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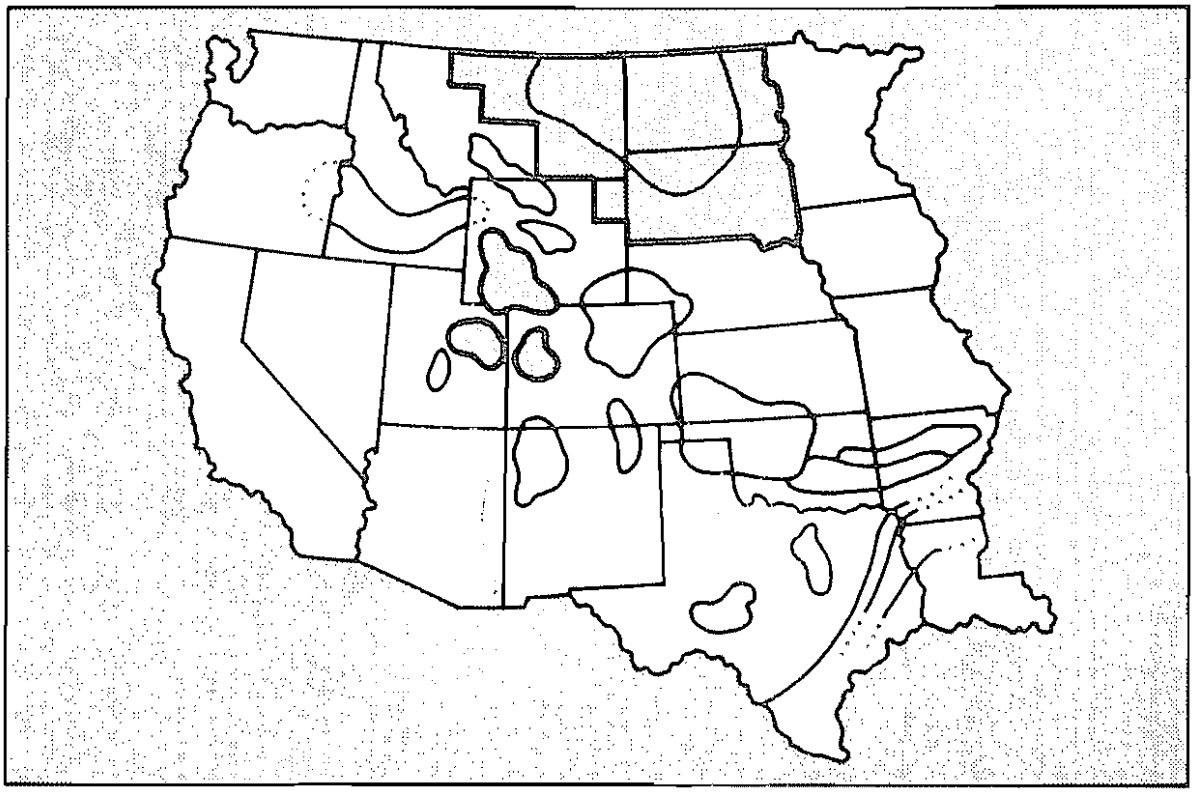
Western Gas Sands Project Status Report



1 June – 30 June 1979

Prepared for
U.S. Department of Energy

Bartlesville Energy Technology Center
Charles H. Atkinson
Project Manager

Compiled by CER Corporation
Las Vegas, Nevada

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1. SUMMARY

This edition of the WGSP Status Report summarizes June, 1979 progress of 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, Status Report, NVOI0655-1 00*

C. H. Atkinson (DOE), R. L. Mann (CER Corporation), and D. A. Northup (Sandia Laboratories) met in Las Vegas, Nevada, June 5-6, to discuss the WGSP Multi-Well Program. C. H. Atkinson (DOE), and G. R. Luetkehans and R. L. Mann (CER Corporation) attended a DOE Unconventional Gas Recovery review meeting in Morgantown, West Virginia on June 11-12 Work by the USGS toward resource assessment in the four primary study areas continued. CK GeoEnergy started a core hole in Grand County. Utah.

During June, projects of the National Laboratories and Energy Technology Centers continued. Bartlesville Energy Technology Center continued work on fracture conductivity. rock-fluid interaction, and log evaluation and interpretation techniques. Experimental and theoretical work on hydraulic fracturing mechanics and analysis of well test data continued at Lawrence Livermore Laboratory.

The CER Corporation RB-MHF 3 final report has been distributed. Cyclic gas injection began again on CIG's Sprague No.1 well. The DOE well test facility was transported to Vernal, Utah for minor repairs and storage. The GPE wells, Natural Buttes Units 9, 14 and 18 flowed to sales. The Mitchell Energy Muse-Duke No.1 well flowed 3,000 MCFD in June. Attempts to kill the Mobil PCU F31-13G well failed. Exploratory coring of the Sandia Hole No.6 Formation Interface Fracture Experiment resumed in June.

2. PROJECT MANAGEMENT

2.1 TECHNICAL MONITORING AND EVALUATION

H. E. Newman (CER Corporation) attended the American Association of Petroleum Geologists (AAPG) meeting held in Casper, Wyoming, June 4-6.

J. E. Evered (CER Corporation) attended the Natural Gas Planning Conference in Arlington, Virginia, June 11-12 and also visited with TRW and GRI personnel to discuss WGSP programs.

C. H. Atkinson (DOE), R. L. Mann (CER Corporation), and D. A. Northrop (Sandia Laboratories) met in Las Vegas, Nevada, June 5-6, to discuss the WGSP Multi Well Program.

C. H. Atkinson (DOE), R. L. Mann, and G. R. Luetkehans (CER Corporation) attended a DOE Unconventional Gas Recovery review meeting in Morgantown, West Virginia, June 11-12.

R. L. Mann (CER Corporation) attended a National Petroleum Council meeting in Denver, Colorado, on June 20.

C. H. Atkinson and A. Crawley (DOE), M. Hanson (LLL), J. Boyer, B. Allen and H. Carroll (BETC), W. Bailey and W. Murphy (TRW), D. Northrop (Sandia Laboratories), and CER Corporation personnel met in Las Vegas, Nevada, June 21-22 to work on the Gas Resources R&D Management Plan.

2.2 TECHNOLOGY TRANSFER

2.2.1 Documentation and Reports

The WGSP Financial Supplement for May, 1979 was distributed and data for the June supplement was compiled. Work on the WGSP Project Plan FY 1980 continued. The DOE Well Test Facility Manual was modified in June. Work on a geologic review of the Northern Great Plains Province by CER Corporation personnel continued. A draft copy of the WGSP First Quarter Basin Activities Report, 1979 was prepared. A report on the WGSP Logging Program was revised and updated.

2.2.2 Project Data Bank

A USGS Open File Report entitled "Preliminary chart showing electric log correlation section *DDI* of some Upper Cretaceous and Tertiary rocks, east flank Rock Springs Uplift, Wyoming" and Public Information Circular No. 10, a complilation of abstracts of papers presented at a recent joint meeting of the Survey, Wyoming Geological Association and the University of Wyoming's geology department were added to the project file. Work continued on the WGSP bibliography.

2.2.3 Articles and Publications

APPLICATION OF *A NEW METHOD FOR DETERMINING FLOW CHARACTERISTICS* OF *FRACTURED GAS WELLS IN TIGHT SANDS*

J. O. Scott
Cities Service

Flow characteristics of fractured gas wells in low permeability sands of the Green River Basin of Wyoming show behavior similar to models for limited flow capacity fractures. Analysis methods are shown to analyze pressure buildup tests to identify relative fracture conductivity and length.

Gas production histories of wells have been curve fitted and are shown to conform to limited conductivity type curves. Pressure buildup tests before and after long production periods indicate low initial fracture conductivity improving with time. Calculated effective fracture lengths are smaller than expected.

PRESSURE TRANSIENT ANALYSIS OF *TIGHT WESTERN GAS SANDS- PRE- AND POST-FRACTURING*

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 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 preliminary results for the Mobil F31-13G well located in the Piceance Creek Gas Field, 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.

2.3 CALENDAR OF EVENTS

The 5th Annual DOE Symposium on Enhanced Oil and Gas Recovery and Improved Drilling Technology will be held August 22-24 in the Performing Arts Center, Tulsa, Oklahoma.

3. RESOURCE ASSESSMENT

3.1 U.S. GEOLOGICAL SURVEY ACTIVITIES

3.1.1 Uinta-Piceance Basins

C. W. Keighin started a mineralogical investigation of core samples from the Upper Cretaceous Sego Sandstone, southeastern Uinta Basin, Utah.

A paper entitled "Influence of diagenetic reactions on nonmarine Upper Cretaceous rocks of Southman Canyon Gas Field, Uinta Basin, Utah", by C. W. Keighin and T. D. Fouch, was published.

3.1.2 Greater Green River Basin

C. W. Spencer presented a talk on the progress of USGS geologic investigations at the Morgantown DOE meeting, West Virginia, June 12-13.

An open-file report on Cretaceous measured sections, Sandwash Basin area by L. W. Kiteley, is being reviewed for publication.

3.1.3 Northern Great Plains Province

Two talks were presented at the Casper, Wyoming meeting of the Rocky Mountain Section of AAPG/SEPM, by D. D Rice and D. L. Gautier.

Petrographic analysis of Eagle Sandstone equivalent rocks from the Joseph J. C. Paine -- DOE cored well was completed.

X-ray diffraction analysis of clay minerals from the Joseph J. C. Paine DOE cored well continued.

Research began for a paper on the production, accumulation and reservoir potential of biogenic gas.

The first draft of a paper entitled "Reservoir Geometry of Eagle Equivalent Sandstones, Southeastern Montana" by G. W. Shurr was completed.

X-ray diffraction analysis began on Pierre Shale cores from the Hayes and Turner wells, Pierre area, South Dakota.

Petrographic and scanning electron microscope analysis of Mesa Petroleum core of Eagle-equivalent shelf sandstones from the Liscomb Creek Gas Field, southeastern Montana was initiated.

A final draft of a paper entitled, "Petrology of the Eagle Sandstone, Bearpaw Mountains area, North-Central Montana" by D. L. Gautier was completed.

"The development of shallow gas reserves in low-permeability reservoirs of Late Cretaceous age, Bowdoin Dome area, north-central Montana": 1979 SPE Symposium on low-permeability gas reservoirs proceedings, pages 315-324, SPE 7945, 1979 by G. L. Nydegger, D. D. Rice, and C. A. Brown was published.

"Post-depositional control of gas-reservoir quality in Eagle Sandstone of Bearpaw Mountains, north-central Montana" (abs.): Am. Assoc. Pet. GeoL Bull., v. 63, no. 5, p. 827, 1979 by D. L. Gautier was published.

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

Chandler and Associates, Exxon and David B. Munson were contacted concerning participation in the WGSP Coring Program for their wells in the Piceance Basin. Mapco and Coseka Resources were contacted concerning their well locations in the Uinta Basin. No agreements were reached.

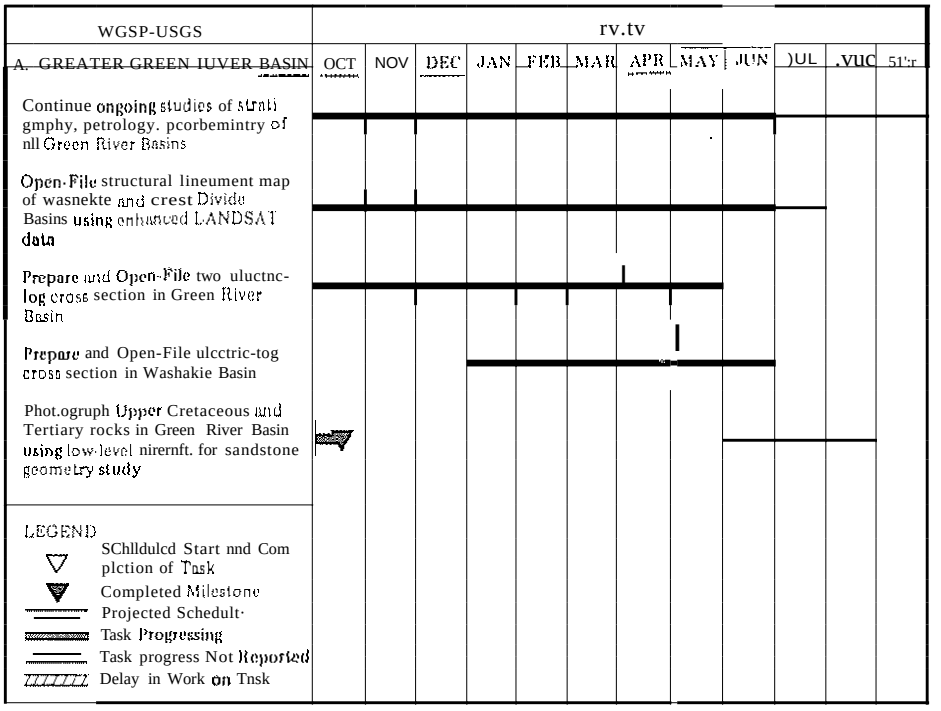
3.3 SURVEY OF BASIN ACTIVITIES

3.3.1 Greater Green River Basin

Twenty-one wells of interest to the WGSP in the Greater Green River Basin added 12,645 MCFD of new gas in June (Three IPFs were not available). Three of 15 development wells and 3 of 6 wildcats were completed D&A. Producing horizons were the Frontier, Almond and Lewis.

Twenty-six new wells were staked in June: 13 development wells and 13 wildcats.

Wells of interest to the WGSP are summarized in Table 3-1 and located on Figure 3-2.



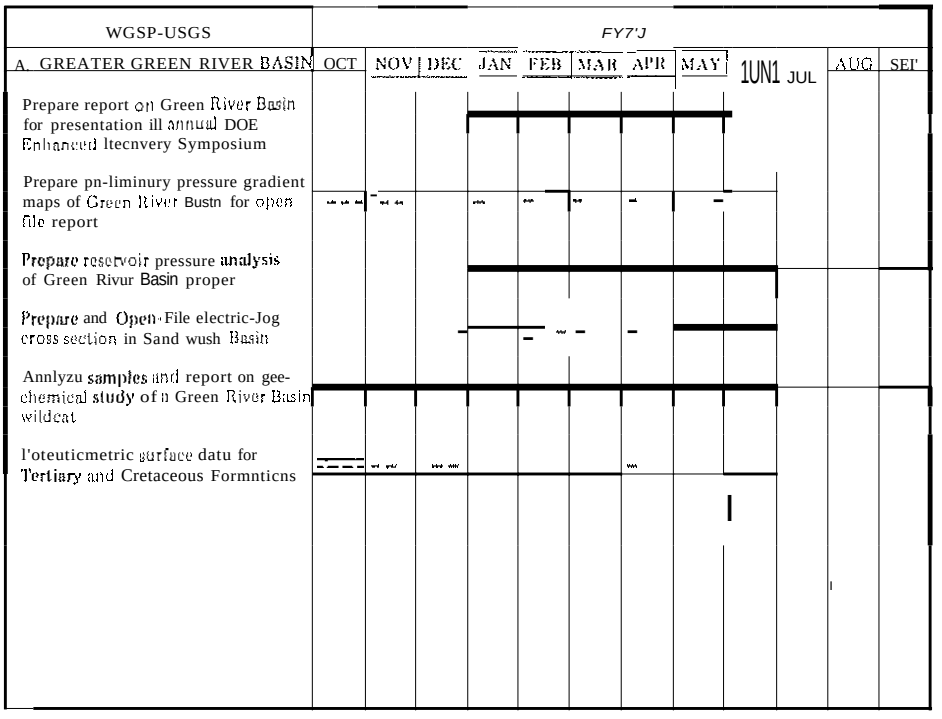
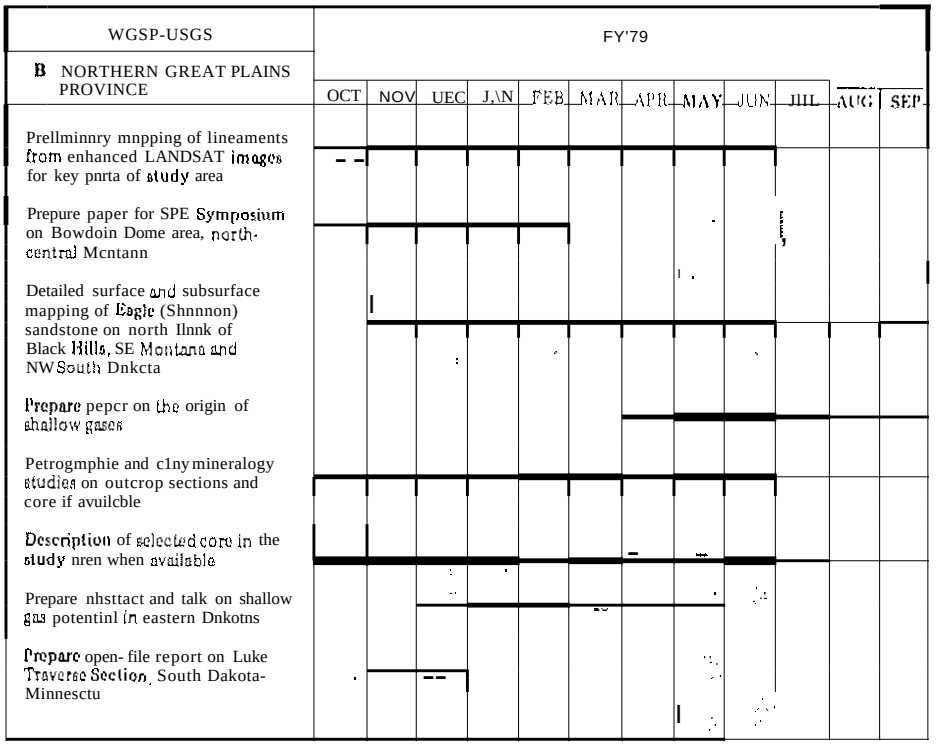


