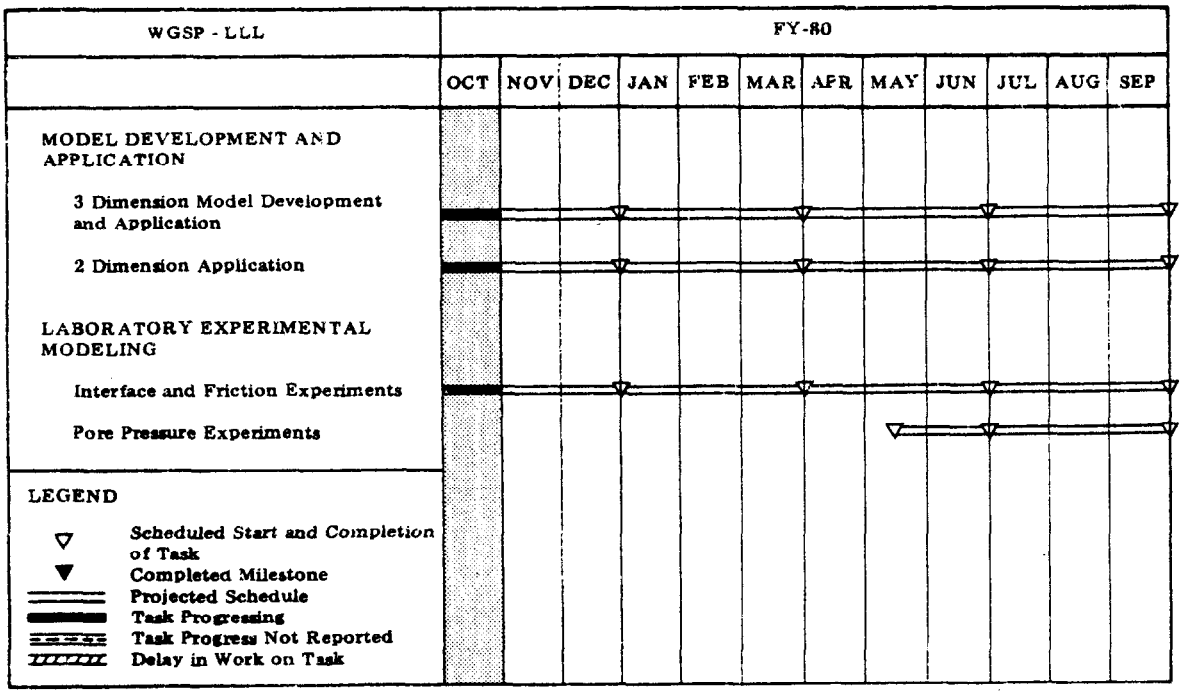


Figure 4-10 Experimental Setup to Study Crack Growth



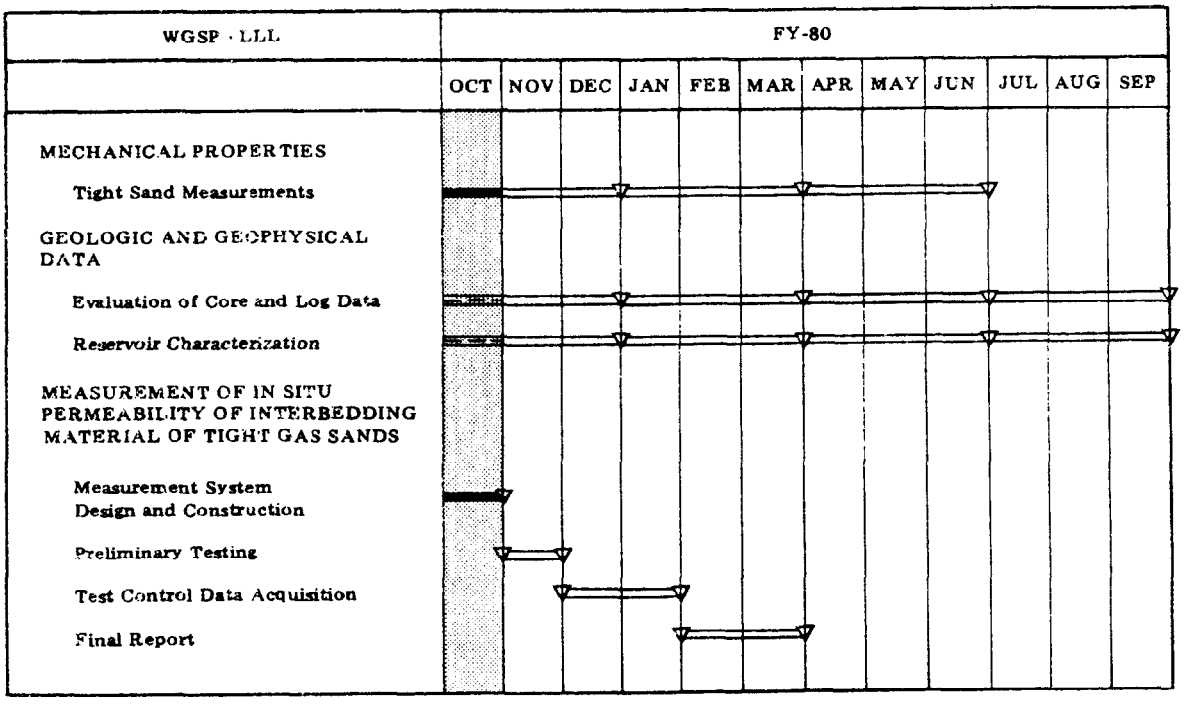


Figure 4-11 Milestone Chart — LLL

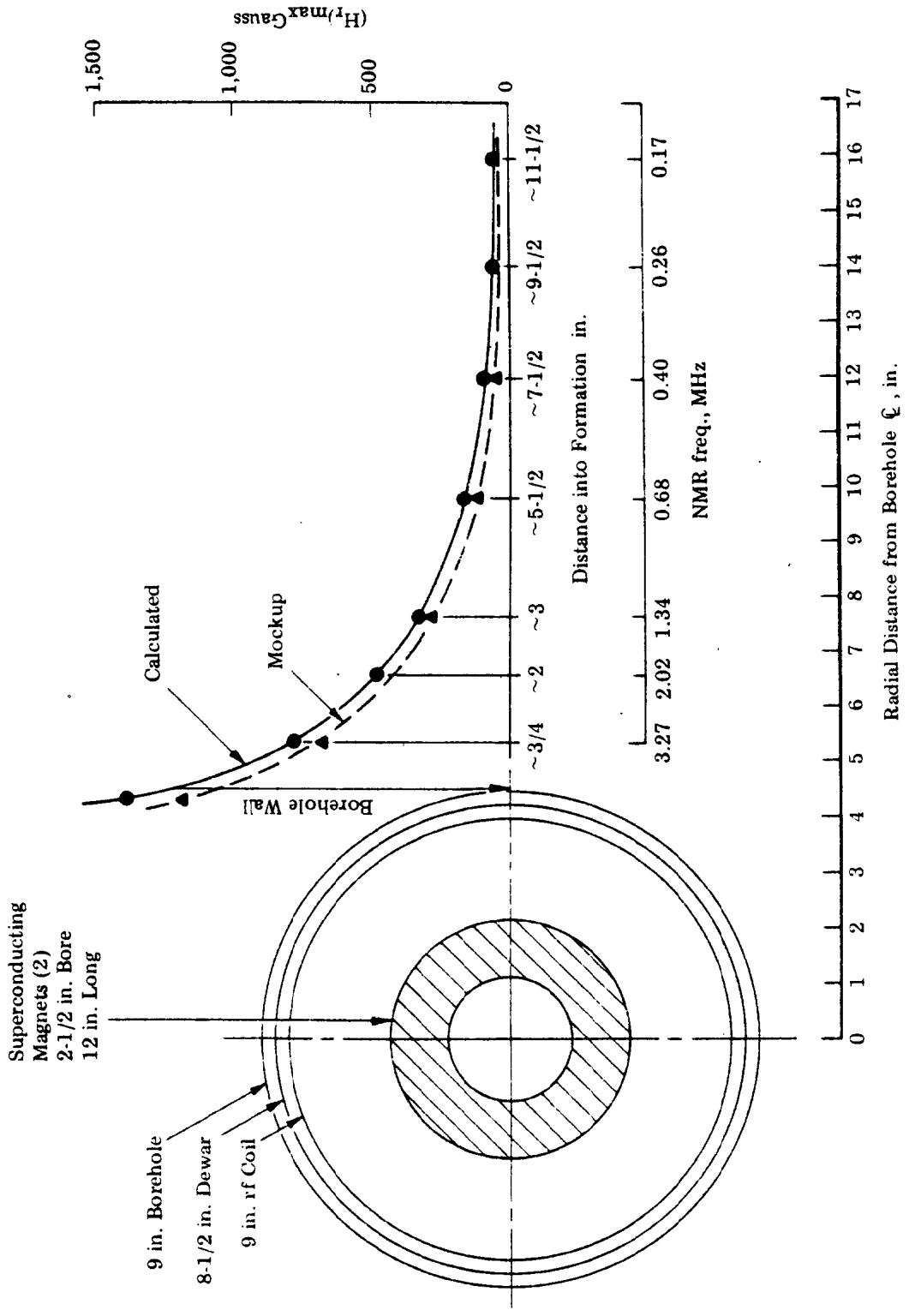


Figure 4-12 Cross Section of Design of Improved Downhole Nuclear Magnetic Resonance Tool

formation. The solid line shows the result of computer calculations and the dotted line shows measurements on a normal wire mockup of the super-conducting magnets which were scaled to the fields in the super-conducting case.

The NMR signal-to-noise ratio (S/N) for distances into the formation surrounding the well-bore was estimated by using 8 in. diameter rf coil experimental data. The experiments, which estimated the S/N from a tool using superconducting magnets, were conducted using a fixed toroid and varying the size of the rf coil. The results suggest that (S/N) varies as $(R/a)^{-5}$. For the normal case where a (radius of magnet) is constant and R (radius of torus) varies, (S/N) should vary as $(R/a)^{-2}$, since the width ΔR of the "resonance" region varies directly with R and the resonance volume $V \propto R(\Delta R)^2 \propto (R)^3$. With all other factors constant, $(S/N) \propto (1/R)^2$.

The 8 in. coil electromagnet data (S/N = 4.5:1 in 18 sec) were taken at a frequency of 0.5MHz and a toroidal radius of 14 cm (5.51 in.). Therefore, the S/N to be expected at a radius R and frequency f is estimated as follows:

$$(S/N) = 4.5 \times (5.51/R)^2 \times (f/0.5)^2$$

Using Figure 4-12, R = 11.93 inches:

$$H_r = 94 \text{ Gauss}, f = 0.4 \text{ MHz}$$

$$(S/N) = 4.5 \times (5.51/11.93)^2 \times (0.40/0.50)^2 = 0.61 \text{ in } 18 \text{ seconds}$$

S/N can then be calculated for other times using the relation

$$(S/N)_2 = (S/N)_1 \sqrt{T_2/T_1}.$$

If S/N was expected in 1 sec instead of 18 sec, then

$$(S/N)_1 = (S/N)_{18} \sqrt{1/18} = 0.61 \times 1/4.24 = 0.14$$

The electromagnetic experiments were not conducted under ideal conditions, so the following estimates of predicted improvements in S/N were applied:

- It is believed that due to field inhomogeneity around the torus, approximately 25 percent was effective in producing a signal. This deficiency will be corrected in a working tool, and a factor of four was applied to account for the expected increase.

- The noise level was quite high and far from optimum. It is estimated that about one-half of the observed noise was due to 60 Hz pickup and will be eliminated in a carefully designed tool. A factor of two was applied.

- The remaining noise could be reduced through careful design, particularly by using superconducting magnets. Noise levels could be reduced through cryogenic fluids which would cool the magnets. If all the noise in the electronic devices was thermal, then the S/N reduction would be expected to vary.

$$\text{as } \frac{1}{T}\text{; i.e. S/N} \propto \frac{300}{4} = 75.$$

A conservative estimate of the expected S/N gain would be to assume that the noise decreases as $\sqrt{T}$ instead of T. This results in (S/N) $\propto \sqrt{300/4} = \sqrt{75} = 8.7$. For ease of calculation, a factor of 10 was applied. However, there is a possibility that use of liquid helium could yield greater sensitivity of modern quantum interference devices to gain a larger increase in S/N.

Results of these factors are given in Table 4-4. The signal integration time for a given S/N at a particular depth is shown in Figure 4-13.

A factor which has not been included is the correction for the ratio (R/a) when extrapolating from the 4 in. electromagnet to the superconducting magnet with 2-1/2 in. bore. The effective diameter (about average diameter of windings) of the superconducting magnet was 3 in. in the calculations. The width R of the "resonance" region is directly proportional to (R/a), where a is the radius of the magnet. Therefore, the torus width will be 4/3 larger with the 3 in. superconducting magnet. The toroidal area will be larger by $(4/3)^2 = (1.33)^2 = 1.78$, and the S/N will be 78 percent larger with the superconducting magnet. This factor provides a conservative estimate.

4.4.2 Schedule Status

Figure 4-14 is a milestone chart depicting LASL's WGSP status.

4.5 SANDIA LABORATORIES

4.5.1 EGR Instrumentation and Diagnostic Program

4.5.1.1 Hydraulic Fracture Characterization

A downhole current injection probe, approximately 18 ft long, has been designed for use with the surface electrical potential system (SEPS). The injection electrode is 12 ft of 1-1/2 in. diameter stainless steel rod stock and is separated from the wireline by 7 ft of steel-reinforced hydraulic hose, bonded at each end and backed up with two special hose clamps. The probe is designed to operate to 250°F and is scheduled for use in December by Shell Oil at Lake Texoma, Texas.

