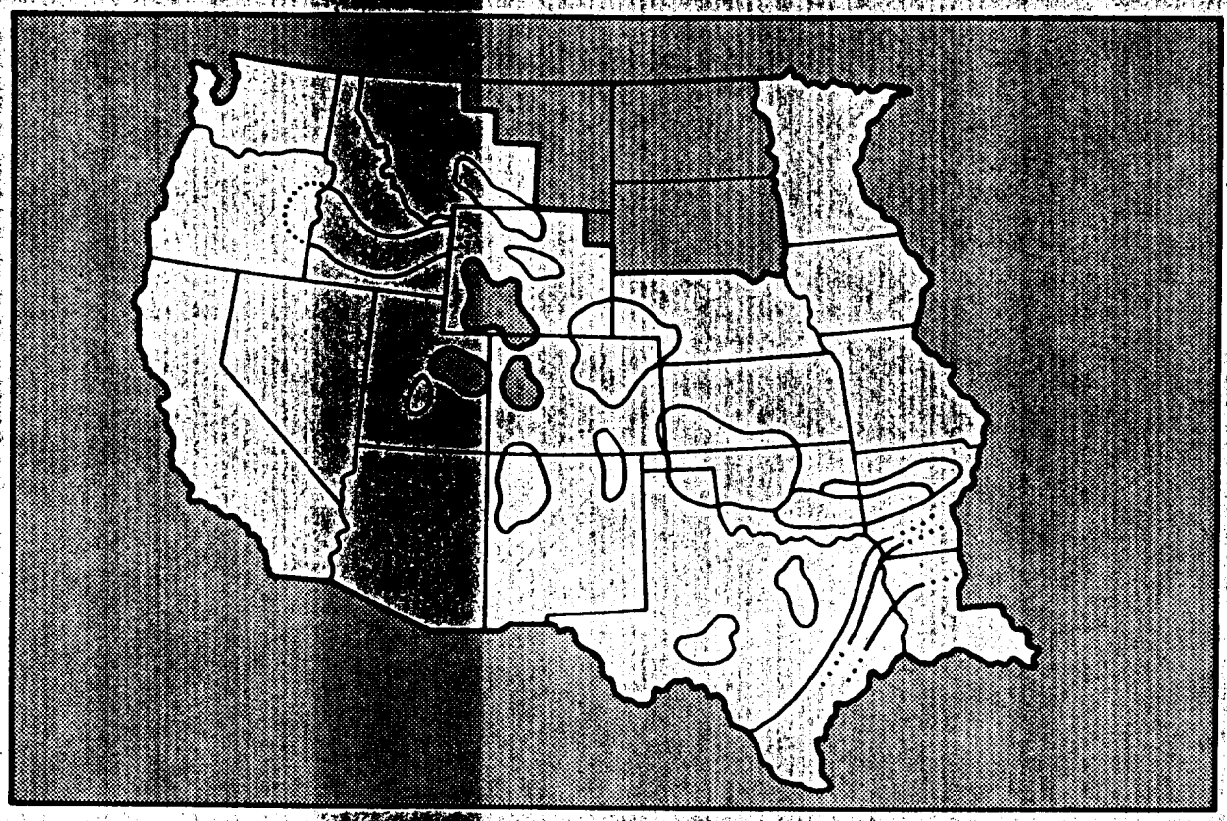
DOE/BC/10003-15

Western Gas Sands Project Status Report



1 August – 31 August, 1980

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CONTENTS

SUMMARY 1

SECTION 1

PROJECT MANAGEMENT 3
Technology Transfer 3

SECTION 2

RESOURCE ASSESSMENT 5
U.S. Geological Survey Activities 5
Survey of Basin Activities 6
C K GeoEnergy 14
Gas Research Institute Sponsored Projects 14
TRW Western Gas Sands Support 14
Multi-Well Experiment 14

SECTION 3

RESEARCH & DEVELOPMENT BY ENERGY TECHNOLOGY CENTERS & NATIONAL LABORATORIES 17
Bartlesville Energy Technology Center 17
Lawrence Livermore National Laboratory 20
Los Alamos Scientific Laboratory 27
Sandia National Laboratories 31

SECTION 4

FIELD TESTS & DEMONSTRATIONS 37
Background 37
Colorado Interstate Gas Company 40
DOE Well Test Facility 46
Gas Producing Enterprises, Inc. 46
Mitchell Energy Corporation 51
Sandia National Laboratories – Mineback 53

TABLES

Table 2-1	Summary of Wells — Greater Green River Basin	10
Table 2-2	Summary of Wells — Northern Great Plains Province	11
Table 2-3	Summary of Wells — Piceance Basin	12
Table 2-4	Summary of Wells — Uinta Basin	13
Table 3-1	Analysis for Mitchell Muse-Duke No. 1 Well	18
Table 3-2	NMR Relaxation Times and Mercury Porosimeter on WGSP Core Samples	29
Table 3-3	Pumping Data During Use of Borehole Seismic System	32
Table 3-4	Status of Signal Reception	32
Table 4-1	MHF Contract Location and Frac Data	38

FIGURES

Figure 2-1	Milestone Chart — USGS	7
Figure 2-2	Greater Green River Basin Showing Wells of Interest and USGS Designated Core Areas	10
Figure 2-3	Northern Great Plains Province Showing Wells of Interest and USGS Designated Core Areas	11
Figure 2-4	Piceance Basin Showing Wells of Interest and USGS Designated Core Areas	12
Figure 2-5	Uinta Basin Showing Wells of Interest and USGS Designated Core Areas	13
Figure 2-6	Milestone Chart — Multi-Well Experiment	16
Figure 3-1	Buildup — Short Flowback Period	21
Figure 3-2	Buildup — Long Flowback Period	22
Figure 3-3	Production Forecasts	23
Figure 3-4	Milestone Chart — BETC	24
Figure 3-5	Parallel Strain, ϵ_y, as a Function of Position, δ, in the Material Across the Frictional Interfaces from a Pressurized Crack	26
Figure 3-6	Milestone Chart — LLNL	28
Figure 3-7	Milestone Chart — LASL	30
Figure 3-8	Plan View of Seismic Events	33
Figure 3-9	Comparison of 1-D and 2-D Models	33
Figure 3-10	Milestone Chart — Sandia National Laboratories	35

FIGURES Continued

Figure 4-1	Production and Injection Volumes and Associated Pressures of CIG Miller No. 1 Well	41
Figure 4-2	Production and Injection Volumes and Associated Pressures of CIG Sprague No. 1 Well	42
Figure 4-3	Production History of Natural Buttes No. 9 Well	47
Figure 4-4	Production History of Natural Buttes No. 14 Well	47
Figure 4-5	Production History of Natural Buttes No. 18 Well	48
Figure 4-6	Production History of Natural Buttes No. 19 Well	48
Figure 4-7	Production History of Natural Buttes No. 20 Well	49
Figure 4-8	Production History of Natural Buttes No. 22 Well	49
Figure 4-9	Stress Intensity Factor (K_I) for a Crack Approaching an Interface Normalized by K_I for a Homogeneous Material	55
Figure 4-10	Average Stress Fracture Criteria Compared to Stress Intensity Factor (K_I)	55
Figure 4-11	Milestone Chart — Sandia Mineback	56

SUMMARY

August progress of government-sponsored projects, directed towards increasing gas production from the low permeability gas sands of the western United States, is summarized in this edition of the WGSP Status Report. The September 1977 Status Report, NVO/0655/100, provides background information.

Superior Oil has not yet made a decision concerning the use of their lease as a possible MWX site. Bartlesville Energy Technology Center has completed embedment tests of 20/40 mesh bauxite into grey berea and typical tight gas sand cores. At Lawrence Livermore National Laboratory, numerical routines have been developed for computing unsteady growth of hydraulically-driven cracks in plain and circular geometries. Three studies have been initiated at Sandia National Laboratories: laboratory determination of the fracture crack-tip process zone; detailed petrographic characterization of a Mesaverde tight gas sand lens and surrounding shale; and determination of oil-base drilling fluid invasion in support of the MWX.

SECTION 1

PROJECT MANAGEMENT

TECHNOLOGY TRANSFER

DOCUMENTATIONS AND REPORTS

The June *WGSP Status Report* has been distributed, the July *WGSP Status Report* is almost complete and work is continuing on the *Quarterly Basin Activities Report* for the second quarter, 1980. Statistics and production information on the Piceance and Uinta Basins have been compiled and the history has been essentially completed. A Wasatch structure map of the Uinta Basin is being compiled, with formation tops of all wells being tabulated for future reference. Facies maps of the Greater Green River Basin are being finalized. Comments on the WGSP Project Plan Document FY 1981 draft are being incorporated and the document is being finalized for distribution.

PROJECT DATA BANK

The following maps have been added to the project data bank:

"Base Map of the Wind River Basin, with wells posted to August, 1980," east and west halves, scale: 1 in. = 2 mi, mylar sepia.

"Wind River Basin Structure Map," based on the Dakota Formation, wells posted to August, 1980, and geology updated to January, 1978, scale: 1 in. = 2 mi, mylar film.

Updating and cataloging of the WGSP bibliography and map file continued.

SECTION 2

RESOURCE ASSESSMENT

U.S. GEOLOGICAL SURVEY ACTIVITIES

UINTA-PICEANCE BASINS

Field work on Lower Tertiary and Upper Cretaceous low-permeability reservoirs in the Piceance Basin continued.

Stratigraphic and petrographic studies continued.

An abstract was published entitled, "Some relations between diagenesis and porosity (real and imagined) in sandstones of the Mesaverde Group, Uinta Basin, Utah," by C. W. Keighin in AAPG Bulletin v. 64, no. 5, p. 732.

A paper was published entitled, "Characteristics of pores in some Upper Cretaceous nonmarine sandstones, Uinta Basin, Utah," by C. W. Keighin in *Scanning Electron Microscopy/1980*, p. 559-564.

GREATER GREEN RIVER BASIN

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

Work continued on pressure-temperature-source rocks for deep wells in the Merna and Pinedale areas of northern Green River Basin, Sublette and Sweetwater Counties, Wyoming.

Petrographic and clay mineralogy studies were initiated of Belco (Inexco) WASP A-1 well, Sec. 28, T36N, R112W, northern Green River Basin.

A lineament study continued using enhanced Landsat photography of the Great Divide and Washakie Basins.

A paper was published entitled, "Evaluation of organic matter, subsurface temperature and pressure with regard to gas generation in low-permeability Upper Cretaceous and lower Tertiary sandstones in Pacific Creek area, Sublette and Sweetwater Counties, Wyoming," by B. E. Law, C. W. Spencer and N. H. Bostick in *The Mountain Geologist*, v. 17, no. 2, p. 23-25.

An abstract was published entitled, "Patterns of shallow-marine deposition Upper-Cretaceous of northern Colorado," by L. W. Kiteley and M. E. Field in AAPG Bulletin, v. 64, no. 5, p. 733.

NORTHERN GREAT PLAINS PROVINCE

A paper was published entitled, "Shallow, low-permeability reservoirs of northern Great Plains — Assessment of their natural gas resources," by D. D. Rice and G. W. Shurr in AAPG Bulletin v. 64, no. 7, p. 969-987.

Low energy and storm generated sandstones near the eastward pinchout of Eagle Sandstone in central Montana were examined.

A paper is being prepared for SEPM Special Publication on geometry of sandstone bodies in the Upper Cretaceous Shannon Sandstone Member, southeastern Montana.

Core was received from three Davis Oil Co. wells for analysis. The samples, taken from the Gammon interval in northwestern South Dakota, were from the following wells:

Davis Oil No. 1 Tom, Sec. 5, T13N, R6E;

Davis Oil No. 1 Burke, Sec. 13, T14N, R5E; and

Davis Oil No. 1 Orwick, Sec. 13, T14N, R7E.

SCHEDULE STATUS

Figure 2-1 is a milestone chart of the USGS WGSP progress.

SURVEY OF BASIN ACTIVITIES

GREATER GREEN RIVER BASIN

Davis Oil has scheduled a 10,500-ft wildcat test at 1 Goldenrod, Sec. 30, T27N, R109W, Sublette County, Wyoming. The nearest well is a 15,850-ft dry hole 3½ miles to the north in Sec. 7, drilled by Davis in 1978. The new wildcat is 8 miles northeast of the one-well Monument Butte Field (Frontier production) and 18 miles east of Big Piney Field, which produces from the Wasatch, Mesaverde, Frontier and Bear River horizons. Thirty-two newly-staked locations were reported this month: 23 development and 9 wildcat.

Woods Petroleum Corporation has been testing the Bear River sands extensively at USA Reardon 17-1, Sec. 17, T28N, R111W, Sublette County. Two drill stem tests in Bear River recovered significant amounts of gas in the sample chamber. The chamber contained 11.9 cu ft of gas at 1,400 psi and shut in pressure went from 4,860 to 5,588 psi. Present drilling is at 11,880 ft. In Sweetwater County, Energy Reserves Group has set pipe at 13,098 ft at an offset to its Nickey Field Mesaverde discovery. The 1-13A Unit, Sec. 13, T24N, R96W, is less than a quarter mile southeast of the 1-13 Nickey Unit discovery, completed last year flowing 919 MCFD from the Almond Formation.

Twelve wells were reported this month: 10 development wells were producers, 1 wildcat was a discovery, and 1 development well was D&A. Total initial potential flow of new gas was 12,342 MCFD, with the Frontier Formation contributing the most (6,161 MCFD).

Table 2-1 is a summary of completed wells and newly-staked locations, and Figure 2-2 shows their locations.

NORTHERN GREAT PLAINS PROVINCE

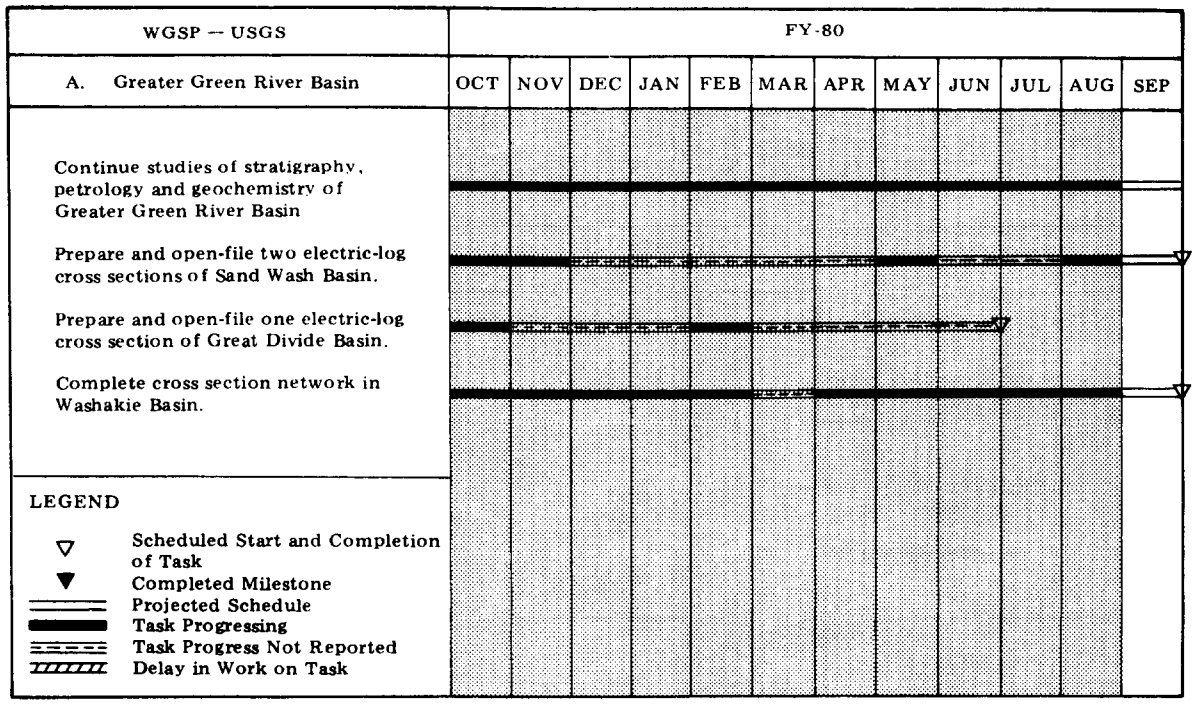
Brownlie, Wallace, Armstrong and Bander have set pipe at 2,465 ft in 9-22 Miles, Sec. 9, T1N, R53E, a remote Shannon wildcat test in Custer County, Montana. Total depth is 2,491 ft. This well is 4½ miles northwest of the operator's 19-31 Miles, Sec. 19, T1N, R54E, an indicated discovery which flowed an ungauged amount of gas during a drill-stem test of Shannon from 1,800 to 1,892 ft. Closest production to 9-22 Miles is Pumpkin Creek Field, 30 miles to the west.

Lario Oil & Gas and Amber Resources have set pipe at 1,181 ft in 1-9 Lario-Amber-Federal, Sec. 9, T14N, R3E, a wildcat in Butte County, South Dakota. Log tops include the Eagle at 756 ft and Shannon at 954 ft. Total depth is 1,250 ft. The indicated discovery is over 6 miles south-southwest of Cady Creek Field with shut in Shannon production, and 11 miles southeast of West Shore Pine Hills Field which has produced more than 1 billion cu ft of gas from Shannon since discovery in 1977.

Thirty-five wells were reported during August: 7 development wells were producers, 7 wildcat wells were discoveries, 8 development and 10 wildcat wells were D&A and 2 development and 1 wildcat were completed and shut in. Initial potential flow assigned to these wells was 6,918 MCFD, with the Eagle, Greenhorn, Bow Island, Phillips and Shannon horizons as pay zones.

Forty-four newly-staked locations were reported during August: 36 development and 8 wildcat. Milan R. Ayers has staked 1 Boucher, Sec. 20, T29N, R5W, a 2,350-ft wildcat to the Dakota Formation. The well will test Bow Island sands in the Lake Francis area. Its location is 3½ miles southwest of a Bow Island gas discovery drilled last year. The drillsite was selected on the basis of log analysis from a water well drilled for a U.S. Air Force Missile site. That log shows a possible gas pay in the Bow Island.

Table 2-2 presents a summary of completions and newly-staked locations in the province,