Figure 3-1 Milestone Chart — USGS



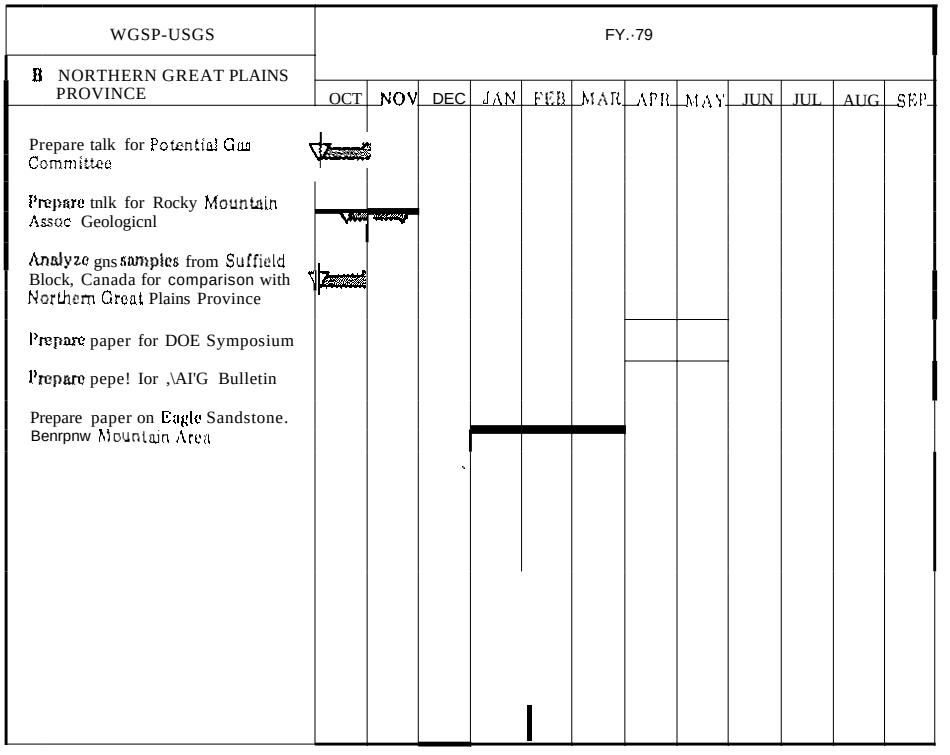


Figure 3-1 Continued

WGSP-USGS	FY-79											
C. PICEANCE OASIN	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Prepare and release cross secucn relating rock types, lithufueics, engineering data for rocks between Degeque and Jttne. Colorndo												
Prepnre und retccse cross section in style above (or southernmost Piceance Basin												
Cross section as above from Cnthe dral DJuffs to Rio Blnneo area												
Report results of nnulysla of core from Rio Blanco area												

WGSP-USGS	FY-79											
D. UINTA DASIN	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Prepare and release cross section reluting rock types. lithofacies, engineering data for rocks from Wasatch Mountains to southcentral Uinta Basin												
Investigate mineralogy and stratigruphy, and rock properties of core from Southmnn Canyon region of Uinta Basin												
Analyze dutu from San Arroyo Wash surface exposures of Cretaceous and Tertiury units of the southeast Uinta Basin Report results as they become available												
Prepare report on "tight gas" resetvoirs in Tertiary rocks of south-central Uinta Basin												
Prepnro report on diagenetic reactions and controls on Upper cretececus gas reservoirs lit SOULII mun Cunycn Field. to he published in SPE voturnc												
Core analysis—Upper Cretaceous and Lower Tertiary units. southwest Uinta Bnain												
Investigate mineralogy of core [rom the Sego Sandstune. Upper Creteceons southeast Uinta Basin. Utah												

Figure 3-1 Continued

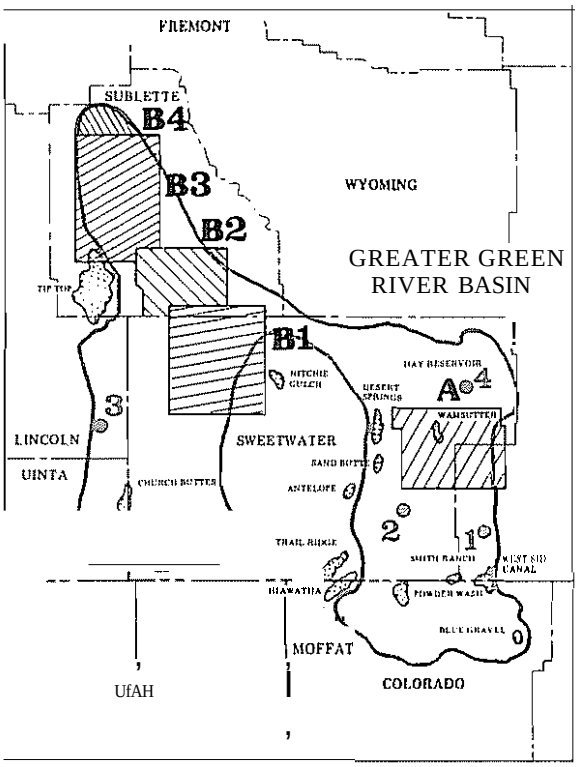


Figure 3-2

Greater Green River Basin Showing Wells of Interest and USGS Designated Core Areas (refer to Table 3-1)

Table 3-1 Summary of Wells Greater Green River Basin

OPERATOR	WELL NAME	MAP INDEX NO,I	LOCATION *Sec/T/R*	HORIZON[2] ft	FINAL I'D	FRACTURE TREATMENT	STATUS	IPF in MCFD
'Texus Oil and Gas	1 Fcdcrnl-Y	1	nwse *14/15N/91W* Cherokee Creek Field Carbon Otv , WY	2nd Frontier ('7,734-7,754)	B,500 PB: 8,110	Acfdlaud with 3,500 gal *sandi* ernul fracture	Ccmp. develop-mcnt well 3·5-79 No cores.	652
Amoco Production	1 Champlin 535 Amoco-A	2	csw *17/16N/97W* Unnamed Field Sweetwater Cty . WY	Almond (13,620-13,746)	14,200 PB: 14,126	Acidlzed with 5,982 gal	Camp" develop-ment well 2-27-79. Almond Discovery New Field	50
Amoco Production	1 Champlin 361 Amoco-A	3	swsw *31/20N I* 113W Wildcat Field Lincoln Cty , wy	Fronttcr (12,440)	12,250	10'1,686 gal ernul. 203,700lb sand	Camp, Wildcat 5·23-79" D&A	
Michigan-Wisconsin Pipe Line	1-4 Lost Creek	4	e½se *4/23N 194W* Unnamed Field Sweetwater Cty, WY	Lewis (11,794-12,053)	14,613		Camp Wildcat 8·10·'18. Lewis-Discovery New Field No cores	2.437

IRefer to Figure 3-2
'2Horlzon - projected depth or producing interval

3.3.2 Northern Great Plains Province

Fifteen wells of interest to the WGSP were completed: 10 development wells (3 D&A) and 5 wildcats (3 D&A). Producing horizons (Muddy. Bow Island and Phillips) added 5,215 MCFD of new gas in June. One IPF was not available.

Fifty-six new wells were staked by month end (48 development wells and 8 wildcats).

Wells of interest to the WGSP are summarized in Table 3-2 and located on Figure 3-3 and 3-4.

Table 3-2 Summary of Wells - Northern Great Plains Province

OPERATOR	WELL NAME	MAP INDEX NO.[1]	LOCATION Sec/T/R	HORIZON[2] It	FINAL TD	FRACTURE TREAI'MENT	STATUS	IPF In MCFD
Orlyn Terry	35-1 Federal	1	nene 35/IS/56E Wildcat Field Carter Cty, MT	Muddy 0,410)	1.440		Camp, Wildcat 5-7-79. Muddy-Discovery New Field	121
Midlands Gus	1 Federal-3412	2	swnw 34/31N/32W Bowdoin Field Phillips CW, MT	PhUllps (1.089-1.159)	1,305 PB: 1.229	*171.900 set* Nitrogen 40.0001b sand	Comp develop-mont well 5-7-79 No log tops No cores or tests	276
Denmark Resources	1·17 Fisher	3	nwnw 17/32N{35E Swanson Creek Field Phillips ctv. MT	Phillips (1,111·1.124)	1,342	40.0001b sand	Comp. develop-ment well 4-10-79. No cores or tests	240
Joseph J. C Paine	2-14 BLM	4	enw 4/129NI 106W Little Missouri Field Bowman Cty, ND	Eagle (L500)			Development well Fr 6-4-79. Operator has 20 additional Eagle tests in this locale,	

IRefer to Figures 3-3 and 3-4
2Horizon - projected depth or producing lnterval

3.3.3 Piceance Basin

The Mesaverde and Mancos horizons produced 2,129 MCFD of new gas in June. Five wells were completed in these horizons of interest: 3 development wells and 2 wildcats (1 D&A).

Thirty-one new wells were staked: 29 development wells and 2 wildcats.

Wells of interest are summarized in Table 3-3 and located on Figure 3-5.

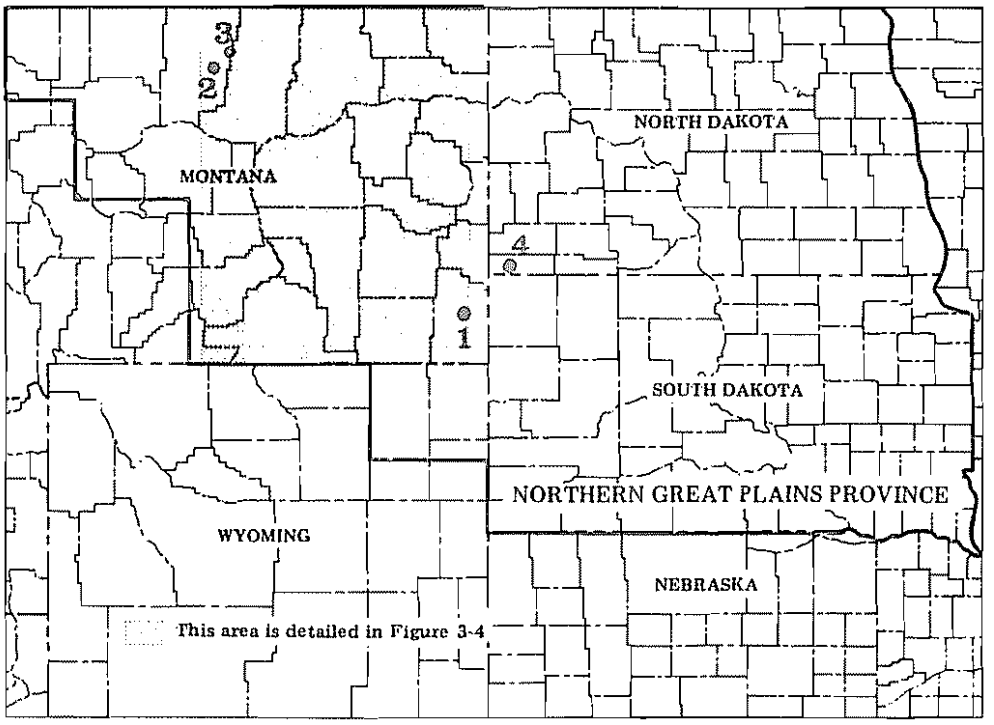


Figure 3-3

Northern Great Plains Province Showing Wells of Interest (refer to Table 3-2)

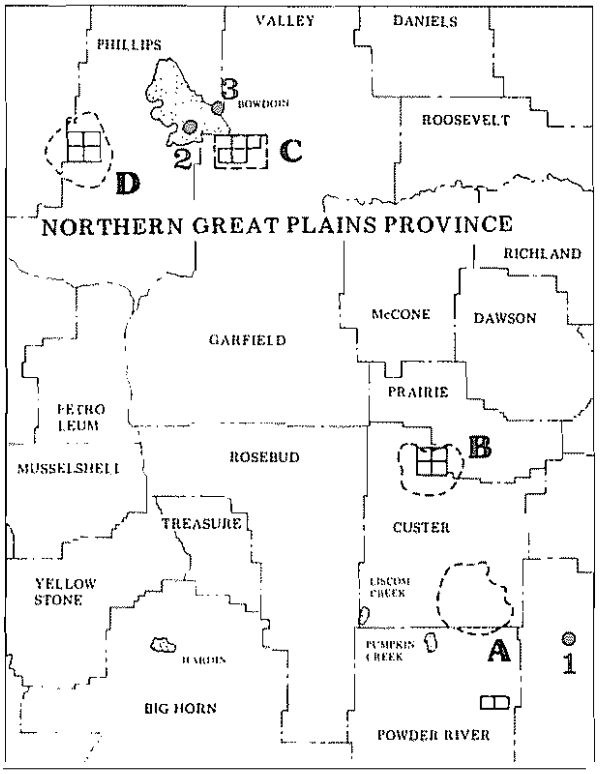


Figure 3-4

Detail of USGS Designated Core Areas (refer to Table 3-2)

Figure 3-5

Piceance Basin Showing Wells of Interest and USGS (Designated Core Areas (refer to Table 3·3)

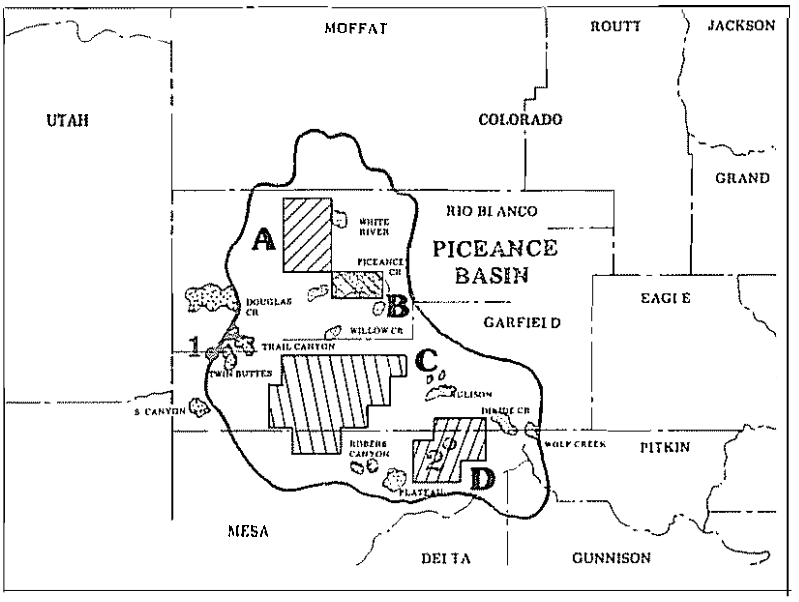


Table 3-3 Summary of Wells - Piceance Basin

OPERATOR	WELL NAME	MAP INDEX NO.[1]	LOCATION Sccrr/R	HORIZON[2] ft	FINAL TO	FRACTURE TREATMENT	STATUS	IPF In MCFD
Cosckc Resources	1·R·23 Federal	1	swnc 23/4S/102W Thunder Field Rio Blanco CtV, CO	Mancos (3,932-4,028)	4,500	sund jwuter fracture	Camp, develop-munt well 5-5-79 No cores or tests	129
Exxon Corporation	2 Vega Unit	2	nwsw 34/9S/93W Unnamed Field Mesa ety, CO	Mesaverde (7.847-8,052)	8,894 PB: 8,140	250 gul add 152,000 gal emul 274,9001b sand	Camp" Wildcat 9-15-78. No tests Mesaverde Exton-tlon Unnnrncd Field. Located in core area D.	440

I Refer to Figure 3-5
2Horizon. projected depth or producing interval

3.3.4 Uinta Basin

Fourteen development wells (2 D&A) added 16,983 MCFD of new gas in June from the Mesaverde and Wasatch horizons.