Table 4-4 Summary of Performance Estimates for NMR Logging Tool

Radius cm (in.)	Dist. into Form (in.)	(Br) Bo	B_r (Gauss)	f MHz	(1) $(R/R_1)^2$	(2) $(f/0.5)^2$	(3) Relative (S/N) (1) x (2)	Signal to Noise Ratio in 18sec (x4.5) *	W/x4 for complete torus*	W/20:1 Noise Reduction in 18 sec. *	Signal to Noise Ratio in 1 sec. *	Time (S/N=2)	Time (S/N=4)	Time (S/N=8)	Time (S/N=16)
10.6 (3.9)		0.0703	1,406	5.98	1.66	143.00	237.0	1,066							
13.65 (5.37)	.87	0.0384	768	3.27	1.00	42.77	42.8	192	~800	16,000	3,771	.2 μsec	1.120 μsec	4.50 μsec	18.00 μsec
16.55 (6.52)	2.00	0.0237	474	2.02	0.68	16.32	11.1	50	200	4,000	943	4.5 μsec	18.000 μsec	72.00 μsec	.29 μsec
19.40 (7.64)	3.14	0.0157	314	1.34	0.49	7.18	3.52	16	64	1,280	302	4.4×10^5 0.44 msec	.170 msec	0.68 msec	2.72 msec
24.90 (9.8)	5.30	0.0080	160	0.68	0.30	1.85	0.56	2.5	10	200	47.14	.018 sec	0.072 sec	0.29 sec	1.20 sec
30.30 (11.93)	7.43	0.0047	94	0.40	0.20	0.64	0.13	0.6	2.4	48	11.31	0.031 sec	0.120 sec	0.48 sec	2.00 sec
35.60 (14.02)	9.52	0.0030	60	0.26	0.15	0.27	0.041	0.18	0.72	14.4	3.39	0.350 sec	1.400 sec	5.60 sec	22.90 sec
40.80 (16.06)	11.56	0.0020	40	0.17	0.11	0.12	0.0013	0.06	0.24	4.8	1.13	3.130 sec	12.500 sec	50.00 sec	200.00 sec

* Extremely high S/N figures are for relative calculations only.

UGR File #216
October 1979
DOE/BC/10003-1
CER Corporation

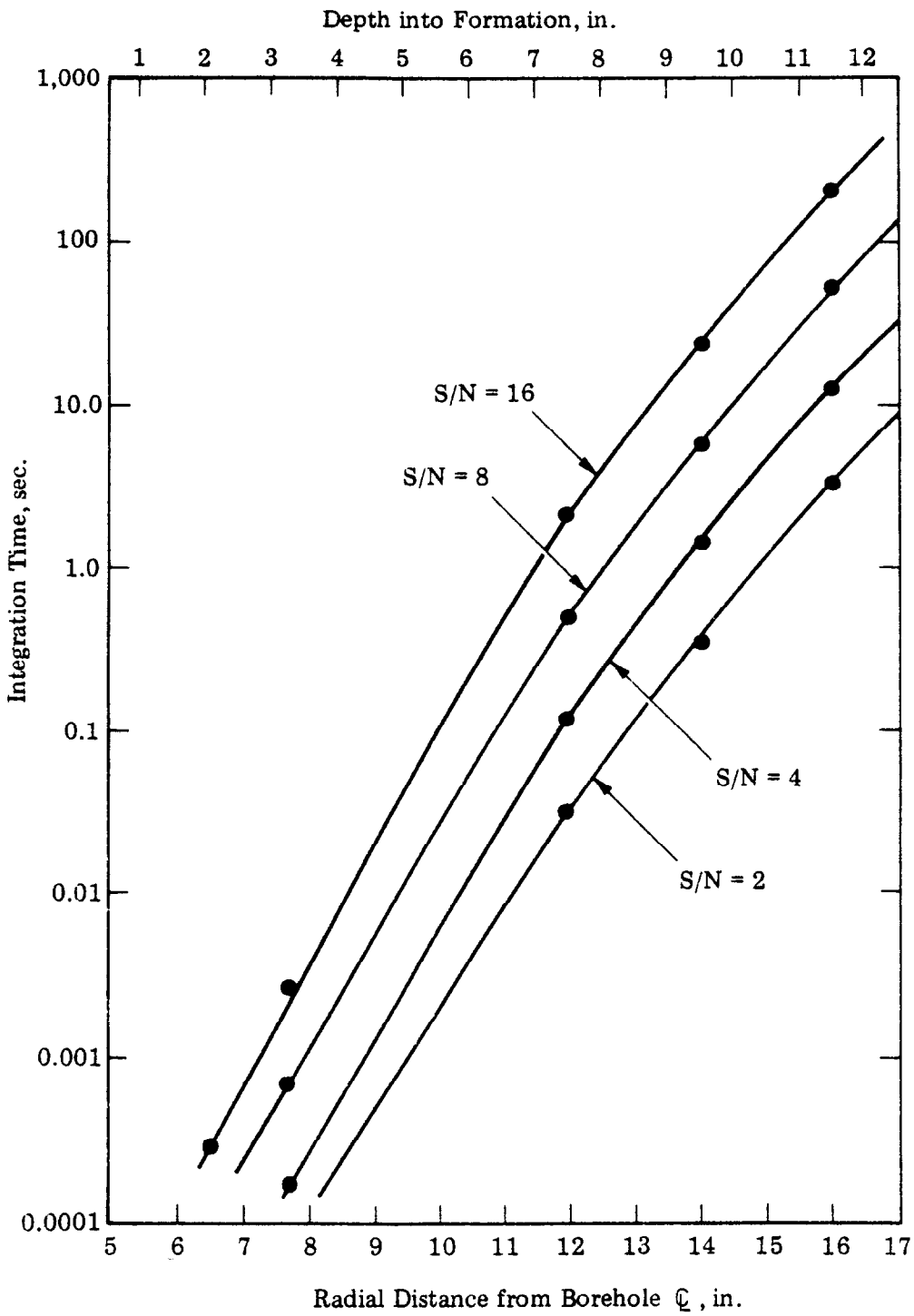
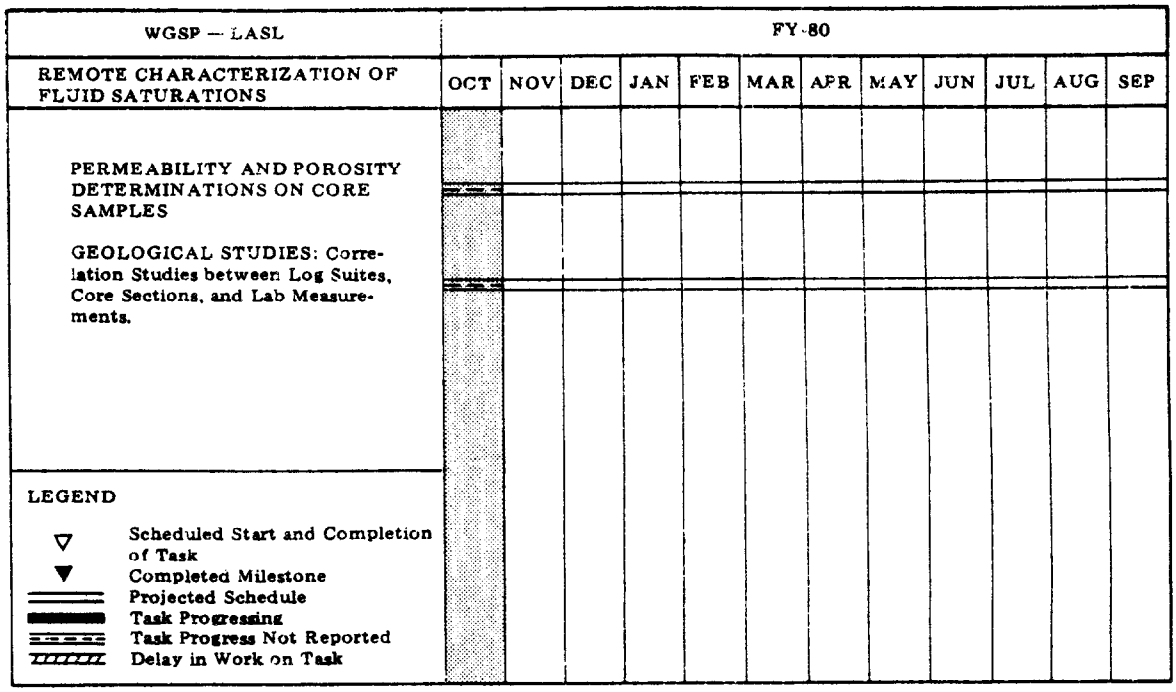


Figure 4-13 Signal Integration Time for Given S/N Ratios At Particular Depths



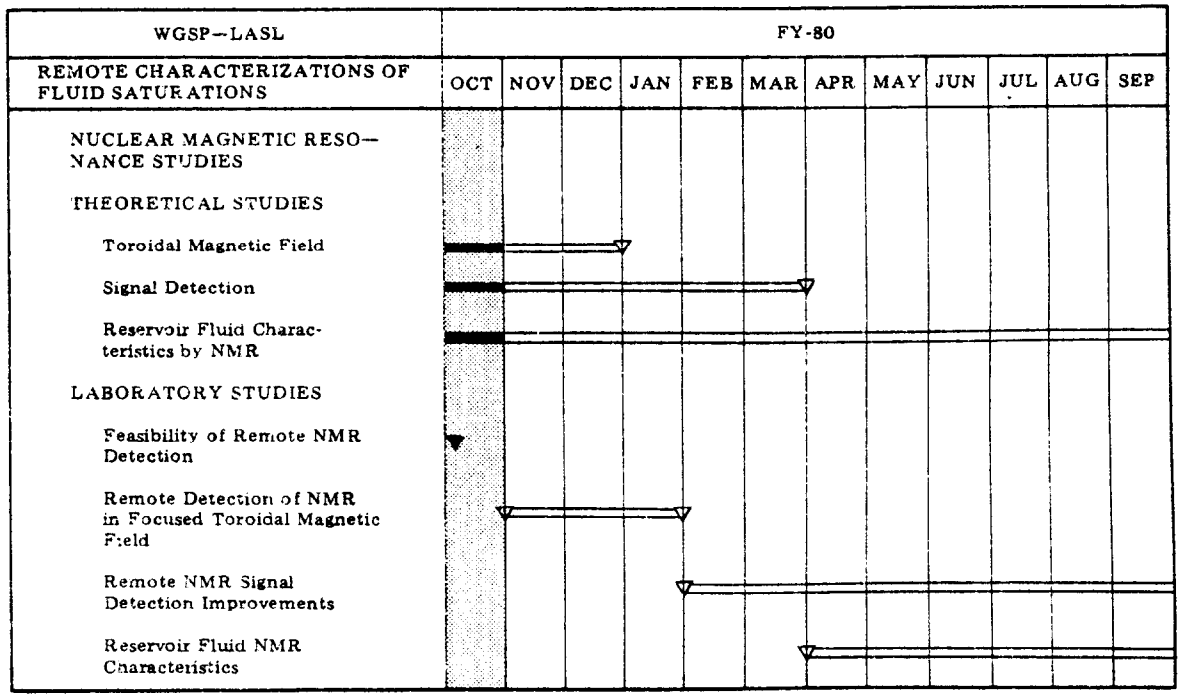


Figure 4-14 Milestone Chart — LASL

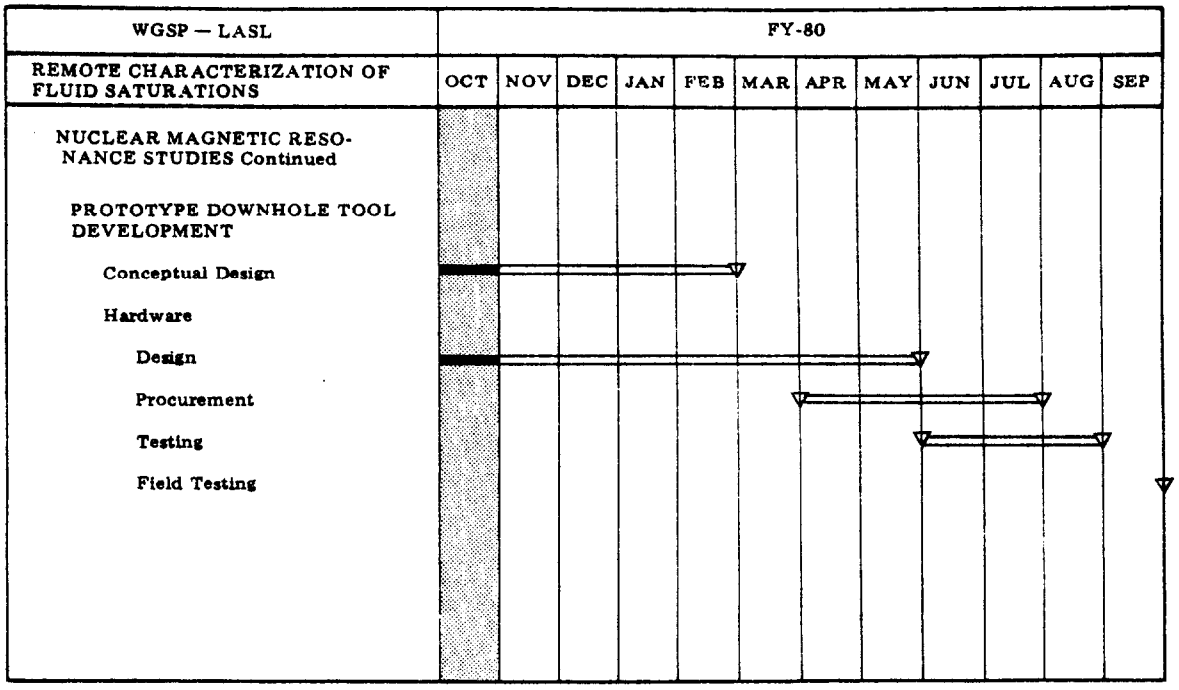


Figure 4-14 Continued

4.5.1.2 Borehole Seismic System

Programs are being developed for the PDP-11 mini-computer for use in the acquisition and analysis of borehole seismic data. These programs will perform the following functions:

- real-time acquisition and graphic presentation,
- acquisition from magnetic tape and graphic presentation, and
- post-test analysis with graphic and tabular data presentations.

A 4-channel track-and-hold system has been installed as an interface between the analog seismic system and the PDP-11 mini-computer to eliminate phase errors introduced by sequential sampling. This system will be mobilized for the Amoco experiment in November.