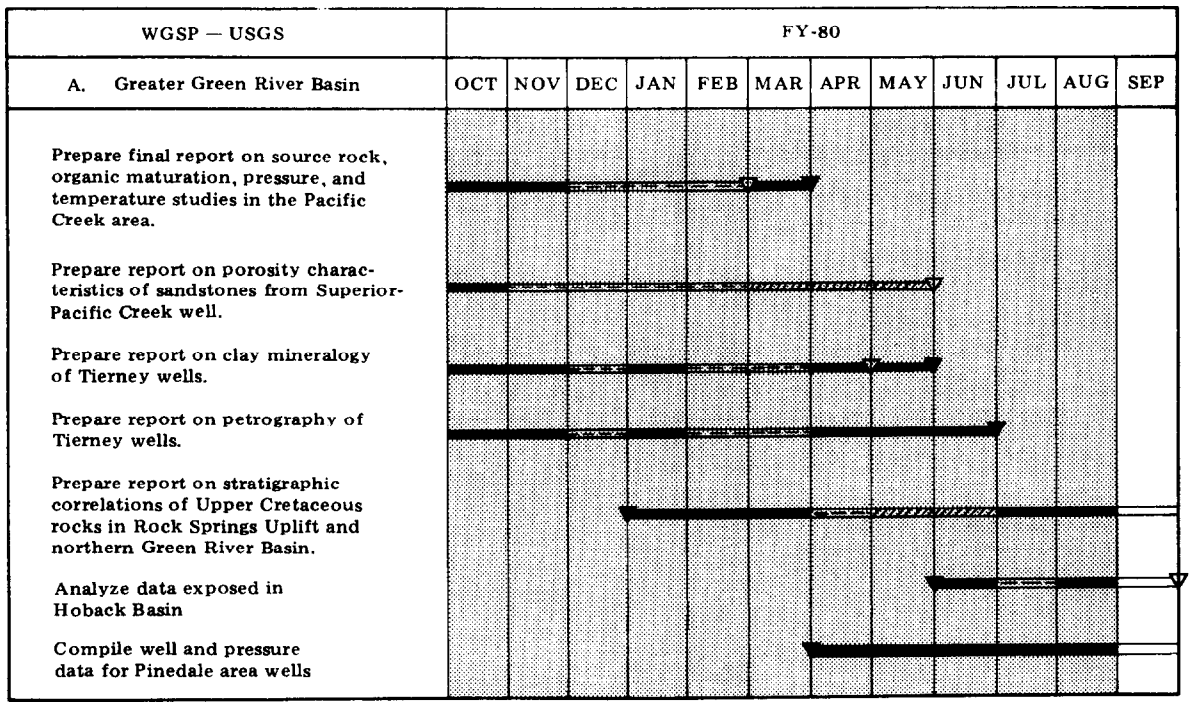
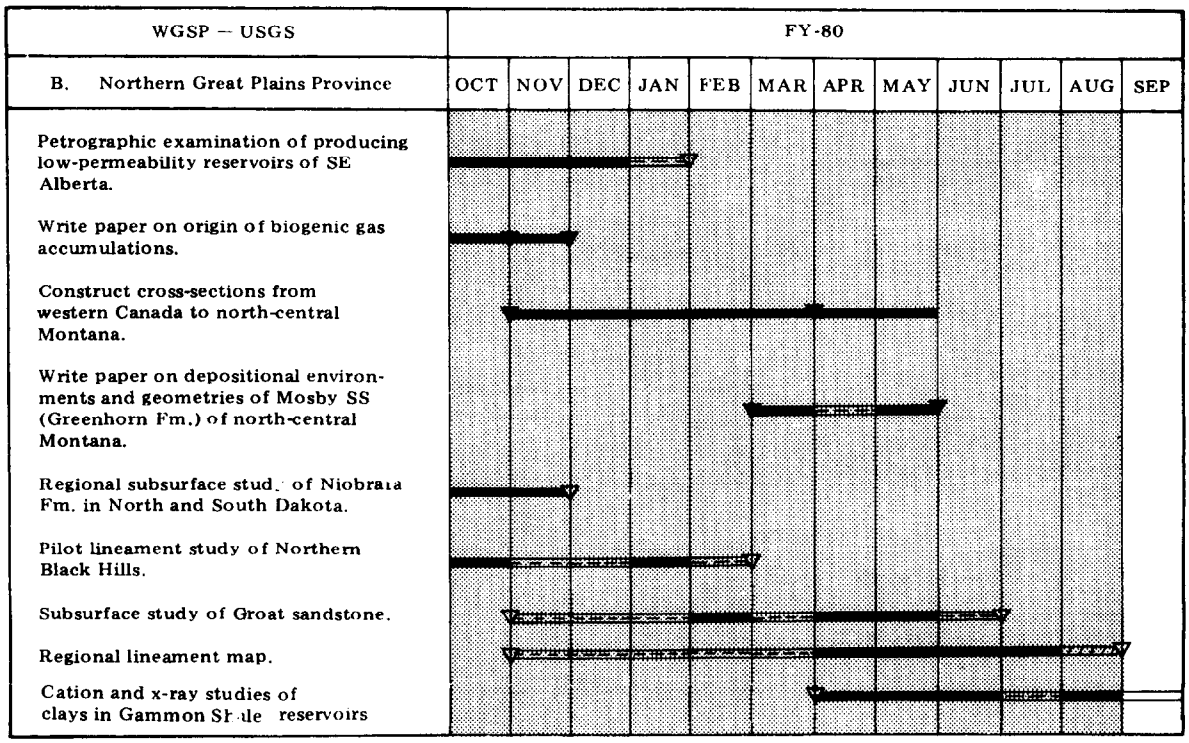
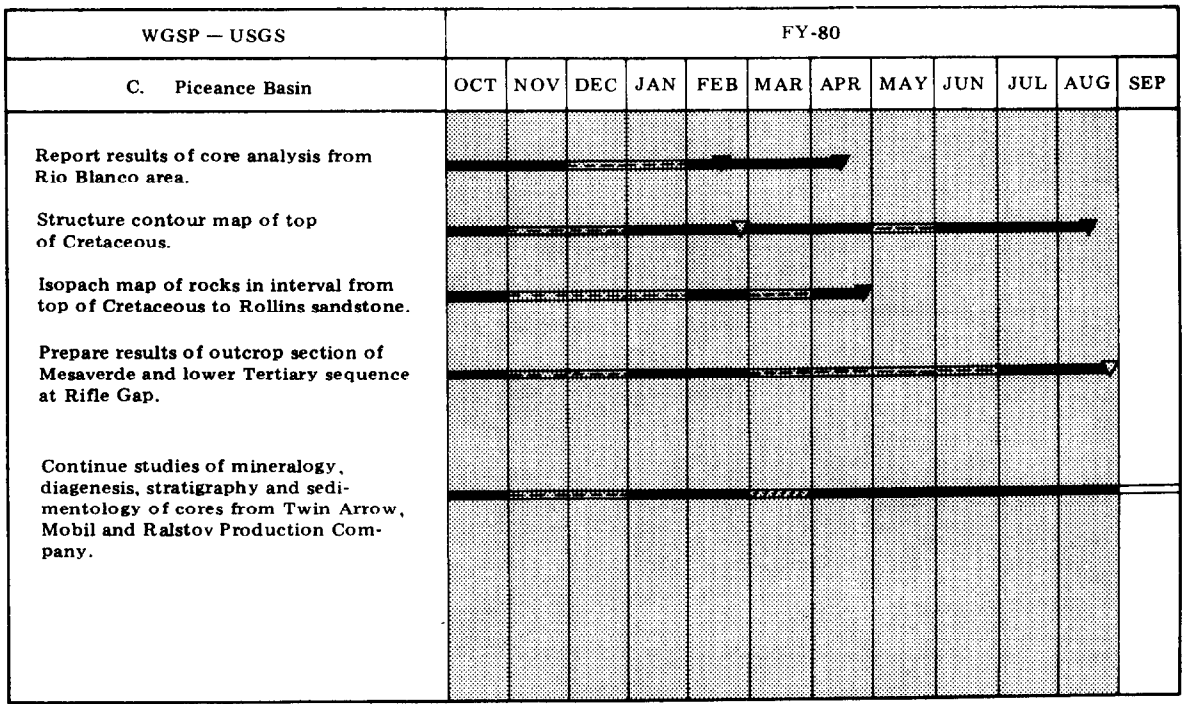


Figure 2-1 Milestone Chart — USGS





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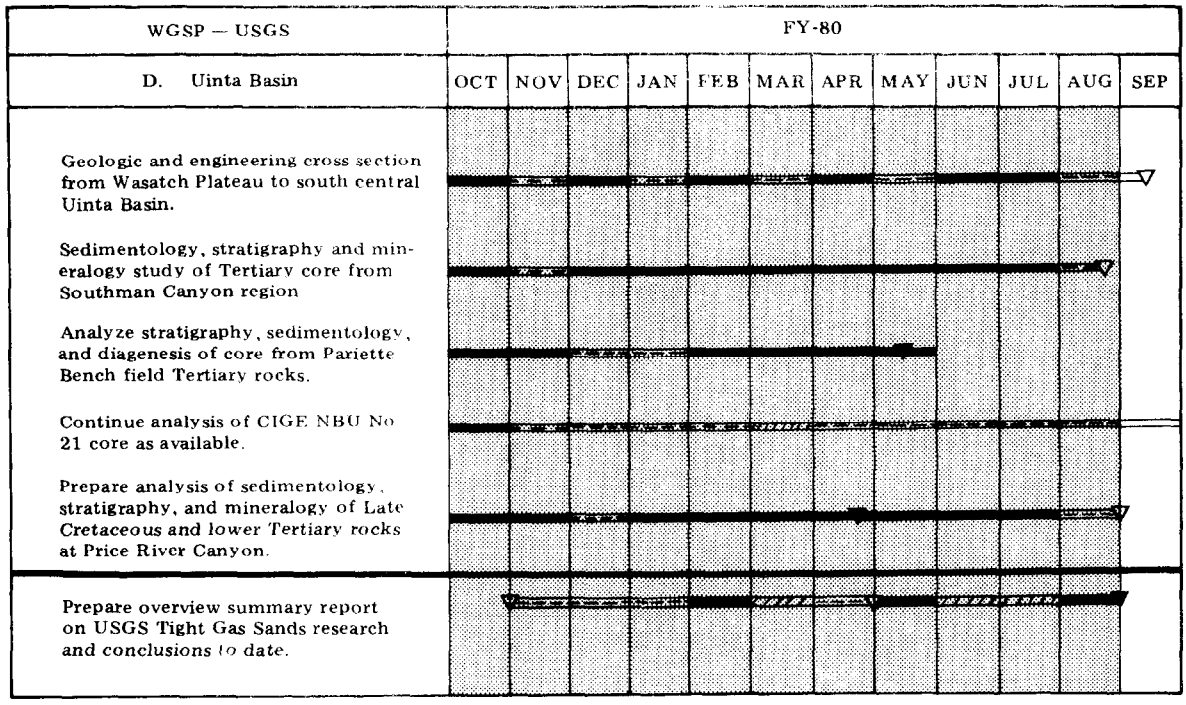


Figure 2-1 Continued

and Figure 2-3 shows their locations.

PICEANCE BASIN

Teton Energy was active in this basin during August. In Rio Blanco County, it has set casing at 5,800 ft in 16-3 Federal, Sec. 16, T1S, R97W, a 5,825 TD wildcat. The venture, scheduled to test the Wasatch, is three miles north of Piceance Creek Field, which is productive in the Wasatch and Mesaverde. About 20 miles to the northwest, Teton will drill a 5,500-ft wildcat, 24-1 Colorado Division of Wildcat — Exxon, Sec. 24, T1N, R98W. This well is five miles southwest of the White River Field, which is productive in the Wasatch.

Nine new locations were reported by month's end: 6 development and 3 wildcat. Five wells were reported as completed: 4 development wells were producers and 1 wildcat was a discovery. Total initial potential flow was 2,963 MCFD, with production from the Corcoran, Mesaverde undifferentiated and the Mancos B. The Corcoran Formation yielded the most new gas with 2,153 MCFD.

Table 2-3 is a summary of completed wells and newly-staked locations, and Figure 2-4 shows their locations.

UINTA BASIN

Total initial potential flow assigned by the operators for August in this basin was 1,825 MCFD, all from the Wasatch horizon. Three completed development wells contributed to this amount. Also reported during this month were 2 D&A development wells and 1 D&A wildcat well.

Sixteen newly-staked locations were reported: 10 development and 6 wildcat. Table 2-4 presents a summary of newly-staked locations and completed wells, and Figure 2-5 shows their locations.

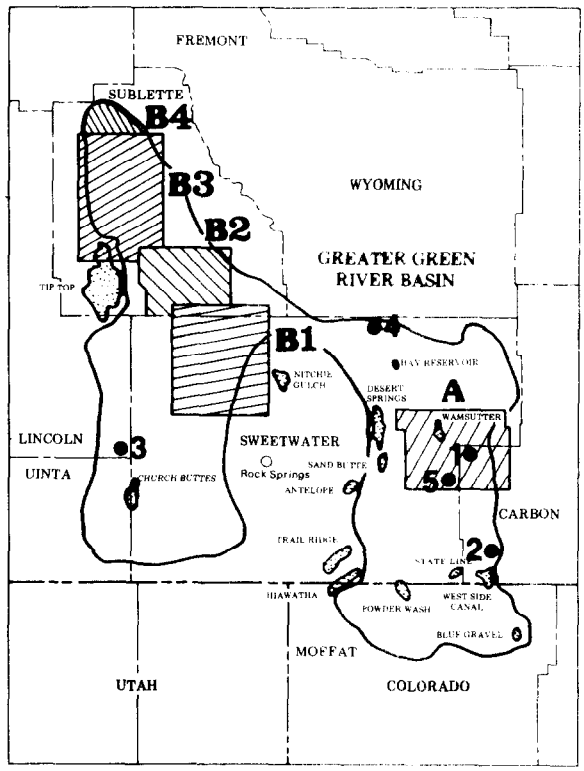


Figure 2-2 Greater Green River Basin Showing Wells of Interest and USGS Designated Core Areas

Table 2-1 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
Amoco Production	1 Champlin 242 Amoco-H	1	csw 25/19N/93W Echo Springs Field Carbon Cnty, WY	Mesaverde 8,910-9,246 (gross)	9,509 PB: 9,290	Acidized w/ 4,662 gal; fractured w/ 154,308 gal gel, 300,000 lb sand.	Develop. well, comp. 6-25-80. No cores or tests. Spud 3-24-79.	1,137
Energy Operating	1 Alvin E. Denny	2	senw 27/13N/90W Unnamed Field Carbon Cnty, WY	Mesaverde 3,593-3,703	10,130 PB: 8,400	Acidized w/ 1,000 gal.	Wildcat field discovery, comp. 12-10-79. Spud 6-15-79.	250
Amoco Production	10 Wilson Ranch	3	nwse 7/19N/112W Wilson Ranch Field Lincoln Cnty, WY	Frontier 11,368-11,436	11,580 PB: 11,496	128,520 gal gel, 373,923 lb sand.	Develop. well, comp. 6-15-80. Cored; no tests. Spud 6-6-79.	650
Davis Oil	5 Picket Lake	4	swne 13/26N/97W Picket Lake Field Sweetwater Cnty, WY	Lewis 13,545-13,613	13,725 PB: 13,660	83,950 gal gel, 105,000 lb sand.	Develop. well, comp. 7-9-80. No cores or tests. Spud 8-3-79.	527
Santa Fe Energy	1-8 Federal	5	swsw 8/17N/94W Wild Rose Field Sweetwater Cnty, WY	Mesaverde 13,500			Develop. location, reported 8-21-80. Located in Core Area A.	

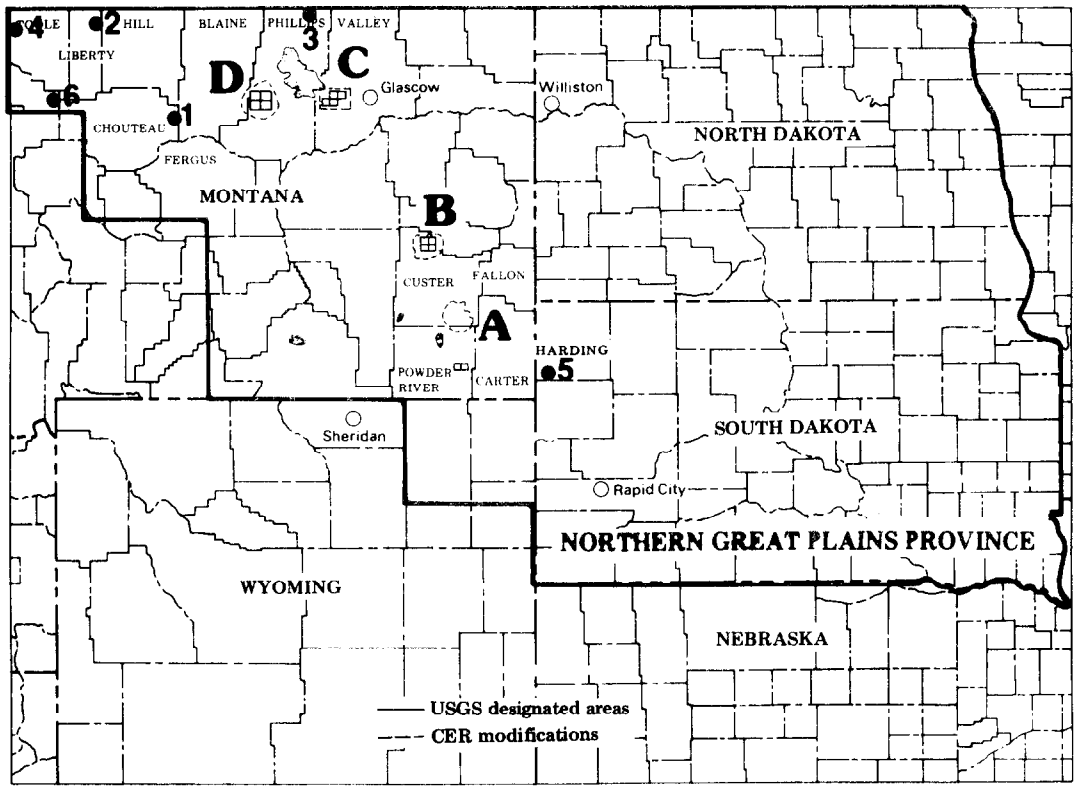


Figure 2-3 Northern Great Plains Province Showing Wells of Interest and USGS Designated Core Areas

Table 2-2 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
Tricentrol United States	8-3 Phillips	1	nenw 8/26N/17E Bullwacker Field Chouteau Cnty, MT	Eagle 1,819-1,824	2,200	Sand fracture w/18,000 lbs	Wildcat outpost extension, comp. 2-7-80. No cores; drill stem tested. Spud 2-2-80.	104
Lawrence J. McCarthy	1-19 Tempel Farms	2	sese 19/36N/7E Unnamed Field Liberty Cnty, MT	Bow Island 2,065-2,243 (gross)	2,310		Wildcat field discovery, comp. 3-29-80. No cores; drill stem tested. Spud 3-24-80.	85
Elenburg Exploration	1 Federal 0572	3	nesw 5/37N/32E Wildcat Field Phillips Cnty, MT	Muddy 2,500	2,118		Wildcat test, comp. 6-24-80 D&A. No cores; drill stem tested. Spud 6-20-80.	
Webb Resources	2-4 Baldwin	4	nwnw 2/36N/4W Fitzpatrick Lake Field Toole Cnty, MT	Bow Island 1,536-1,552	1,768 PB: 1,604	Acidized w/ 250 gal; fractured w/ 12,500 gal gel, 25,000 lb sand.	Develop. well, comp. 10-13-79. No cores or tests. Spud 9-18-79.	145
Jerry McCutchin Jr.	1 State Placid	5	nwnw 16/15N/3E Cady Creek Field Harding Cnty, SD	Shannon (no interval given)	3,500		Wildcat field discovery, comp. 9-7-79. OWWO: comp. 6-30-73 D&A. Re-entered 9-1-78.	900
General Well Service	1 Anderson	6	swsw 27/27N/2E Hardpan Field Pondera Cnty, MT	Bow Island 865-870	900		Wildcat field discovery, comp. 7-26-80. No logs run; no cores or tests. Spud 9-6-79.	90

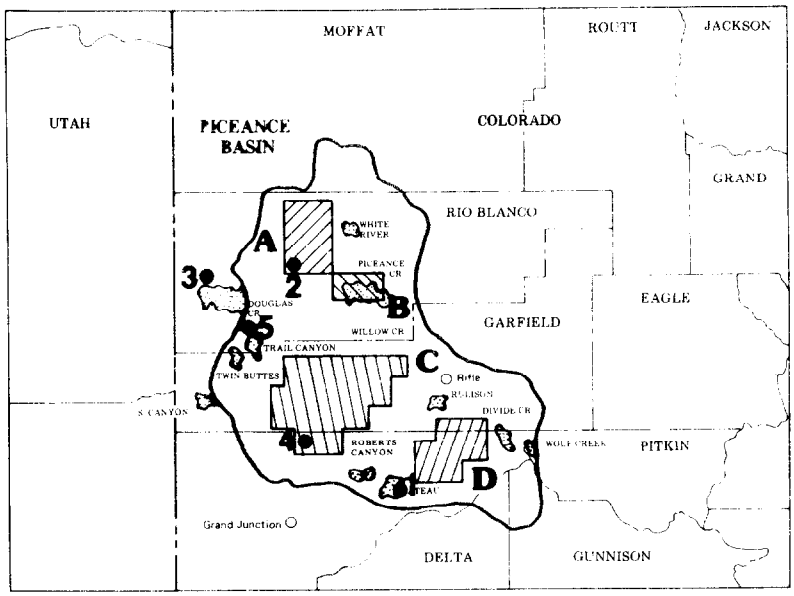


Figure 2-4 Piceance Basin Showing Wells of Interest and USGS Designated Core Areas

Table 2-3 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	2-7 Big Creek Cattle-Federal	1	nene 7/10S/95W Plateau Field Mesa Cnty, CO	Corcoran 4,711-4,795	4,880 PB: 4,822	Acidized w/ 500 gal; fractured w/ 57,570 gal water, 120,000 lb sand.	Develop. well, comp. 6-17-80. No cores or tests. Spud 4-19-80.	364
Teton Energy	14-1 Yellow Creek-Federal	2	nene 14/1S/99W Unnamed Field Rio Blanco Cnty, CO	Mesaverde 7,747-8,678 (gross)	8,706 PB: 8,698	Acidized w/ 3,500 gal; fractured w/ 117,111 gal emul, 245,000 lb sand.	Wildcat field discovery, comp. 9-15-79. No cores or tests. Spud 12-30-78.	500
Chandler & Associates	7-14-1-2 Federal	3	swne 14/1S/102W North Douglas Creek Field Rio Blanco Cnty,	Mancos B 2,221-2,326	2,541 PB: 2,407	Acidized w/ 6,000 gal; fractured w/ 115,000 gal water, 358,000 lb sand, 130 tons CO_2.	Develop. well, comp. 5-2-80. No cores or tests. Spud 3-7-80.	310
Adolph Coors	1-26 HG USA	4	nwsw 26/8S/99W Wildcat Field Mesa Cnty, CO	Entrada 8,800			Wildcat location, reported 8-21-80. Horizon below WGSP interest, but could be good for core information. Located in Core Area D.	
Twin Arrow	3-16 Continental	5	swsw 16/3S/100W Cathedral Field Rio Blanco Cnty, CO	Mancos 4,470			Develop. location, reported 8-22-80.	