Seventeen new wells were staked by month end (3 development wells and 14 wildcats},

Wells of interest to the WGSP are summarized in Table 3-4 and located on Figure 3-6.

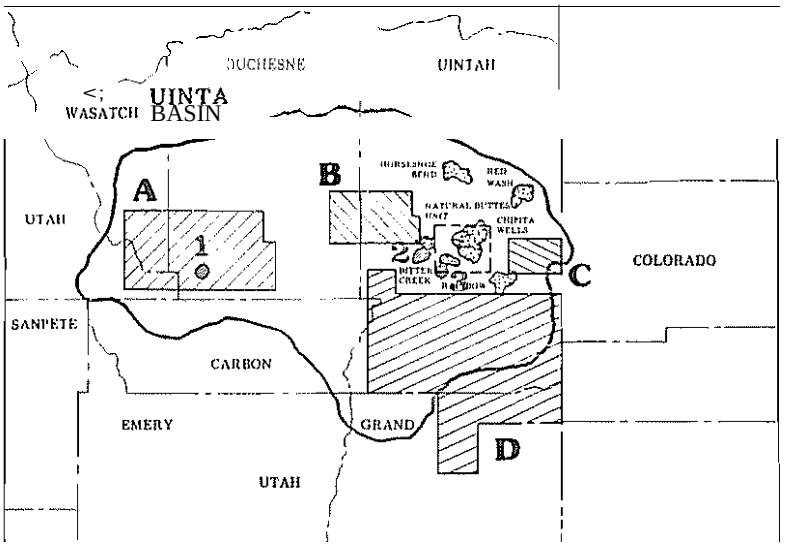


Figure 3-6

Uinta Basin Showing Wells of Interest and USGS Designated Core Areas (refer to Table 3-4)

Table 3-4 Summary of Wells - Uinta Basin

OPERATOR	WELL NAME	MAP INDEX NO,1	LOCATION SecfTfH..	HORIZON[2] ft	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Burton-Hawks	31-1 Alkali Canyon-Federal		swne 31jGSt1W Wildcat Field Duchesne Cty, UT	Wasatch (4,950)			Reported 6-12-79, located in core area A	
Belco Petroleum	43-36B Natural Buttes Unit	2	senw 36/98/20E Natural Buttes Field Uintah ety. trr	Wasatch (6,215-7,007)	7,0'78	46,000 gal water 106,OOOIb sand	Ccmp. development well 11·11·'78 No cores or tests	7,120
eIG Exploration	20-20-10-21 CIGE	3	scsw 20/105/21E Natural Buttes Field Uintah Otv, UT	Wasatch (4,651-6,002)	6,200 PB: 6,172	2,000 gal acid 70,,000 gal gel 150,0001b send	Camp development well 5·7-79 No cores or tests.	1,000

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

3.4 CK GEOENERGY

During June, CK GeoEnergy started a core hole (SW-SE section 16, TI7S, R24E Grand County, utah) in the Westwater Canyon area. The hole is on the location of a shut in gas well, During road and location preparation work the bulldozer opened a joint in a near surface sandstone layer and produced a five minute gas blow. This probably resulted from leaky casing in the shut in Pease well. Coring was initiated using a blowout preventer to reduce the risk of injury or damage if a subsurface gas flow was encountered. Coring operations at 660 ft were suspended until a better equipped drilling contractor could be obtained to finish the hole (the current contractor was using some marginal or submarginal drill pipe). Himes Drilling was contacted and agreed to finish the hole as soon as a rig was available,

An additional well in the Uinta Basin is expected to be made available for logging and pressure build-up analysis in July.

The following companies have made wells available for analysis:

- Diamond Shamrock,
- Gas Producing Enterprises, and
- Beleo Petroleum Corporation.

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

4.1.1.1 Core Retriever Design and Test

Design work has been completed on modifications to the Diamond Oil Well Drilling Company (DOWDCO) pressure core barrel that will be used to test the Sandia 2-piece bit and low invasion coring fluid. Fabrication and assembly of parts will be completed and available for the drilling test on August 7, 1979 at Terra Tek's Drilling Research Laboratory. A field test is planned in late August.

A preliminary investigation for incorporating a low-invasion fluid compressibility compensation system is being undertaken to assess the complexity of such a system.

4.1.1.2 Core Fluid Tests

Design work for the dynamic test apparatus has been completed. Equipment has been designed which will allow testing of coring fluids under simulated drilling conditions. This dynamic test system will test the low-invasion fluids at pressures up to 1,000 psi and temperatures up to 400°F. Test fluids of various viscosity and solids content can be circulated at controlled rates of up to 30 gal/hr. This equipment should be delivered, assembled, and in operation in about eight weeks.

Currently, low-invasion coring fluid is being tested for compressibility and the amount of air entrained in the fluid during mixing is being calculated. The theoretical compressibility of the coring fluid (based upon the difference between theoretical and actual fluid density) will be checked by laboratory testing at high pressures. A technical review meeting was held on June 19 with BETC representatives which evaluated the current status of the low-invasion coring fluid project. BETC requested additional testing to assure quality control of laboratory data.

4.1.1.3 Bit Design and Fabrication

Brazing of compax cutters to the 2-1/2 in. pilot bits is the preferred method at present since problems still exist with the diffusion bonding to bit bodies. Brazed pilot bits will be used in the Terra Tek tests.

Three 6·1/2 in. bit bodies will be fabricated jointly by DOWDCO and Sandia Laboratories, and be available for testing in August,

4.1.1.4 Bit Test

Full core barrel and bit tests are scheduled at Terra Tek on August 7 and field tests are planned in the Denver City area, Texas, in late August.

4.1.2 In Situ Permeability

Measurement of Formation Characteristics for Western Tight Sands - Institute of Gas Technology

Gas permeabilities of core No. 6475.5 from the Uinta Basin, Utah were measured. Results of preliminary measurements made at different mean pore pressures (to evaluate the extrapolated Klinkenberg permeability) are shown in Figure 4-1. The Klinkenberg permeability appears to be a strong function of net confining pressure. The observations need to be compared with liquid permeability measurements made under the same confining pressures. Gas permeability measurements were obtained for core Nos. 8498, 9957, and 9957A from the Mobil PCU F31·13G well, Piceance Basin, Colorado. Results of high differential pressure measurements made on core No. 8498 (Figure 4·2) indicate that at high differential pressures a plot of permeability versus reciprocal mean pressure curves away from the straight line obtained from measurements made at low differential pressures. The value of permeability extrapolated to infinite mean pore pressure under a net confining pressure of 4,500 psi was 0.00021 md compared with 0.017 md obtained from measurements made at 120 psi net confining pressure. Figure 4·3 shows the results of measurements made at 120 psi net confining pressure. Figure 4·3 shows the results of measurements made on core Nos. 9957 and 9957A. The permeability characteristics of the two core plugs drilled from the **same core are similar"**

Liquid permeability measurements have been made on core Nos. 9957 and 8498 from the Mobil Well No. PCU F31·13G using kerosene as the flowing phase. Results are presented in Table 4-1. The permeability values change continuously. This may be due to the movement af fines within the core. The apparatus is being modified to enable the flow direction to be changed during the experiments. All liquid permeability measurements were made under a net confining pressure of about 0.5 x depth in ft. The liquid permeability of core No. 9957 varies between 1.513 x 10'3 md and 1.35 x 10.^{5} md, The extrapolated Klinkenberg gas permeability value under the same conditions of confining pressure is 4 x 10'3 md.

Results of mercury capillary injection tests performed on cores from the Twin Arrow well C&K 4·14x, Rio Blanco County, Colorado and Pacific Transmission Supply Company well No. 2·19 Federal, Sublette County, Wyoming are shown in Figures 4·4 and 4·5, respectively. Permeability measurements on these cores will begin in July.