4.5.1.3 Borehole Hydrophone System

Some analyses have been made of the data from the Sandia borehole test in area Y. The hammer blow series has been digitized and plotted and various ranges of bandpass filtering were included. A sampling period of 1 millisecond was used. Although the Nyquist frequency of this sampling rate was approximately 400 Hz, most of the energy of the signals was in the range of 100 to 200 Hz. The data was taken from hammer blows at 20 ft and 50 ft, then in 50-ft intervals to 300 ft. At 20 ft and 50 ft, the early part of the signals showed frequency content in the range of 600 to 700 Hz. However, because of the sampling rate used, very little above 400 Hz was clear. Some of the signals at 100 ft and 150 ft distances were examined in more detail and clearly showed measurable differences in arrival times at the hydrophones. However, higher frequency sampling rates are required in determining the location of signal sources with any degree of accuracy.

Assembly of the ITC system has started. A flexible cable has been designed and built in place of the 10-ft rigid center section. This will increase the ease in handling and storing of the tool.

4.5.1.4 Formation Mapping

Crew unavailability has further delayed the initiation of seismic field testing. Completion of the topographic surveying of the 2,700 station points at Bryson Canyon site has also been delayed; however, this task should be underway by early November.

With the cooperation of C K GeoEnergy, a basic geometric model of channel size (primarily height and width), as well as frequency in various members of the Mesaverde Group have been established. This information, together with available sonic and density log data from nearby wells, will be used to provide information as to channel shape and size effects on the resolution of seismic data. This seismic modeling program will be carried out with the cooperation of the seismic stratigraphy group at USGS (Denver).

4.5.1.5 Electromagnetic Logging

In the September WGSP status report, it was stated that a histogram distribution function, A(k), fit the dielectric data of Poley, et al. During October, this function was transformed into a distribution function of pore shapes using the techniques of Sillars.

Sillars modeled a composite dielectric as being a nonconducting matrix material with spheroidal inclusions. In Sandia's work, this matrix is quartz and the inclusions are pores. Pores come in various shapes and are represented as spheriods with different unique, a, and nonunique, b, dimensions. Table 4-5 gives an example of aspect ratios calculated from A(k) for rocks of nearly the same porosity (12.7 vs. 12.9 percent). The dielectric response of these two rocks was considerably different.

The inverse process for determining constitutive parameters is unique in that only one set of parameters will be found if the two inherent assumptions are valid. These assumptions are:

- An earth formation is linear, isotropic, and homogeneous; and

- Coils are single-turned, coaxially aligned, and small enough to support only dipole mode couplings.

Table 4-5 Aspect Ratios calculated from A(k)

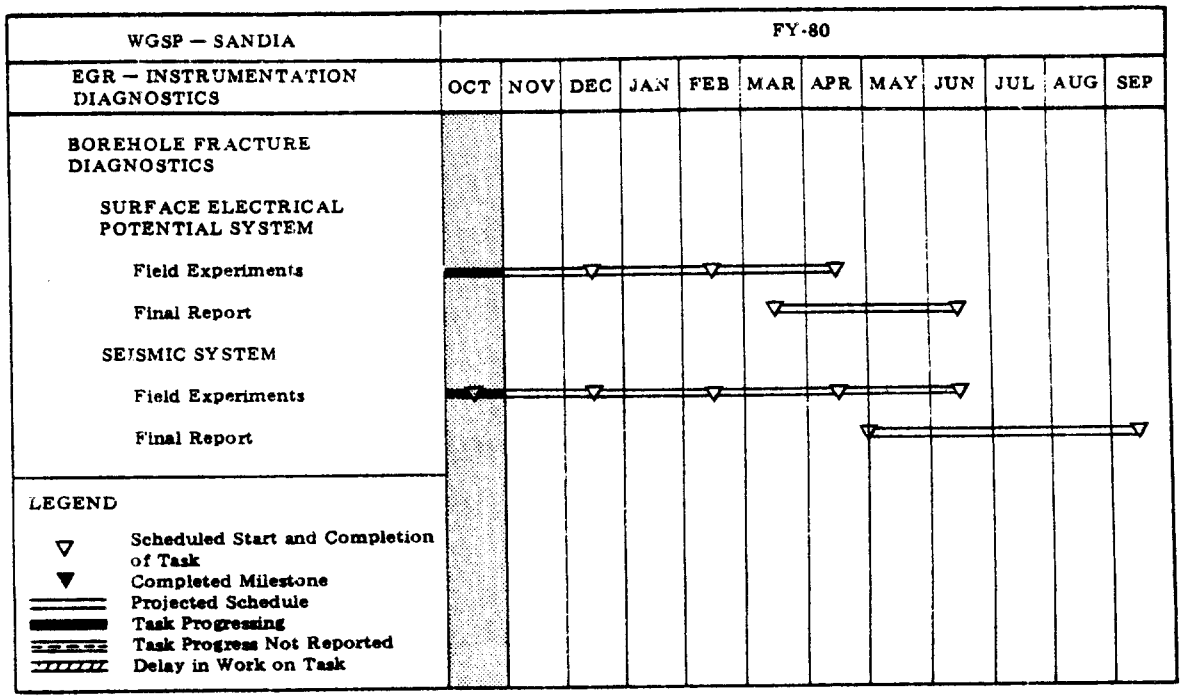
	Specimen .127		Specimen .129	
Range, a/b	Volume Fraction, Φ_i	$(\Phi_i/\Phi) \times 100$	Volume Fraction, Φ_i	$(\Phi_i/\Phi) \times 100$
1 to 1	.1219	96.0%	.1084	84.0%
10 to 48	.0033	2.6	.0160	12.4
48 to 180	.0018	1.4	.0046	3.6

Practical implementations will encounter difficulties in meeting these assumptions. The assumption for an earth formation can be relaxed somewhat by a less stringent assumption, i.e., to allow a borehole with a cylindrical surface separating two zones. The constitutive parameters of these zones are allowed to be distinct, although each set will still be under the original assumption. The inverse process for determining the constitutive parameters of the formation outside the borehole is being established by assuming the medium inside the borehole is known across the entire operating frequencies. The last assumption is not trivial in practice, for borehole fluids are not known to have been characterized *in situ*. Rather, most investigators have assumed that borehole-fluid effects are negligibly small in altering coil responses. If this assumption is true, the inverse process for a homogeneous earth would readily apply for a bored formation. Work planned for November will give quantitative results, indicating to what extent the assumption can be accepted.

Currently, all the numerical integrations are performed by Science Applications, Inc. (SAI) under a Sandia contract. The two-zone solution has been coded, as analytically required and reduced to the homogeneous solution already reported. Because of the slow convergence under the original form of solution, it has been concluded that an extensive transformation using analytic continuity is warranted.

4.5.1.6 Schedule Status

Figure 4-15 is a milestone chart depicting Sandia Laboratories' WGSP progress.