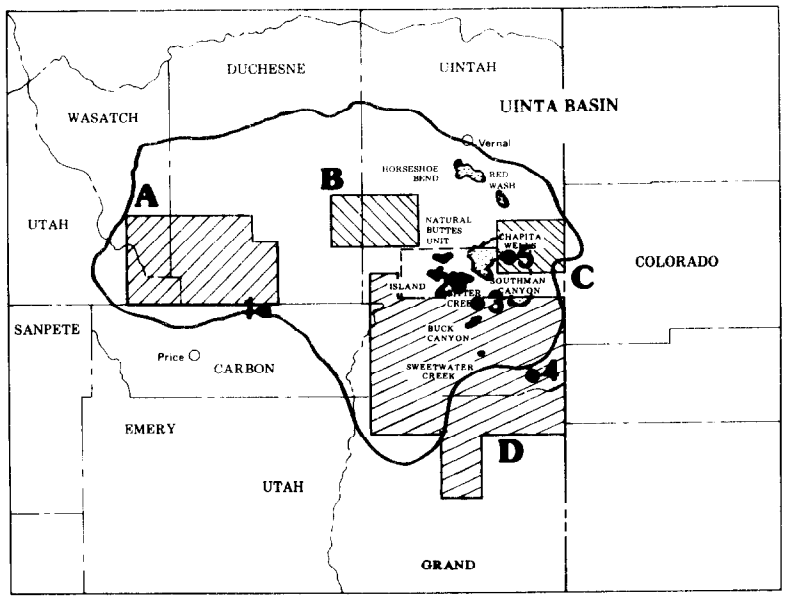


Figure 2-5 Uinta Basin Showing Wells of Interest and USGS Designated Core Areas

Table 2-4 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
Mountain Fuel Supply	2 Whitmore Park	1	senw 34/12S/12E Wildcat Field Carbon Cnty, UT	2,965 Cretaceous test	3,000		Wildcat test, comp. 12-6-79 D&A. No cores or tests. Wasatch log top: 2,681 ft.	
CIG Exploration	69-19-10-21 CIGE	2	senw 19/10S/21E Natural Buttes Field Uintah Cnty, UT	Wasatch 4,676-6,160 (gross)	6,275 PB: 6,239	Acidized w/ 2,400 gal; fractured w/ 75,800 gal gel, 140,000 lb sand.	Develop. well, comp. 6-25-80. No cores or tests. Spud 3-10-80.	350
Cotton Petroleum	1 Love Unit	3	csw 11/11S/21E Unnamed Field Uintah Cnty, UT	Wasatch 6,312			Develop. well, formerly comp. in Mesaverde, 1-19-80; PB 6,550, testing Wasatch.	
Arco Oil & Gas	31-1 Federal	4	nwsw 31/15S/24E Wildcat Field Uintah Cnty, UT	Morrison 7,830			Wildcat location, reported 8-18-80. Below WGSP horizons of interest, but could be good core information. Located in Core Area D.	
Belco Petroleum	55-20 Chapita	5	sesw 20/9S/23E Natural Buttes Field Uintah Cnty, UT	Mesaverde 8,485			Develop. location, reported 7-29-80. Located in Core Area C.	

C K GEOENERGY

Seventeen of twenty outcrop locations had been completed in the Green River Basin by the end of August. Coring will begin in the Wind River Basin when the Green River Basin project is completed in September.

GAS RESEARCH INSTITUTE SPONSORED PROJECTS

Work continued on the development of a matrix or information model to identify the state-of-the-art in tight gas sands technology and resource evaluation. A proposed matrix format was presented to the GRI Project Advisors in July, and refinements continue. The Technology Matrix was completed and distributed to the GRI Program Manager and Project Advisors. Work continued on the development of the Resource Matrix, Technology Priority Matrix and Resource Priority Matrix.

EVALUATION OF SEISMIC DATA FOR DETAILED STRATIGRAPHIC STUDIES OF LENTICULAR SANDS

A final report is being prepared and will be issued as a Sandia Laboratories Report. A draft of the report was submitted to GRI.

SECONDARY BASIN STUDIES

A draft of a geologic report on the tight gas potential in the Arkoma Basin/Ouachita Mountains Province in Oklahoma and Arkansas is in review. Geologic review continued on the Raton Basin of New Mexico and Colorado. Preliminary background work has begun for the Anadarko Basin of Oklahoma and Texas, and the Wind River Basin of Wyoming.

HYDRAULIC FRACTURE CHARACTERIZATION

Certain items in the subcontract with M. D. Wood, Inc. have been renegotiated. Field work has not commenced.

A comprehensive Annual Report is in preparation, covering all activities during the period from project inception through August 1980.

TRW WESTERN GAS SANDS SUPPORT

The final report for the study of alternatives for implementing a computerized WGSP data base is being completed. The report will be published in September. Work has commenced on the generation of abstracts for the Level 1 data base.

Review comments on the draft FY 1981 WGSP Project Plan Document were received. Appropriate modifications were drafted, reviewed and incorporated into the Document, which will be distributed in September.

A general review of work accomplished to date on the CER/TRW WGSP Technical and Administrative Support Contract was held in Las Vegas, August 18. A. Crawley, (DOE WGSP Manager), C. Atkinson, (DOE WGSP Field Manager), and CER and TRW personnel attended the review.

Work is continuing on the economic analysis of gas production in selected Western basins, with current emphasis on Wattenberg Field data.

MULTI-WELL EXPERIMENT

No decision has been made by Superior Oil Company concerning the use of their lease in Sec. 34, T6S, R94W, Garfield County, Colorado, as a possible MWX site. Superior has indicated their decision will be made in September. A site inspection report is on file concerning the logistics for operating a MWX Project at that site.

Preliminary environmental assessment reports were sent to LLNL and assessment will begin after the location is obtained.

Appropriate Colorado Oil & Gas Conservation Commission Forms are being prepared in anticipation of the agreement with Superior Oil.

CORE PROGRAM

Discussions with IGT and the MWX Core Advisory Committee in August concentrated on the following topics:

- the importance of determining any deviation from the net stress hypothesis in tight gas sands;
- the approach to water saturation measurements in tight gas sands by IGT through the generation of a capillary pressure curve; and
- the preliminary work by IGT evaluating directional permeabilities.

Revisions to the core gamma apparatus have been made based on several inputs. After additional design details are completed, it will be ready for fabrication.

The first experiment in the formation and core invasion study was conducted at Sandia National Laboratory (SNL) this month. Dry Tennessee sandstone core was subjected for four hours to oil-base mud at 250 psi and 150°F. Invasion of slightly over one inch was observed. The invasion zone in turn was divided into three nearly equal band widths. Only the middle one fluoresced. A preliminary interpretation is that the innermost zone (greatest invasion) is water, the middle band is oil, and the outer band of the rock (least invasion) seems plugged with asphaltines or paraffin-like material. This mud is similar to what will be used for the MWX and it has 10 percent water dispersed throughout. Further analyses will be made of the three zones. Additional runs will be made to scope the problem.

MWX MODEL

A technical/economic system analysis of gas production from tight sand lenses has been initiated at SNL. The analysis will combine geologic, stimulation and economic models to examine the sensitivity of gas production to various parameters. As part of this effort, a number of computer subroutines for reservoir behavior have been written and debugged; their purpose is to predict gas production rates with time for three varying fracture geometries:

- production from a massive hydraulic fracture (MHF) in a sand lens with the fracture running down the length of the lens and contained within the lens;
- production from an MHF with the fracture running perpendicular to the lens axis, breaking out of the lens, and breaking back into neighboring sand lenses; and
- production from a gas-fraced multiple radial fracture in a sand lens.

SCHEDULE STATUS

Figure 2-6 shows the progress of the MWX.

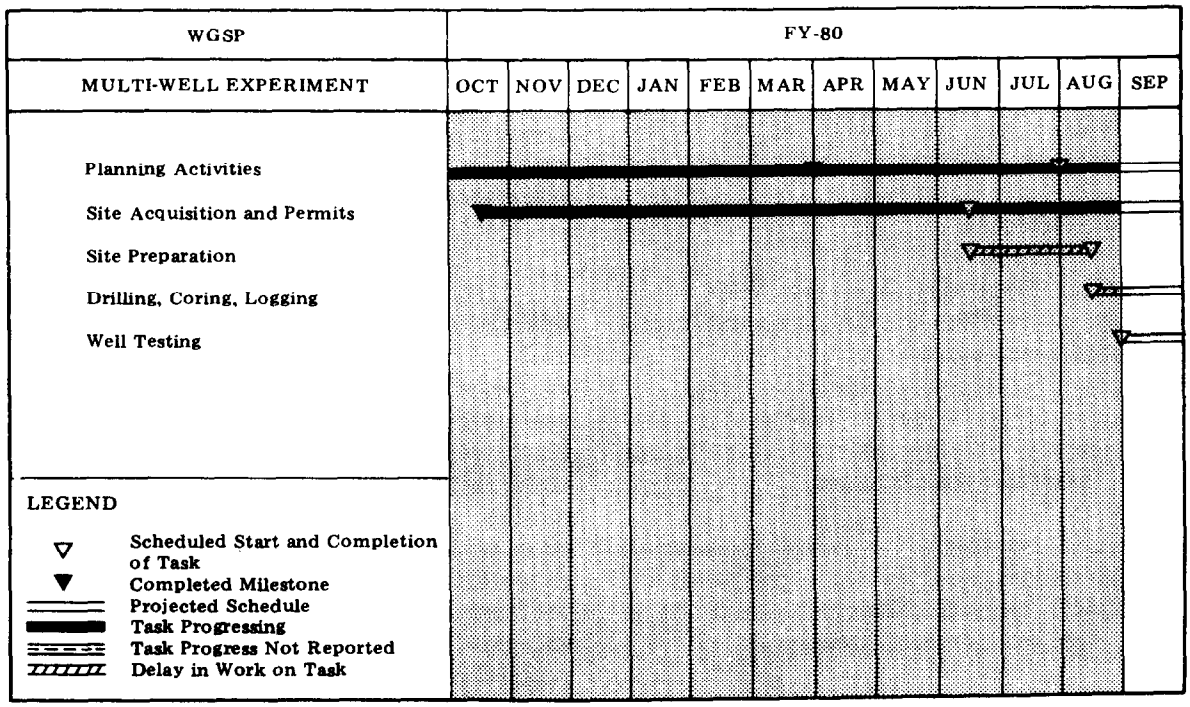


Figure 2-6 Milestone Chart – Multi-Well Experiment

SECTION 3

RESEARCH & DEVELOPMENT BY ENERGY TECHNOLOGY CENTERS & NATIONAL LABORATORIES

BARTLESVILLE ENERGY TECHNOLOGY CENTER

IMPROVED PRESSURE CORING SYSTEM – SANDIA NATIONAL LABORATORIES

Core Retriever Design and Testing

During August, 48 out of 49 pressure cores attempted were obtained, representing a 98 percent recovery rate. The one failure resulted from a core breaking off vertically because too much length extended below the core catcher. This prevented complete retraction of the inner core barrel and produced ball valve closure.

Design layouts have been submitted of a pressure core barrel that is capable of providing oriented cores. The drawings were reviewed and a more compact design has been requested that does not require as much length. A large steel block, which simulates the metal mass of the drill bit, is being measured to see how it influences a compass bearing so standoff distance can be optimized.

A strain gauge pressure transducer is being installed in the core barrel so internal pressure can be read when the core barrel reaches the surface. Calibrations of four Kulite pressure transducers and DJ Instruments digital readout were performed so a local PCI pressure reference standard could be obtained.

Core Fluid Testing

Experiments were performed inserting a core into a pressure core barrel at a nominal rate of 4 min/ft for a simulated drilling rate of 15 ft/hr. The low invasion fluid presently used (10 lb/BBL HEC and 300 lb/BBL $CaCO_3$) gave slightly lower pressures than did the old mixture (15 lb/BBL HEC and 100 lb/BBL $CaCO_3$). The measured pressure was 70 psi, which is equal to a 344 lb force on the end of a 2.5 in. diameter core. It is believed that this force is too great to apply to the unconsolidated sands found in Louisiana, which PCI has been asked to core. Experimentation is required to develop a less viscous low intrusion fluid.

IN SITU PERMEABILITY

Permeability of Interbedding Material of Tight Western Gas Sands – Lawrence Livermore National Laboratories

During August, progress was slowed by vacation of key personnel. Repair of the instrumentation system was completed and the associated computer software modification was almost finished.

During September, the software modification should be completed and permeability measurements should resume on four samples at ambient temperature and effective pressures up to 50 MPa.

LOGGING STUDIES

Interface Conductivity Studies

In July a model for low permeability rock was derived based on rectangularly-shaped capillaries. This model predicted that permeability should be a third order function of confining stress. Permeability data appears to fit the model and work is continuing to obtain data from cores with a greater range of permeability and formation depth.

Table 3-1 Analysis for Mitchell Muse-Duke No. 1 Well

Sample No.	Porosity, Texas A&M	Porosity, Core Lab	Matrix Density, gm/cc	Matrix Travel Time, ms/ft
M1	2.4	3.0	2.68	48.6
M2	2.8	1.6	2.69	48.0
M3	2.5	1.9	2.69	50.5
M4	1.7	1.3	2.69	49.6
M5	2.0	2.5	2.69	48.7
M6	2.1	1.4	2.69	50.1
M7	1.8	1.3	2.71	49.5
M8	2.3	1.3	2.76	48.8
M9	2.3	3.7	2.69	50.8
M10	1.8	1.0	2.69	52.5

Mapping and Contouring Water Resistivities in Tight Western Gas Sands — Texas A&M University

Work in the Mesaverde formations will continue despite the current sparse activity in that horizon.

A recent assessment indicated that there are 552 water analyses from formations other than Upper Cretaceous, with the bulk from the Wasatch. Their reliability remains doubtful for reasons discussed previously. Commingling of formation waters in the Wasatch prevails just as in the Mesaverde. Dilution by drilling fluid filtrates is also a serious problem. Nevertheless, the information available suggests that a close examination may prove fruitful.

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

Activities this month included analysis of the Mitchell Energy Muse-Duke No. 1 well in Limestone County, Texas, which produces from a carbonate reservoir. Log analysis is conventional since the characteristic physical parameters are known. Porosities have been measured on 10 samples from the well, and they have been compared to those from core analyses performed by Core Laboratories. The most likely reason for the observed differences, shown in Table 3-1, is because Core Lab performed a whole core analysis while Texas A&M used smaller plug analysis.

Table 3-1 also lists calculated matrix densities and matrix sonic travel times. These tend to fall within the expected ranges for a carbonate reservoir. For this reason, analysis of the Mitchell Energy well is considered complete.

ADVANCED LOGGING TECHNIQUES AND INTERPRETATIONS

Use of Sonic Techniques to Measure In Situ Stresses — Lawrence Livermore National Laboratory

A pair of quarter-cylinder wedges were designed and constructed. Various incident angles can be generated by changing the transducer/wedge contact position. Both refracted body waves and surface waves were observed and identified for single-face configuration. The data acquisition system has been completed and the data recorded on the LSI-11 Computer can be transferred to the LLNL computer system through a PDP-11 for real-time data analysis.

Discussions were held with Dr. J. Heyman at NASA-Langley on ultrasonic stress measure-

ment techniques. He has developed methods for measuring stress in bolts using ultrasonic waves.

HYDRAULIC FRACTURING AND FRACTURE CONDUCTIVITY

Proppant Embedment in Hydraulically Fractured Reservoirs

Proppant Embedment Studies

Embedment tests of 20/40 mesh bauxite into grey berea and typical tight gas sand cores have been completed. The results need to be corrected for compression of the rock to arrive at true embedment. As part of the procedure, the proppant is now being saturated with 2 percent KCl brine (~ 24 hr) prior to embedment tests. The use of wetted proppant allows proppant positioning without applying a grease film to the rock.

Since Berea Sandstone was used as a base material in these studies, tests were performed to measure its hardness and indirect tensile strength. These tests will also be performed on other core used in the studies. An average Rockwell hardness value of 104 (L-scale) was measured for saturated Berea. Indirect-tensile strengths, using ¾ in. by 1½ in. diameter Berea slabs, were found to be 535 psi for dry and 440 psi for saturated slabs.

Proppant Transport in Massive Hydraulic Fracturing — University of Tulsa

During the past month attention has been directed to improving the computational model for hydraulic fracturing. A new temperature model has been constructed which is sensitive to the operating parameters of the fracturing process. Having identified the required analyses, numerical or analytical subroutines together with "stand-in" subroutines were generated. These subroutines have been integrated by means of a main program called TUFRAC1, which in its present state enables producing data to be examined for effects resulting from selected fracturing parameters. These data are in reasonable agreement with similar data in the literature but a sufficient check on the model has not been obtained.

RESERVOIR SIMULATOR STUDIES

Reservoir Simulator for Hydraulically Fractured Gas Wells in Lenticular Formations — University of Oklahoma

Modification and debugging of the two-dimensional gas well simulator was completed during August. Additional effort was directed toward using the simulator to test the performance of gas wells completed in blanket sands in order to further verify the validity of the computer program. The present program is coded so blanket sands and noncontinuous lenticular sands can be investigated. The literature is being researched to obtain actual field test data to use as input to the simulator. Once reliable simulated well performance results are duplicating existing literature data on blanket sands, data from lenticular gas sands will be inputed to the simulator.

A three-dimensional general purpose fractured reservoir simulator was secured, key punched and verified. This program will be debugged and modified to include all the effects currently incorporated into the two-dimensional version.

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

During this month, the effect of fracture fluid remaining around the fracture during the test period was examined. The base model for this work was created using the Two Phase Fracture Propagation Model that was recently developed by Intercomp. A reservoir 60-ft

thick with .015 md permeability, 5 percent hydrocarbon porosity and initial reservoir pressure of 4,670 psia at a depth of 10,614 ft was fractured and then allowed to flowback against a constant bottom hole pressure. The fracture treatment of 13,600 gals of fluid and 32,800 lbs of propping sand created a fracture 60-ft high, .017-in. wide with a propped half-length of 550 ft.

The first buildup test was run after the well had flowed for 5 days, recovering 2.6 percent of the fracture fluid. Using the Three-Dimensional Radial Gas Model, a match of the pressure transient response was obtained when the model had identical reservoir properties and a fracture half-length of 550 ft with .35 md-ft conductivity. Figure 3-1 is the plot of the two pressure responses, showing good agreement in the latter portion of the curves. The discrepancy in the early part of the curves is due to the much coarser grid used in the Fracture Propagation Model.

The second buildup test was run after the well had flowed for 185 days, recovering 9.1 percent of the fracture fluid. A match of the pressure transient response was obtained when the model had a fracture half-length of 550-ft and conductivity of 5.0 md-ft, applying an enhanced zone around the fracture with permeability of 1,000 md. The pressure responses of the two models are plotted in Figure 3-2 and show close agreement in the latter portion of the curves. The discrepancy in the early portion is again due to the coarse grid used in the Fracture Propagation Model.

Comparing the analysis of the long flowback with that of the short flowback, it can be seen that the analysis indicates a cleaner, more permeable fracture when the well is allowed to clean up before testing. Even though the incremental amount of clean up of fracture fluid is small (only 6.5 percent more) there is still a pronounced difference in the fracture permeability.

Figure 3-3 is a plot of the production forecasts obtained from the two matching models and the Fracture Propagation Model. Using the match characteristics with short flowback analysis produces a production curve much lower than that of the long flowback analysis. It also has a cumulative production half as large over the 10-year production history. It can be seen that the long flowback analysis more closely approximates the production history of the Fracture Propagation Model.

SCHEDULE STATUS

The milestone chart for BETC is shown in Figure 3-4.

LAWRENCE LIVERMORE NATIONAL LABORATORY

THEORETICAL ANALYSIS

Analysis has continued of some specific aspects of fracture growth due to the effect of frictional interfaces. Observation of field results from the mineback of hydraulic fractures at NTS by Sandia showed that fractures make an abrupt step in certain places. LLNL has theorized that a variation of friction along a discontinuity or interface could cause the abrupt steps. Consequently, a set of laboratory experiments was performed where a lubricant was used to create a variation in friction along an interface. A hydraulic fracture in these laboratory specimens displayed a similar geometry.