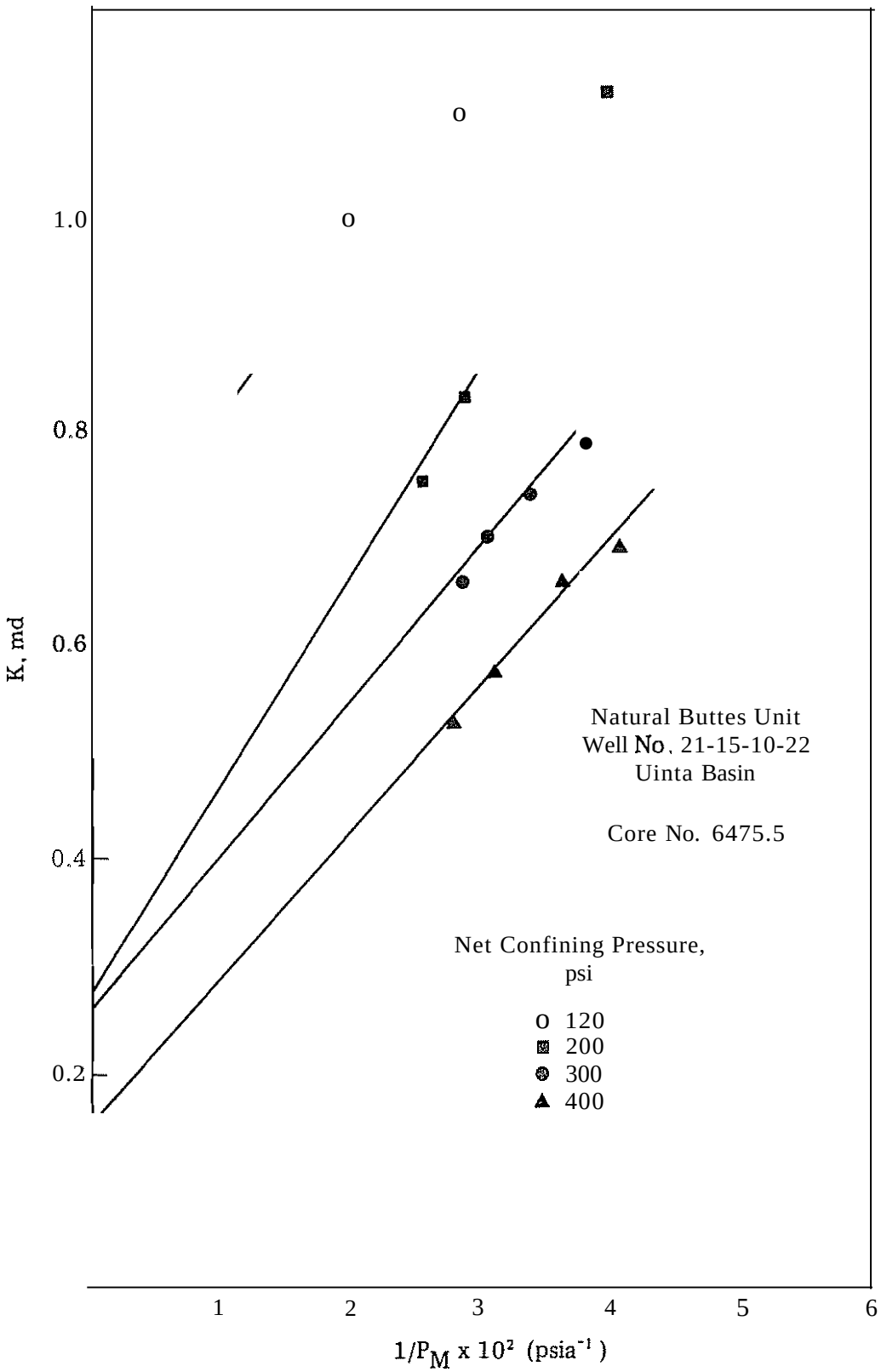


Figure 4-1 Effect of Confining Pressure on Klinhenberg Extrapolations

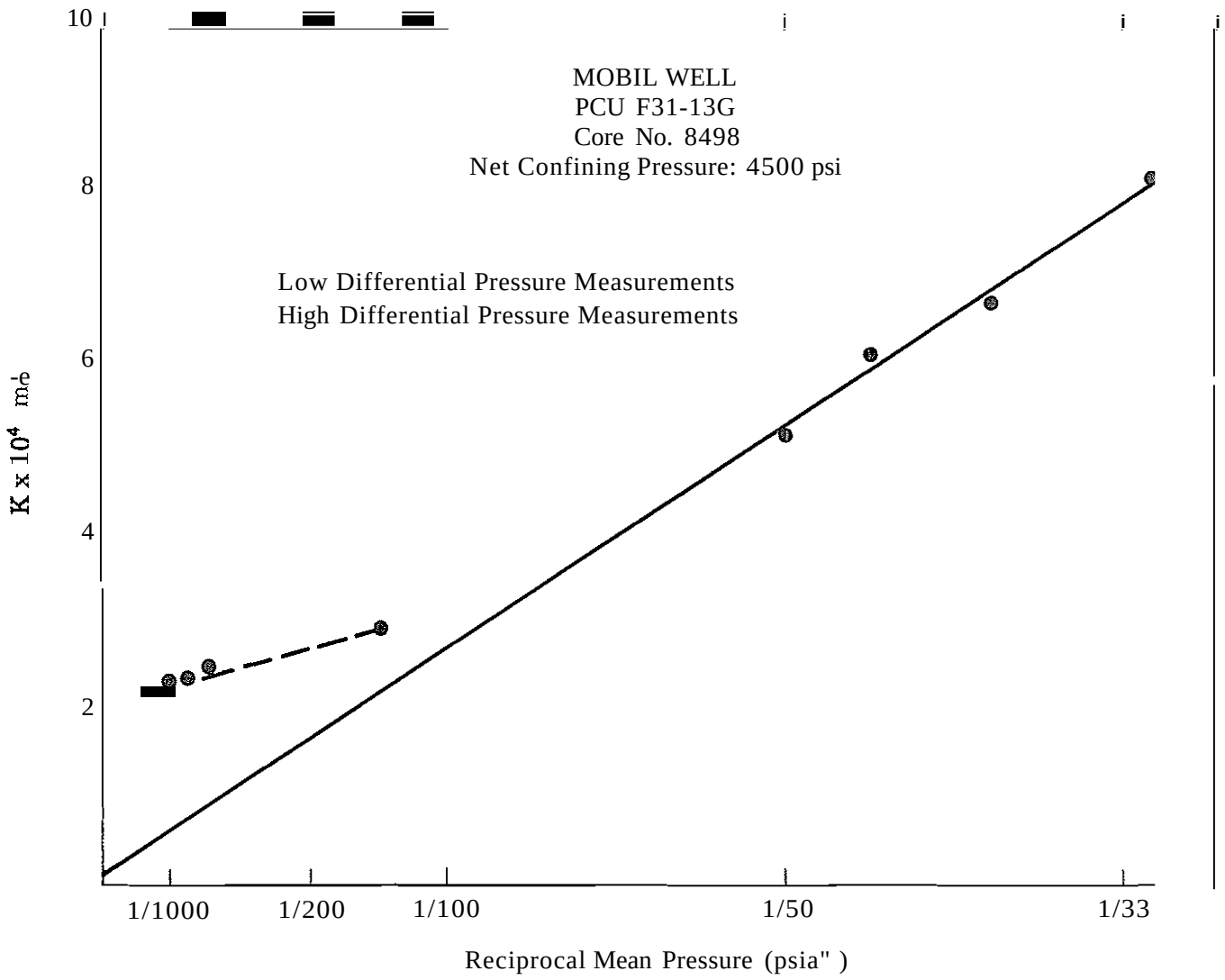


Figure 4-2 Effect of Pore Pressure on Gas Permeability

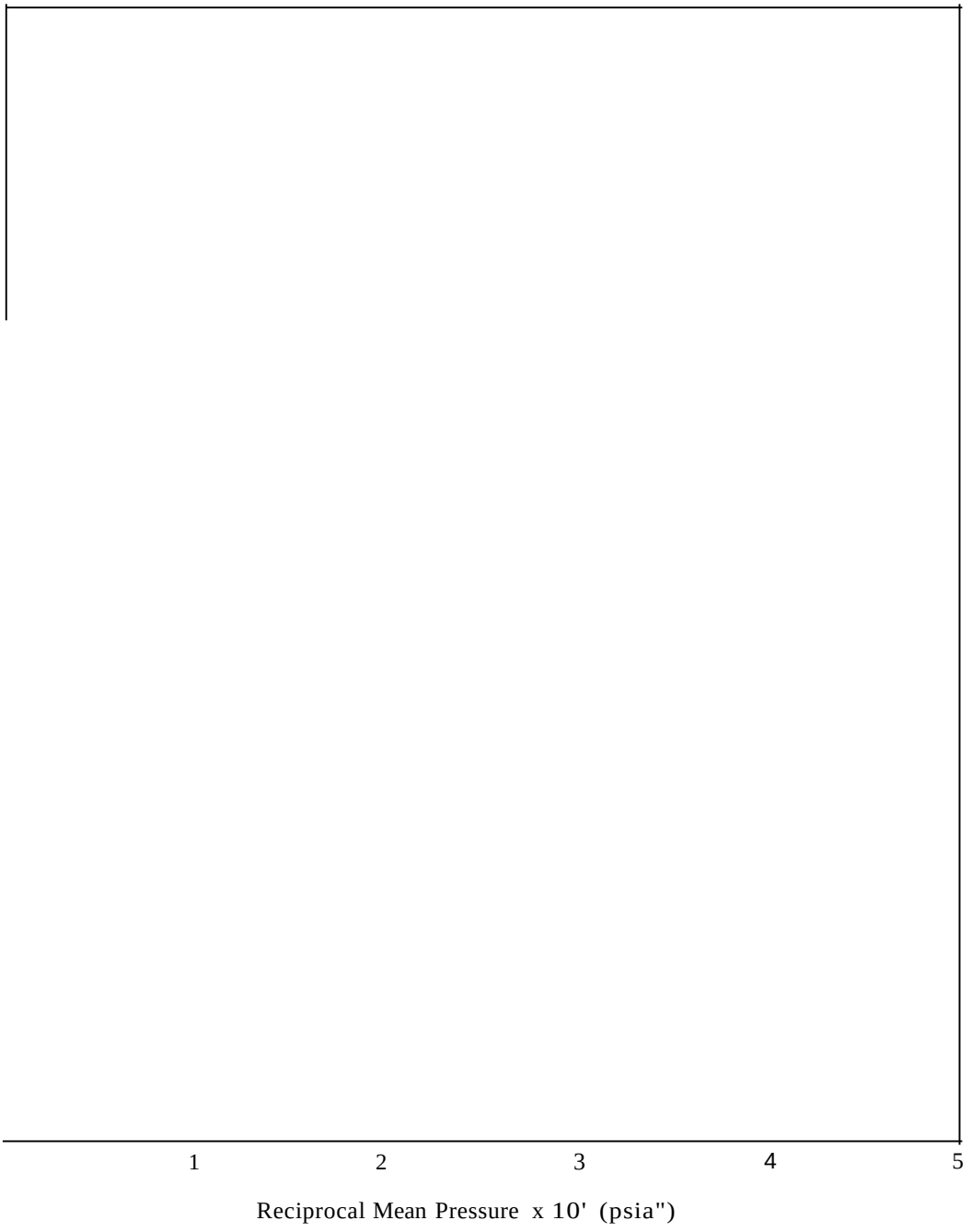


Figure 4-3 Effect of Pore Pressure on Permeability at Low Confining Pressure

Table 4-1 Liquid Permeability Measurements on Core from Mobil PCU F31-13G Well

Core Depth: 8,498 ft
Core No.: 8,498A

Net Confining Pressure: 4,200 psi Differential Pressure: 300 psi			Net Confining Pressure: 4,200 psi Differential Pressure: 1,000 psi		
Time		K (md)	Time		K (md)
	5 min	1.0706×10^{-3}		0 min	3.0152 x 10-'
	20 min	5.4808 x 10-'		15 min	3.2086 x 10-'
1 hr	20 min	2.8973 x 10-'		30 min	2.0942 x 10-'
2 hrs	0 min	1.2587 x 10-'		60 min	1.0578 x 10-'
2 hrs	35 min	9.6212×10^{-5}	1 hr	30 min	1.9744 x 10-'
3 hrs	5 min	6.8244×10^{-5}	1 hr	50 min	4.2416 x 10-'
3 hrs	45 min	5.4688×10^{-5}	2hrs	15 min	2.8545 x 10-'
22 hrs	30 min	1.4503 x 10-'	4 hrs	20 min	1.7826 x 10"
22 hrs	55 min	1.0802 x 10-'	5 hrs	0 min	2.0412 x 10-'
23 hrs	20 min	1.1222 x 10-'	5 hrs	15 min	1.6683 x 10-'
24 hrs	10 min	7.5672×10^{-5}	5 hrs	20 min	2.5722 x 10-'
26 hrs	55 min	2.6766 x 10-'	5 hrs	30 min	2.9993 x 10-'
27 hrs	15 min	2.6541 x 10-'			
	0 min	2.0565 x 10-'		0 min	1.7718×10^{-5}
	25 min	8.1356 x 10-'		35 min	2.4907×10^{-5}
	45 min	6.0956 x 10-'	1 hr	5 min	2.8671 x 10-'
1 hr	10 min	3.3245 x 10-'	1 hr	20 min	7.7476×10^{-5}
1 hr	40 min	3.3544 x 10-'	3 hrs	45 min	1.3624×10^{-5}
2 hrs	15 min	7.8412 x 10-'	4 hrs	5 min	1.3483×10^{-5}
2 hrs	30 min	7.1480×10^{-4}	4hrs	50 min	3.2247×10^{-5}
3 hrs	5 min	6.6032 x 10-'	5 hrs	15 min	3.5007×10^{-5}
3 hrs	25 min	7.6304 x 10-'	21 hrs	45 min	4.8896×10^{-5}
18 hrs	30 min	1.5126×10^{-3}			

Core Depth: 9,957 ft
Core No.: 9,957

Net Confining Pressure: 4,600 psi Differential Pressure: 300 psi	Net Confining Pressure: 4,600 psi Differential Pressure: 1,000 psi

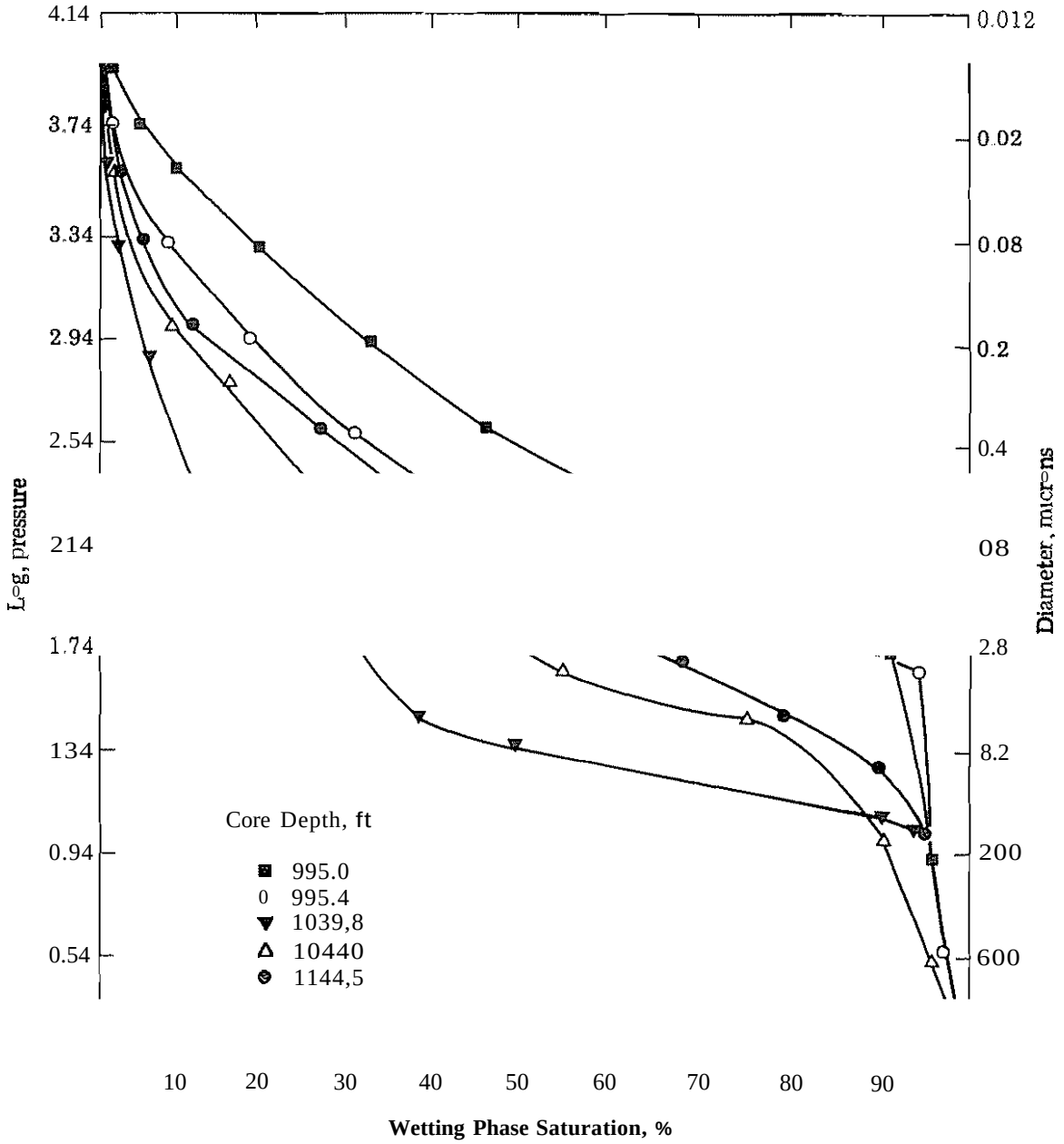


Figure 4-4 Mercury Capillary Injection Measurements on Core from Twin Arrow C&K 4-14 Well, Rio Blanco County, Colorado

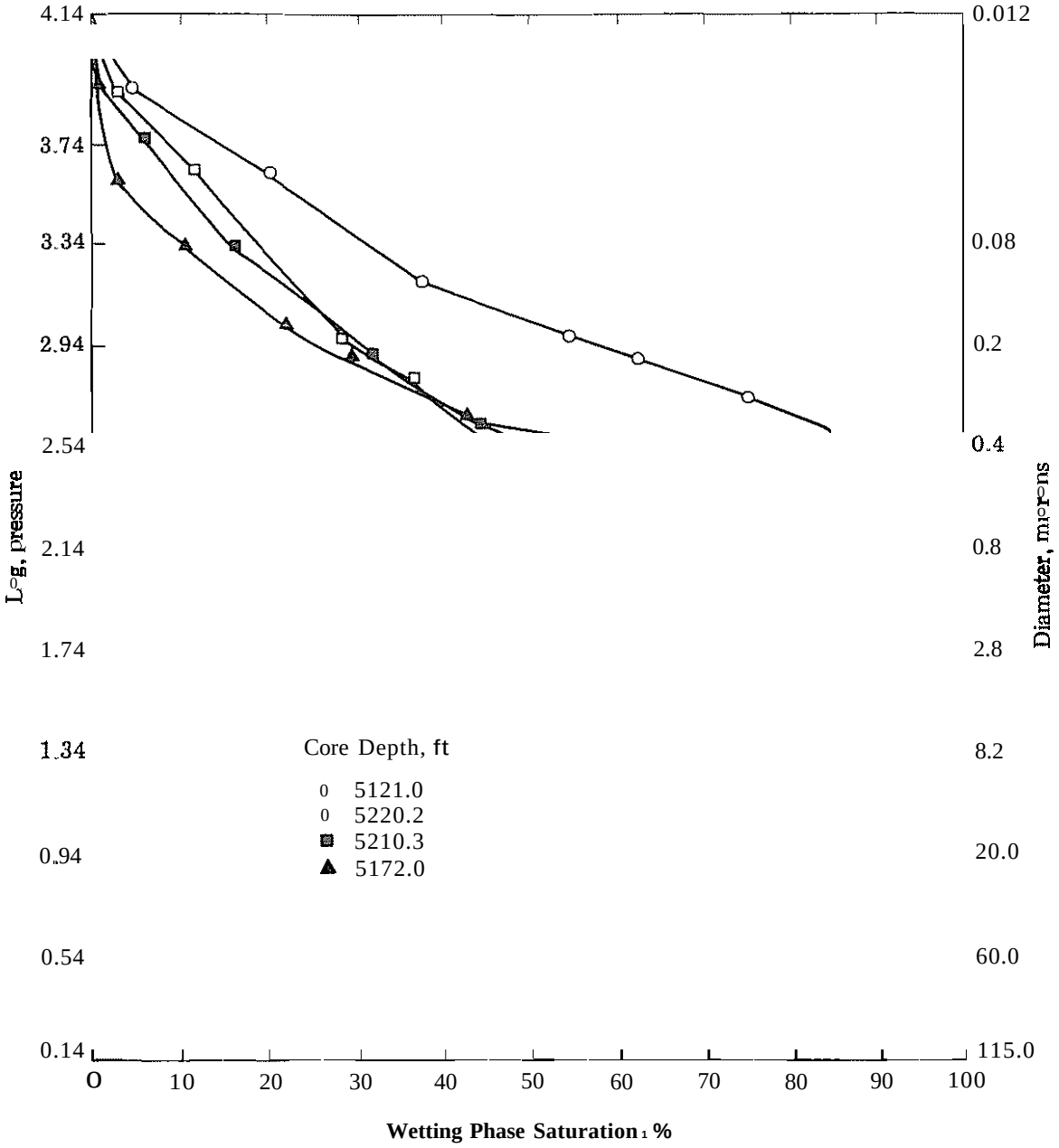


Figure 4-5 Mercury Injection Capillary Pressure Tests on Core from Pacific Transmission Supply Company 24-19 Federal Well, Sublette County, Wyoming

4.1.3 Advanced Logging Techniques and Interpretations

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

All logs where good core data are available from the western area have been gathered and well information are also being obtained.

Logs were digitized in terms of sonic (At), density (bulk density), gamma ray (API units), Rt and neutron after the well was located. In the future, some wells may require a different suite of logs to be digitized.

Computer runs of digitized data were made. Data were gathered from the sonic, density, gamma ray, induction and neutron log. Presently, neutron porosity cannot be input because of problems with the program. Runs were made from:

Run 1	4,400 - 4,500 ft
Run 2	6,400 - 6,500 ft
Run 3	7,400 - 7,500 ft
Run 4	8,400 - 8,500 ft

These trials are not final and formation water resistivity (Rw) must be studied. Also, the values of matrix and "shale" density and travel time must be accurately defined. Core analysis fits the calculated values in the log analysis. There are some areas which are recording porosities that are too high (considering input parameters). For this reason, zones are not adequately described; shale, sandstone-limestone or sandstone-dolomite, and lignite must be clearly defined. More core will be required.

4.1.4 Instrumentation for Formation Evaluation and Advanced Logging Techniques — Sandia Laboratories

Working arrangements between Sandia Laboratories and Chevron have been formalized. Eleven core samples from CIGE No. 21 will be shipped to the Chevron labs in La Habra, California. Porosity and permeability (air and brine) measurements will be made by Petroleum Testing Services, Santa Fe Springs, California, while NMR, cation exchange capacity, and X-ray diffraction measurements will be made by Chevron. Additional SEM and mineralogic studies are in progress on sections taken from these core samples by USGS, Denver, Colorado.

The INDINV computer code is being developed to model the response of an induction tool in a borehole with variable conditions of horizontal layering and depths of filtrate invasion. A subroutine has been added to the code to automatically reduce the spatial mesh spacing when finer resolution is required for the rapidly varying electromagnetic fields near the source. Testing is continuing

Analytical studies of induction tool coil designs began with a literature survey. Available papers and patents indicated that theoretical studies were all based on the assumption that an ideal magnetic dipole existed for induction probes. Theoretical formulations from ground-zero have been undertaken in the Sandia project. Results to date indicate that coil windings as sketched in patents and publications cannot maintain magnetic-dipole purity and could distort logging data interpretations. A coil has been designed that will produce only magentic dipole moment and is being constructed for testing.

The boundary value problems for induction logging tools have been directed toward mathematical transformations between cylindrical and spherical Hankel functions, resulting in improved analytical understandings of tool limitations without numerical integrations. Asymtotic expansions have established the criteria for neglecting borehole effects without introducing measurable errors in formation evaluations. The criteria are in agreement with numerical results published by U.S. and Soviet investigators. The remaining problems concerning invasion-zone effects are more difficult and cannot be treated without numerical integrations. Thus, numerical integrations are being pursued. Coding efforts have begun and programming will begin in July.

In the course of the investigation of models for electrical response, the following additional observations have been made

- Alternate models need to be considered in which the dielectric properties are constant, whereas the conductivity is dispersive (data in the frequency region 1 to 10^6 Hz).

- Data are required to test the proposed relation between the fluid flow permeability and the dispersive dielectric properties of rocks. Likewise, data concerning three-component systems are needed.

- Any logging tool operating under the principles of this paper will be a broad band device. Present logging systems are limited in this capability.

- Sulfides, clays and other matrix materials with complicated electrical properties may negate the assumption of a nondispersive conductivity. This assumption may not be strictly valid for any rock matrix.

- Statistical models of rock grain and pore geometries are compatible with information potentially available from broad band measurements and they need development

4.1.5 Reservoir Simulation Studies

A computer model for simulating the performance of vertically fractured gas wells completed in lenticular Iorrnations is being developed. A literature survey was conducted to review published research in this area.