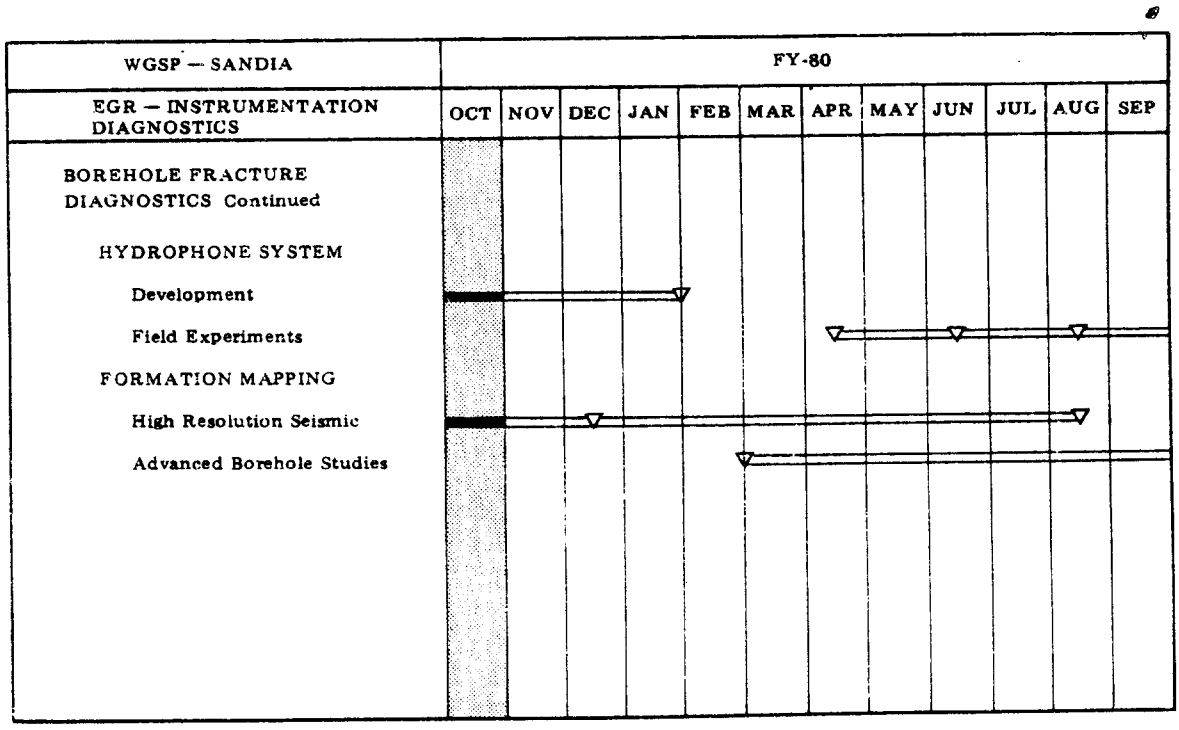


Figure 4-15 Milestone Chart — Sandia

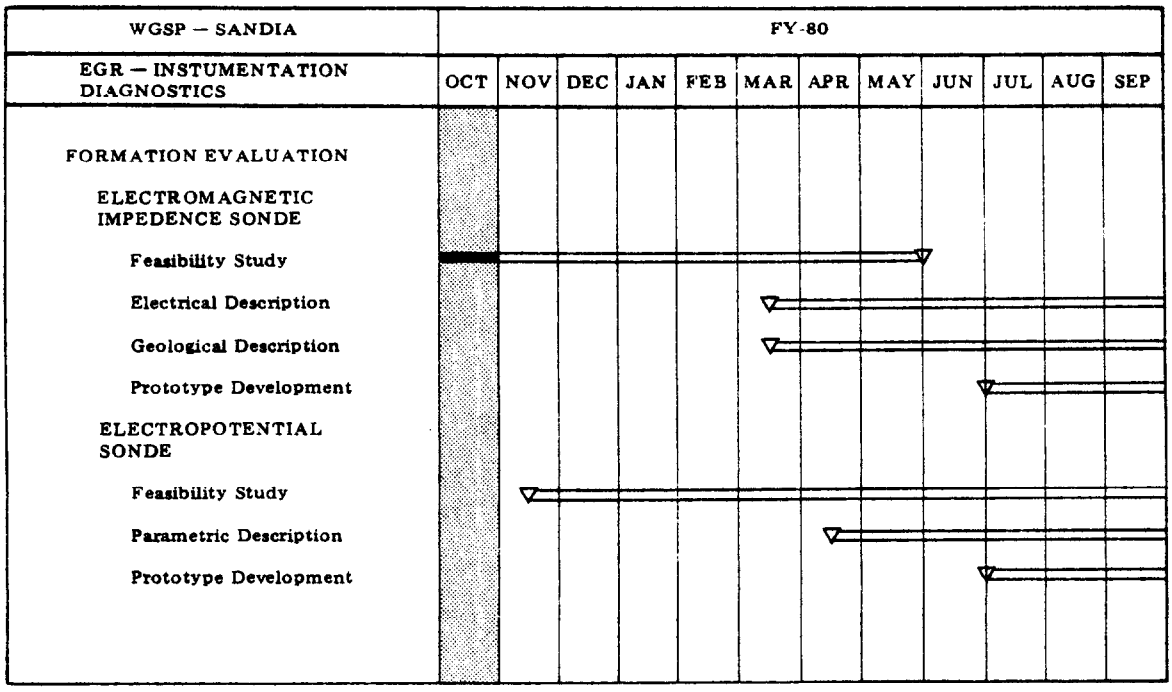


Figure 4-15 Continued

5. FIELD TESTS AND DEMONSTRATIONS

5.1 BACKGROUND

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

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

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

Table 5-1 MHF Contract Location and Frac Data

Company Basin & Formation	Location T/R/Sec	Well	Interval Fractured ft	Fracture Date	Fracture Treatment Lb of Sand	Injected Fluid 10^3 Gal	Production Rates MCFD Before	After	Ratio
AUSTRAL Piceance, Mesaverde	7S/94W/Sec 3 Garfield Cty, Colorado	Federal 3-94	6,198-6,333	8-13-76	420,000	226 Gel	35	62	1.8
			5,170-5,630	8-25-76	720,000	316 Gel			
CONSORTIUM MANAGED BY CER CORPORATION Piceance, Mesaverde	3S/98W/Sec 11 Rio Blanco Cty, Colorado	RB-MHF-3	8,048-8,078	10-23-74	400,000	117 Gel	60	60	—
			7,760-7,864	05-02-75	880,000	285 Gel	—	40	—
			5,925-6,016	04-04-76	815,000	400 Gel	42	160	3.8
			5,851-5,869	11-03-76	448,000	228 Gel	57	70	1.2
DALLAS PRODUCTION Fort Worth, Bend Cong.	Ben D. Smith Survey A-779 Wise Cty, Texas	Ferguson A-1	5,957-6,794	09-16-76	506,000	139 Foam 198 Emul	40	15	—
EL PASO NATURAL GAS Northern Green River, Fort Union	30N/108W/Sec 5 Sublette Cty, Wyoming	Pinedale Unit No. 5	10,950-11,180	07-02-75	518,000	183 Emul 8 Gel	150	340	2.3
			10,120-10,790	10-20-75	1,422,000	459 Gel	—	150	—
GAS PRODUCING ENTERPRISES, INC. Uinta, Wasatch and Mesaverde	10S/22E/Sec 10 Uintah Cty, Utah	Natural Buttes No. 18	6,490-8,952	09-22-76	1,480,000	745 Gel	—	1,400	—
	10S/21E/Sec 21 Uintah Cty, Utah	Natural Buttes No. 19	8,909-9,664	09-21-76	424,000	280 Gel	—	166	—
			7,224-8,676	09-28-76	784,000	364 Gel			
	9S/21E/Sec 22 Uintah Cty, Utah	Natural Buttes No. 14	6,646-8,004	03-15-77	1,093,000	544 Gel	38	800	21.0
	9S/21E/Sec 28 Uintah Cty, Utah	Natural Buttes No. 20	8,498-9,476	06-22-77	826,000	322 Gel	75	1,200	16.0
	10S/22E/Sec 18 Uintah Cty, Utah	Natural Buttes No. 22	6,838-8,550	11-21-77	1,151,000	499 Gel	—	700	—
	9S/22E/Sec 19 Uintah Cty, Utah	Natural Buttes No. 9	5,661-8,934	03-27-78	554,000	349 Gel	140	540	3.9
	10S/21E/Sec 29 Uintah Cty, Utah	CIGE No. 2	9,237-9,653	06-22-78	170,500	203 Gel			
			7,251-8,774	08-08-78	1,965,000	722 Gel			
	10S/22E/Sec 7 Uintah Cty, Utah	Natural Buttes No. 23	5,080-6,294	10-04-78	470,000	240 Gel	—	800	—
MITCHELL ENERGY Cotton Valley, Limestone Trend	Limestone Cty, Texas	Muse-Duke No. 1	11,235-11,418	11-15-78	2,800,000	891 Gel	2,000	6,600	3.3
MOBIL Piceance, Mesaverde	2S/97W/Sec 13 Rio Blanco Cty, Colorado	F31-13G	10,549-10,680	06-22-77	580,000	316 Gel	300	800	2.7
			9,392-9,538	08-24-77	600,000	260 Gel	700	2,600	3.7
			8,765-8,972	05-10-78	388,000	150 Gel	479	430	—
			8,163-8,650	07-06-78	660,000	288 Gel	—	360	—
			7,704-7,794	09-07-78	218,000	120 Gel	—	180	—
			7,324-7,476	11-15-78	700,000	365 Gel	1,000	2,000	2.0
PACIFIC TRANSMISSION Uinta, Mesaverde	8S/23E/Sec 25 Uintah Cty, Utah	Federal 23-25	NO FRACTURES PERFORMED						
RIO BLANCO NATURAL GAS Piceance, Mesaverde	4S/98W/Sec 4 Rio Blanco Cty, Colorado	Federal 498-4-1	6,150-6,312	10-22-76	766,000	276 Gel	57	130	2.3
			5,376-5,960	11-30-77	243,000+ 22,500 Beads	164 Gel	80	350	4.4
WESTCO Uinta, Mesaverde	10S/19E/Sec 34 Uintah Cty, Utah	Home Fed. No. 1	10,014-10,202	12-21-76	500,000	248 Gel	33	155	4.7
			7,826-9,437	10-01-76	600,000	412 Gel	40	Water	—

UGR File #216
October 1979
DOE/BC/10003-1
CER Corporation

RIO BLANCO MASSIVE HYDRAULIC FRACTURING EXPERIMENT

EY-76-C-08-0623

CER Corporation
Las Vegas, Nevada

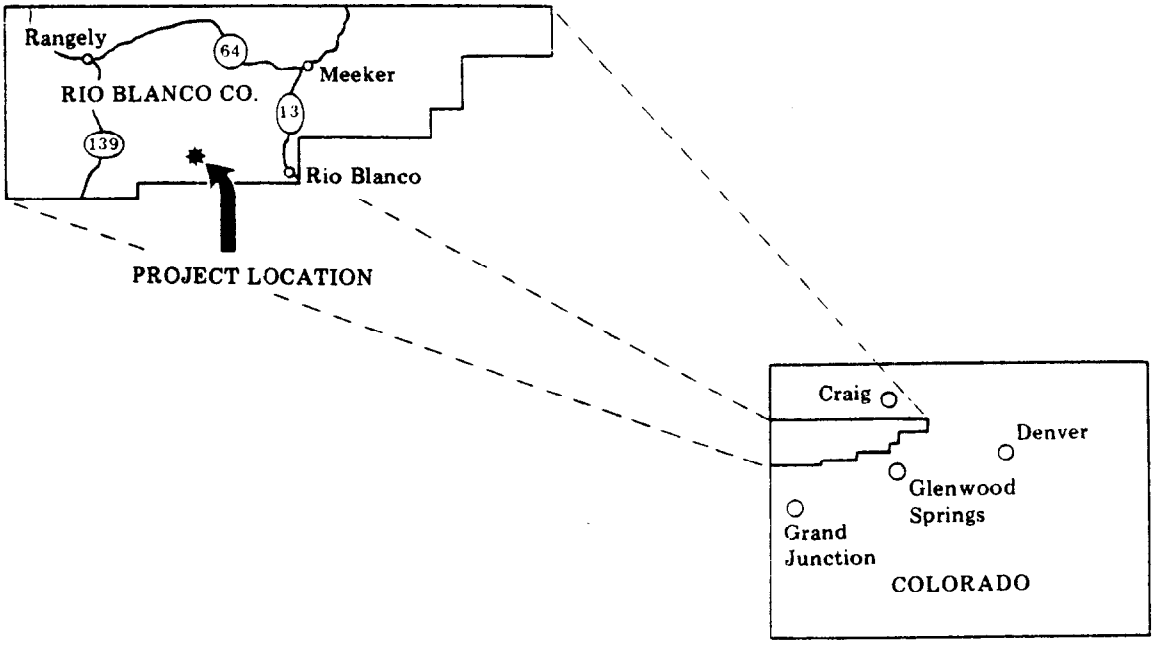
Interagency Agreement Date:	June 19, 1974
Anticipated Completion Date:	July 1, 1979 (Closing)

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

DOE Contract No. 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 terms of the contract.

Field activities on the RB-MHF 3 well have been suspended. CER Corporation is transferring the MHF well to an operator who will attempt to complete the well, commingle the previously fractured zones, test the well and provide the data to the industrial participants and DOE.

The transfer is still pending.

WATTENBERG FIELD

EY-77-C-08-1514

Colorado Interstate Gas Company
Colorado Springs, Colorado

Status: Active

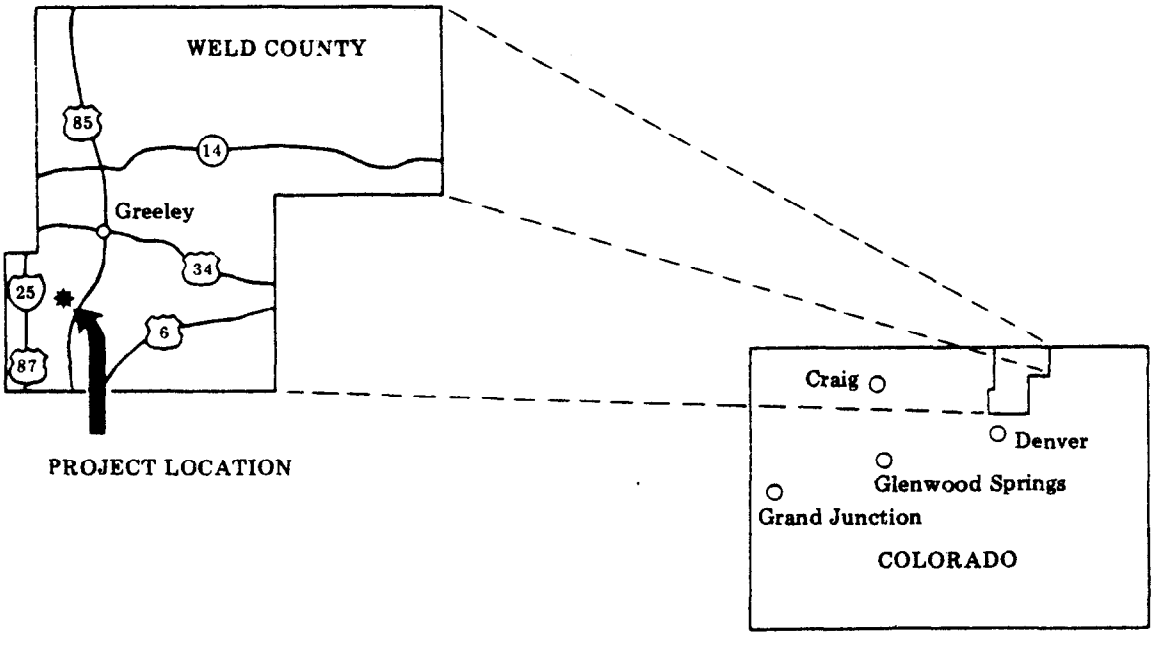
Contract Date:	September 1, 1977
Anticipated Completion Date:	March 1, 1981

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

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

OBJECTIVE

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



5.3 COLORADO INTERSTATE GAS

Cyclic injection and production of dehydrated gas continued at the Miller No. 1 and Sprague No. 1 wells, as have the interruptions and shutdowns that have been affecting the project. As a result, the following changes and alterations will be made to the facilities.

- Four gravity-feed methanol drip tanks will be installed, one high pressure tank at each wellhead and one low pressure tank at the discharge of each separator, in an attempt to control or reduce freezing problems.

- The existing regulator at the suction side of the compressor will be replaced with a Texsteam diaphragm-operated regulator. The existing controller will be retained.

- An automatic governor for the compressor throttle will be installed so the rpm will be reduced when suction pressure falls below a set point in an attempt to reduce the frequency of compressor shutdowns. The compressor is now set to operate at 400 rpm.

- Pneumatic actuated counters on the producer's water dump valves will be installed so the number of times the separators are dumped will be recorded. Thus, the amount of water discharged in this operation may be estimated by multiplying the number of dumps by the amount of water discharged per dump.

Figure 5-1 illustrates the production and injection volumes and associated pressures of these wells.

A table detailing this figure is available upon request. This table also includes the volume of makeup gas obtained from CIG's gathering system, the number of hours the compressor was operating and the amount of fuel used.

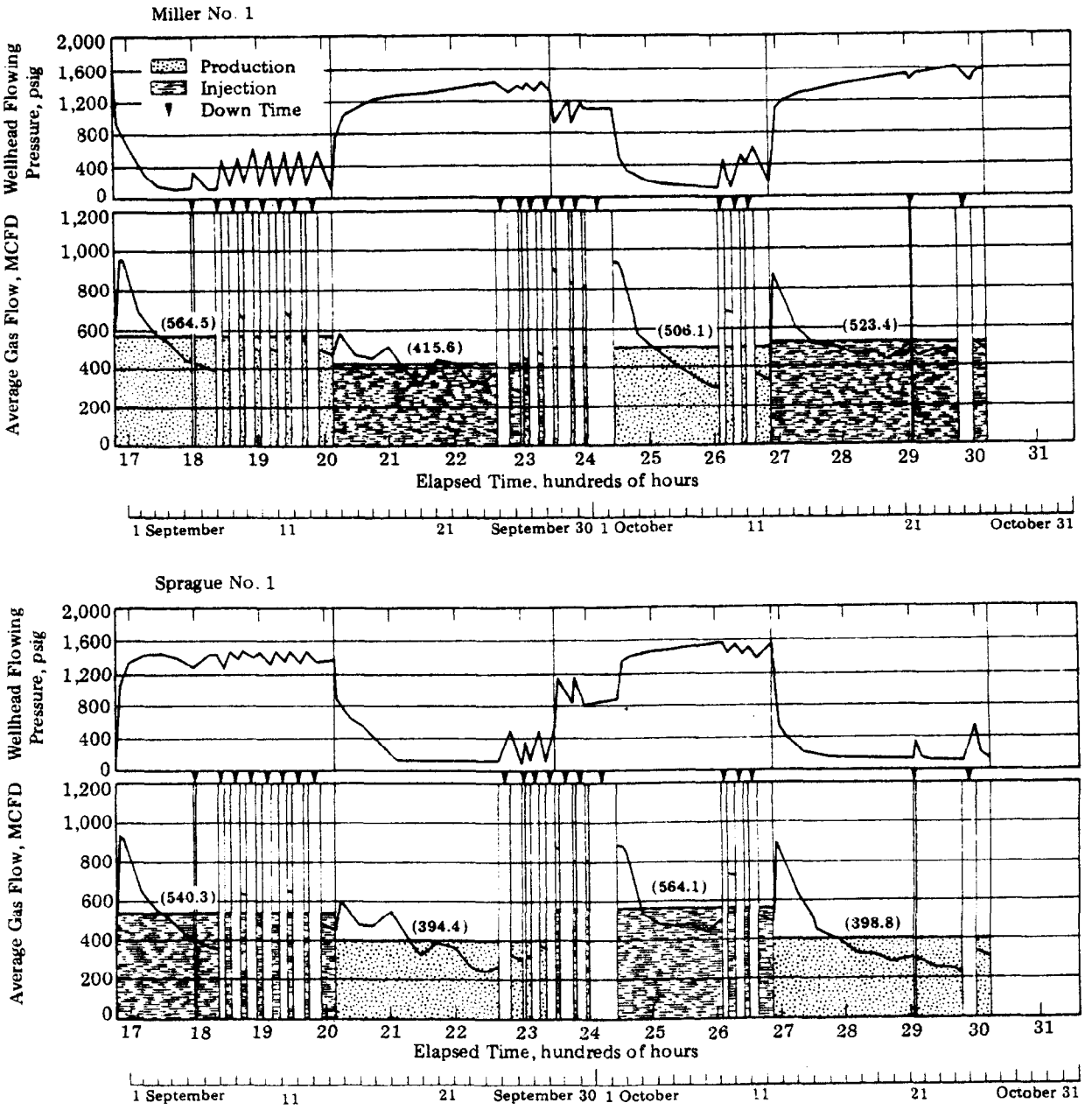


Figure 5-1 Production and Injection Volumes and Associated Pressure of CIG Miller No. 1 and Sprague No. 1 Wells