To quantify this phenomena, the theoretical models used for the analysis have been modified. Preliminary results from a calculation are shown in Figure 3-5. The geometry of the problem is shown in part (a) of the figure. The two-dimensional calculation was performed in plane strain geometry, and Young's modulus and Poisson's ratio for the material were 20 GPa and 0.25, respectively. Friction along the interface varied as shown on the dotted line along the lower section of part (b). The solid line in parts (a) and (b) shows

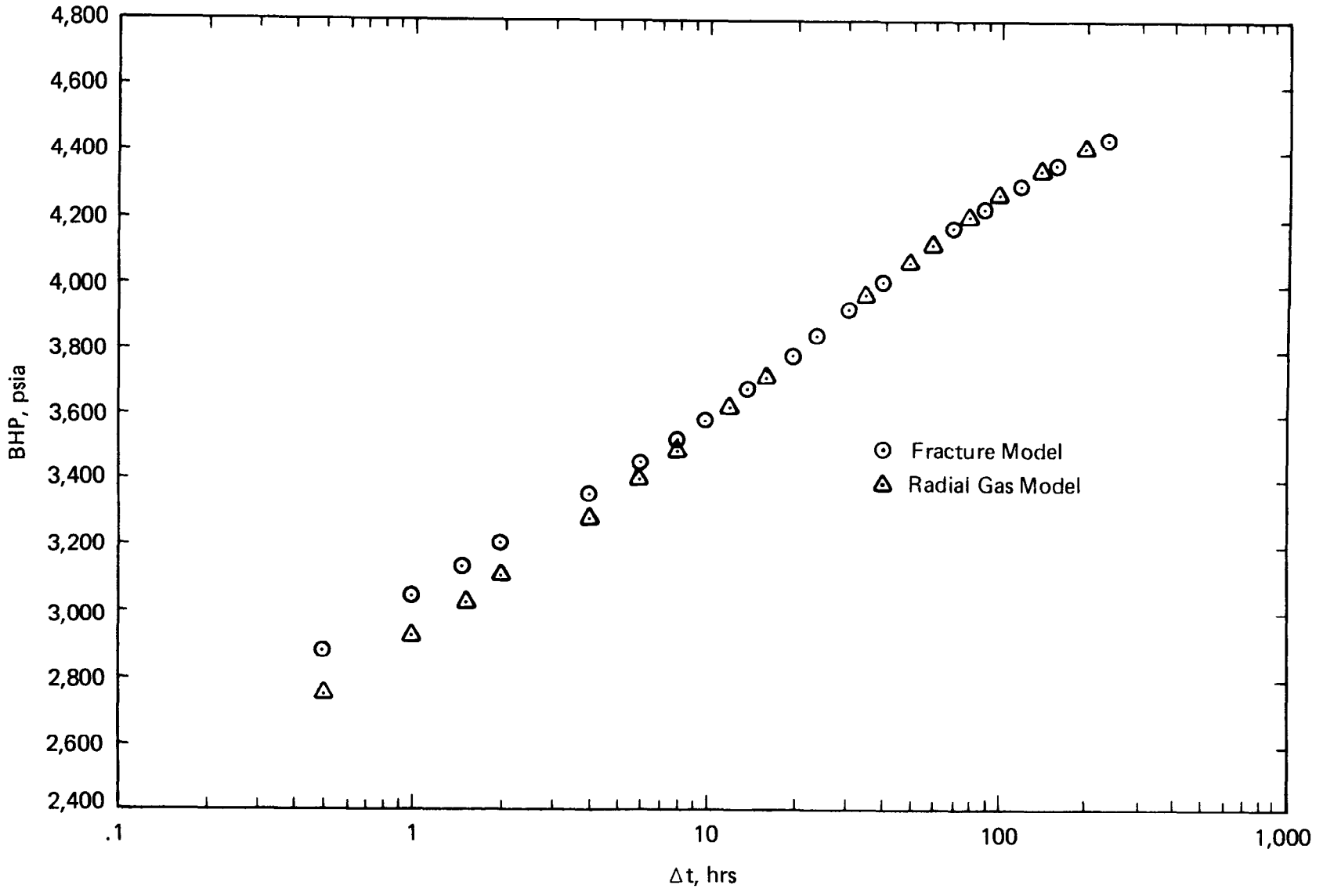


Figure 3-1 Buildup — Short Flowback Period

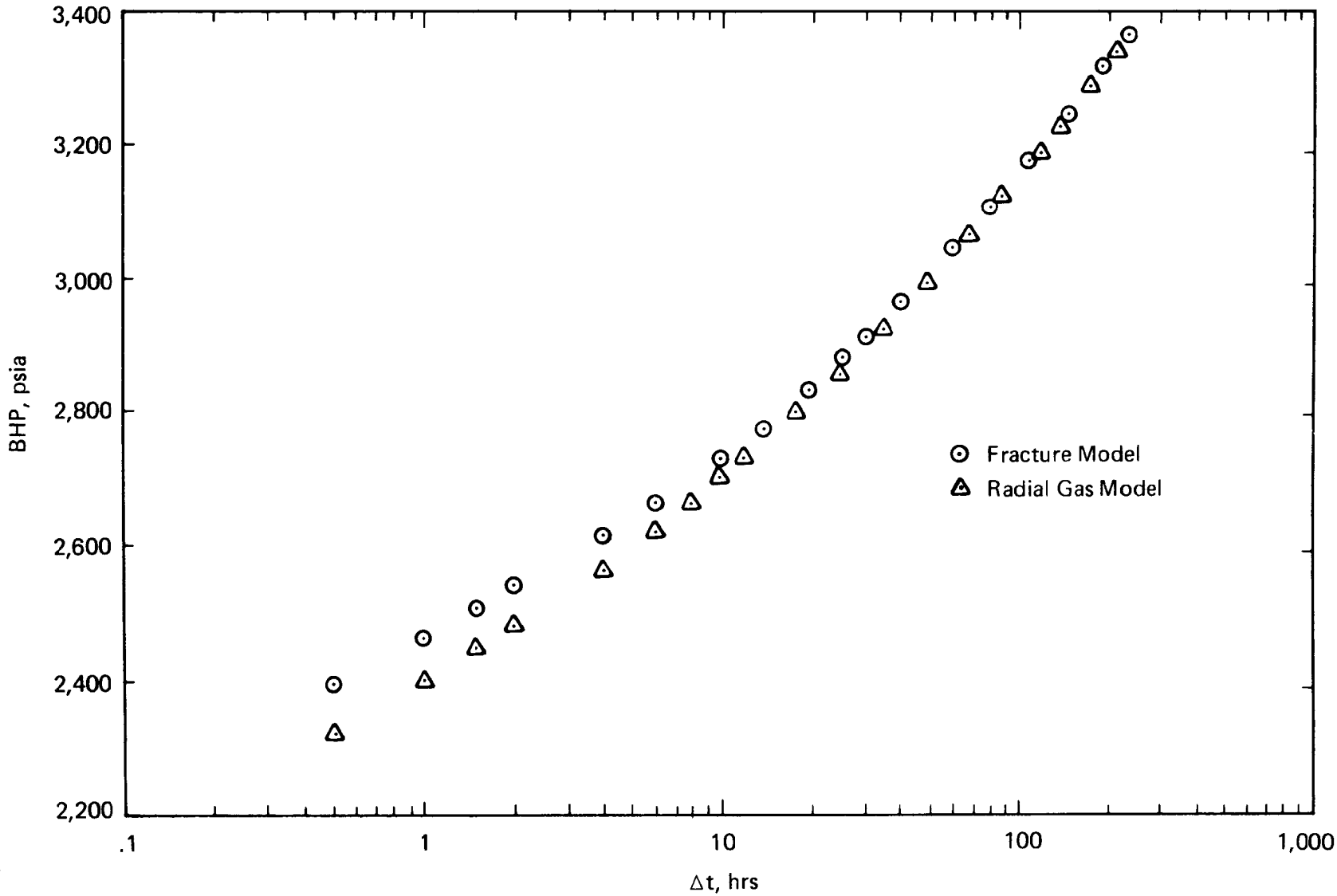


Figure 3-2 Buildup – Long Flowback Period

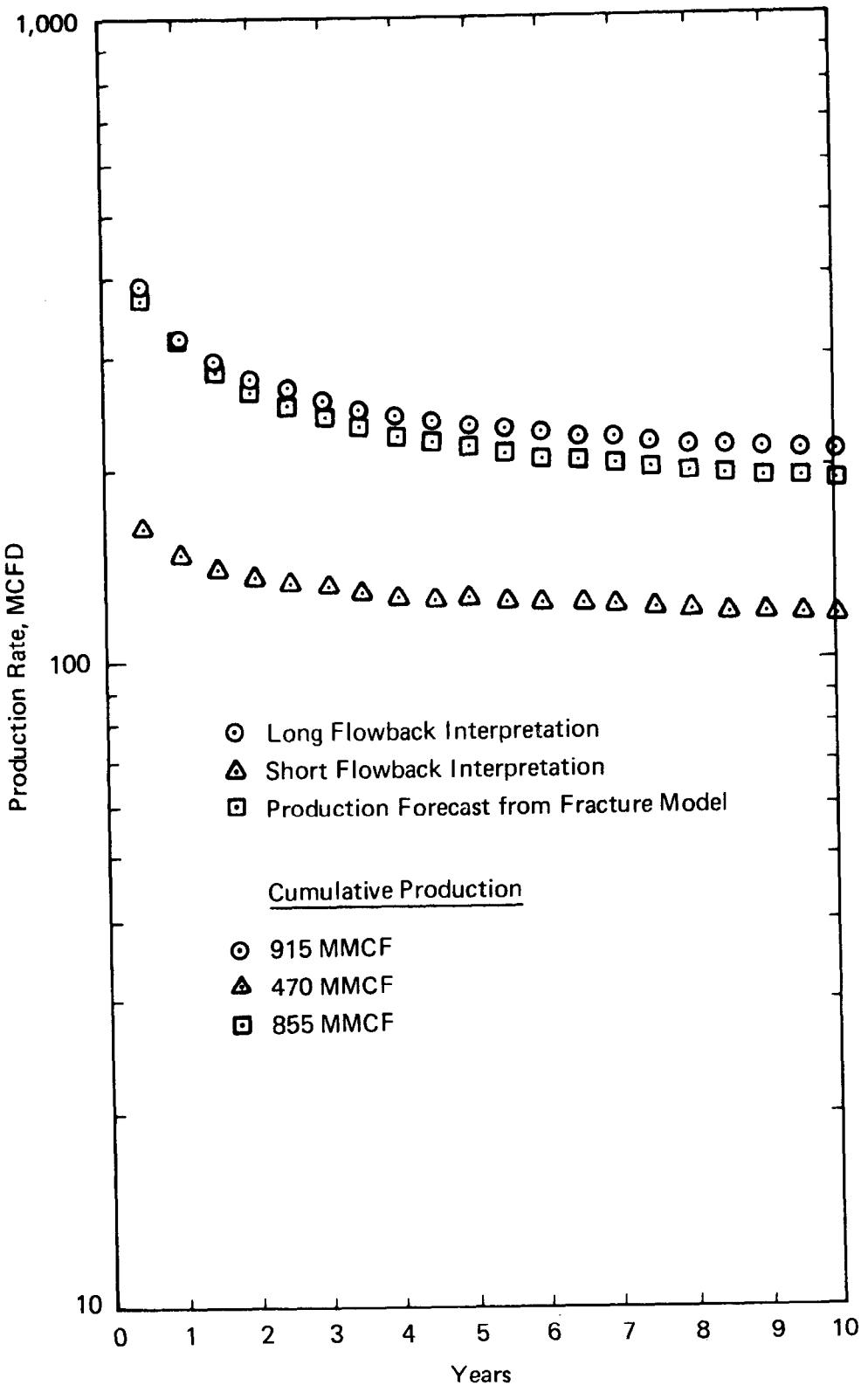
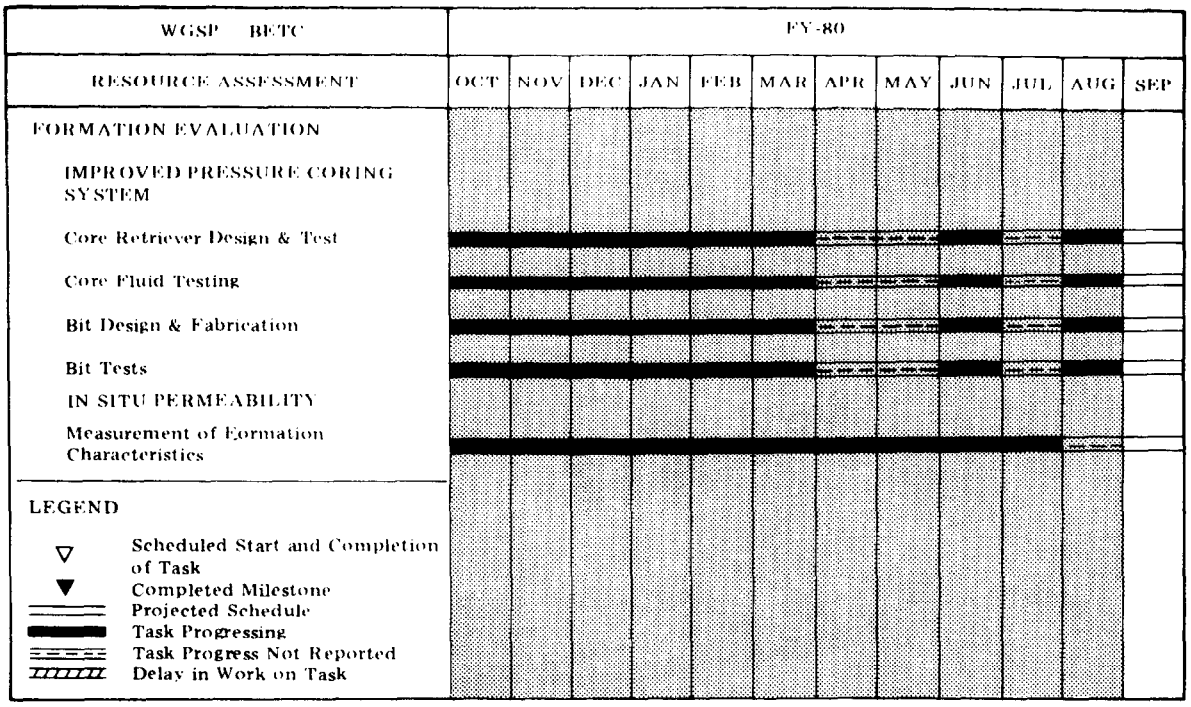


Figure 3-3 Production Forecasts



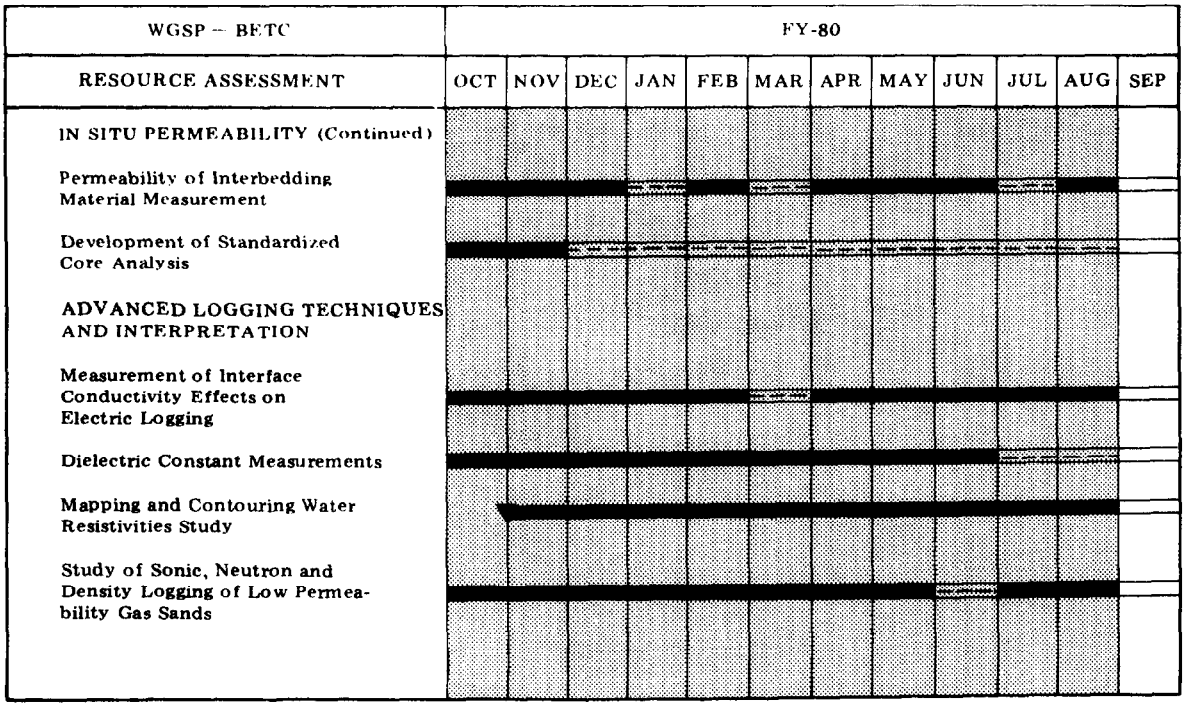
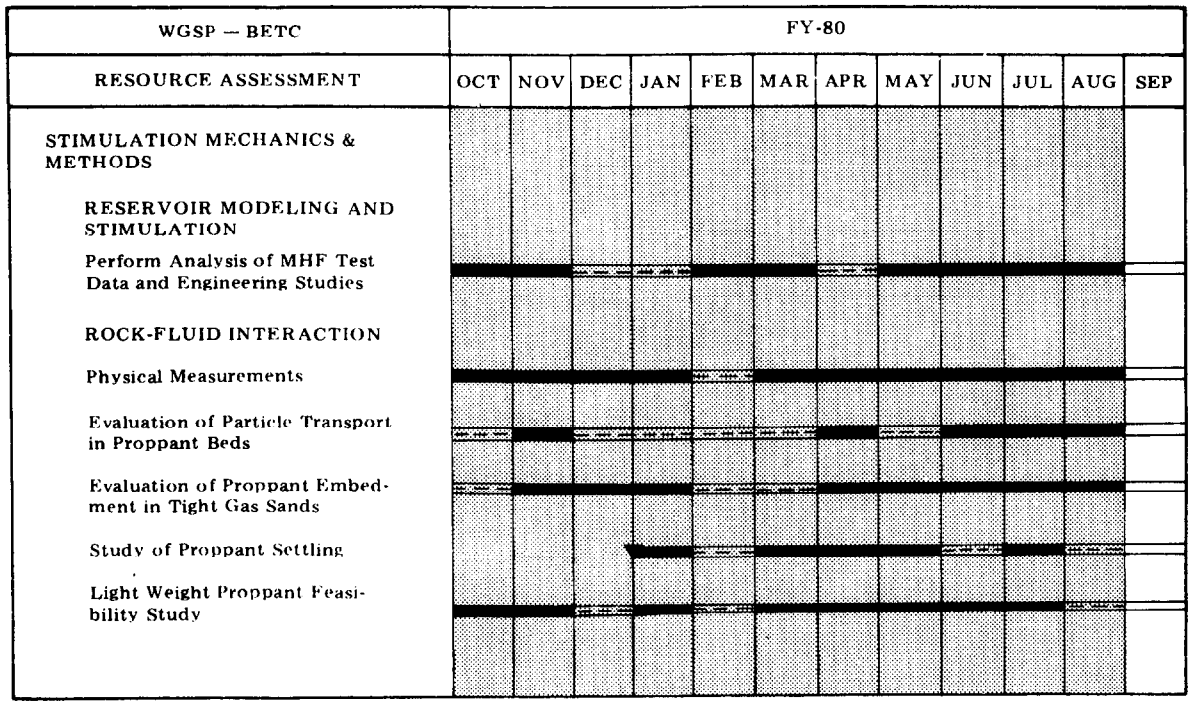


Figure 3-4 Milestone Chart – BETC



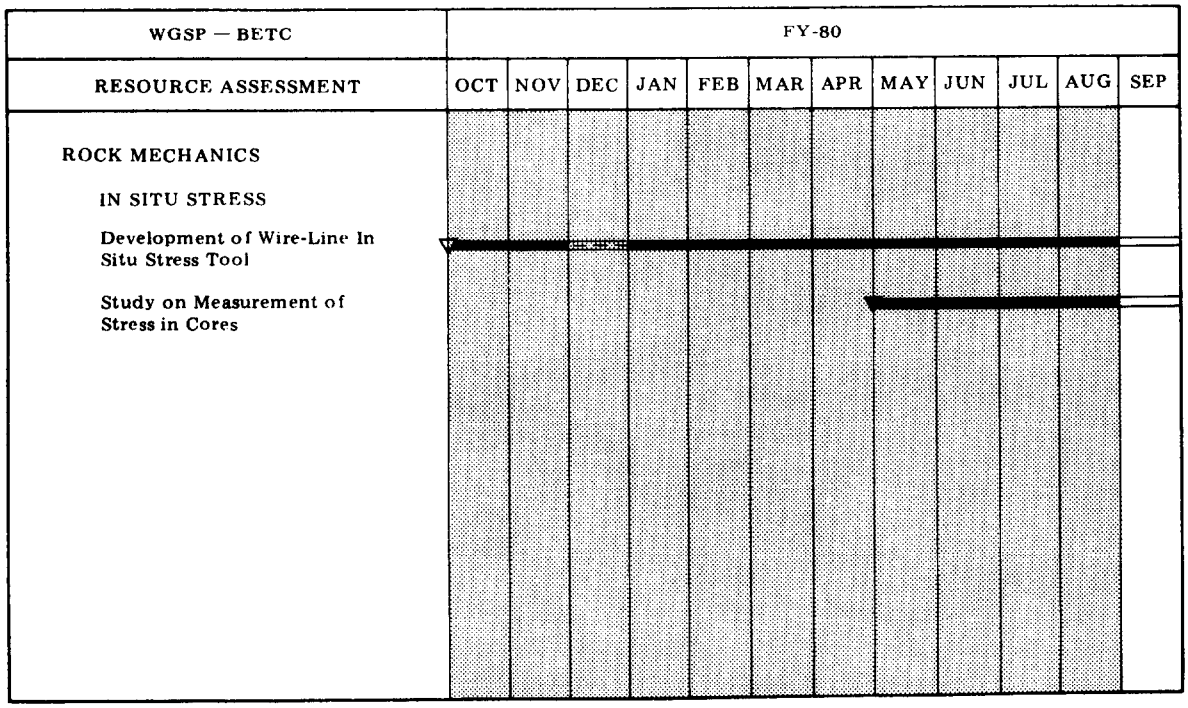


Figure 3-4 Continued

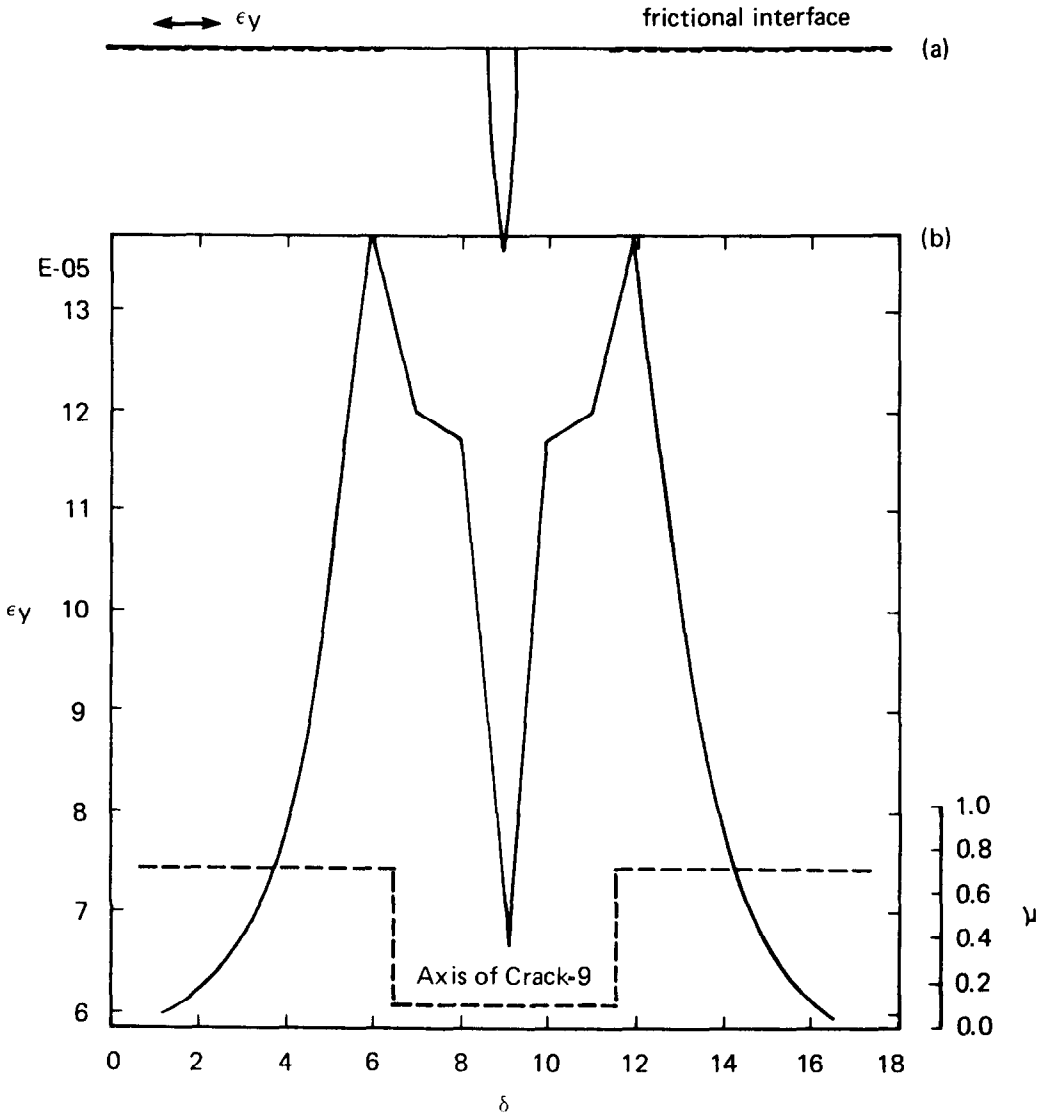


Figure 3-5 Parallel Strain, ϵ_y, as a Function of Position, δ, in the Material Across the Frictional Interfaces from a Pressurized Crack

the strain parallel to the interface, ϵ_y, in the material across the interface from the pressurized fractures as a function of distance along the interface. The primary imposed stress in the calculation was perpendicular to the interface.