A Darcy flow model which combines a two-dimensional reservoir model and a one-dimensional fracture model has been programmed and debugged on the BETC computer.

The mathematical equations necessary to modify the existing computer model to include the effects of non-Darcy flow in the reservoir and the fracture, wellbore storage effects, formation damage effects, frictional pressure drop in the production string, and lenticular effects are being developed. Computer subroutines have been coded for incorporation into the existing program in order to handle a wide range of reservoir PVT conditions.

The extension to a full three-dimensional reservoir model will be fairly straightforward upon completion of the combined two-dimensional/one-dimensional models.

4.1.6 Rock-Fluid Interaction

The main elements for the Monte Carlo model of fracture propagation at BETC are listed below.

- The expanding vertical frac will be divided into a number of sectors, eight initially, but increasing with time in order to keep the perimeter points approximately equally spaced. This insures that an expanding crack tip point will not "miss" any of the earth stress grid boxes.

- The stress intensity factor at each crack tip point will be calculated from the formula

  $$K_i = m(p-s)\sqrt{\pi r_i}$$

  where $m = 2/\pi$ for a penny-shaped crack and $m = 1$ for a Griffith crack

  The curvature factor, m, will be incorporated by finding the local curvature at each crack tip point. Pressure is also important in determining K_i.

  The critical stress intensity factor K_c will be calculated from

  $$K_c = \sqrt{\frac{2E\gamma}{1-\nu^2}}$$

  where r is surface energy. If K_i is > K_c the crack tip point propagates a distance proportional to $K_i - K_c$ The actual distance must be found by iteration until injected volume equals expanded volume when all sectors are considered.

- The equations of Geertsma and de Klerk (1969) were applied to each sector, and it was assumed the sectors were independent. This is probably the weakest link in the model. After all the sectors in one cycle have expanded, the pressure in each section will be projected back to the wellbore. The resulting bottom-hole pressure will be calculated from the average of the individual sector pressures.

Remaining tasks include using "realistic" parameters to estimate the probability of obtaining a certain fracture length when a given spectrum of inhomogeneities in stress (initially) or fracture toughness K_c are imposed, and to extend the Monte Carlo model to include crack tips which can propagate out of the plane of the frac.

Sintered bauxite proppant (12-20 mesh) was tested for embedment into two sandstone cores (7698.4 and 6,903 ft) and a representative shale core. These core slabs were saturated with 2 percent KCl prior to use.

The maximum diameter proppant was 1.59 mrn, This was considered to be the width of a propped fracture with no embedment.

The proppant was placed between a steel plate and the core slab due to the limited amount of core material. The compressing force was transmitted through a 5/8 in. diameter ball bearing to compensate for non-parallel core faces. Three proppant coverages were used: a complete monolayer (0.249 g/cm^2), 75 percent of a monolayer, and 50 percent of a monolayer. The proppant was held in place on the steel plate by silicone grease.

In general, embedment occurred rapidly with low applied pressure but the rate decreased at higher pressures. This was due to seating of the larger proppant and increased support by the smaller proppant. The lower proppant coverages seemed to reach a plateau more rapidly than the 100 percent coverage. The absolute magnitude of the embedment is subject to greater errol' than the relative embedment because of the difficulty in defining the zero point embedment. This problem may explain the apparent lower value by lower proppant coverages. The embedment can range upward to 25 percent on a single face. About 30 percent of the proppant contacted the core at the maximum pressure of about 7,000 psi.

Although the shale fractured more readily, it seemed to hold up about as well as the sandstones to embedment.

4.1.7 Schedule Status

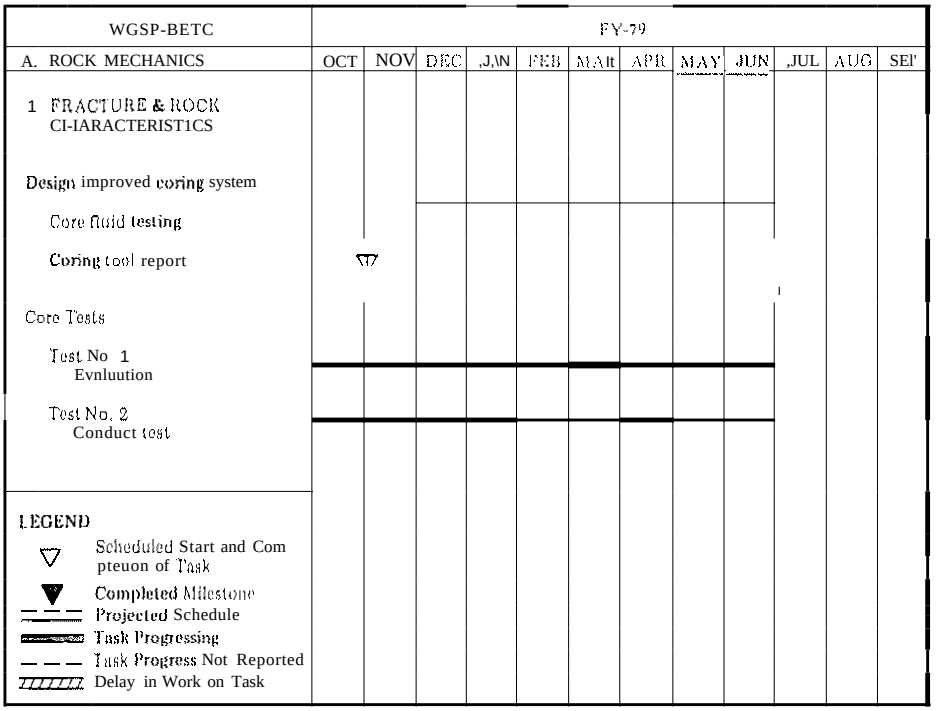
Figure 4-6 is a milestone chart depicting June progress of BETC projects.

4.2 LAWRENCE LIVERMORE LABORATORY

4.2.1 Theoretical Analysis

Two-dimensional analyses of the dynamic propagation of fractures near interfaces are being performed with the dynamic elastic computer code TEMS.' This code has been used extensively to study dynamic fracture propagation and earthquake source mechanics, and is based on Lagrangian techniques to solve equations describing the continuum. It requires the use of a calculational grid over which the response of the continuum is calculated. The numbel' of nodal points (grid blocks) in the calculational grid must be limited since computers are of finite size and calculations must be performed within a reasonable amount of computer time. Hence, the grid is terminated over some finite part of the continuum. Boundaries of the calculational grid then act as reflection surfaces to the dynamic phenomenon which is being studied and, if the grid boundaries do not coincide with physical boundaries, non-physical reflections result. These limitations strongly influence the grid size requirements for a calculation because the calculations are normally terminated before the non-physical boundary reflections cross the areas of interest in the grid.

, A. G. Petschek and M. E. Hanson, Difference Equations for Two-Dimensional Elastic Flow, J. Camp. Phys. 3, 307-320 (1968).



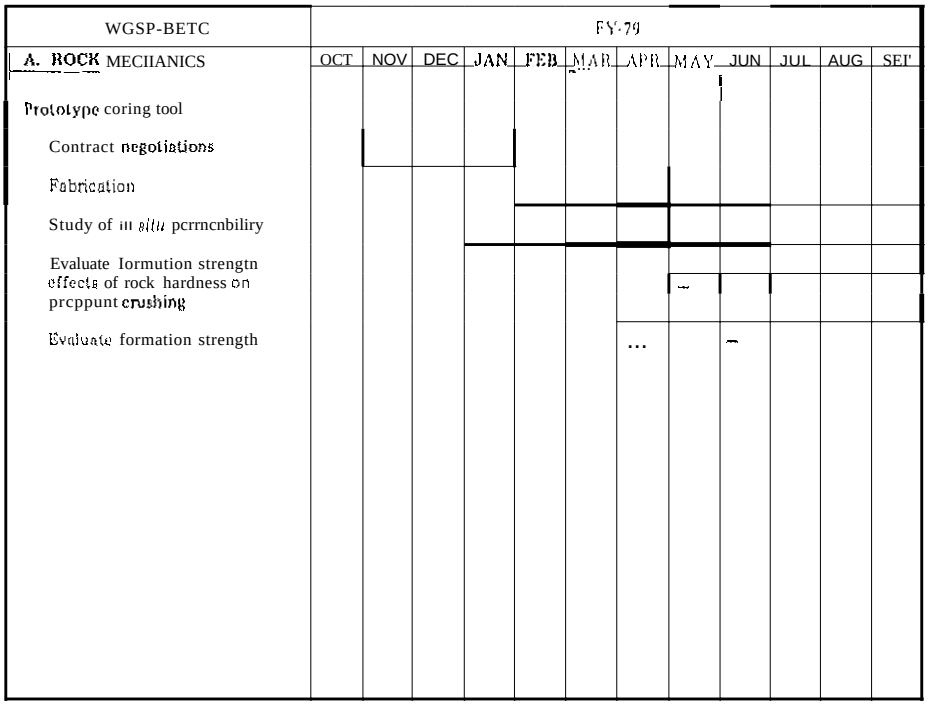


Figure 4-6 Milestone Chart - BETC

WGSP-BETC	fY·79											
B. FORMATiON DAMAGE	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1 ROCK-FRAC FLUID INTERACTION												
Current research intemul report												
Physical measurements												
Core anmples												
Filulltion tests												
I'ermenbtttues												
Prelimtnnry nnalysis and data correlation												
Annuul report												
2 FORMATION DAMAGE FROM FRAC-FLUID COMPONENTS												
Literature review												
Damage evaluntlon												

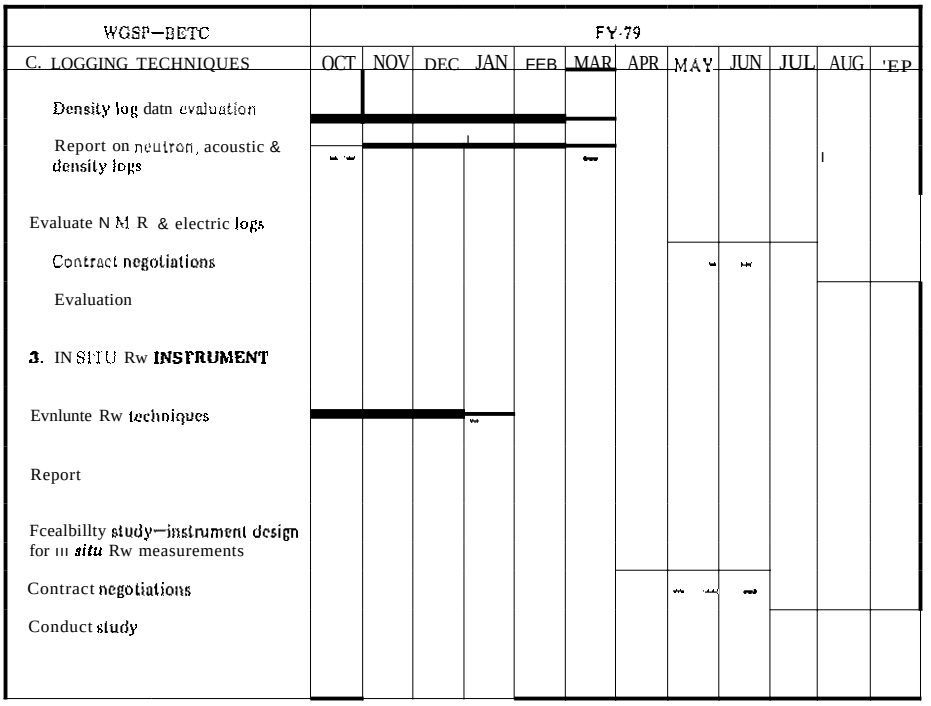
WGSi'-BETC	FY-79											
n. FORMATION DAMAGE	OCT	NOV	DEC	JAN	FED	MAR	APR	MAY	JUN	JUL	AUG	BEP
3 PROI'I'ANI TRANSPORT & EMDEDMENT												
Evaluation of pnrttcte transport in proppnnt beds												
Evaluation of prcppant embedment in tight gas sands												

Figure 4-6 *Continued*

WGSP-BETC	FY-79											
C. LOGGING TECHNIQUES	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
MAPPING & CONTOUR OF Rw												
Review current research												
Study of current legs												
Internnl report												
Extnnt datu assembly												
lsoreslstlvlty mnps												
Computer contours												
Annual report												
Report on contour of nw & wntor components in Llintn Basin												
Exumine and contour Rw & water components in Piceance Basin												

WGSP--BETC	FY-79											
C. LOGGING TECHNIQUES	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
2 LOGGING EVALUAnON												
Effects of lnterfnce conductivity on electric logging												
Physical mensurcmcnrs												
Core preparation & selection												
Resistivity												
Data correlations												
Conductivities from Rink & Shopper equation												
rermeautnues												
Report												
Study of Logging Technntquus												
Neutron log dntn evalunuon												
Acoustic log dntn evnluution												

Figure 4-6 Continued



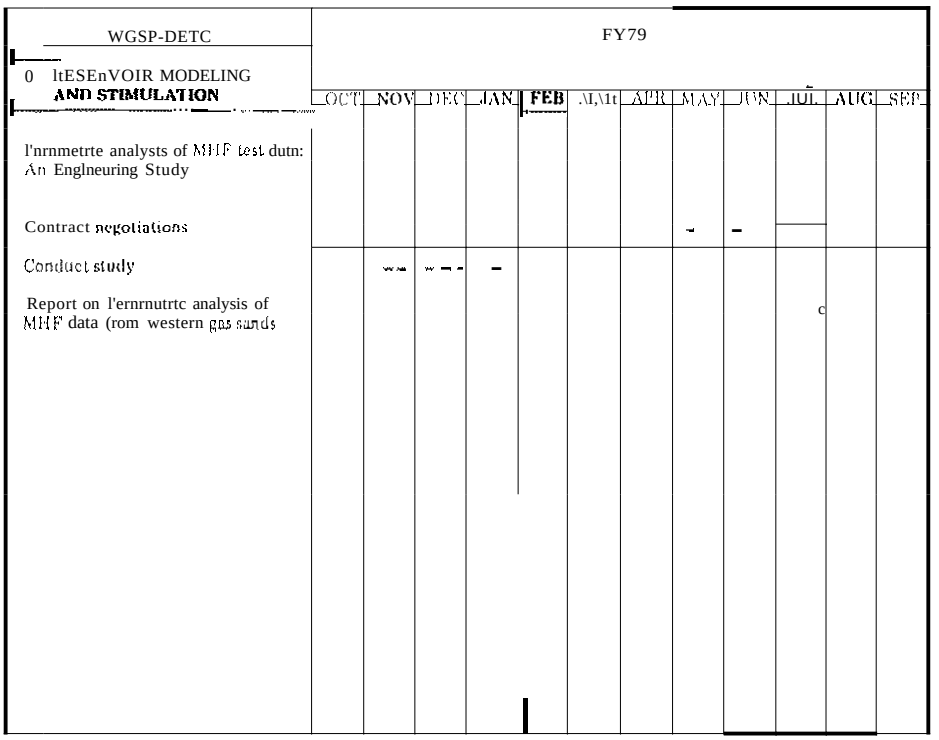


Figure 4-6 *Continued*

Recently, techniques have been proposed to remove or significantly reduce reflections from calcualted mesh boundaries.?,[3] The Dirichlet and Neumann conditions are summed incrementally at the boundaries of a finite element/finite difference mesh to eliminate reflections. This incremental approach eliminates reflections as soon as they occur. Application of the technique requires a small superposition mesh around the boundary of the regular calculational grid (Lagrangian mesh), Two complete solutions are then possible, one in the regular mesh and the other in the superposition mesh. Reflections at a boundary are then eliminated by adding to solutions incrementally in the two overlapping grids. The two overlapping grids have separate boundary conditions: fixed in the normal direction, free in the tangential direction, and free in the normal direction and fixed in the tangential direction. All variables in the two grids are then averaged every third and fourth computational cycle.

The technique significantly reduces boundary reflections and is being included in the dynamic fracture code which is being used to analyze dynamic fracture propagation near interfaces. This should decrease computer time and size requirements, and aid in interpretation of the results,

Finite element analyses of dynamic crack propagation near an interface have been expanded. In this model a crack propagates bilaterally in a material which is sandwiched between a second material, Previously, calculations were terminated when the crack reached the interface. The grid size was expanded, the crack stopped at the interface, and the calculations were continued since the dynamics of the medium was important.

Three calculations were made corresponding to the elastic values of the adjacent material: *112* = λ_2 = 10, 30, and 90 OPa, The center material (where the crack propagates) was characterized by λ_1 = *III* = 30 OPa for all three calculations. Hence, the second calculation was the isotropic homogeneous case, The elastic constants varied by less than one order of magnitude.