October 1979
DOE/BC/10003-1
CER Corporation

DOE WELL TEST FACILITY

DE-AC08-79-BG01569

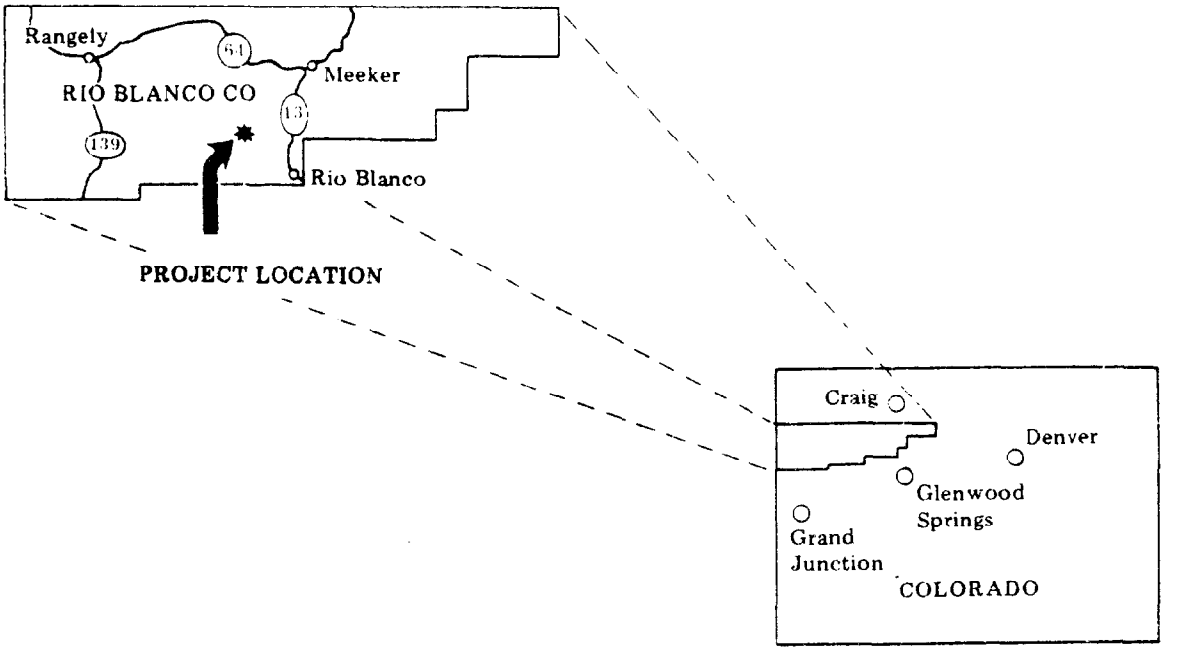
CER Corporation
Las Vegas, Nevada

Status: Operational

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

OBJECTIVE

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



5.4 DOE WELL TEST FACILITY

The DOE Well Test Facility remained on site at Rio Blanco Natural Gas Company No. 397-19-1 Government well until mid October. The facility and personnel had been on site since early July to acquire reservoir data and to provide analytic support for the joint GRI/RBNG fracture experiment.

The final buildup test commenced on October 5 following a 10,000 gallon, 15 percent MSR breakdown. The tabulated consolidated data are presented in Table 5-2 and Figure 5-2 is a Horner plot of the BHP buildup data. A flow capacity of 5 μd-ft is indicated by the last few data points.

It has been determined from four BHP buildup tests that the formation flow capacity is between 4 μd-ft and 20 μd-ft, and in all probability less than 10 μd-ft. This indicates a reservoir of insufficient quality to effect a valid and meaningful fracture stimulation experment. On October 16, after termination of the tests, the Well Test Facility went into temporary storage at the DOE facility in Grand Junction, Colorado.

Table 5-2 BHP Buildup Test Commencing October 5, RBNG No. 397-19-1 Government Well

Net Gas Pay = 1.00 ft
Well Radius = .2100 ft
Gas Specific Gravity = .69000
Carbon Dioxide = 0.0000 mol pct

Formation Porosity - 7.5000
Bottom Hole Temp. = 226.0°F
Hydrogen Sulfide = 0.0000 mol pct
Nitrogen = 0.0000 mol pct

Buildup Test
Flow Time: 30.00 hrs.
Flow Rate: 15.00 MCFD

Time (ΔT) (hrs)	Horner Time	Pressure (psi)	Slope (psi/cycle)	P-Star (psi)	kh (μd-ft)	Skin
26.00	2.15	684.0	131.3	771.8	417.0	.73
48.50	1.62	787.0	1,703.0	1,247.0	317.0	-2.11
50.00	1.60	1,000.0	8,940.0	2,730.0	58.9	-1.59
56.00	1.54	1,044.0	2,557.0	1,521.0	20.5	-1.96
64.00	1.47	1,095.0	2,790.0	1,563.0	18.7	-1.95
72.00	1.42	1,142.0	3,040.0	1,602.0	17.0	-1.94
78.00	1.38	1,173.0	3,111.0	1,613.0	16.6	-1.94
84.00	1.36	1,200.0	3,798.0	1,703.0	13.6	-1.91
88.00	1.34	1,227.0	3,329.0	1,645.0	15.4	-1.93
96.00	1.31	1,250.0	3,000.0	1,608.0	17.1	-1.94
102.00	1.29	1,274.0	3,950.0	1,716.0	12.9	-1.90
108.00	1.28	1,296.0	6,017.0	1,944.0	8.5	-1.81
114.80	1.26	1,341.0	7,560.0	2,101.0	6.7	-1.74
118.80	1.25	1,361.0	6,028.0	1,949.0	8.4	-1.81
124.80	1.24	1,385.0	5,673.0	1,916.0	8.9	-1.82
130.80	1.23	1,407.0	5,641.0	1,913.0	8.9	-1.83
136.80	1.22	1,427.0	6,113.0	1,955.0	8.2	-1.81
142.80	1.21	1,449.0	6,309.0	1,971.0	7.9	-1.80
148.80	1.20	1,467.0	6,115.0	1,955.0	8.2	-1.81
154.80	1.19	1,485.0	6,368.0	1,975.0	7.8	-1.80
158.80	1.19	1,495.0	6,563.0	1,990.0	7.6	-1.79
162.50	1.18	1,507.0	9,363.0	2,199.0	5.3	-1.68
173.50	1.17	1,551.0	9,563.0	2,211.0	5.2	-1.68
185.50	1.16	1,588.0	8,417.0	2,135.0	5.9	-1.72
197.50	1.15	1,617.0	8,439.0	2,137.0	5.9	-1.72
209.50	1.14	1,647.0	9,748.0	2,215.0	5.1	-1.67
221.50	1.14	1,678.0	9,960.0	2,226.0	4.9	-1.67
233.50	1.13	1,703.0	9,960.0	2,226.0	4.9	-1.67

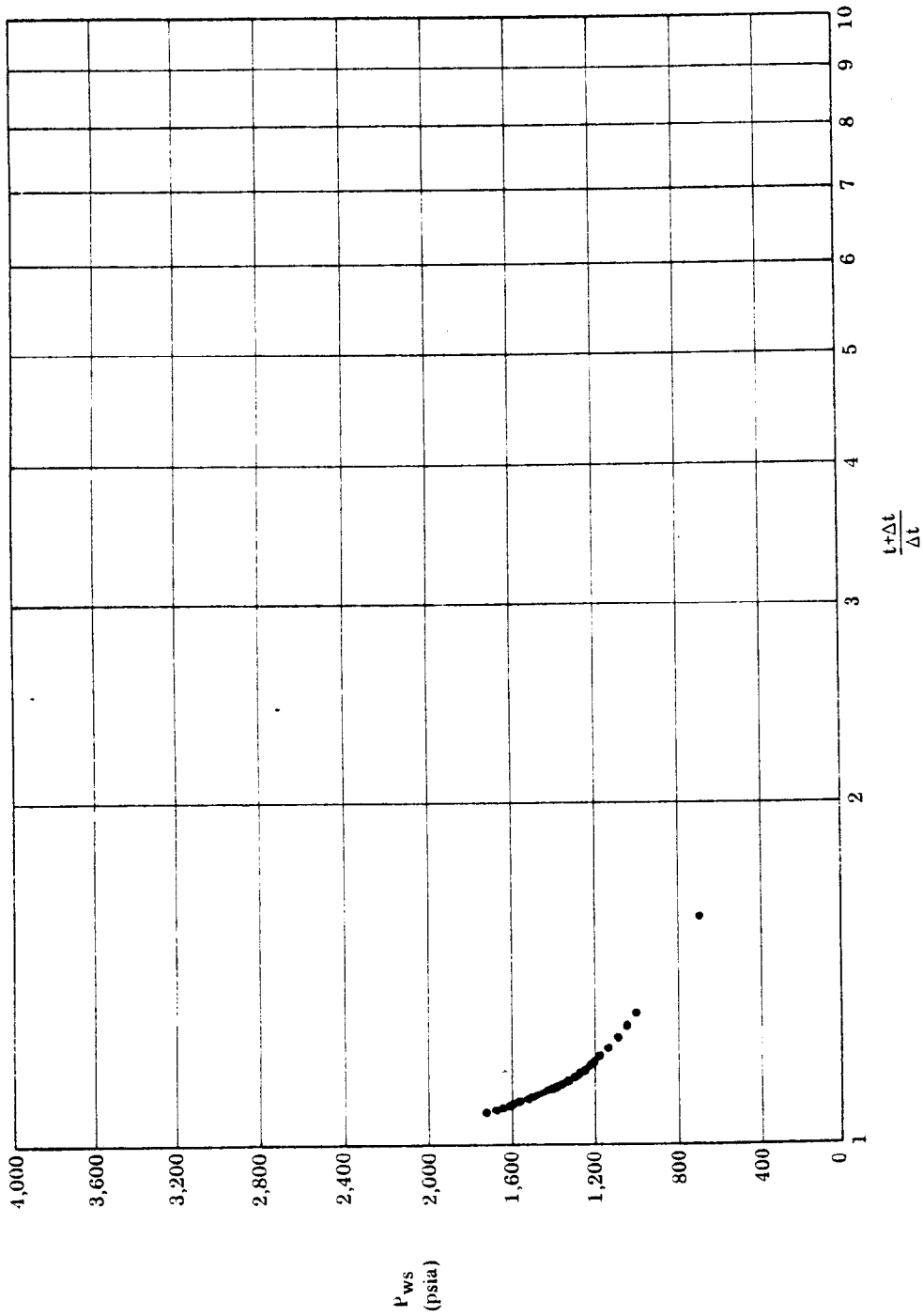


Figure 5-2 Horner Plot for October 5 BHP Test, RBNG No. 397-19-1 Government Well

October 1979
DOE/BC/10003-1
CER Corporation

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

DE-AC08-76 ET 12060

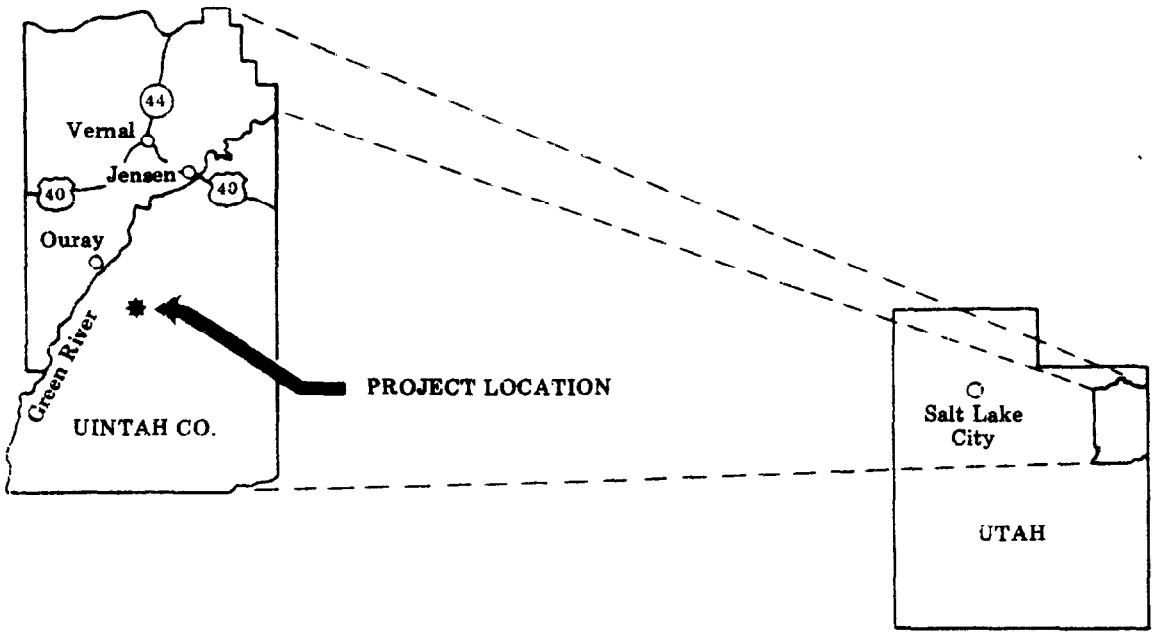
Gas Producing Enterprises, Inc.
Subsidiary of Coastal States Gas Co.
Houston, Texas

Status: Active

Contract Date:	July 1, 1976	
Anticipated Completion:	March 31, 1980	
Total Project Cost (estimated):	DOE	$2,827,000
	Industry (prior costs)	1,881,000
	Industry (new costs)	3,051,000
	Total	$7,759,000
Principal Investigator:	W. E. Spencer	
Technical Project Officer for DOE:	C. H. Atkinson	

OBJECTIVE

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



5.5 GAS PRODUCING ENTERPRISES

The GPE wells, Natural Buttes Units 9, 14, 18 and 20 flowed to sales during October. Natural Buttes Unit 19 and 22 were shut in (NBU No. 19 was shut in for fluid proration). NBU No. 21 was temporarily abandoned in the Mesaverde horizon, but GPE will try to complete it in the Wasatch. Figure 5-3 through 5-8 show the production figures.

A comprehensive final report is being prepared.

Gas Producing Enterprises' contract No. DE-AC08-76ET 12060 has been extended to March 31, 1980.