The results of the calculation indicated large shear stresses in the regions where the friction changed abruptly and, as displayed in Figure 3-5, high tensile strains in the material across the interface from the fracture. These high tensile strains would obviously result in a fracture propagating perpendicular to the maximum tensile strain.

LABORATORY EXPERIMENTS

Polycarbonate is being considered as material (alternative to PMMA) for use in studying fluid flow in cracks. During August, test blocks of this material were constructed. The 2 x 6 x 6 in. blocks made so far are not as transparent as PMMA, which makes observation of fluid flow in the interior more difficult. Techniques of machining and polishing the surface to enhance transparency are being investigated.

Laboratory observations have been made of time-dependent hydraulic fracture growth in various geometries within transparent material samples. The observations were made under various confining stresses and excessive pressure conditions. Studies have also been conducted of interaction between simultaneously propagating fractures in blocks of brittle cement with confining pressure.

A comprehensive set of practical design formulae has been derived; these have been based on a suitable self-similar description of fluid flow and crack propagation for calculating length and width of hydraulic fractures produced by typical underground operations. Their predictions compare favorably with experimental observations. New models capable of predicting shapes of fracture evolution in representative reservoir structures have been developed. These can incorporate a number of mechanisms which have been identified as dictating fracture shapes in typical reservoir formations.

Numerical routines have been developed for computing unsteady growth of hydraulically-driven cracks in plain and circular geometries.

Fabrication of the high pressure plug for the 1.0 GPa high pressure vessel intended for simultaneous multi-directional sound wave velocity measurements was completed. Work continued on preparation of specimens of Colorado Mesaverde sandstone for equation of state studies.

SCHEDULE STATUS

Figure 3-6 is a milestone chart of LLNL.

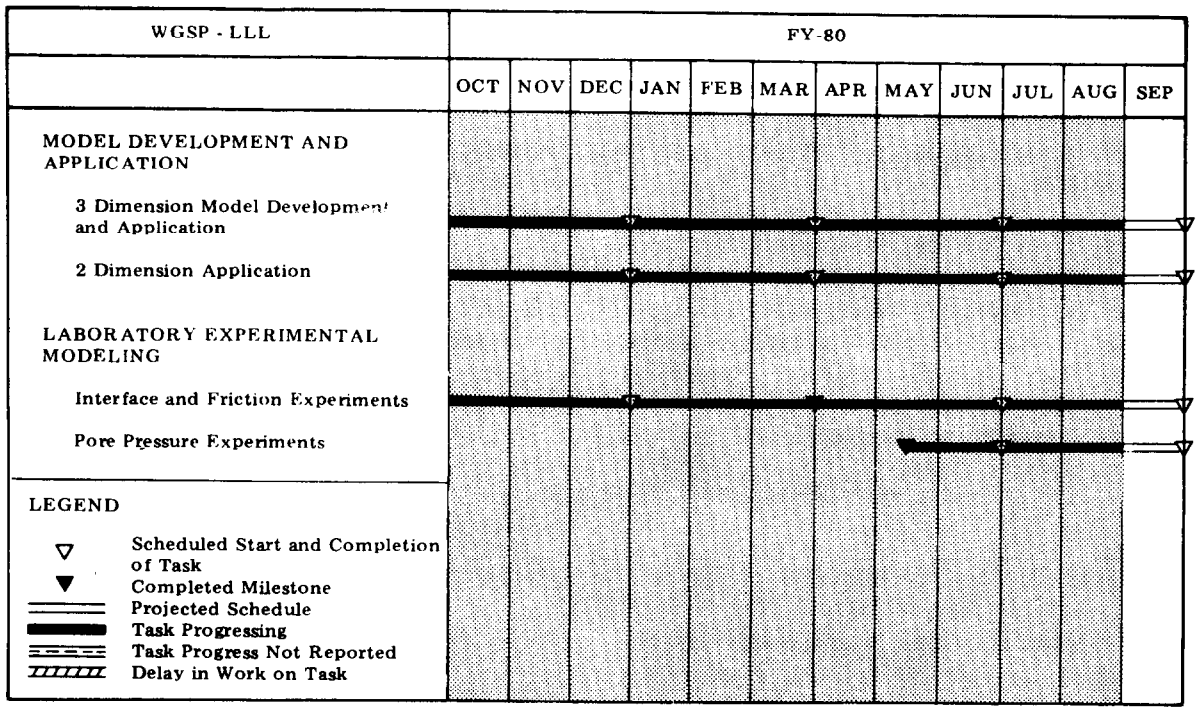
LOS ALAMOS SCIENTIFIC LABORATORY

LABORATORY STUDIES OF FLUID NMR PROPERTIES IN POROUS MEDIA

NMR Measurements on Sandstone Cores

Longitudinal (T_1) and transverse (T_2) relaxation times at 20 MHz were measured for saturating fluid protons (water or methyl alcohol) of core samples from three western tight gas sands wells. The completed analysis of the data shows several interesting effects.

For all samples, T_2 exhibited extremely nonexponential recovery, reflecting a distribution of relaxation times. However, the spin-lattice relaxation time, T_1, was well represented by a single relaxation time during the initial ~ 40 percent of the signal recovery. As seen in Table 3-2, these T_1 values correlate well with the open porosity measured by mercury porosimetry. Also, for the three cases investigated, the initial amplitude of the NMR free-induction decay (FID) correlated well with the measured percent open porosity. The FID is a measure of the



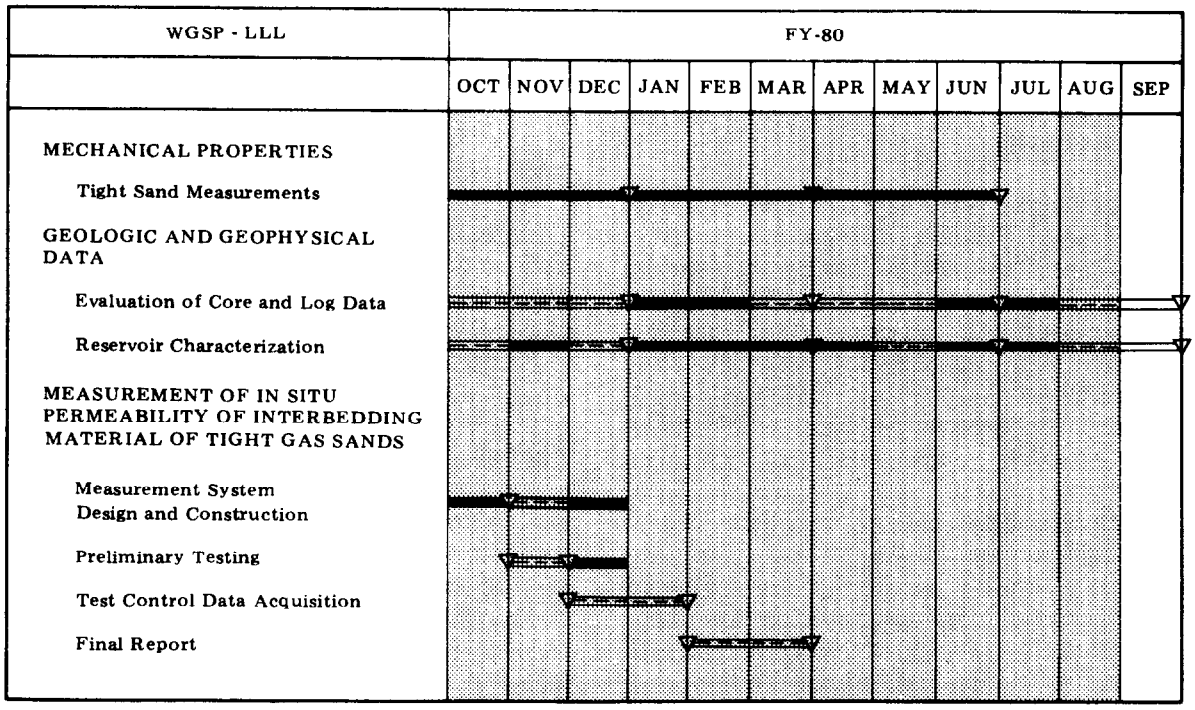


Figure 3-6 Milestone Chart – LLNL

Table 3-2 NMR Relaxation Times and Mercury Porosimeter on WGSP Core Samples

Core No.	Sat. Fluid	Bulk Porosity,+ percent	Open Porosity,+ percent	Avg. Pore Size,+ μm	T_1, msec	T_2, range, msec	Initial FID
2c	H_2O	7.67	2.52	.9421	4.62 (.29)	2.93-9.85	.33
2b	H_2O	8.64	2.67	1.7357	4.49 (.29)	1.78-44.50	
6	H_2O	12.01	3.91	2.6081	– – –	.67-9.35*	
5	H_2O	15.13	4.69	4.9645	13.90 (1.2)	6.09-14.80	.40
3	H_2O	18.06	10.78	1.9265	37.50 (2.2)	8.06-50.87	1.00
2	H_2O	19.94	11.04	2.1306	42.30 (2.2)	11.69-76.08	
2c	CH_3OH	7.67	2.52	.9421	2.18 (.25)	3.02-16.65	
6	CH_3OH	12.01	3.91	2.6081	2.38 (.35)	3.04-9.85	
3	CH_3OH	18.06	10.78	1.9265	22.90 (3.5)	2.86-27.59	

+ Mercury porosimeter results
* Anomalous NMR results, possibly due to saturation failure

total number of nuclear spins contributing to the NMR signal.

The lack of correlation of the T_1 values with measured average pore size is believed to be caused by extremely irregular pore size distribution in the samples. Further measurements on prepared standard samples are planned to investigate this possibility.

Laboratory Hardware Improvements

Progress was made in several areas towards improvement of the laboratory NMR spectrometers:

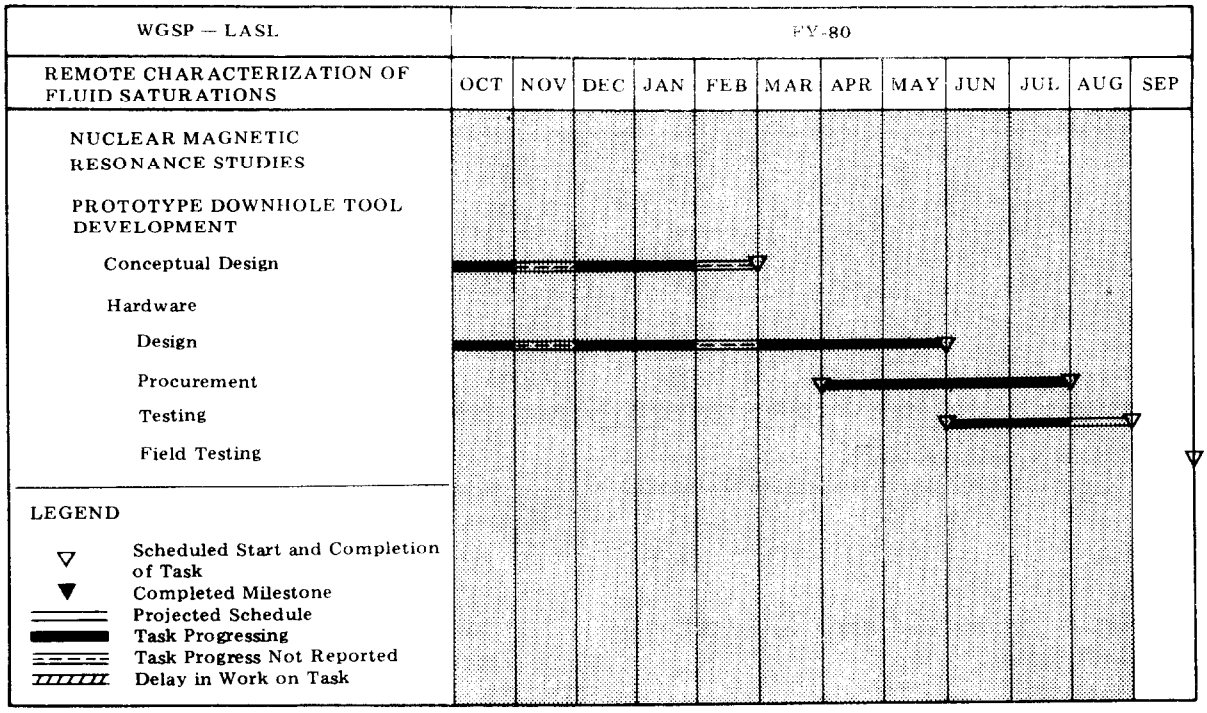
- Engineers from the Electronics Division of LASL have been consulted concerning procedures for optimum damping of spectrometer ring-down following high-power pulses. Studies and experiments are underway.
- A variable trigger delay was implemented to preserve signal averaging resolution during measurement of long (> 50 msec) relaxation times.
- The 20 MHz spin-lock spectrometer was modified to allow it to act as a pulse programmer for the 0.5 MHz spectrometer.
- The Bruker 3225 variable-frequency pulsed NMR spectrometer was received from the Laramie Energy Technology Center, and installation has begun.

Six-inch diameter permanent magnets have been ordered for incorporation into the prototype tool. Computer simulations have shown that a 3/4-in. diameter hole in the center of the magnets has negligible effect on field homogeneity. This will greatly facilitate design of the rf circuitry. Mechanical design of the tool has commenced.

A 0.5 MHz to 20 MHz pulsed transmitter has been ordered to accompany the wideband receiver previously ordered. These units will form the basis of the prototype tool spectrometer.

SCHEDULE STATUS

Figure 3-7 is a milestone chart depicting LASL's WGSP progress.



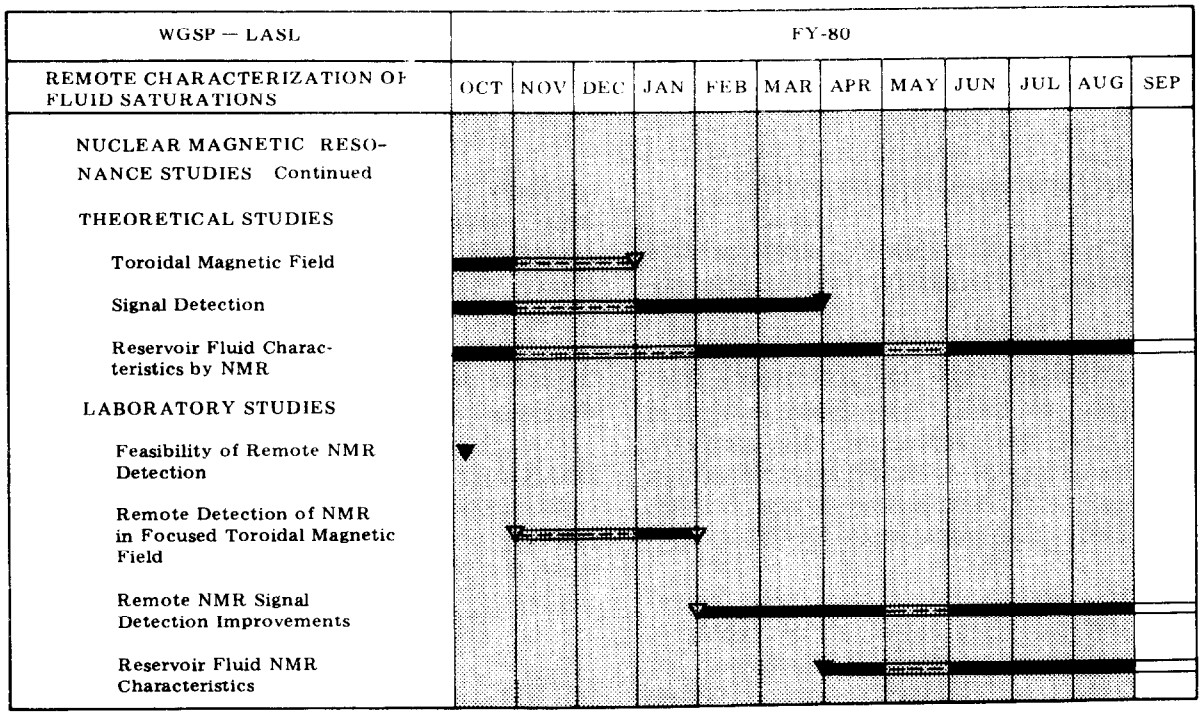


Figure 3-7 Milestone Chart — LASL

SANDIA NATIONAL LABORATORIES

HYDRAULIC FRACTURE CHARACTERIZATION

Between August 13 and August 21, nine intervals were hydraulically fractured in a Kernridge Oil Company well in South Belridge Field, Kern County, California. Sandia provided the borehole seismic system for monitoring seismic signals on five of the treatments. This was an effort to determine quality of seismic signals generated by fracturing diatomaceous earth and to determine fracture orientation if the signals were present.

The borehole seismic system was implanted just below the treatment interval. A set of three near-surface explosive charges were detonated for orientation purposes. In between each shot background noise level was recorded. The formation was then hydraulically fractured and shut in immediately after breakdown. Any seismic activity that occurred was recorded for ten to twenty minutes while the well was shut in. This was followed by a pre-pad and a pad pump, each of which was followed by a quiet period to record seismic activity generated by the induced fracture.

Table 3-3 shows the stages, zones and pumping data for which the borehole seismic system was used. During Stage A there were a number of lubrication leaks and a blowout preventer failure. The borehole seismic system leaked the first time it was downhole. A backup unit was placed into service, but a connector broke, which resulted in the loss of the capability to record all three geophones. The two horizontal geophones recorded, which will provide azimuth information but any vertical height information was lost. A hydraulic packoff unit was used on the lubricator which still leaked. This was replaced by a grease injection unit on the remaining stages. A tape recorder malfunction on Stage A produced a recording that will require extensive playback procedures to recover the data.

During Stage D, a marsh marine connector leaked, which resulted in the geophone amplifiers being forced off-center. This resulted in a loss of dynamic range but it is felt that reasonable signal analysis can be obtained. For the remaining stages (G, H and I) the geophone amplifiers were ac-coupled and no further problems were encountered.

Table 3-4 summarizes the status of signal reception and position by the borehole seismic system. The high noise level for Stage A prevented any signal detection and was probably due to the leaking hydraulic packoff unit. The high noise level observed during Stages D, H and part of I also prevented signal detection following the pre-pad and pad. The source of this noise is unknown; however, it is probable that the noise was produced by the bridge plug leaking.

Data analysis has not begun and will require a long time-period due to other scheduled tests. However, preliminary analysis on some of the data will be started shortly to determine the quality of the signals generated in this type of formation.