The primary results of the calculations are the field displacements as a function of time The displacement, perpendicular to the crack, of a point near the interface was chosen to interpret crack penetration characteristics. This displacement varied significantly as the elastic moduli of the adjacent material was changed" Changing 1'2 and λ_2 from 90 GPa to 10 GPa caused the displacement to double after the crack stopped at the interface.

4.2.2 Experimental Program

Sandblasting the interfaces increases the coefficients of friction for limestone and sandstone while the addition of water increases friction for limestone and decreased friction for sandstone. Results of the friction experiments are summarized in Figure 4-7

[2] W. Smith, A Non-Reflecting Plane Boundary for Wave Propagation Problems, J. Compo Phys, 15,492-503 (1973),

[3] P. A. Cundall, R. R. Komar, P. C. Carpenter, and J. Marti, Solution of Infinite Dynamic Problems by Finite Modeling in the Time Domain, unpublished report (1978).

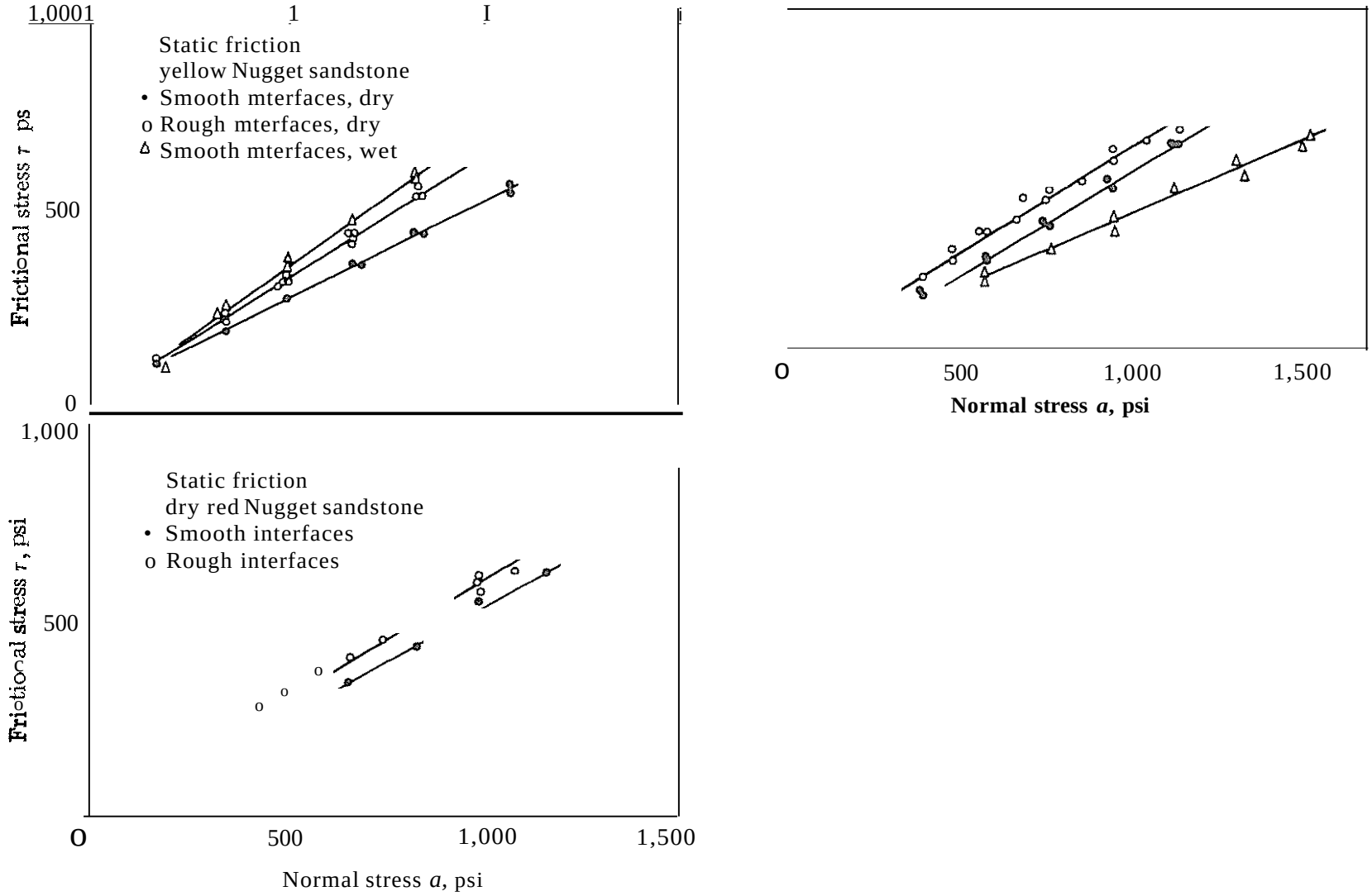


Figure 4-7 Friction Experiments for Limestone and Sandstone

It was found in Indiana limestone that saturation with water decreases the tensile strength. The decrease in tensile strength and the increase in the coefficient of friction with water saturation is consistent with the earlier observed decrease in threshold normal stress required for a crack to cross an unbonded interface in saturated limestone from the threshold value for dry limestone. Also, the decrease in the coefficient of friction between smooth surfaces of Nugget sandstone is consistent with the earlier observed increase in threshold stress for cracks to cross an interface made up of these surfaces.

These results indicate that the presence of water has different effects on crack growth across interfaces of different rock types. Water weakens the rock fabric in limestone and enhances comminution of the sliding surfaces. The presence of water in sandstone appears to lubricate the surfaces. More experiments of this type will be planned to investigate these phenomena.

4.2.3 Rock Mechanics Measurements

During June, efforts were directed toward the foliowing:

- Specimens of Colorado Mesaverde sandstone and shale were jacketed for pressure-volume study and sent to the strain gage shop for mounting of the strain gages,
- Specimens of the Wyoming Mesaverde sandstone, cored perpendicular and parallel to bedding, were prepared for the planned equation-of-state studies, and
- Fabrication of parts for the high pressure vessel, designed to measure ultrasonic velocities in six directions on one rock specimen as a function of confining pressure up to 1.0 GPa, has been completed.

4.2.4 Geology/Geophysics/Logging

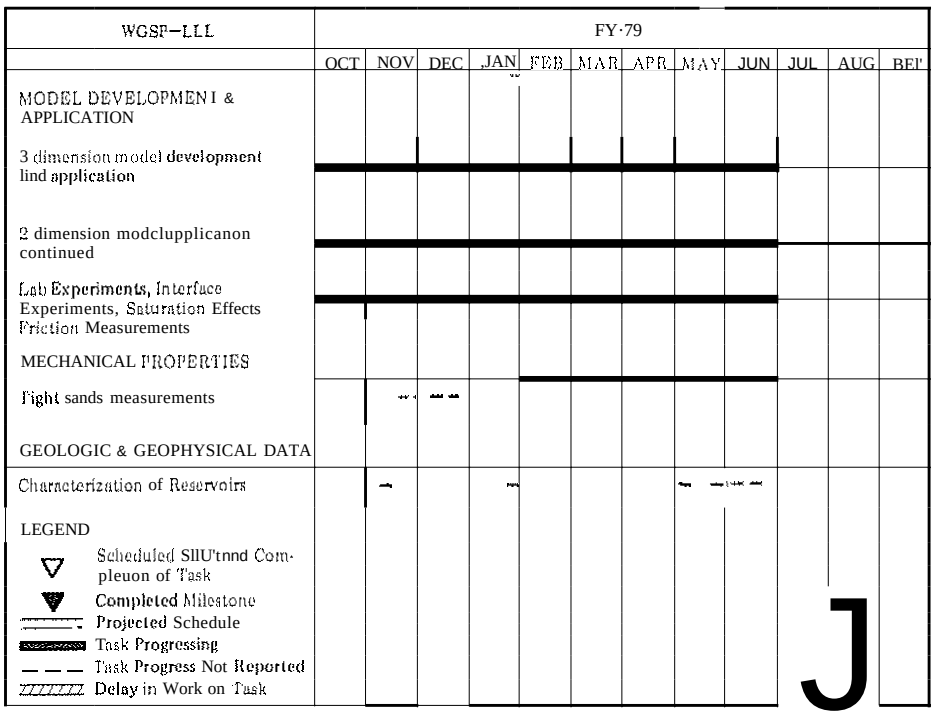
Comparison of core analysis with log cross-plots of gamma ray and density logs shows fair to good estimates of porosity in the Joseph J. C. Paine Midlands Federal No. 1 well, Bowdoin area, Montana. Analysis of neutron and acoustic logs for estimates of gas filled porosity is continuing.

4.2.5 Schedule Status

Figure 4-8 is a milestone chart depicting LLL

4.3 SANDIA LABORATORIES

4.3.1 EGR Instrumentation and Diagnostic Program



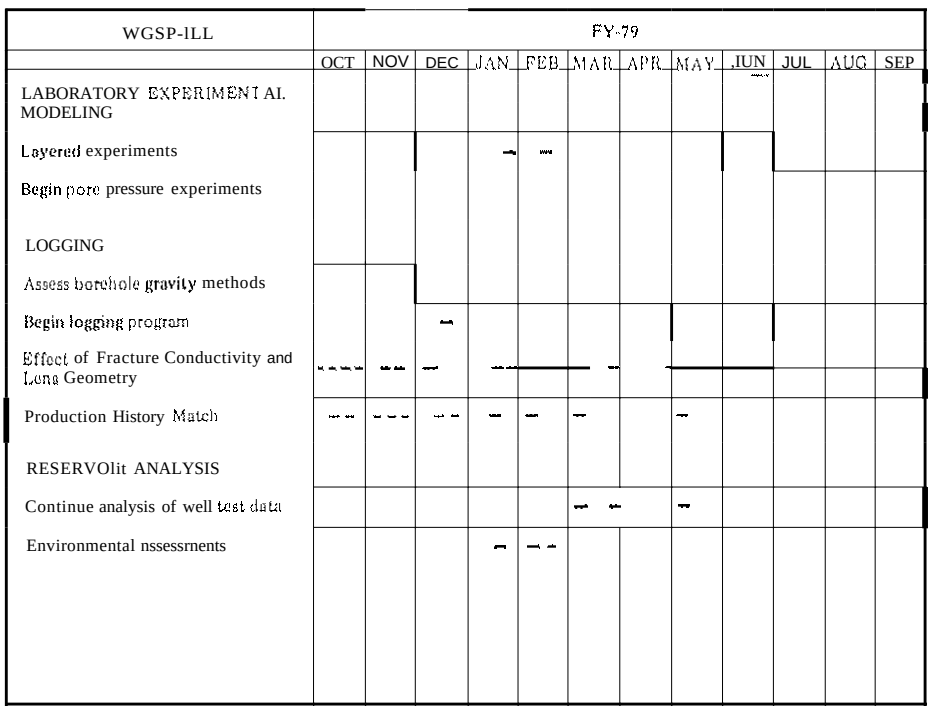


Figure 4-8 Milestone Chart - LLL

4.3.1.1 Borehole Seismic System

A seismic borehole test was attempted in an Amoco gas well near Marshall, Texas. Signals from the geophones could not he transmitted to the surface due to cable characteristics. It was then discovered that a special high temperature logging cable had been brought in which had not been previously tested. The losses were much greater with the high temperature logging cable than the standard logging cables. The borehole system has since been modified to provide greater driver capabilities and amplifiers have been added to the surface instrumentation. Cable characteristics are also being obtained from the manufacturers. Later, two cables were located in the Marshall area that were suitable and the tests are being rescheduled on another well in the same area.

4.3.1.2 Borehole Hydrophone System

The complete 30 ft hydrophone system containing the hydrophones furnished by Edo Western has undergone preliminary testing in the Sandia borehole. Water in the borehole was found approximately 140 ft from the surface. Background signals and signals from unknown sources were observed and recorded. Hammer blows on the surface were measured at 20 ft to 200 ft from the borehole and the resulting signals from the hydrophone system recorded. The signals received showed different times of arrival, in the expected order, as the induced acoustic signal traveled past the transducers. Noise in the system precluded accurate measurement in difference in time of arrival. The system was returned to the laboratory in order to determine the source of the noise and to improve the signal to noise ratio.

The six hydrophone units have been received and plans are underway for electrical and high pressure testing.

4.3.1.3 Formation Mapping

Specifications for a two-phased, three-dimensional seismic reflection program at the proposed southern Uinta Basin site has been incorporated into an extensive proposal by CER Corporation to the Gas Research Institute. This proposal is currently under review.

Drilling has begun in the corehole located at site No.1 of the proposed seismic survey. This corehole together with outcrop mapping of sand lenses will provide important input into the interpretive phase of the proposed seismic survey.

4.3.2 Schedule Status

Figure 4-9 is a milestone chart depicting Sandia's WGSP activities.

4.4 GAS RESEARCH INSTITUTE ACTIVITIES

Work on a project plan is continuing with projects now at a proposal stage.

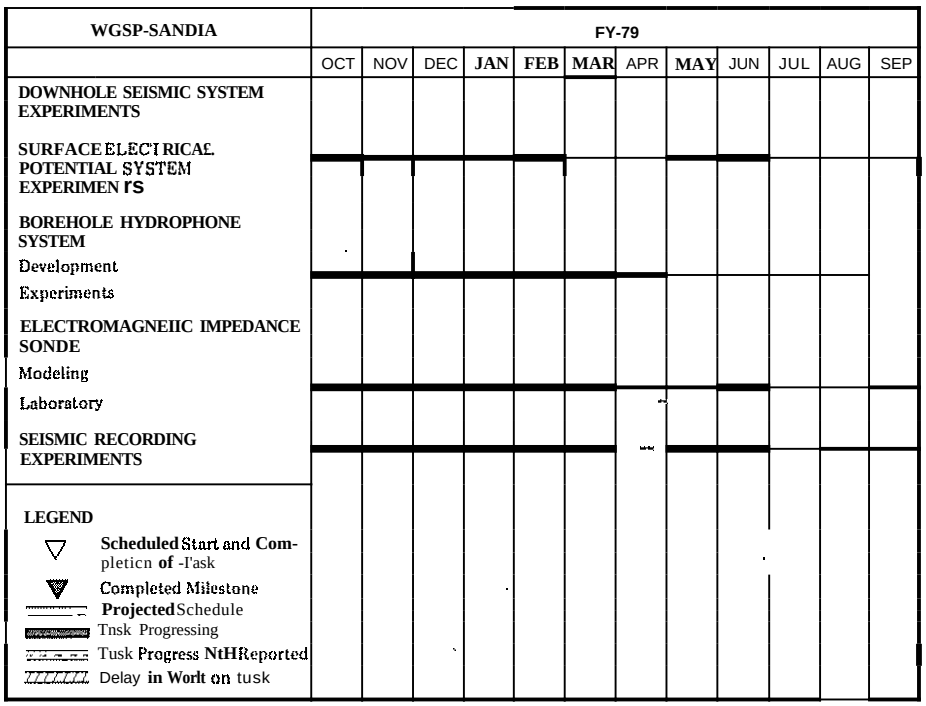


Figure 4-9 Proposed Test Wells Nos. 341 and 343 Lahe Texhoma, Texas

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.

The CER Corporation RB-MHF 3 is on an inactive status pending satisfactory contractual arrangements to perform additional tests, and for final disposition of the well. The RB-MHF 3 Final Report has been issued in a three volume set. A set may be ordered from NTIS, U.S. Department of Commerce, Springfield, Virginia, 22161.