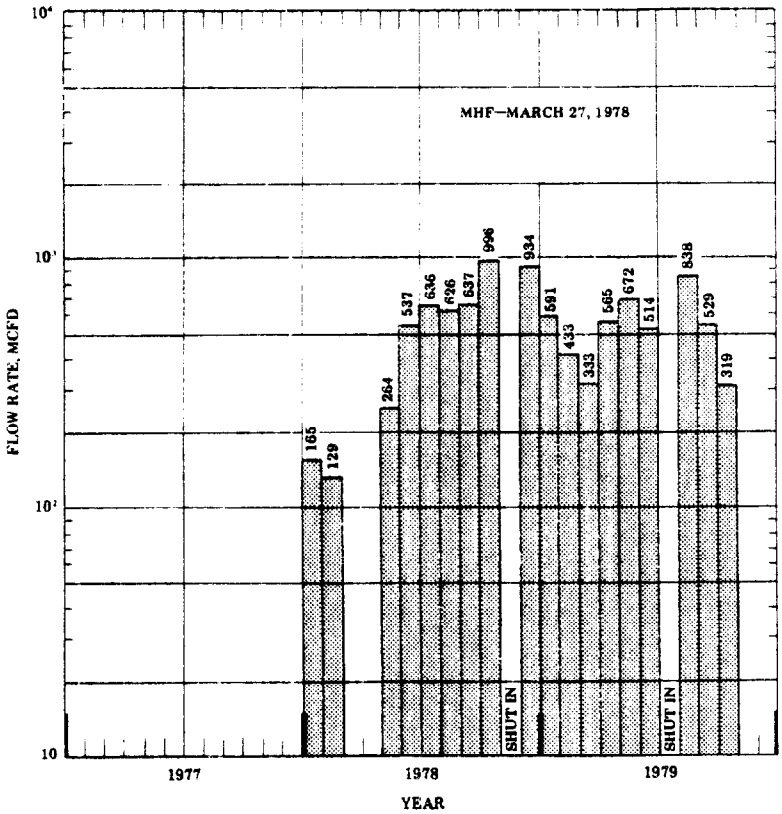


Figure 5-3

Flow Rate Performance of Natural Buttes No. 9 Well

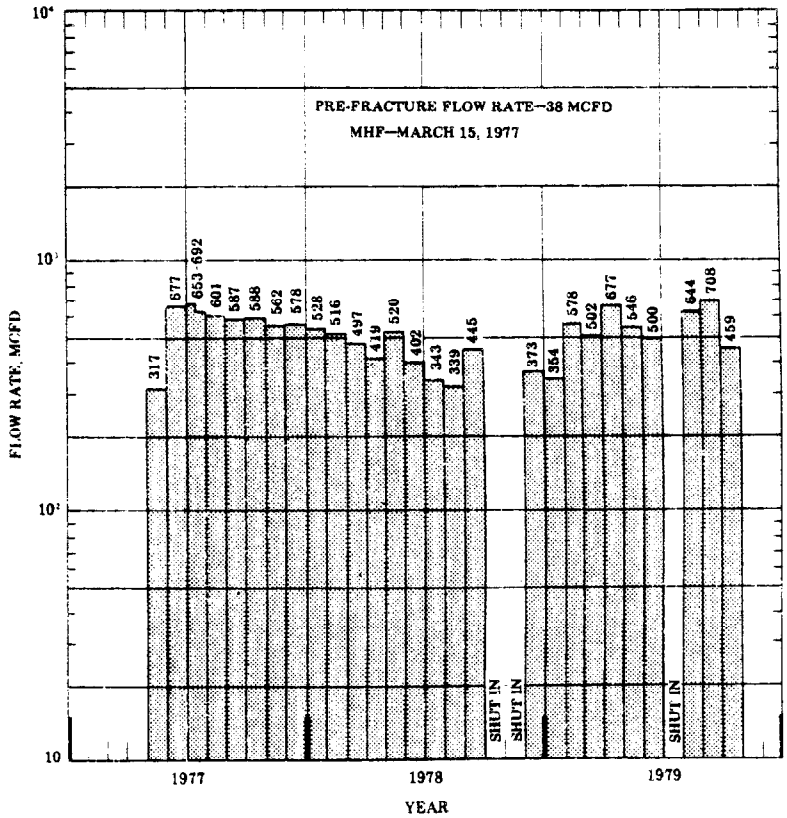
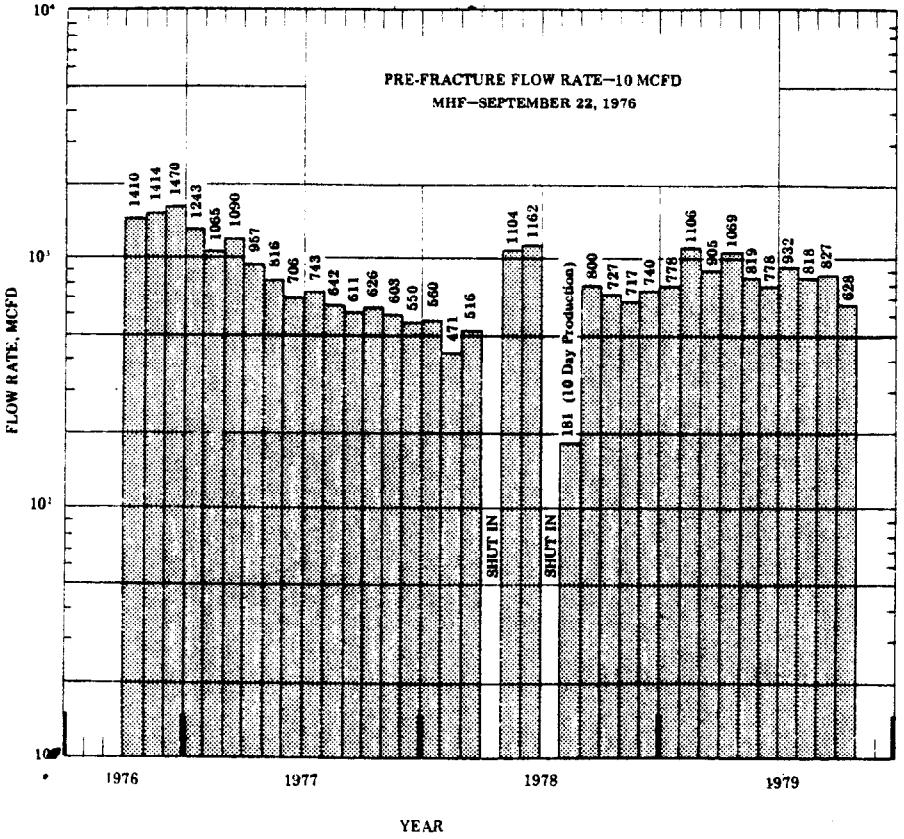


Figure 5-4

Flow Rate Performance of Natural Buttes No. 14 Well

Figure 5-5

Flow Rate Performance of Natural Buttes No. 18 Well



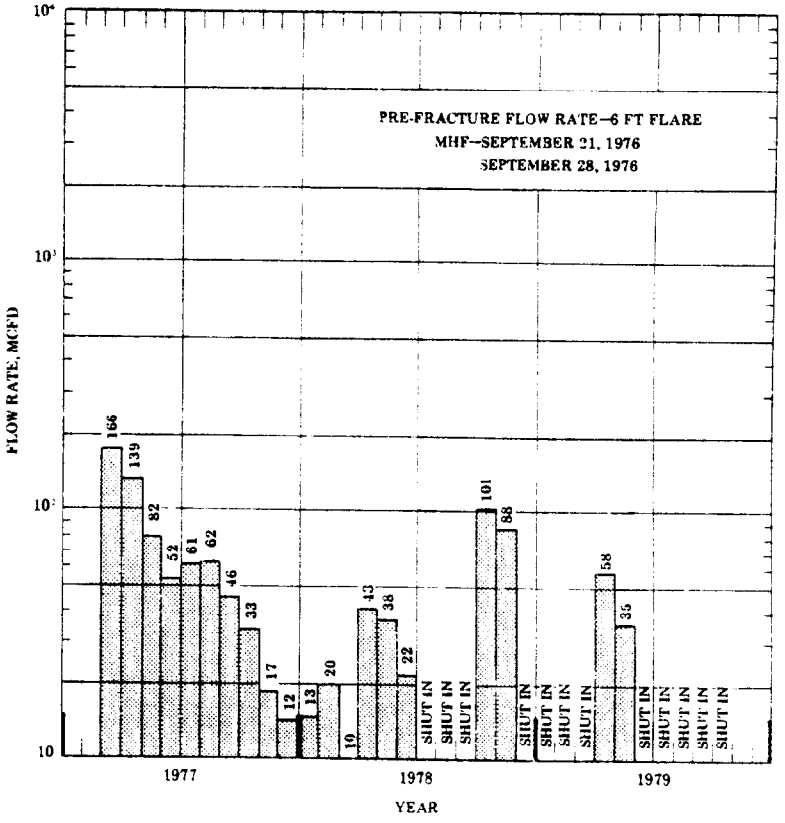


Figure 5-6

Flow Rate Performance of Natural Buttes No. 19 Well

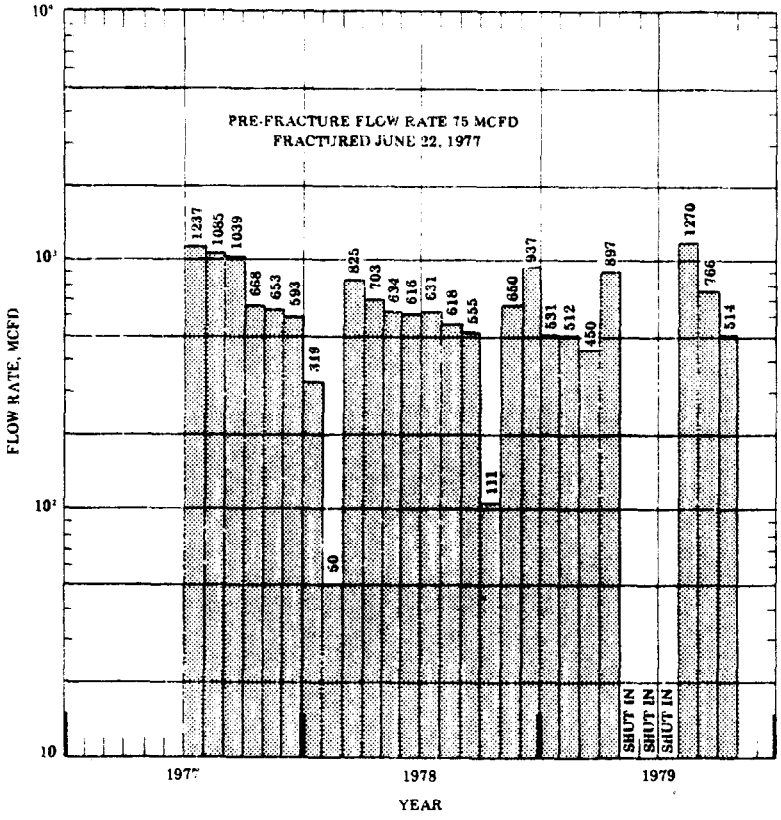


Figure 5-7

Flow Rate Performance of Natural Buttes No. 20 Well

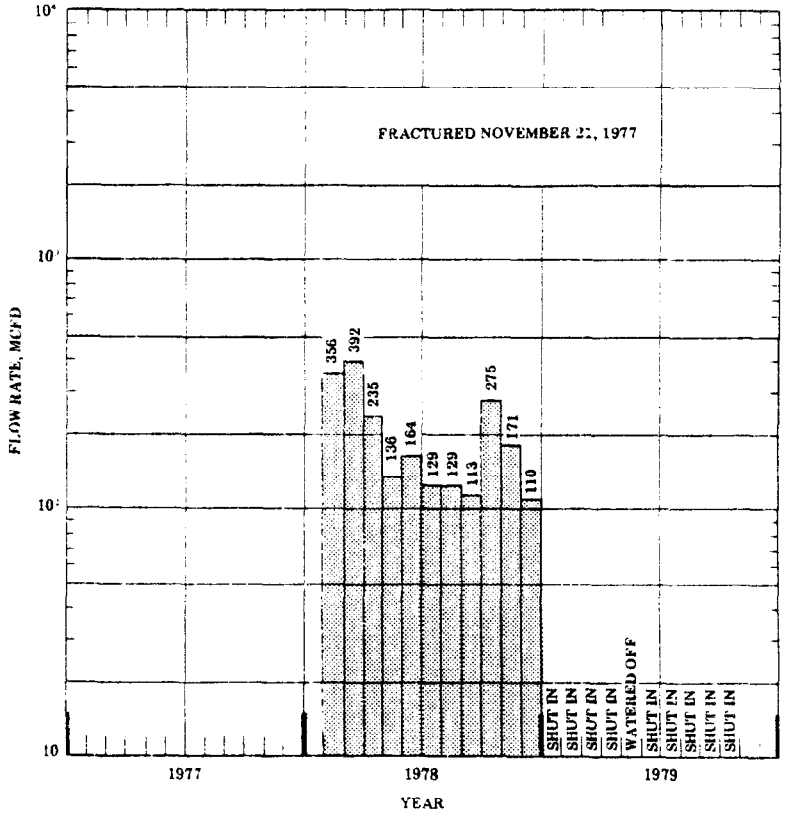


Figure 5-8

Flow Rate Performance of Natural Buttes No. 22 Well

UGR File #216
October 1979
DOE/BC/10003-1
CER Corporation

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

EF-78-C-08-1547

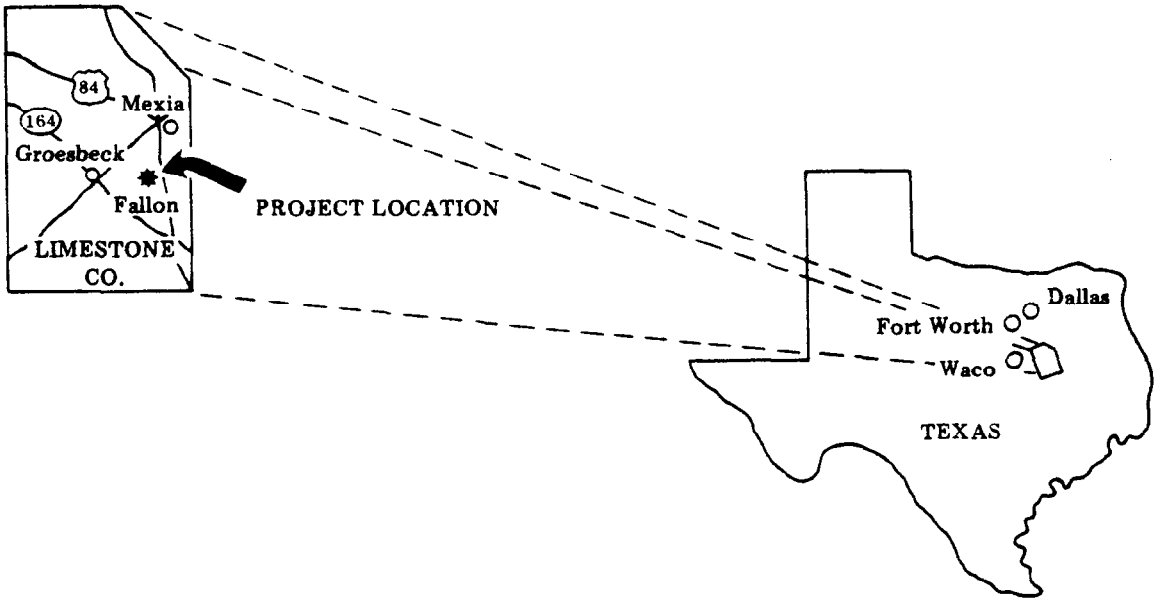
Mitchell Energy Corporation
Houston, Texas

Status: Active

Contract Date:	March 15, 1978
Anticipated Completion:	April 30, 1979 (Extension being processed)
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

The Muse-Duke No. 1 was shut in on August 7, 1979, for approximately 29 days to conduct a post MHF pressure transient buildup test. A bottom-hole tubing pressure difference plot and Ramey's type-curve matching plot were prepared for a better delineation of the type flows. Linear or fractured flow was dominant for the first 360 hours of shut-in time, and the pseudoradial flow regime was reached throughout the remainder of the buildup test.