The data for the Big Mineral Creek experiment with Shell has been further analyzed and is plotted in Figure 3-8. The seismic signals received in the offset well Unit 210 during the main fracture were analyzed for height and orientation, and then projected onto a plane N37°E to S37°W. This offset well was located 547 ft south and 106 ft west of the treatment well Unit 343. Only the lower solutions are plotted and even these indicate a vertical fracture growth upward of more than 500 ft. Analysis of this possibility is continuing as it is a large departure from the planned fracture height.

A mathematical analysis of the hydrophone system has been initiated to determine pulse rise time capability and, under various signal-to-noise ratios, determine the accuracy in measuring the difference in arrival times of two different hydrophone signals. The electronics in the system basically consist of a pressure transducer, a high gain amplifier

Table 3-3 Pumping Data During Use of Borehole Seismic System

Stage	Zone	Treatment Interval, ft	Breakdown Pressure, psi	Breakdown ISIP	Volume Pre-Pad	Volume Pad
A	Brown Shale	2,660-2,710	1,600	500	350	238
D	Brown Shale	1,930-2,040	1,600	320	300	357
C	Diatomite	1,320-1,460	500	370	211	476
H	Diatomite	1,050-1,270	400	200	220	595
I	Diatomite	790-1,000	370	150	225	595

Table 3-4 Status of Signal Reception

Stage	Geophone Depth, ft	Background	Breakdown	Prepad	Pad
A	2,725	2	3	Note (1)	Note (1)
D	2,056	2	7	61	Note (1)
G	1,478	10	73	68	40
H	1,257	1	0	49	Note (1)
I	1,020	0	0	25	17
				Note (2)	

(1) High Noise Level
(2) Several minutes of high noise level prevented signal detection

which contains a low pass filter and a frequency modulation (FM) transmission system used to transmit the information to the surface recording equipment. The approach will be to analyze the condition of the signal at the output of the high gain amplifier and then determine the effect the FM system has on passing the signal to the surface recording device.

BOREHOLE RESISTIVITY SYSTEM

The agreement between the one- and two-dimensional models was improved by providing a larger number of elements (in the 2-D finite element model) in the direction of large field gradients (radially) rather than along the probe. Figure 3-9 shows agreement to within 2 percent.

The ridge regression inversion algorithm was tested successfully on several simple nonlinear systems of equations. The algorithm is now being integrated with the 1-D forward resistivity solution.

ELECTROMAGNETIC IMPEDANCE SONDE

Laboratory Work

Work continued on the digitization of pore pictures reported last month. From these data, it is hoped that useful parameters can be obtained in the modeling of the electromagnetic, the nuclear magnetic resonance, and the fluid flow responses of reservoir materials. For example, the orientation of the pores in a rock is not necessarily isotropic, and such an anisotropy can influence the electromagnetic response as well as the fluid flow permeability.

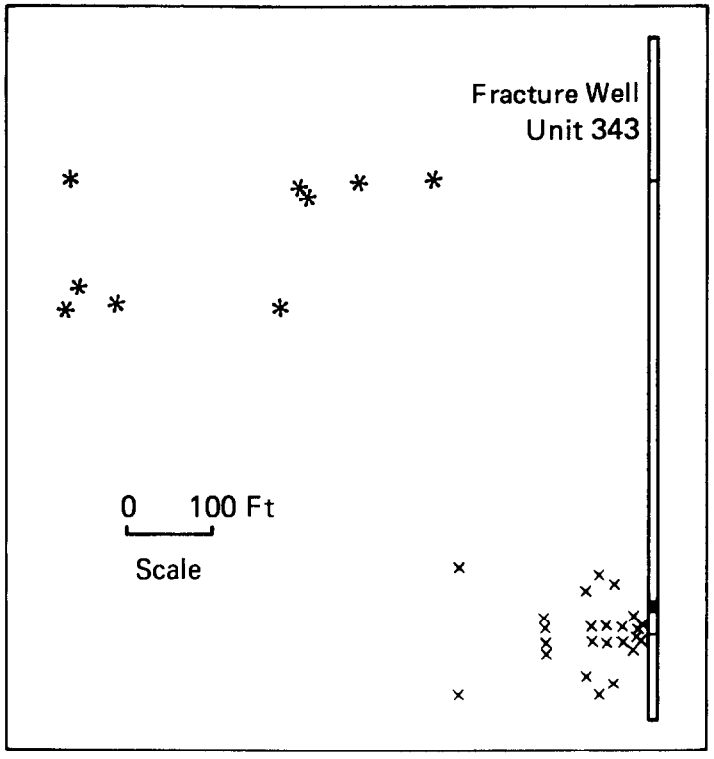


Figure 3-8 Plan View of Seismic Events

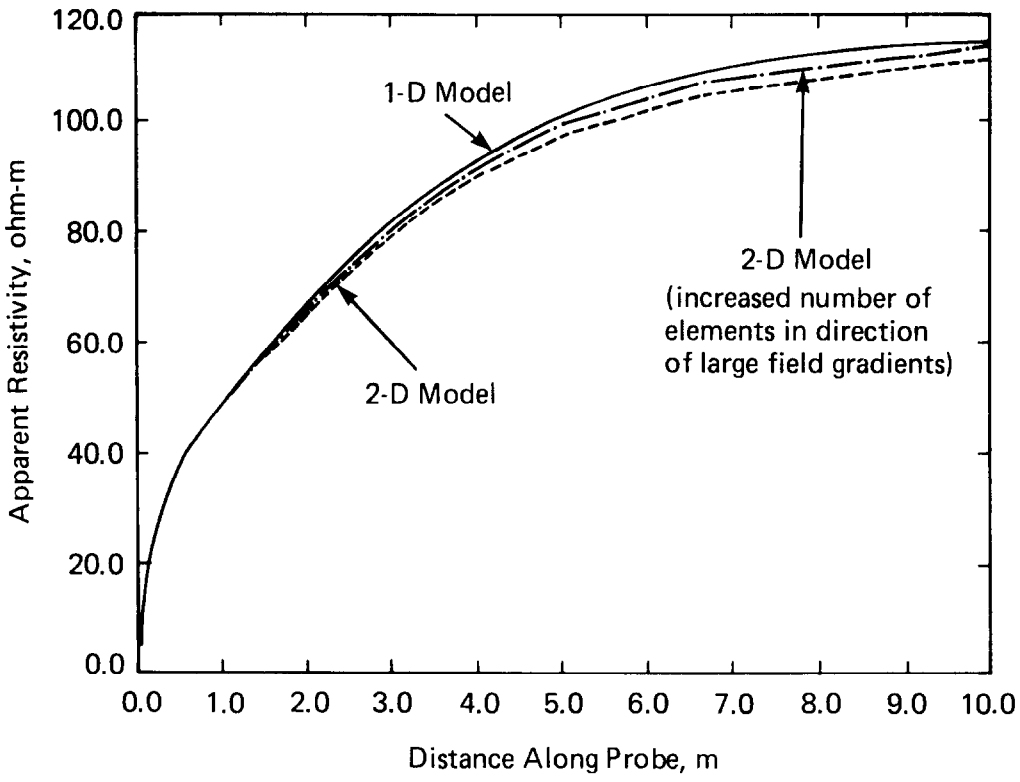


Figure 3-9 Comparison of 1-D and 2-D Models

In thin section experiments, a blue epoxy was injected into the pore structure, and thin section photographs, obtained by the USGS from CIGE No. 21 core specimens, showed a variation in the depth of the blue coloring. This color variation can be caused by a depth effect (deeper pores are a darker shade of blue) or by a dilution of the epoxy by clay fingers protruding into the pore from its walls. It is possible to include this information in the digitization process. Numbers are given to a pore based on the depth of the blue color in the pore; for instance, numbers would correspond to light blue, medium blue and dark blue. These numbers then allow pores of different colors to be excluded from the calculations to note the effect. For example, if all the pores of one sample are included, the calculated porosity (which is based on a statistical model) is more than one and a half times too large. However, if pores of the lightest blue are not counted, the porosity approaches that of the measured value. Work is continuing on the pore pictures to determine what other useful parameters may be measured.

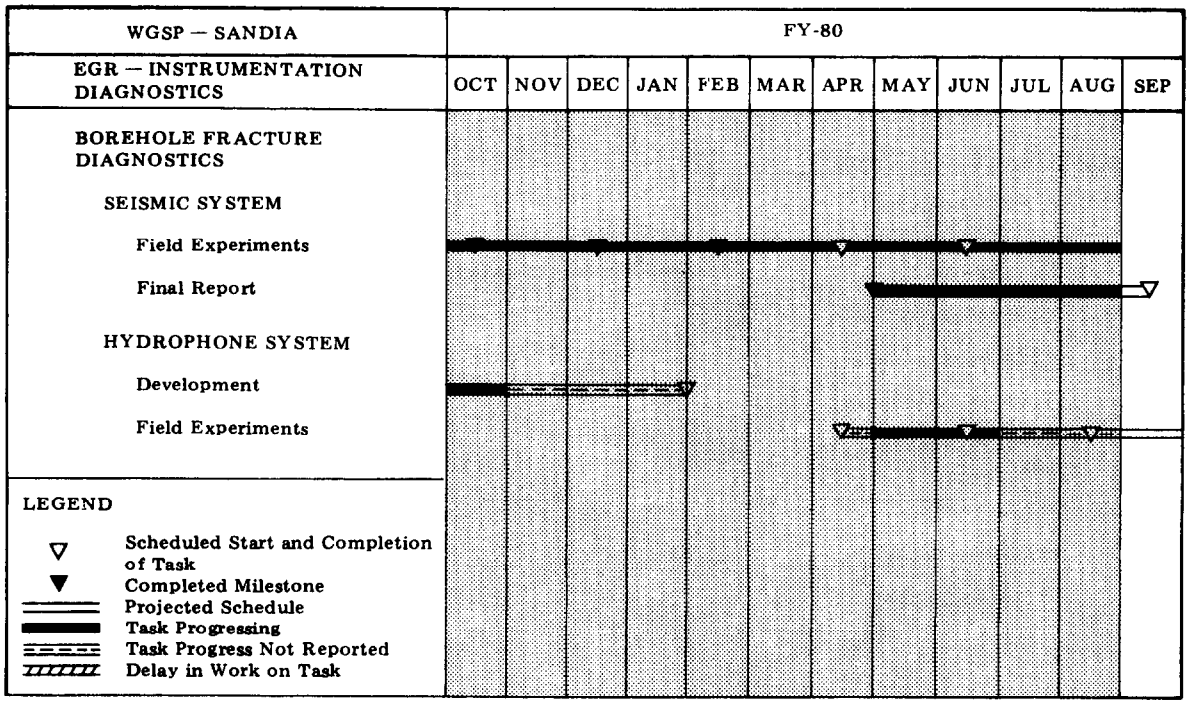
Sonde Modeling

During this month, the fast-convergence integrations for the generalized N-Zone solution of coaxial-coil logging have been successfully implemented. After introducing additional contributions to the previously incomplete solution, preliminary results on two spot-checks have indicated a consistent reduction to both the homogeneous and two-zone solutions.

More extensive checks are in progress. The final goal of this generalized solution is a comprehensive study of boundary-layer effects, including sonde geometry, borehole fluid and invaded-formation profile. The complexity of computation is finally being overcome and useful applications are planned for September.

SCHEDULE STATUS

Figure 3-10 is a milestone chart of Sandia's WGSP progress.



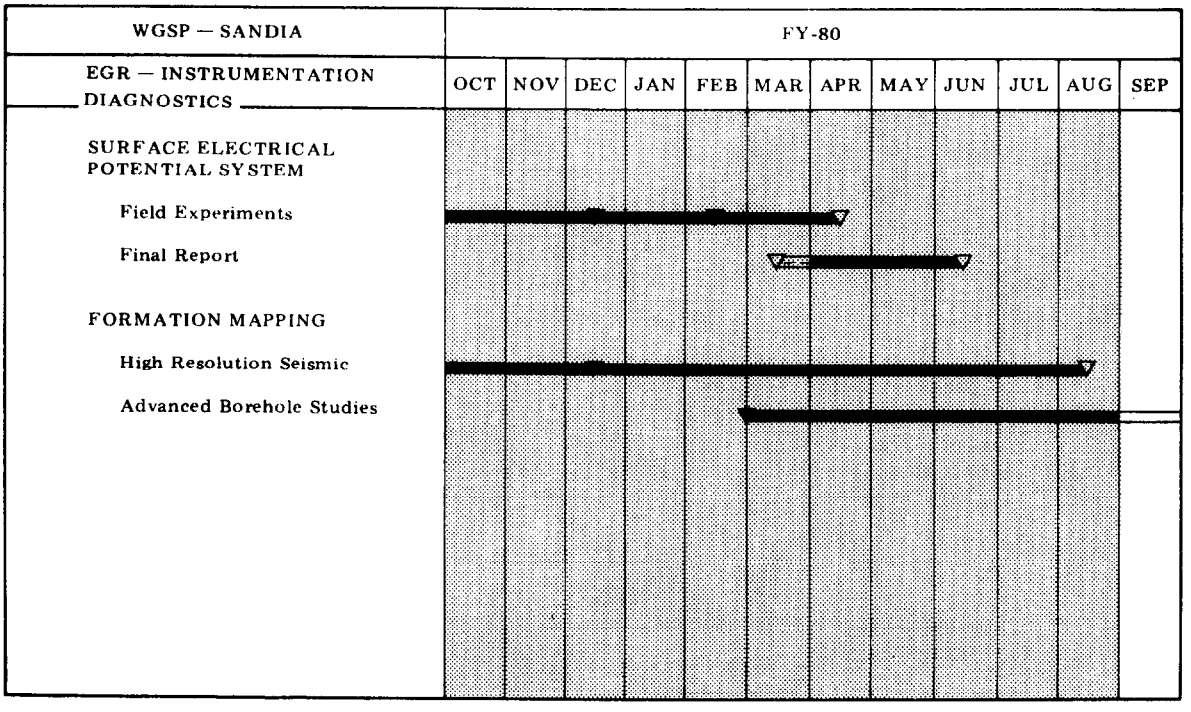


Figure 3-10 Milestone Chart — Sandia National Laboratories

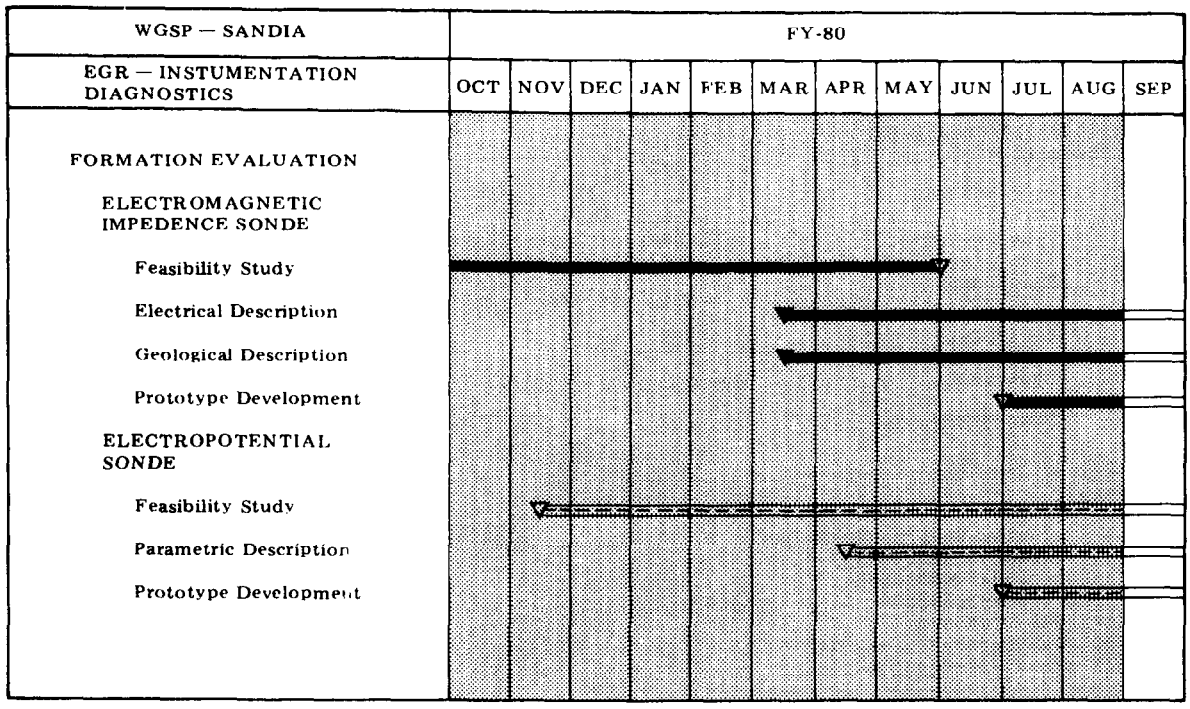


Figure 3-10 Continued

SECTION 4

FIELD TESTS & DEMONSTRATIONS

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, and
- a mineback testing program by Sandia Laboratories.

Table 4-1 summarizes WGSP MHF treatments. Progress of these projects is presented in the following sections.

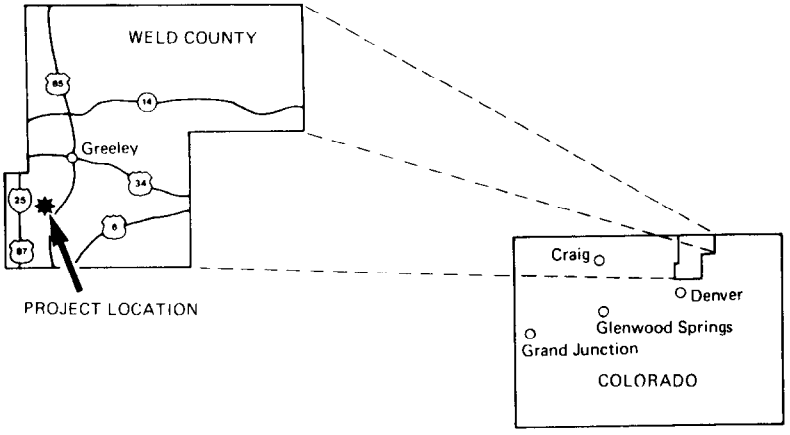
Table 4-1 MHF Contract Location and Frac Data

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	—	Water	—
			7,251-8,774	08-08-78	1,965,000	722 Gel	—	Water	—
	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	—

WATTENBERG FIELD

DE-AC08-77ET12046

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 $369,407
	Total $444,407
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.

COLORADO INTERSTATE GAS COMPANY

Production and injection of dehydrated gas for the Miller No. 1 and Sprague No. 1 wells continued through August. Operations continued normally except for one major downtime period between August 2 and August 12. A new starting air injection valve had to be ordered for the compressor. Water content of the injected gas averaged 4 lbs of water per MMCF.

One three-week injection cycle is planned for the two wells before shutting them in by mid-October in preparation for measuring BHP. The wells will be returned to production after BHP measurements have been completed. Figures 4-1 and 4-2 illustrate the wells' injection and production volumes with associated pressures.