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 Locations and Frac Data

COMPANY, BASIN & FORMATION	LOCATION T/R/Sec	WELL	INTERVAL FRACTURED ft	FRAC DATE	FRAC TREATMENT Lb of Sand	INJEC-I'ED FLUID 10^1 Gal
AUSTrIAl Piceance, Mesaverde	7S/94W Sec 3 Garfield e/Y Colorado	Federal 3·94	5 170- 6,333	8-25-76	1,140,000	642 Gel Gel H 0
CONSORTIUM MANAGEO BY csn CORI'OltATION Piceance, Mesaverde	;IS/D6W. Sec 11 Rio DIlInco CO Colorado	RB-MHF-3	8,048- 8 078 7,760 7,86.\ 5,925- 6,016 5,851- > 869	10-23-74 5- 2-75 5- 4-76 11·· 3,·76	400000 880,000 are 000 448,000	1170cl 285 Gel 400 Gel 228 Gel
GAS PRODUCING ENTERPRISES INC Uinta, Wasatch and Mesaverde	10S/22E/Sec 10 Uintah ely UtAh	Natural Buttes No re	6,490- B 952	9-22-76	1,480,000	745 Gel
	10S/21E/Sec 21 Uintah ely Utah	Natural Buttes No iu	8,909- 9 064 7224- 6676	9-21-76 9'28-76	424,000 784,000	280 Gel 304 Gel
	0S/21E/Sec 22 Uintah Cty Utah	Natural Buttes No 14	6,046- 8,004	3-15-77	1,093,000	544 Gel
	9S/21E/Sec 28 Uintah Cty Utah	Natural Buttes No ao	8 498- 9 476	6-22-77	826 000	322 Gel
	10S/22E/Sec 18 Uintah Cty Utah	Natural Buttes No 22	6 858- 8 550	11-21-77	1,0ll1 000	479 Gel
	9S/21E/Sec 10 Uintah CIY Utah	Natural Buttes No o	5 061 8,934	3-27-76	504,000	349 oet
	10S/21E/Sec 29 Uintah Cty Utah	Natural Buttes No 2	7 251 8,774	8- 8-78	1,965 (01)	722 uer
	10S/22E/Sec 7 Ulntn,h Cty Utah	Natural Buttes No 23	5,080- 6 204	10- 4-78	440 000	240 cet
DALLAS PnOOI/CIION Fort Worth Bend Cong	Ben D. Smith Survey A·779 Wise CIY Texas	Ferguson A·1	5 957- 6,794	9-10-76	506.000	139 Foam 198 Ernul
EL rA50 NATL GAS Northern Green River Fort Unlnn	30N/108W/Sec 5 Sublette Cty Wyoming	Pinedale Unit No s	10 950-11 tal) 10 120-10 790	7 2-75 10-20-75	516,000 1,422,000	103 Emul ll Gel 459 Gel
MITCHELL ENERGY Cotlon Valley Limestone Trend	Limestone Cty Texas	Muse-Duke No 1	11,220-11,430	11-15-78	2.600,000	691 Gel
moan. Piceance, Mesaverde	2S/97W/Sec 13 Rio Blanco Cty Colorado	F31-13G	10 049-10,080 9 aez- 9 538 8 765- 8,972 8,163- 8,660 7,704- 7 794 7,J2·1 7,476	6-22-77 8-24-77 5-10-78 7- 6-78 u- 778 u.rs-ve	580,,000 600 000 388000 660,000 218,000 700, 000	316 Gel 260 Gel 150 Gel 288 Gel 120 oer 365 Gel
PACJFIC TRANSMISSION Uinta Mesaverde	8S/23E/Sec 25 Uintah Cty Utah	Federal 23,·25	NO FRACS PERFORMED			
nrc lILANCO N,\II GAS Piceance, Mesaverde	4S/98W/Sec j Rio Blanco CO ccrcreae	Federal 498-4·1	6 150- 6 312 5,376- 5 960	10-22-76 11-30-77	766 000 243,000+ 22,.500 Beads	276 Gel 164 Gel
WESTCO Uinta, Mesaverde	10S/19E/Sec 34 Uintah Cty Utah	Home Fed No 1	7,826" 9,437 10,014-10,202	12-21»76 10- 1·,76	f100.000 600,000	412 Gel 248 Gel

RIO BLANCO MASSIVE HYDRAULIC FRACTURING EXPERIMENT

EY-76-C-OS-0623

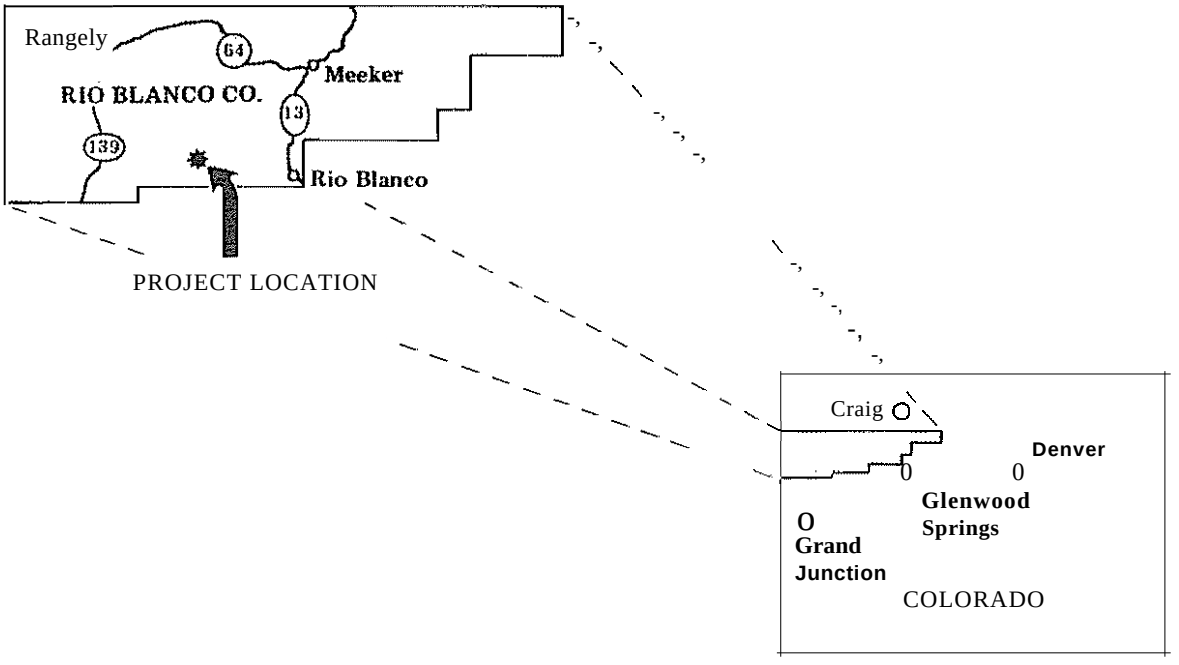
CER Corporation
Las Vegas, Nevada

Status: Awaiting Advisory Committee Decision

Interagency Agreement Date:	June 19, 1974	
Anticipated Completion Date:	July I, 1979	
Project Cost (estimated):	DOE.	$1,990,000
	Industry	1,630,000
	Total.	$3,620,000
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 EY-76-C-08-0623 was awarded to CER Corporation in March, 1974. The original contract provided for the drilling of a new well and two MHF treatments. Contract modifications added two additional MHF treatments and extended the term of the contract.

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

A comprehensive 3 volume final report has been released.

WATTENBERG FIELD EY·77·C·Og·1514

Colorado Interstate Gas Company
Colorado Springs, Colorado

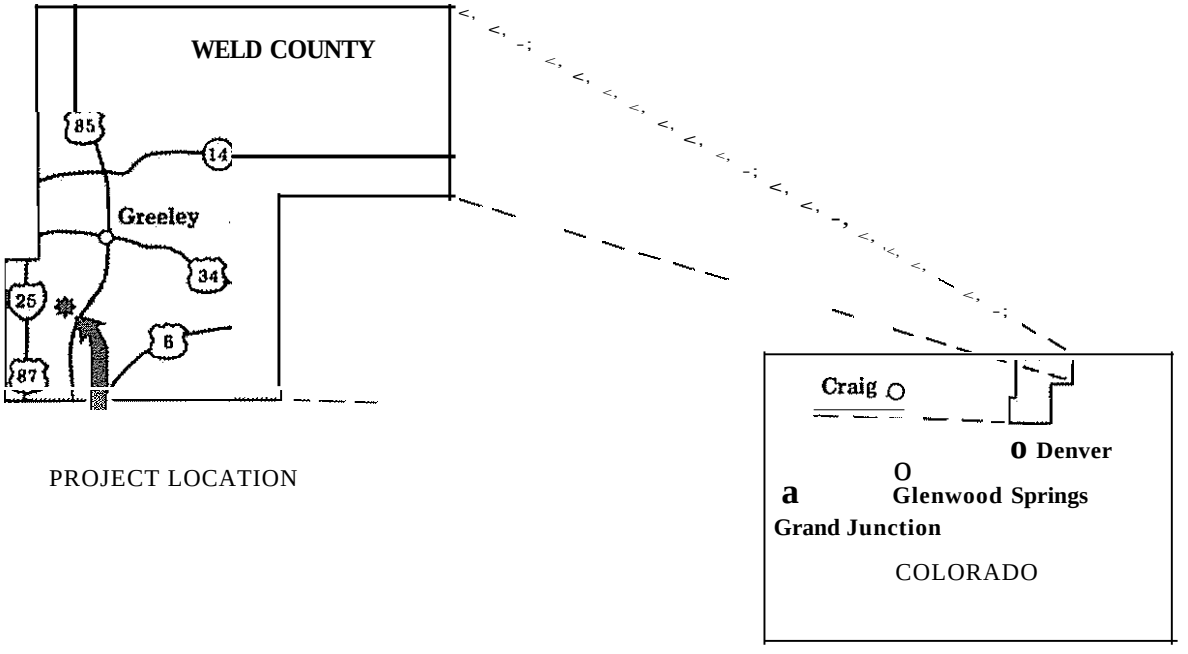
Status: Active

Contract Date:	September 1, 1977	
Anticipated Completion Date:	March 1, 1981	
Total Project Cost (estimated):	DOE	. $ 75,000
	CIG	99,000
	Total	. $174,000

Principal Investigator: Howard Fredrickson
Technical Project Officer for DOE: C. H. Atkinson

OBJECTIVE

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



PROJECT LOCATION

5.3 COLORADO INTERSTATE GAS

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

Cyclic gas injection began again on June 7. The Sprague No. 1 well produced for approximately 24 hours, at which time the compressor shut down due to lack of pressure. The regulators which were installed did not allow a sufficient volume of gas to pass through the compressor at pressures under ISO lbs, While the Sprague No. 1 well was shut down, the pressure built up so that it was possible to restart the compressor and run it another day. Operations will continue until a bypass can be constructed and regulators and controllers can be obtained to divert the gas through the bypass when wellhead pressures are 200 lb or less. To date, approximately 16,790 MCF of gas has been produced from the Sprague No.1 well. Initial wellhead pressures were 1,000 lb at the Miller No.1 well and S50 lb at the Sprague No.1 well. Wellhead pressures as of June 20, 1979, were 1,3751b at the Miller No. 1 well and SO lb at the Sprague No. 1 well.

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

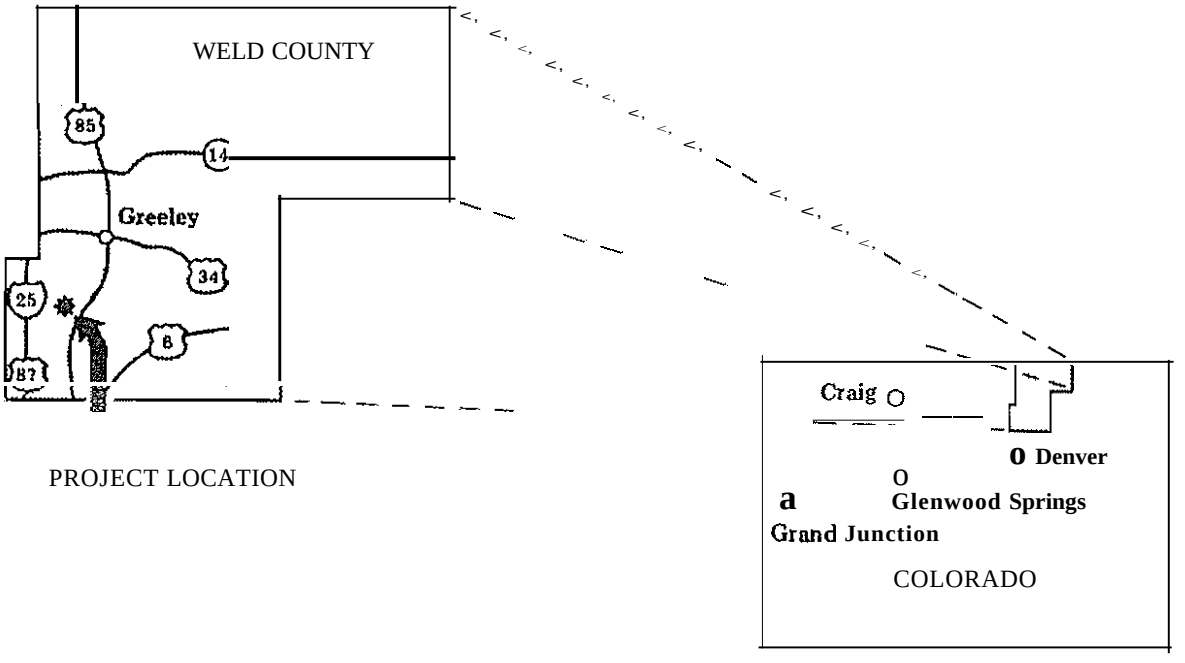
CER Corporation
Las Vegas, Nevada

Status: Equipment checkout and test proceeding

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

OBJECTIVE

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



PROJECT LOCATION

5.4 DOE WELL TEST FACILITY

The DOE Well Test Facility was transported to Basin Machine in Vernal, Utah for minor repairs and storage. Work continued on several computer programs. The "Flow" program used to calculate flow rates through a meter run was modified to he more efficient and versatile, particularly in view of the large volume of data acquired during clrawdown periods. The "Caldat" program was modified to allow more efficient data manipulation and selection.

The G.O. downhole multiplexing temperature tool was tested in a temperature chamber for 2 weeks at temperatures ranging from 210°F to 285°F. The tool appeared to operate successfully but showed severe discoloration and warping of most of the electronic components.

The LLL H.P. pressure-temperature system was shipped to CER Corporation for a 1 year loan. This system will augment the downhole measurement capability as well as provide backup for portions of the facility's present system.

Preparations are continuing for the anticipated utilization of the facility at the proposed fracture treatment of the Rio Blanco Natural Gas Company well 397-19-1. Present plans require the facility to be on site in Rio Blanco County during the second week of July with pre-frac testing commencing during that week.

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

EY·76·C·08·0681

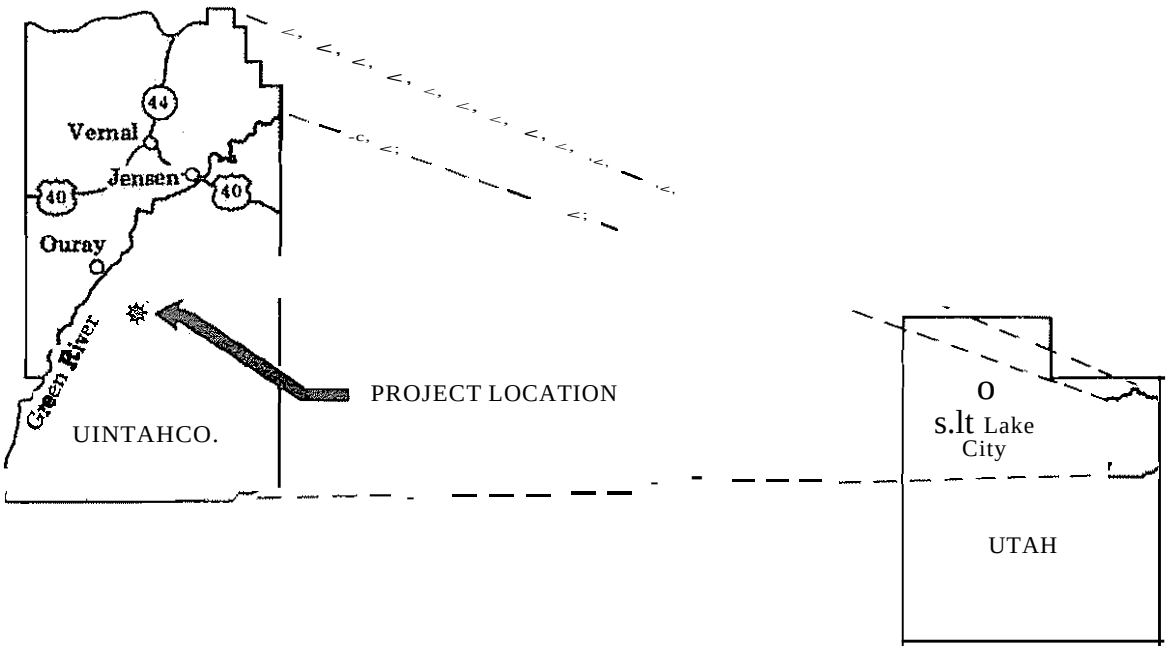
Gas Producing Enterprises, Inc.
Subsidiary of Coastal States Gas Co.
Houston, Texas

Status: Active

Contract Date:	July 1, 1976	
Anticipated Completion:	September 30, 1979	
Total Project Cost (estimated):	DOE	$2,827,000
	Industry (prior costs)	1,881,000
	Industry (new costs)	3,051,000
	Total	$7,759,000
Principal Investigator:	W. E. Spencer	
Technical Project Officer for DOE:	C. H. Atkinson	

OBJECTIVE

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



5.5 GAS PRODUCING ENTERPRISES

The GPE wells, Natural Buttes Units 9, 14 and 18 flowed to sales during June. Natural Buttes Units 19, 20, 21 and 22 were shut-in. Figures 5-1 through 5-6 show production figures.