It was concluded that the values from Ramey, Horner and bottom-hole tubing pressure difference plots are representative of the Cotton Valley Lime matrix within the radii of pressure investigations. After the well was massively fractured, the linear flow period increased from 12 to 360 hrs and the negative pressure loss increased from 510 to 6,220 psi. This would yield a wellbore improvement of approximately 1,100 percent. Qualitatively it is believed that a long fracture having a high flow capacity was obtained by the massive stimulation. This was further substantiated by comparing the pre-MHF and the post-MHF performance data.

The massive hydraulic fracture on the Muse-Duke No. 1 was designed for 210,000 gal of pad and 750,700 gal of gel containing 2,665,000 lb of sand. This would yield calculated created and propped half lengths of 3,504 ft and 2,625 ft, respectively. However, the well sanded up after pumping a pad volume of 235,000 gal, a gel volume of 663,000 gal, and 2,800,000 lb of sand. Thus, on a proportional basis, this size stimulation would have a created length of 3,220 ft, and a propped length of 2,530 ft. Therefore, a half fracture length ranging from 2,500 ft to 3,200 ft would be anticipated if the fracturing performed approximately as designed. To assess the validity of this design, the type-curve method for calculated length and finite capacity was utilized. For the constant rate case, plots of shut-in times versus the differences in the squares of the flowing and static bottom-hole pressures divided by the stabilized gas rate were constructed. These plots were compared with type curves generated by Amoco and S. A. Holditch and Associates, Inc. Although fairly good matches were obtained, the resultant calculations yielded unrealistically short fracture lengths and high capacities. These values were as follows:

Type Curves	Fracture Half Length	Fracture Capacity
Amoco Production	710 ft	13.1 d-ft
S. A. Holditch & Assoc.	775 ft	9.0 d-ft

As of October 12, Muse-Duke No. 1 was shut in because of pipeline curtailment.

UGR File #216
October 1979
DOE/BC/10003-1
CER Corporation

PICEANCE CREEK FIELD, COLORADO, MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

EY-76-C-08-0678

Mobil Research and Development Corporation
Dallas, Texas

Status: Active

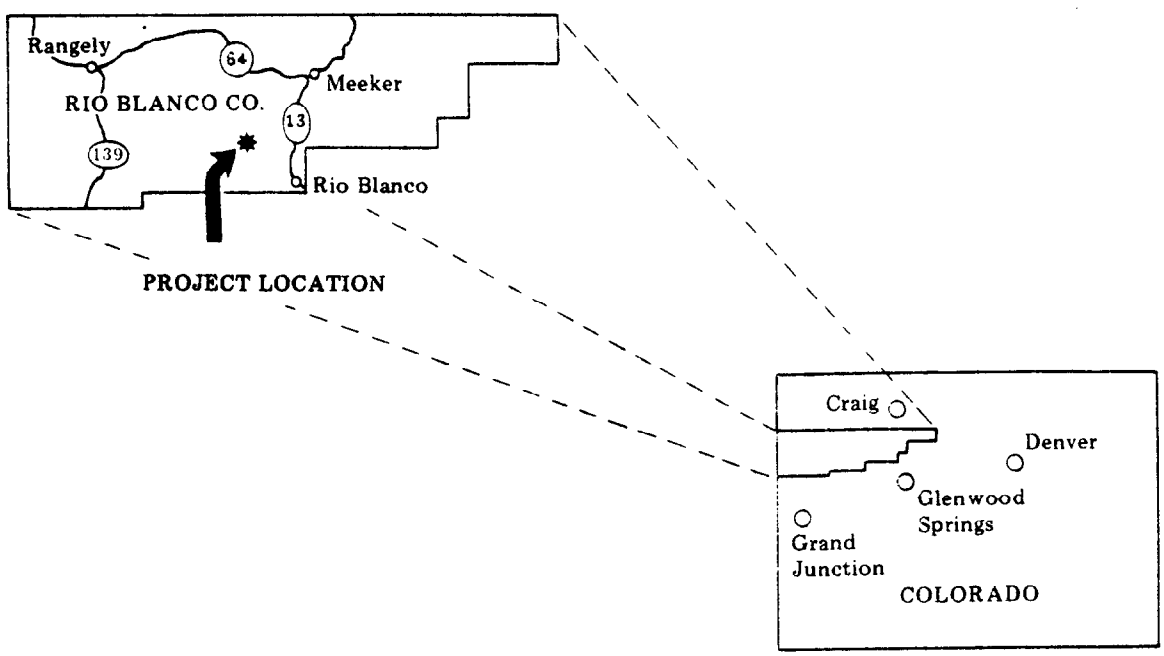
Contract Date:	July 1, 1976
Anticipated Completion:	September 30, 1979

Total Project Cost (estimated):	DOE	$2,510,000
	Contractor (prior costs)	2,376,485
	Contractor (new costs)	1,590,515
	Total	$6,477,000

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

OBJECTIVE

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



5.7 MOBIL RESEARCH AND DEVELOPMENT

A draft of the comprehensive final report was submitted to DOE for comments. The report has been returned to Mobil for printing.

UGR File #216
October 1979
DOE/BC/10003-1
CER Corporation

RIO BLANCO COUNTY, COLORADO MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

EY-76-C-08-0677

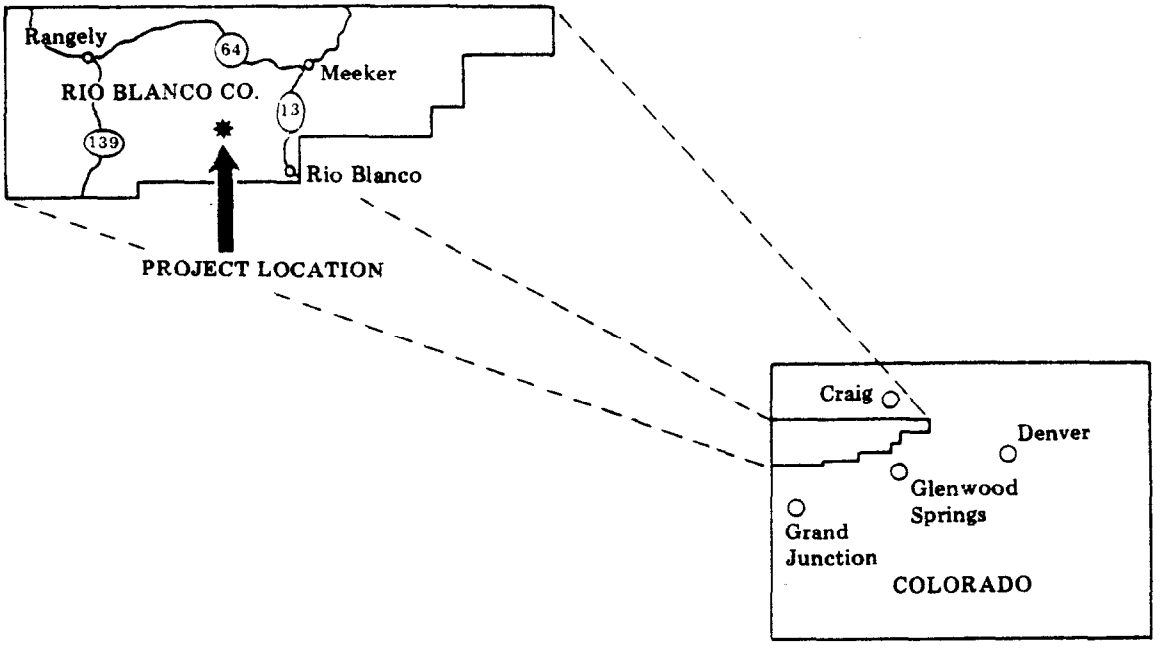
Rio Blanco Natural Gas Company
Denver, Colorado

Status: Active

Contract Date:	August 1, 1976
Anticipated Completion:	July 31, 1979
Total Project Cost (estimated):	DOE ..... $ 410,000
	Contractor 593,000
	Total $1,003,000
Principal Investigator:	Robert E. Chancellor
Technical Project Officer for DOE:	C. H. Atkinson

OBJECTIVE

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



5.8 RIO BLANCO NATURAL GAS COMPANY

DOE Contract No. EY-76-C-08-0677 was signed with Rio Blanco Natural Gas Company in June, 1976. The first MHF treatment was performed on October 22, 1976. A supplemental agreement, effective October 1, 1977, provided for a second MHF treatment which was performed on November 30, 1977.

The final report is in preparation.

UGR File #216
October 1979
DOE/BC/10003-1
CER Corporation

NEVADA TEST SITE
NYE COUNTY, NEVADA
MINEBACK TESTING

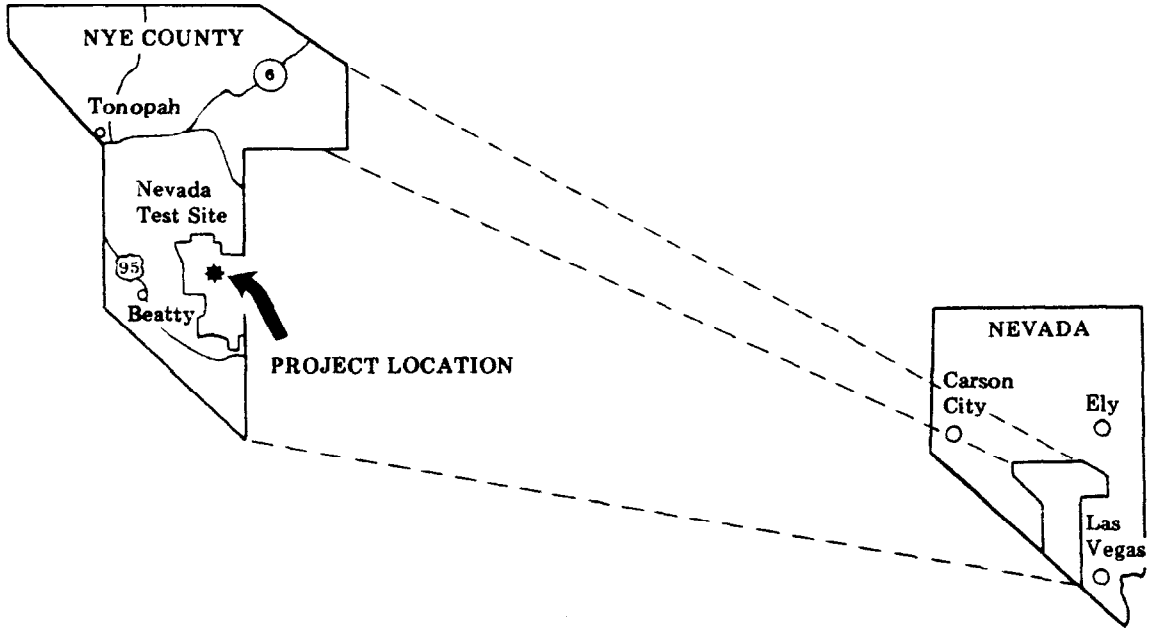
Sandia Laboratories
Albuquerque, New Mexico

Status: Active

Principal Investigator: D. A. Northrop

OBJECTIVE

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



5.9 SANDIA LABORATORIES - MINEBACK

5.9.1 Hydraulic Fracturing Containment Experiments

Sandia Laboratories is conducting research into the development of massive hydraulic fracturing as a practical, economic technique for exploiting tight gas sands. Research being performed includes *in situ* testing of hydraulic fracturing theory and technology, modeling of hydraulic fracturing behavior and laboratory testing. *In situ* testing is being performed at NTS in a tunnel complex through volcanic ashfall tuff under ~ 1,400 ft of overburden. This site provides:

- facilities and equipment for mineback and direct observation of created hydraulic fractures,
- the capability of determining *in situ* stresses and obtaining rock samples for testing in regions of interest, and
- a direct knowledge of the reservoir parameters and structure.

Modeling efforts involve many aspects of fracturing, from details of the processes occurring at the fracture tip to numerical codes describing the fluid/rock mechanics of the entire fracture. Laboratory testing includes the determination of rock properties and small scale experiments.

5.9.1.1 Hole No. 6 Formation Interface Fracture Experiment

The formation interface fracture experiment (Hole No. 6) is an experiment to determine the parameters which influence and control containment of hydraulic fractures. Grout-filled fractures were propagated above and below a welded tuff/ashfall tuff interface and subsequently mined back to reveal the nature of the fractures at the interface. It was found that a fracture which was initiated in the low modulus ashfall tuff propagated through the interface into the high modulus welded tuff. This suggested that present rock mechanics models, which predict a bounding higher modulus material will contain a hydraulic fracture, are in error.