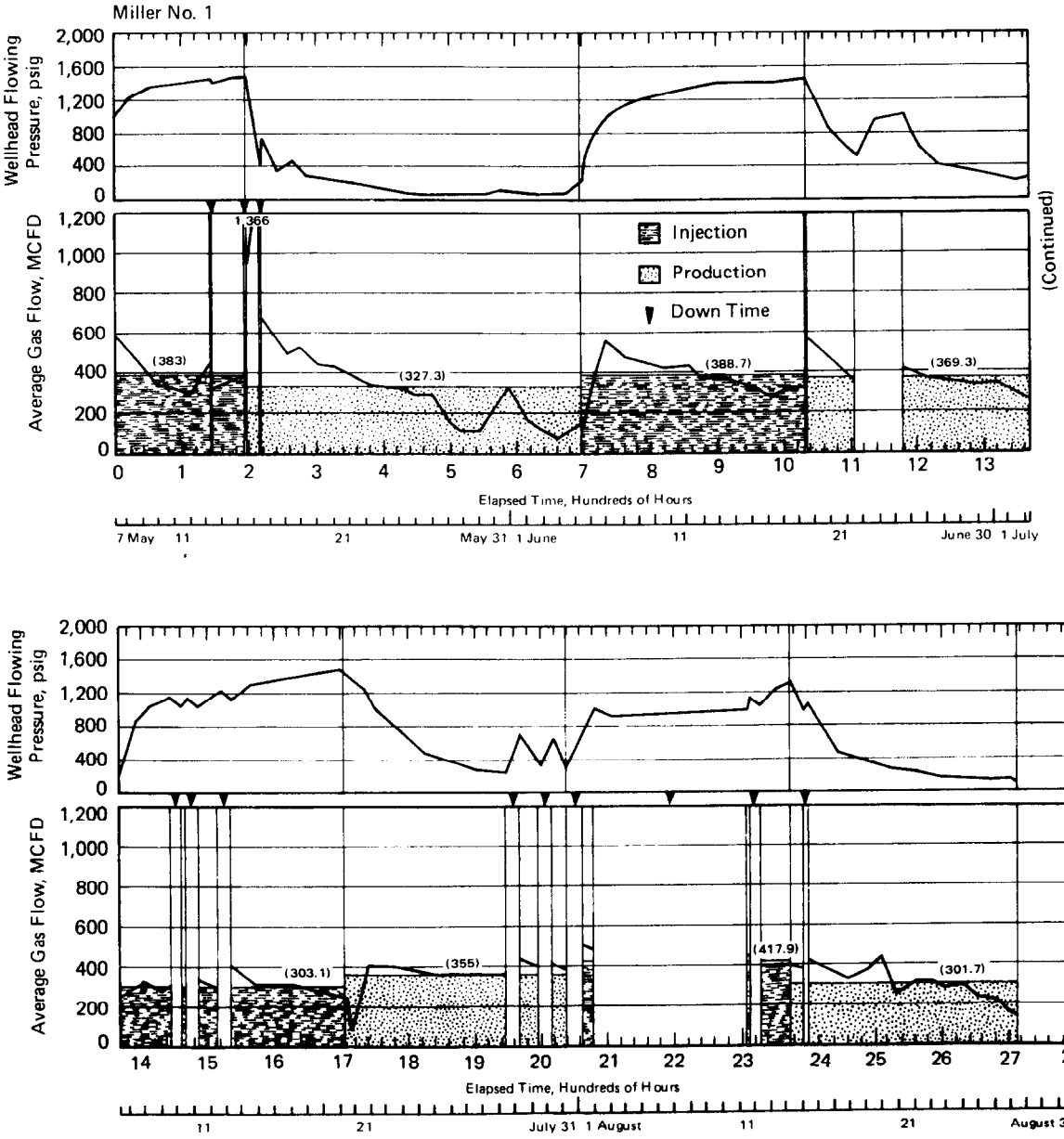


Figure 4-1 Production and Injection Volumes and Associated Pressures of CIG Miller No. 1 Well

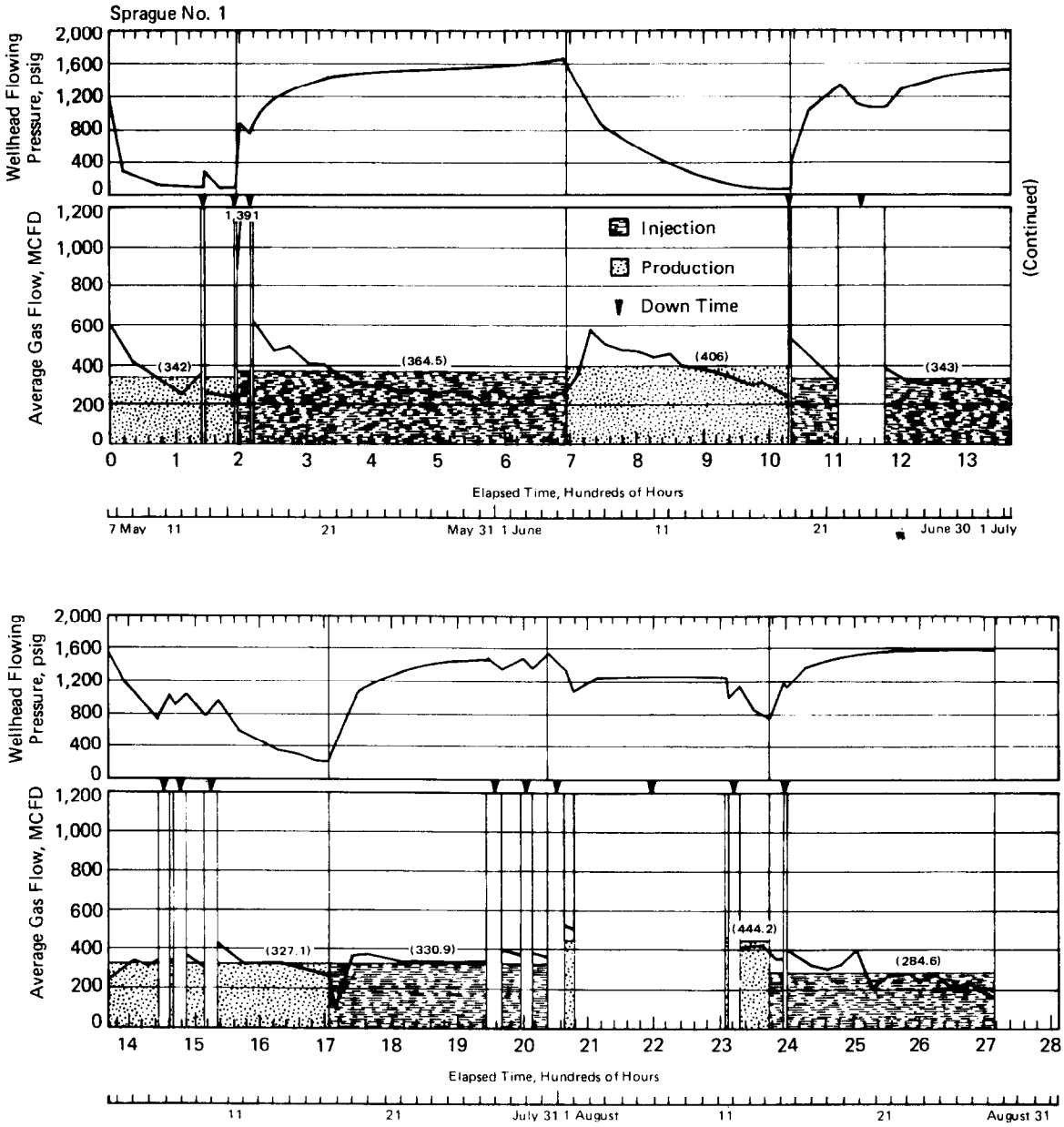


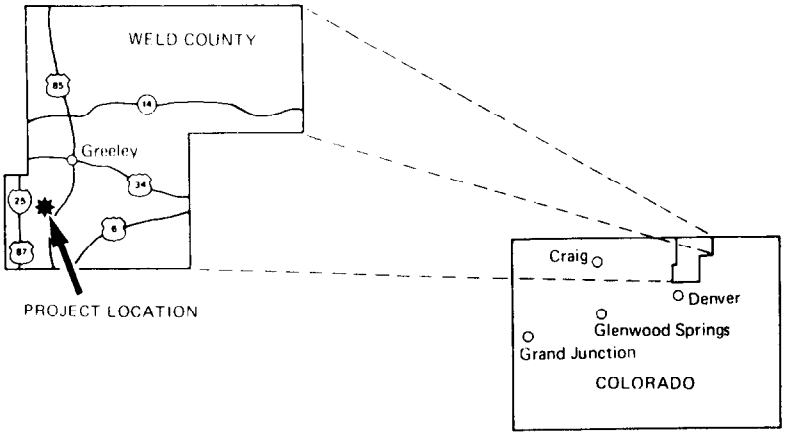
Figure 4-2 Production and Injection Volumes and Associated Pressures of CIG Sprague No. 1 Well

DOE WELL TEST FACILITY

DE-AC08-79-BGO1569

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.

DOE WELL TEST FACILITY

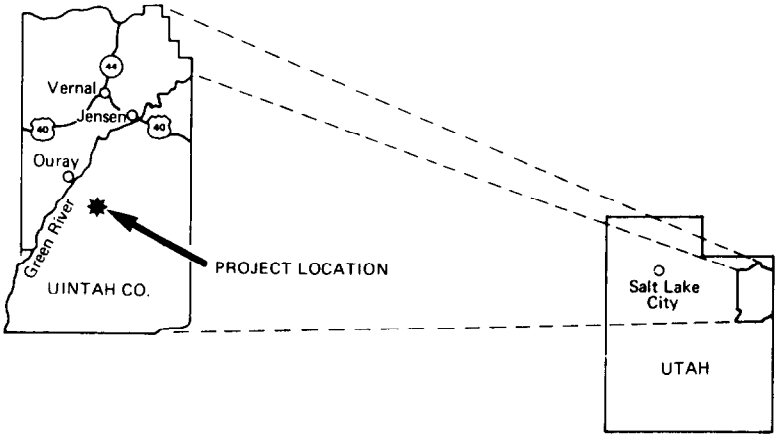
The facility is still undergoing modifications in Las Vegas, Nevada, in preparation for the return to the Wattenberg Field in Colorado.

NATURAL BUTTES
UINTAH COUNTY, UTAH

DE-AC08-76 ET 12060

Massive Hydraulic Fracturing Demonstration

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.

GAS PRODUCING ENTERPRISES, INC.

Three GPE wells flowed to sales this month: NBU Nos. 9, 18 and 22 produced a total 24,592 MCFD of gas. NBU Nos. 14, 19, 20 and 21 were shut in.

Figures 4-3 through 4-8 show the production histories of these wells since their massive hydraulic fractures.