An exploratory coring program is underway to determine the general shape of the fractures which will reflect the influence of the interface and *in situ* stresses on overall fracture propagation and behavior. Twenty-two coreholes have been completed to date, but no further work was performed in October. Approximately five more holes will be cored to complete the experiment and a final evaluation will then be performed.

5.9.1.2 Interface Test Series

In the first two interface tests of this series (designated CFE-1 and CFE-2), a horizontal borehole was fractured in six zones; a number of different flow rates and volumes for fracturing were utilized and each zone was at a different distance from the interface.

Mineback showed that the fractures crossed the interface and propagated into the higher modulus welded tuff; however, fractures did terminate in regions where a sharp increase in the minimum principal *in situ* stress level was measured. Flow rate apparently has a negligible effect on propagation across an interface.

The mineback of the third test, CFE-3, and the associated *in situ* stress measurement hole, CFE-4, was completed in October. Similar behavior was observed in CFE-1, CFE-2, and CFE-3. Figure 5-9 is a schematic of the observed fracture behavior in the three sets of tests. It was found that the fracture growth direction (up or down) was a function of the location of fracture initiation with respect to the minimum *in situ* stress peaks observed in this area. Fractures which were initiated above the upper stress peak, in either the ashfall or welded tuff, had their downward growth terminated by the unfavorable stress gradient; they preferred to propagate into the higher modulus material. Fractures which were initiated between the stress peaks were often confined to that region, as seen in CFE-2. However, a fracture which was initiated in CFE-3 between the stress peaks was observed to propagate through the upper stress peak and into the high modulus material. Fractures which were initiated below the lower stress peak for the most part remained below that peak and primarily propagated downward; however the fractures in CFE-2, which were initiated in zones near or on the peak, did propagate upward.

These experiments show that *in situ* stress is the dominant mechanism controlling hydraulic fracture propagation. The fractures show little or no change as they approach and cross a material property interface, but the unfavorable stress gradients near the peak readily terminate fracture growth.

5.9.1.3 Rock Mechanics

A more realistic fracture criterion should be used for crack growth at an interface rather than the existing models. Since the stress field for a crack near an interface is analytically known, a direct approach is to average the stresses ahead of the crack tip over a region as predicted by the microcrack model. It will be assumed that crack propagation will occur when this average stress reaches some critical value as determined experimentally. This criterion is consistent with the fracture criterion for crack growth in homogeneous materials as based on linear-elastic fracture mechanics.

Tests at Cornell University will examine fracture behavior near a material interface, using several three-point-bend samples of layered concrete and rock. Progress on this investigation is as follows:

- Five different mixes of portland cement have been designed, mixed, cured, and tested for Young's modulus in compression, Poisson's ratio, and uniaxial compressive strength. The moduli range from 2.5×10^6 psi to 6.0×10^6 psi.

- Eighteen Westerly granite ($E \cong 9 \times 10^6$ psi) beam-segments were purchased and prepared (honing, roughening, chevron notch-sawing) for casting in layers with the concrete. Cores and 3-point bend granite samples were prepared for property determinations.

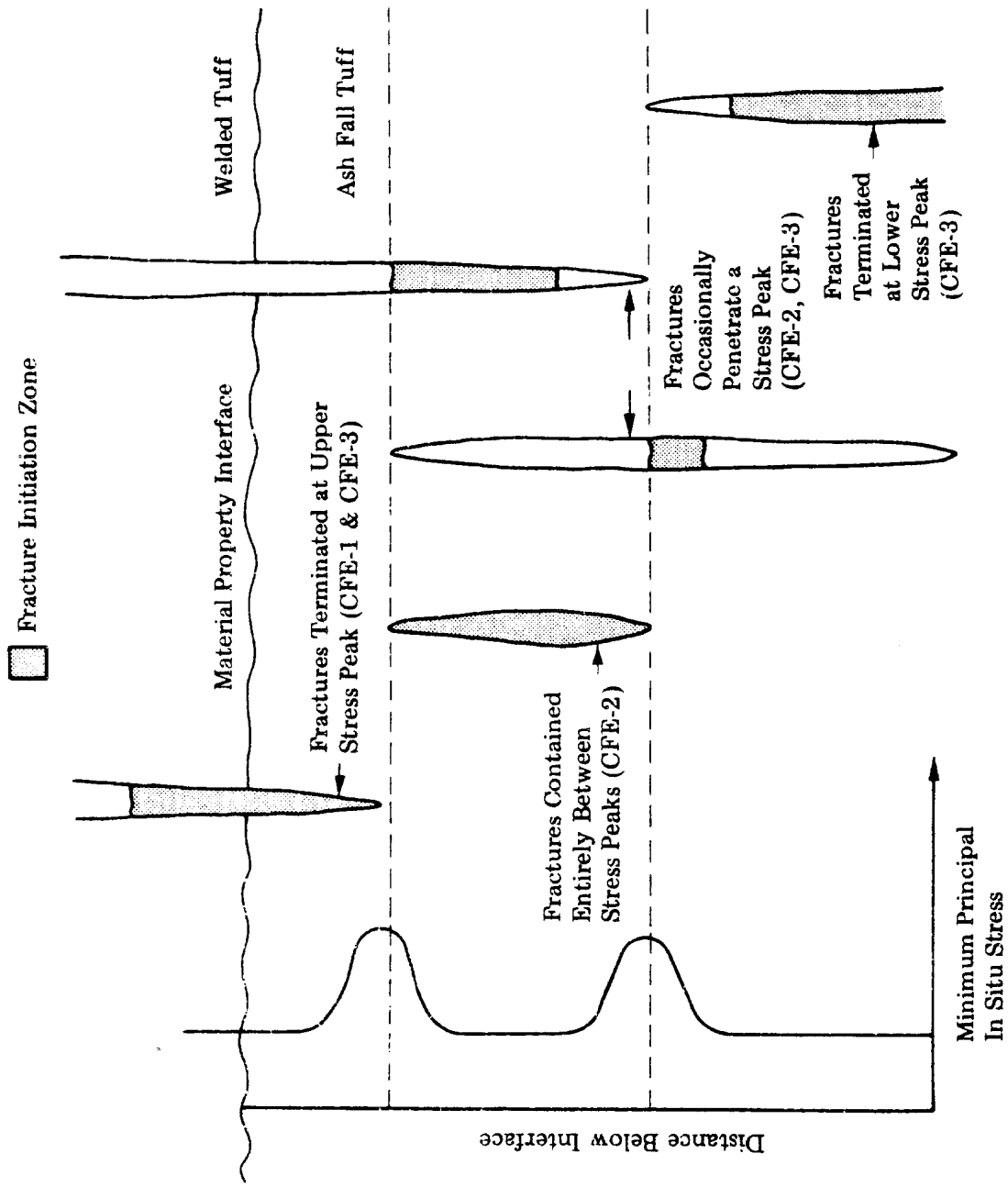


Figure 5-9 Schematic of Fracture Behavior in the Interface Test Series

- All formwork was constructed and the loading system was modified to test these samples. Single-composition concrete beams were tested as dry runs and controlled crack growth was achieved using crack-mouth-displacement as the feedback parameter.

- Two methods for crack tip location monitoring were developed and tested by using fluorescent dyes and crack propagation gauges.

5.9.1.4 Fluid Mechanics

Flow and pressure testing methods for determining the conductivity of a propped hydraulic fracture under *in situ* conditions and as a function of location will be examined. These techniques will be used in small scale hydraulic fracturing experiments to analyze proppant transport, conductivity and distribution.

5.9.2 Geochemistry and Petrology

A petrographic facility is being set up which includes a Leitz Orthoplan polarizing microscope with heating stage, a low-power binocular microscope (for hand specimens) and laboratory equipment necessary for preparing samples for x-ray diffraction and electron microscopy. The microscope facility will also include equipment for point-counting, photomicrography, and cathodoluminescence.

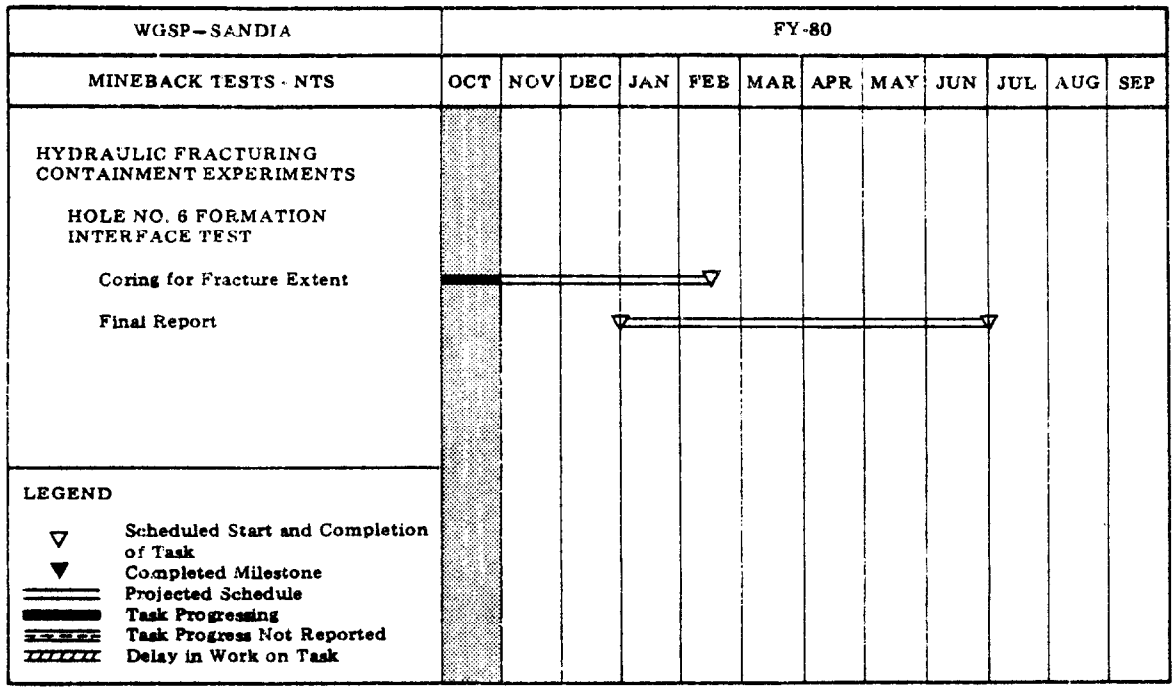
Ten samples of the Mesaverde Group were obtained from Mobil PCU No. F31-13G well in the Piceance Basin, Colorado. Routine thin-section petrography of these samples shows the Mesaverde, in the intervals 8,441 ft to 8,493 ft and 9,964 ft to 9,994 ft, consists of silty or shaly sand which is composed of angular, poorly-sorted quartz grains cemented by variable quantities of silica, calcite, and/or dolomite. In addition, all of the samples contained variable but significant proportions of authigenic clays and detrital grains, primarily feldspar.

Sample composition, as determined by bulk x-ray diffraction, consisted dominantly of quartz with minor amounts of calcite, dolomite, plagioclase, illite, kaolinite, and chlorite.

Preliminary scanning electron microscopy of the Mesaverde sandstone has revealed a great deal of variation within individual samples. Although no quantitative estimates have yet been made of total clay, matrix, and cement content, certain general trends have been recognized. Silica cementation predominates in the uppermost samples, while carbonate cementation appears to increase with depth. Of the clay minerals, only chlorite shows a systematic decrease with depth. Attempts are being made to obtain more core material from the tight gas sands in this area.

5.9.3 Schedule Status

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



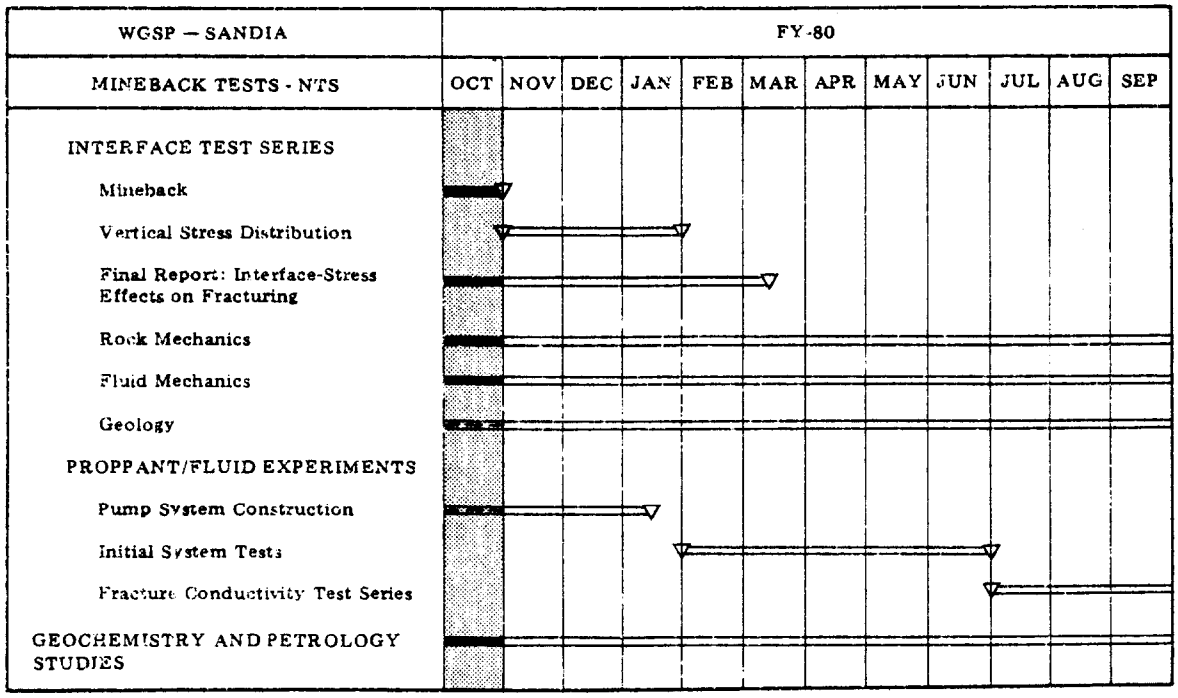


Figure 5-10 Milestone Chart — Sandia Mineback