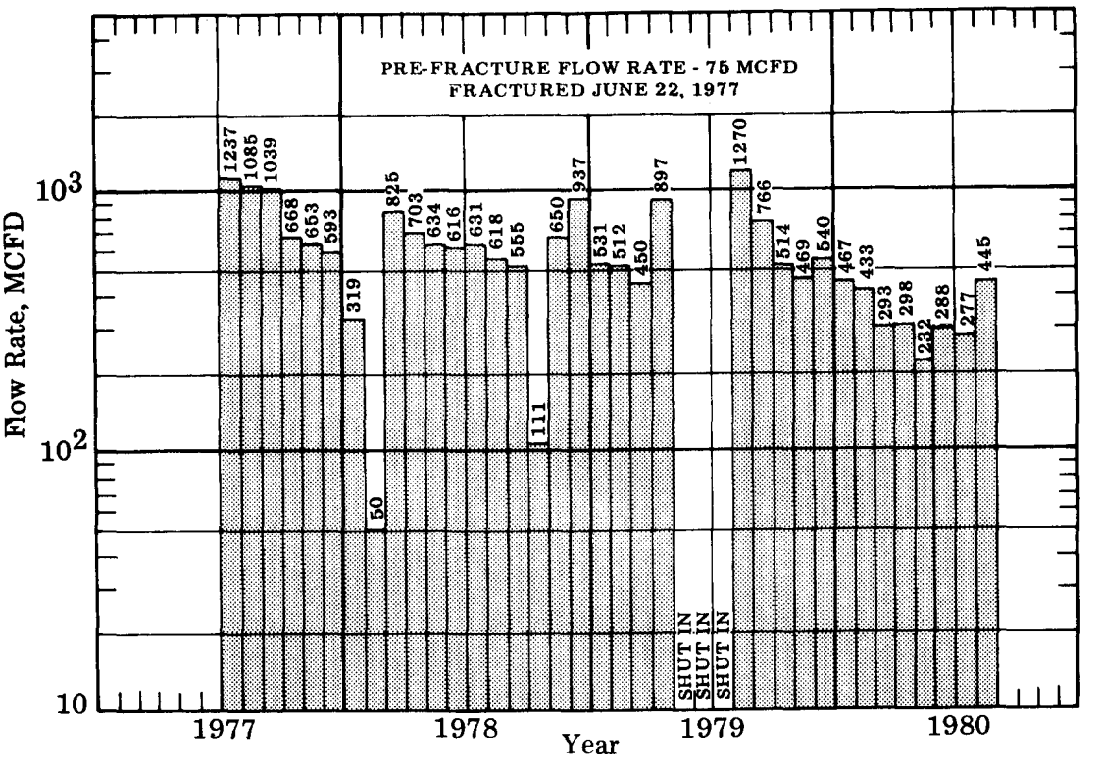


Figure 4-3 Production History of Natural Buttes No. 9 Well

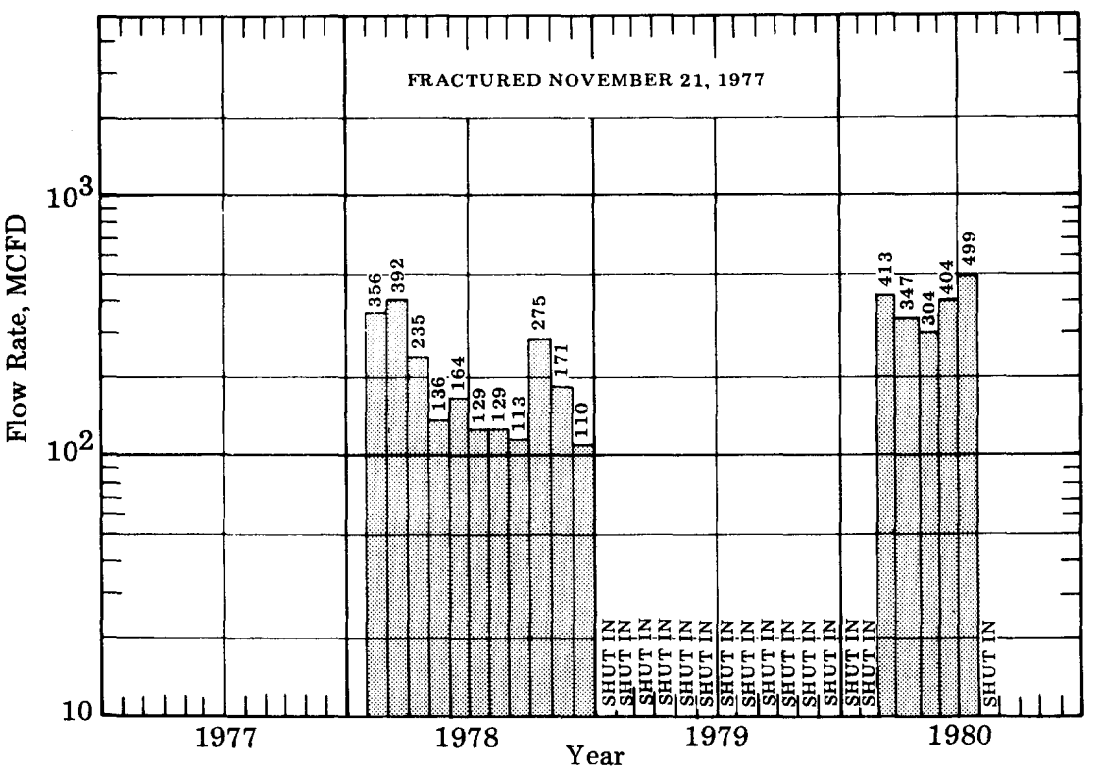


Figure 4-4 Production History of Natural Buttes No. 14 Well

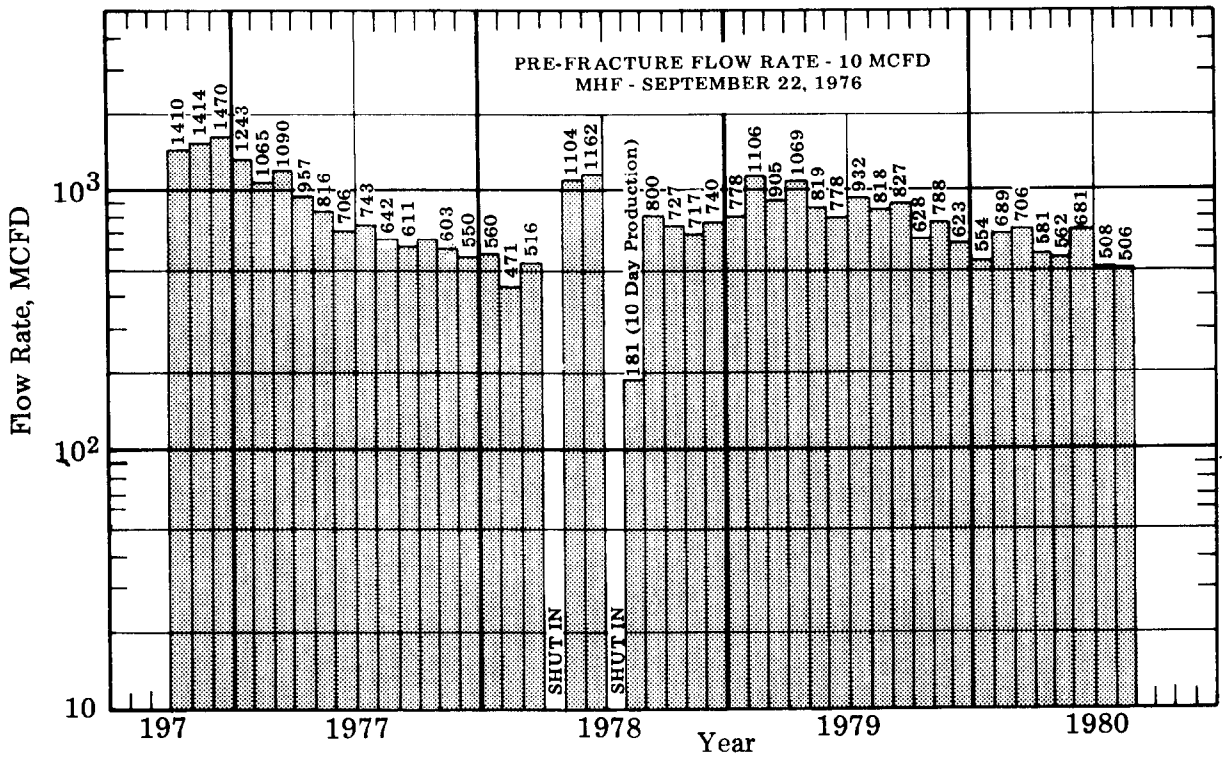


Figure 4-5 Production History of Natural Buttes No. 18 Well

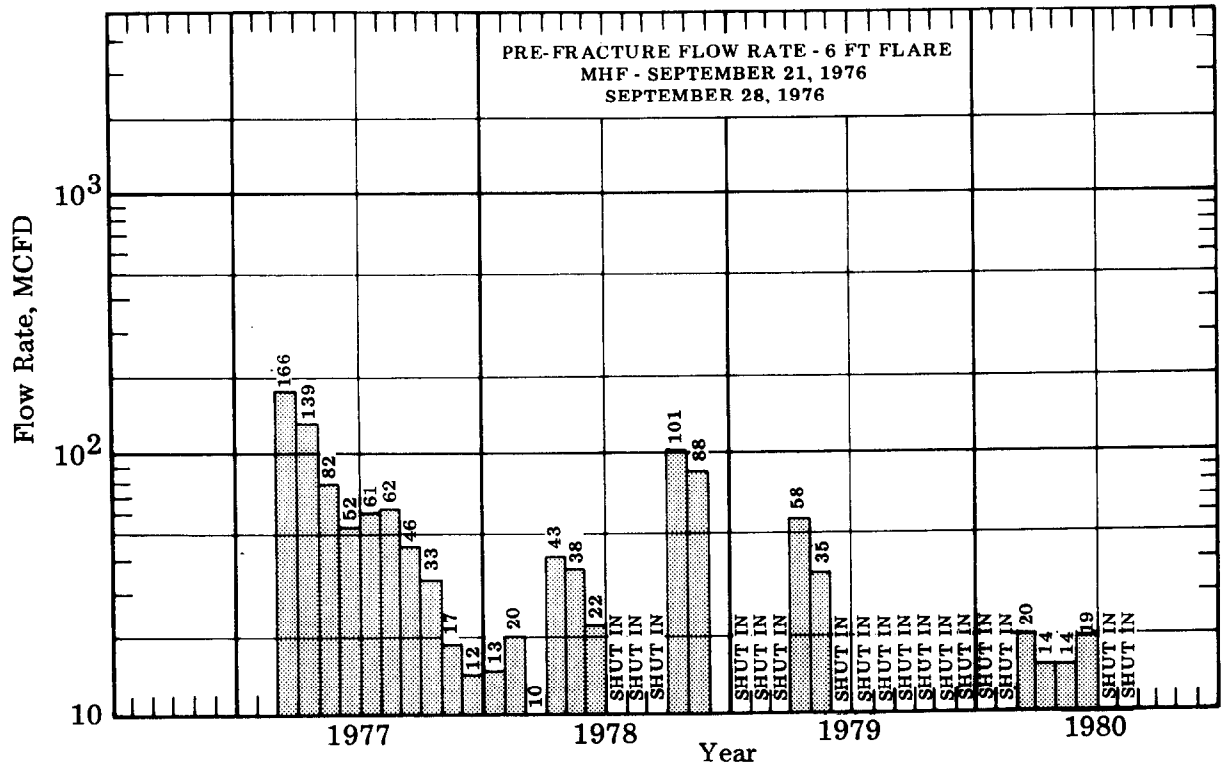


Figure 4-6 Production History of Natural Buttes No. 19 Well

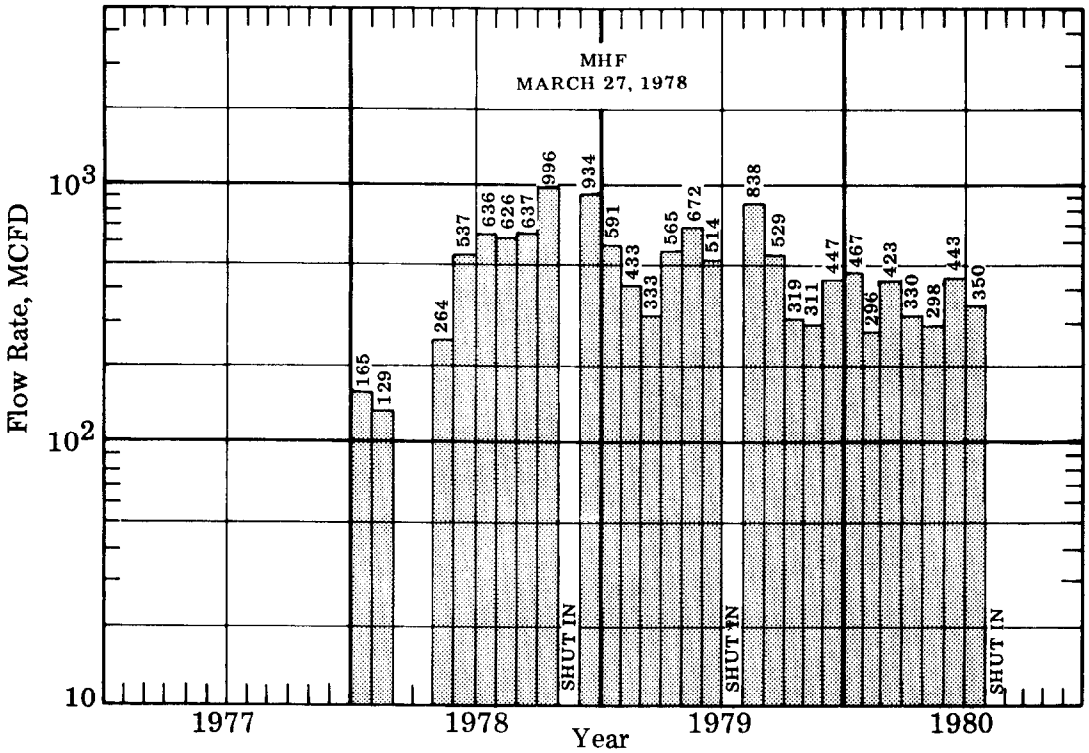


Figure 4-7 Production History of Natural Buttes No. 20 Well

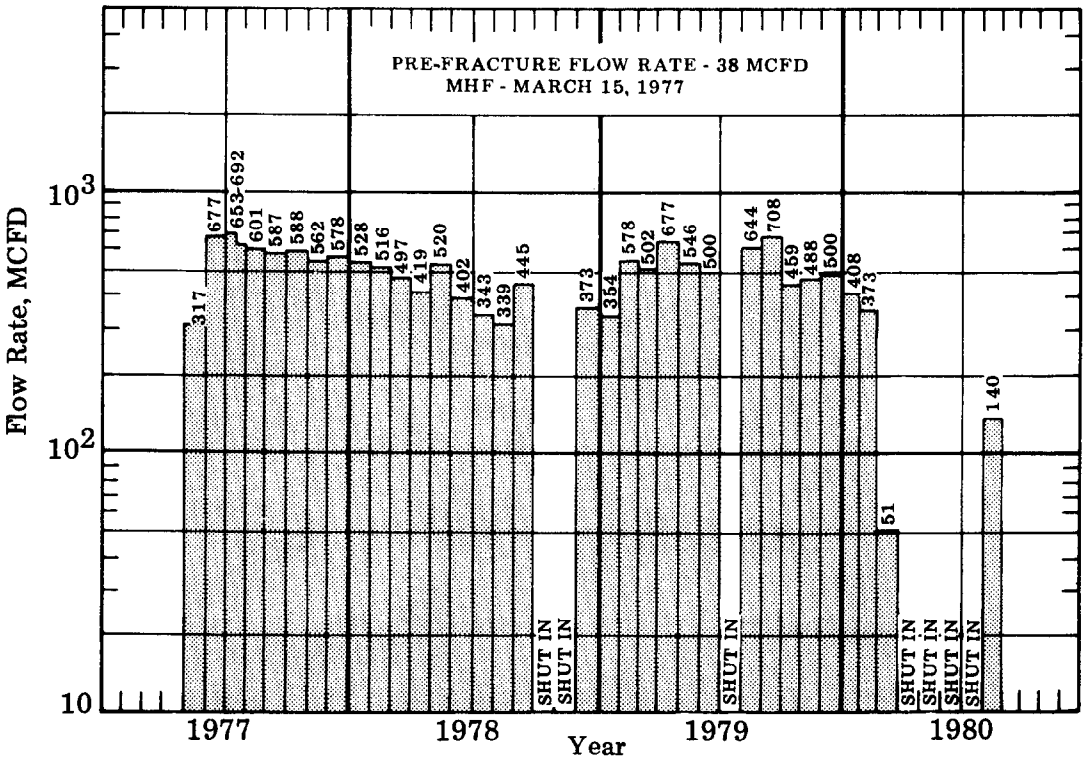


Figure 4-8 Production History of Natural Buttes No. 22 Well

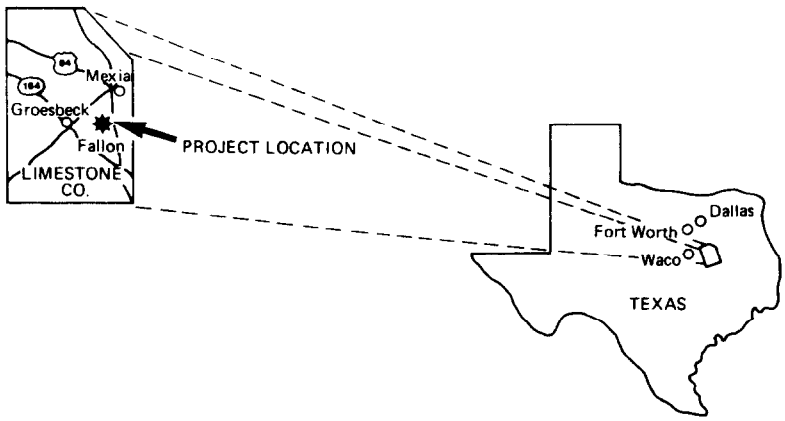
FALLON-NORTH PERSONVILLE FIELD, TEXAS

DE-AC08-78ET12150

Massive Hydraulic Fracturing Demonstration

Mitchell Energy Corporation
Houston, Texas

Status: Active



Contract Date:	March 15, 1978
Anticipated Completion:	Project completed, waiting on final report.
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.

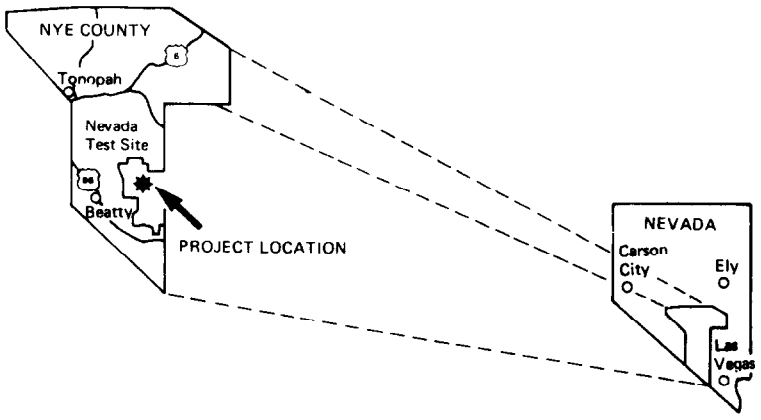
MITCHELL ENERGY CORPORATION

The draft of the final report, due this month, is expected by the end of September.

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.

SANDIA NATIONAL LABORATORIES – MINEBACK

HYDRAULIC FRACTURING

Hole No. 6 Formation Interface Fracture Experiment

Measurement of the vertical stress distribution, which is the final work associated with this experiment, has been delayed until September due to equipment modifications.

Fluid Mechanics/Proppant Transport Experiments

Mineback of the experiment and access drifts was completed in August. The orientations of the in situ stresses in this region were approximately 20° different than expected but were still suitable for the experiment. Work on the preliminary fluid mechanics experiment will begin in September or October.

In Situ Stress Measurement by Hydraulic Fracturing Through Perforations

Five zones in a cased hole have been perforated with four perforations in the farthest zone and two perforations in each of the other four zones. Orientations of the perforations are staggered horizontally and vertically. Fracturing of these five zones was attempted in August. The zone with four perforations (60 ft deep) broke down at 1,925 psi, considerably higher than expected (stress cage ?). The fracturing pressure was about 1,200 psi and the shut in pressure 930 psi. This shut in pressure was slightly higher than expected (800 psi), but the value of the minimum principal in situ stress will not be known until several minifracs are conducted open-hole in a nearby (6 to 8 ft) wellbore. A variable flow rate test showed that the pressure drop through the perforations was insignificant. The second zone (50 ft deep) had two perforations and required 2,400 psi to break down. The fracturing pressure remained near 2,400 psi, which was clearly due to inadequate perforating. No clear shut in pressure was seen.

The tests show that good perforating is a foremost requirement if useful, accurate stress data are to be obtained. No further zones were fractured. An attempt will be made to reperforate the other three zones and to develop an adequate perforating technique for use at the test site. Perforators, which were supposed to penetrate 7.5 in. into the formation leaving a 0.5-in. diameter hole, apparently barely ruptured the casing. This will be further investigated.

Rock Mechanics – A

A model of stress distribution surrounding the crack tip of a finite internally pressurized crack approaching a material interface has been extended to include a realistic internal pressure distribution. The realistic distribution causes a significant decrease in the stress intensity factor when compared to the uniformly pressurized case, as shown in Figure 4-9.

The stress intensity factor is customarily used as a fracture criteria in homogeneous materials. However, it is not clear if this criteria can be applied to a fracture approaching an interface. An alternative criteria is the average stress over a fixed distance beyond the crack tip. This new criteria gives the same results as the stress intensity factor for homogeneous materials, but it may be applied to cracks approaching an interface as well. For several averaging distances, Figure 4-10 shows the variation in the average stress as a crack approaches an interface. Comparison of the average stress to the stress intensity factor, (K_I), indicates that the stress averaging criteria does not inhibit crack growth as severely as the stress intensity factor for distances very close to an interface.

Rock Mechanics – B

The mechanism of crack growth determines the extent of the near crack surface damage produced as the crack propagates. The extent of this process zone damage is one of the factors that determines the permeability of the fracture surface and has a direct bearing on the sizing of a hydrofracture to achieve the desired production rate. In addition, the existence of a process zone provides a mechanism by which cracks can propagate across discrete interfaces between two dissimilar materials.

In a joint study with the University of Maryland, the process zone is being examined and its size and shape under simple loading conditions will be determined. In this study, the crack-tip region is being examined under load using a surface replicating technique. At various stages of the loading history, an acetate film replica is made of the polished surface of the fracture specimen in the region where the crack intersects the surface. The replicas are then examined, using the scanning electron microscope (SEM) to determine the size and shape of the crack-tip process zone. To date, both monotonic loading and cyclic fatigue loading histories have been examined. Preliminary results from the SEM work indicate that the process zone is visible ahead of the crack tip, but apparently not connected to it. This is most likely due to the fact that the crack front is not uniform through the thickness of the specimen and thus, the measurements made on the surface do not reflect the true three-dimensional character of the problem.

In September, measurements of process zone size and shape will be made for the two loading histories. Once this is completed, the effect of hydrostatic pressure on the process zone size will be considered.

PETROLOGY AND GEOCHEMISTRY

Petrographic work has begun on Mesaverde core samples donated by Mountain Fuel Supply Company. These samples were selected from portions of core that contained a sandstone-shale contact. It is thought that over geologic time these shales within and adjacent to sand lenses may act as permeability barriers to upward-diffusing interstitial waters. If this is so, then there might be greater evidence of diagenesis at the sandstone-shale interfaces. In fact, this appears to be the case. Carbonate cementation is more pervasive in these zones and calcite replacement of detrital grains (frequently plagioclase feldspars) is more common. Often these carbonate-replaced grains are surrounded by calcite overgrowths and less frequently, quartz overgrowths are observed. Although this study has only begun, these preliminary observations suggest that diagenetic alteration in the sand lenses may be analogous to the silicons "hard bands" in the NTS tuffs as reported in July.

SCHEDULE STATUS

The progress of the Sandia mineback program is shown in Figure 4-11.

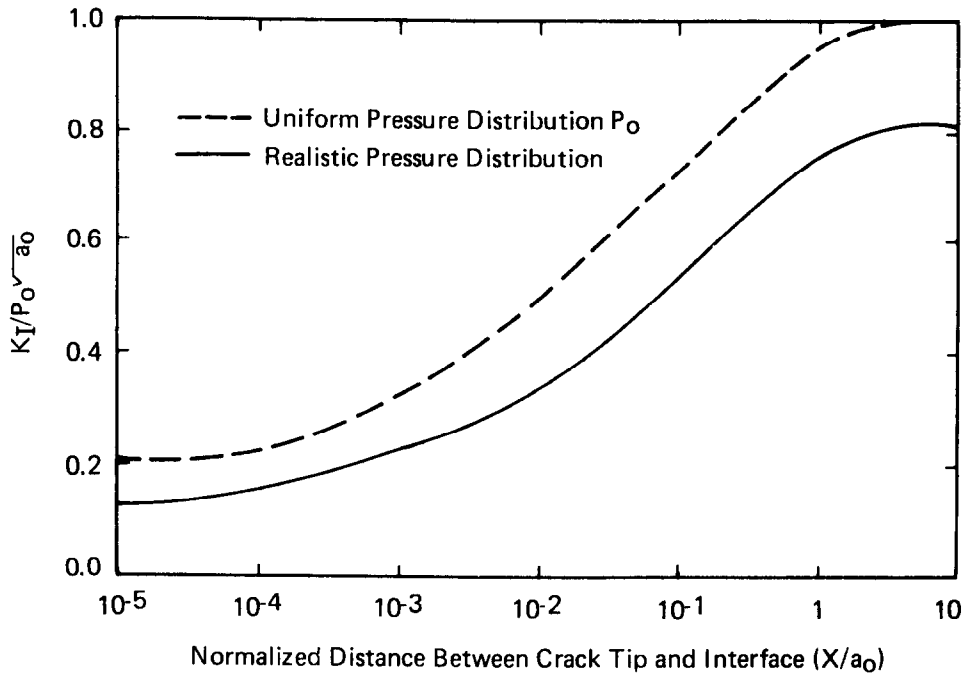


Figure 4-9 Stress Intensity Factor (K_I) For a Crack Approaching an Interface Normalized by K_I for a Homogeneous Material

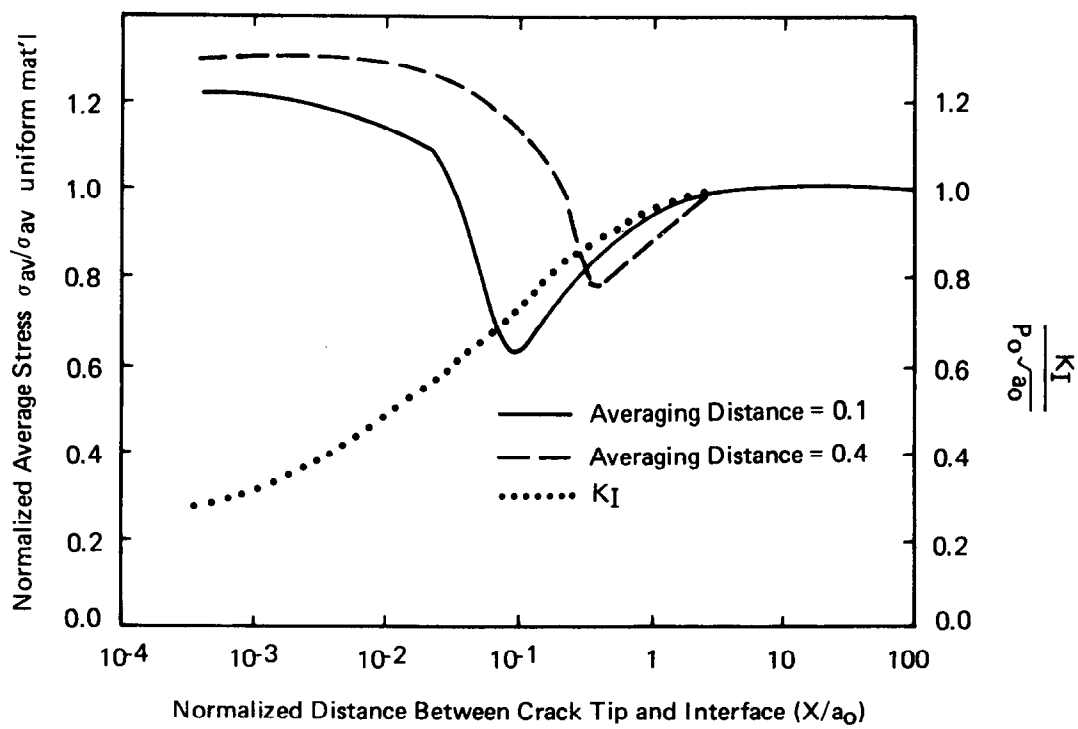
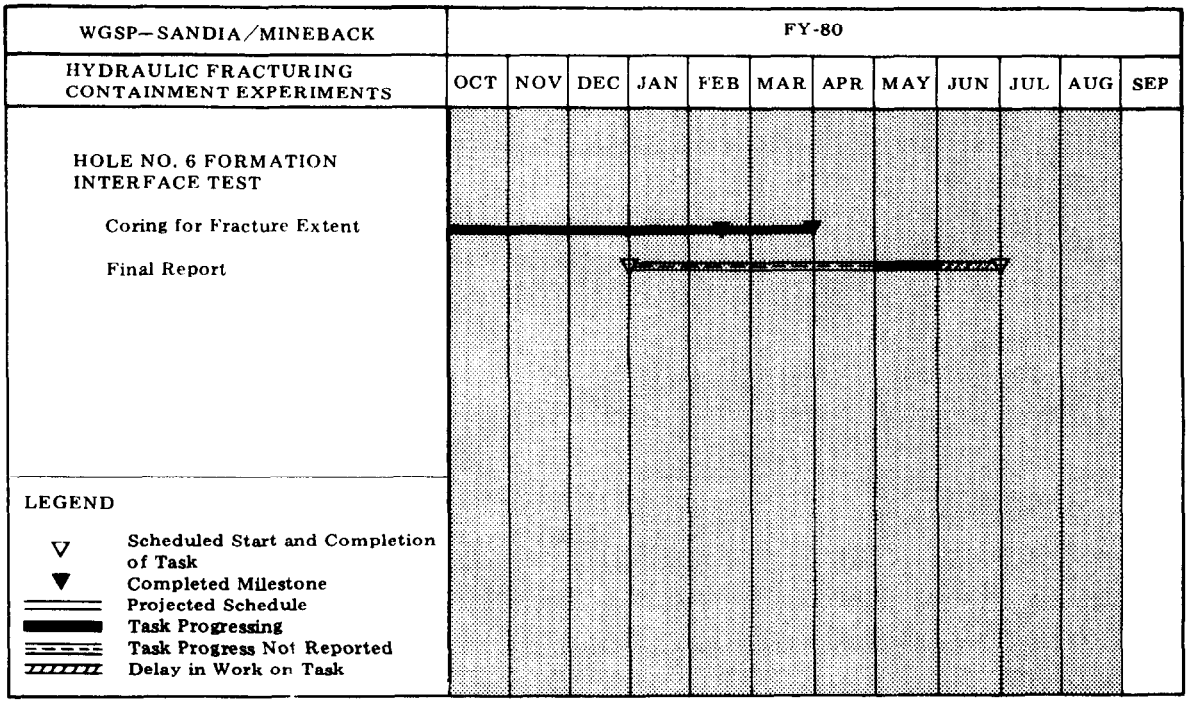


Figure 4-10 Average Stress Fracture Criteria Compared to Stress Intensity Factor (K_I)



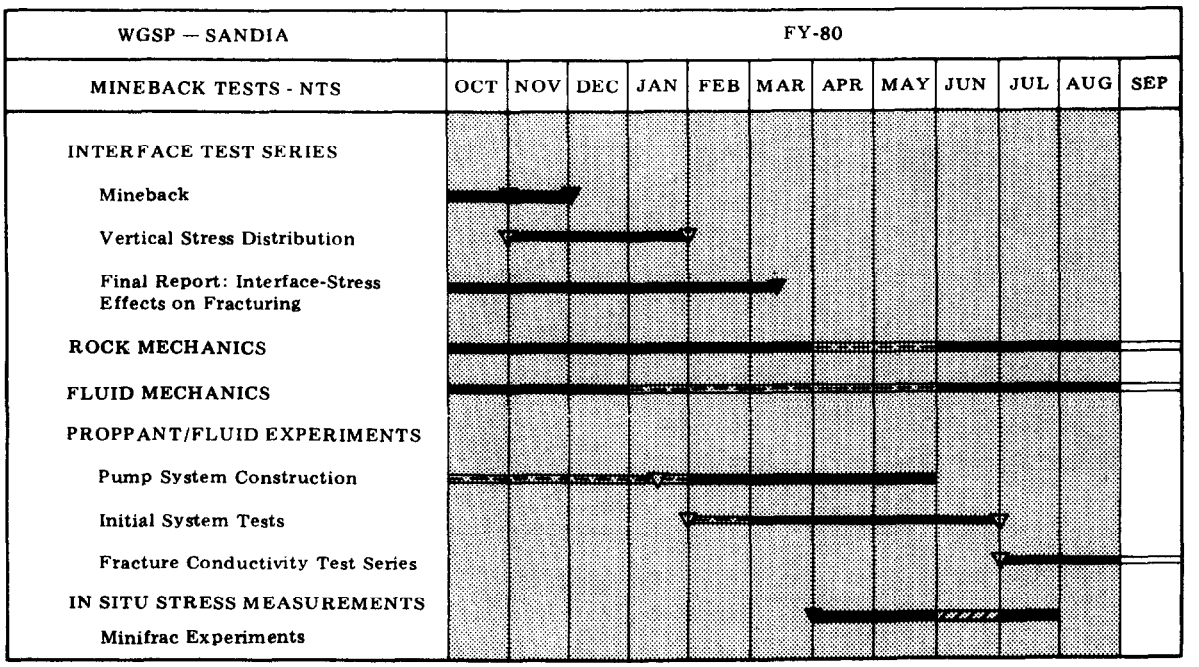


Figure 4-11 Milestone Chart — Sandia Mineback