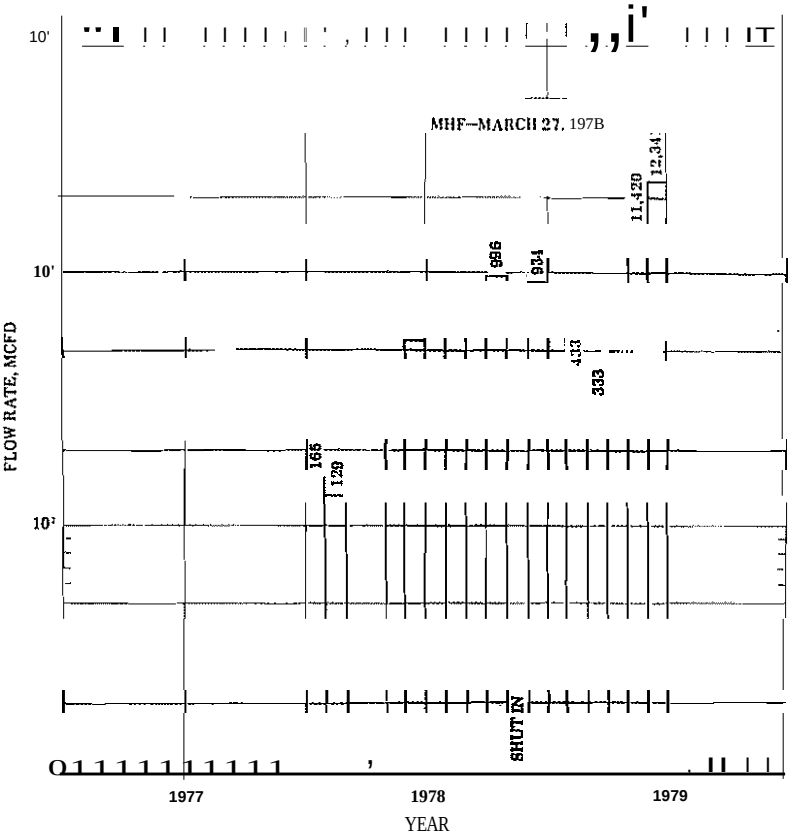


Figure 5-1
Flow Rate Performance of Natural Buttes NO.9 Well

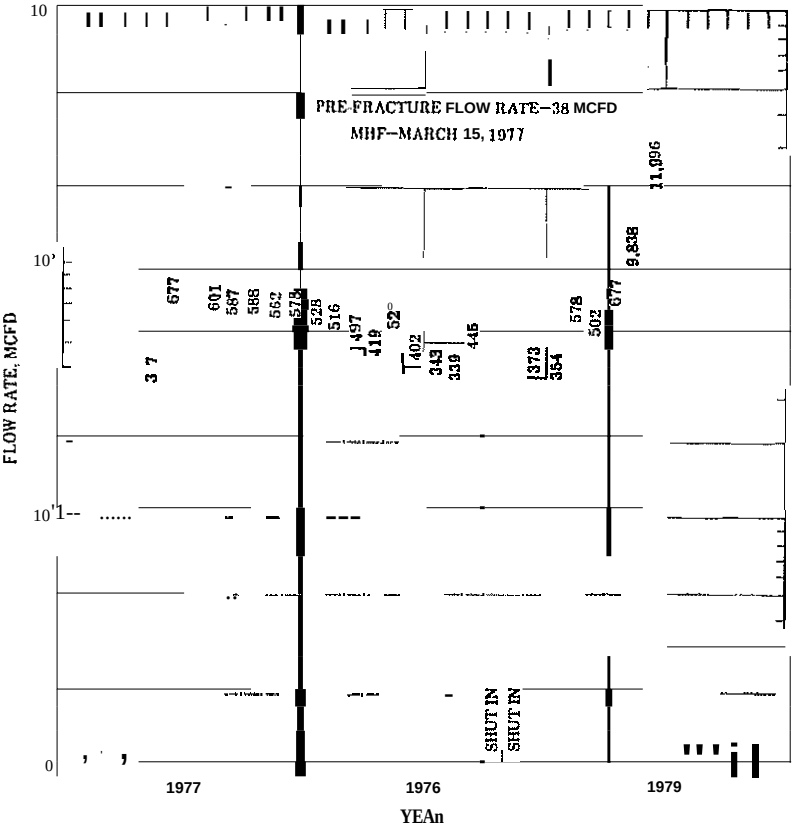


Figure 5-2
Flow Rate Performance of Natural Buttes No 14 Well

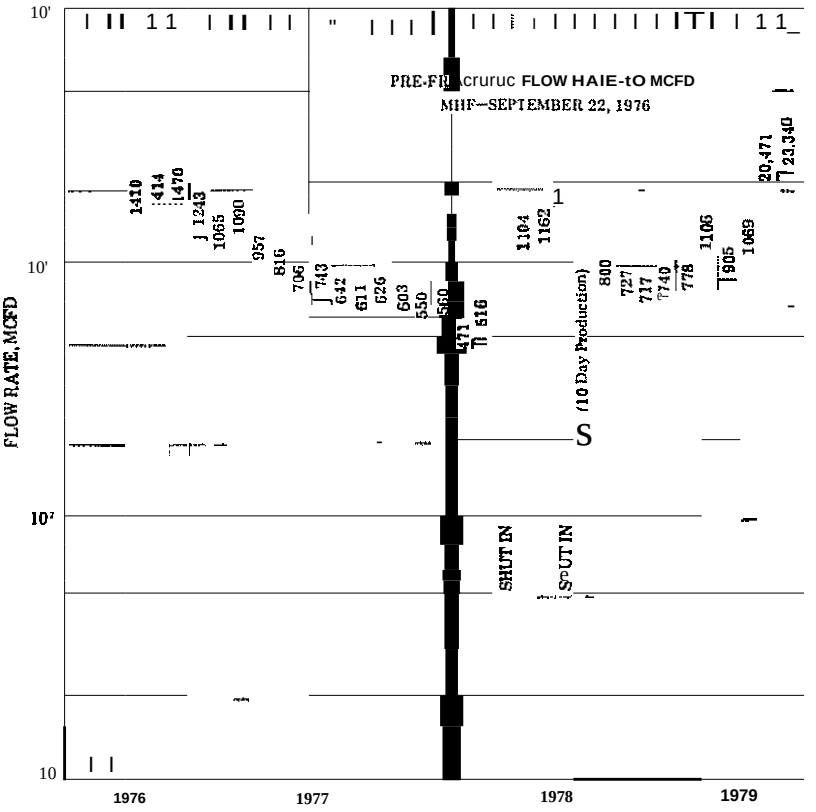


Figure 5·3
Flow Rate Performance of Natural Buttes No. 18 Well

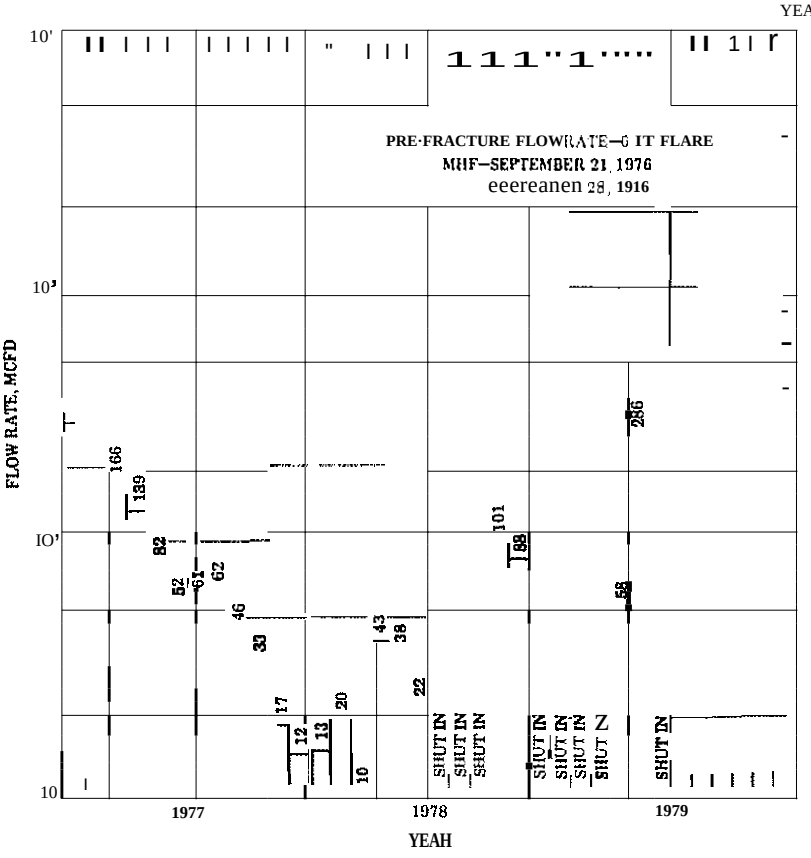


Figure 5-4
Flow Rate Performance of Natural Buttes No. 19 Well

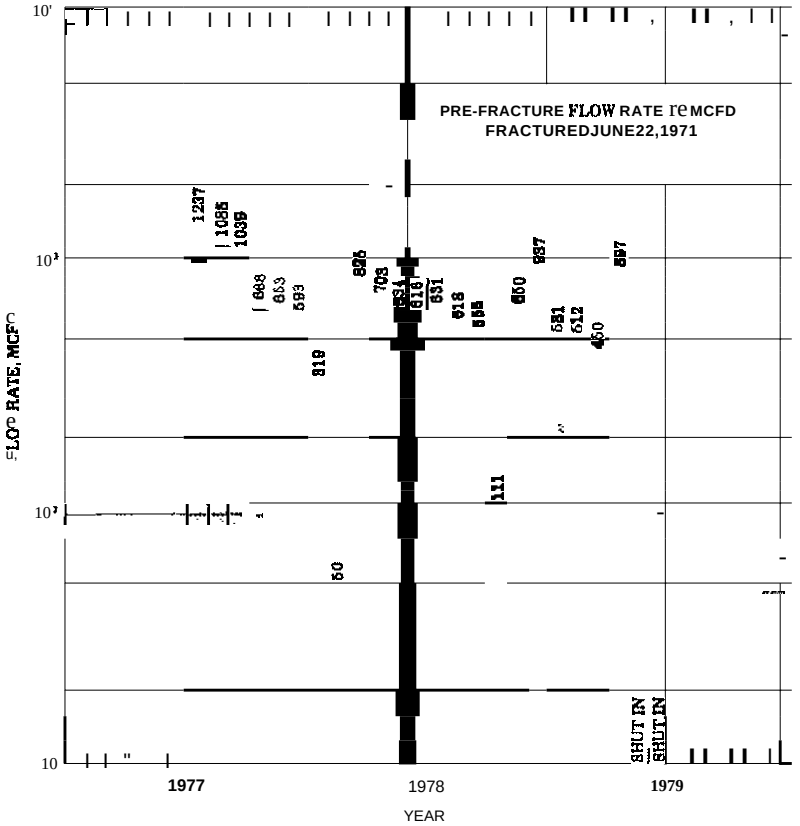


Figure 5-5
Flow Rate Performance of Natural Buttes No. 20 Well

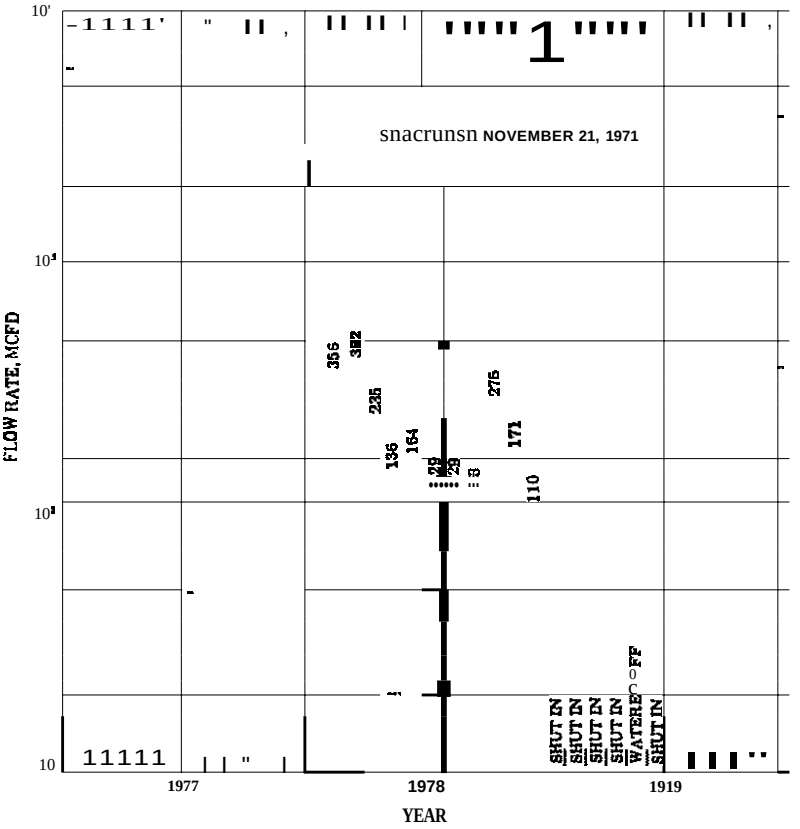


Figure 5-6
Flow Rate Performance of Natural Buttes No. 22 Well

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

EF-7S-C·OS-I547

Mitchell Energy Corporation
Houston, Texas

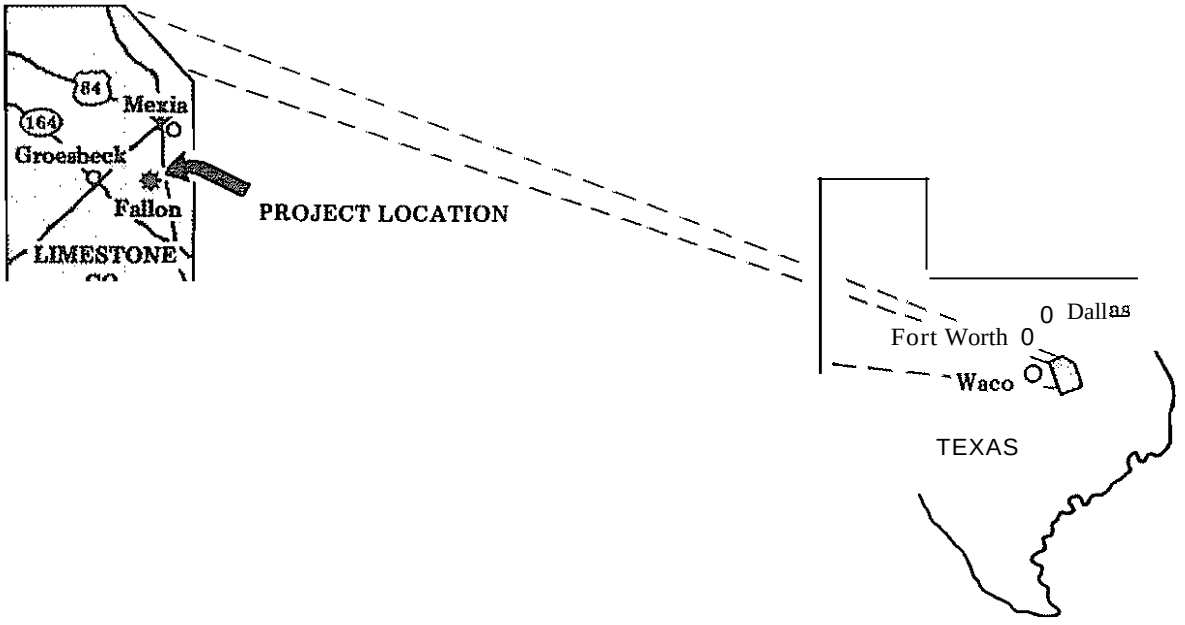
Status: Active

Contract Date:	March 15, 1978	
Anticipated Completion:	April 3D, 1979	
Total Project Cost (estimated):	DOE	$ 553,771
	Industry	1,074,550
	Total	$1,628,321

Principal Investigator: F. D. Covey
Technical Project Officer for DOE: C. H. Atkinson

OBJECTIVE

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



5.6 MITCHELL ENERGY CORPORATION

The Mitchell Energy Corporation Muse-Duke No.1 was flowing 3,000 MCFD and 15 BBL of water per day through a 24/64 in. choke with a flowing tubing pressure of 1,000 psig as of June 30.

The post pressure transient tests are scheduled to begin July 17 and should be completed by the end of the month. Final analysis of the project should be completed by August 3L

PICEANCE CREEK FIELD, COLORADO, MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

EY-76-C-08-0678

Mobil Research and Development Corporation
Dallas, Texas

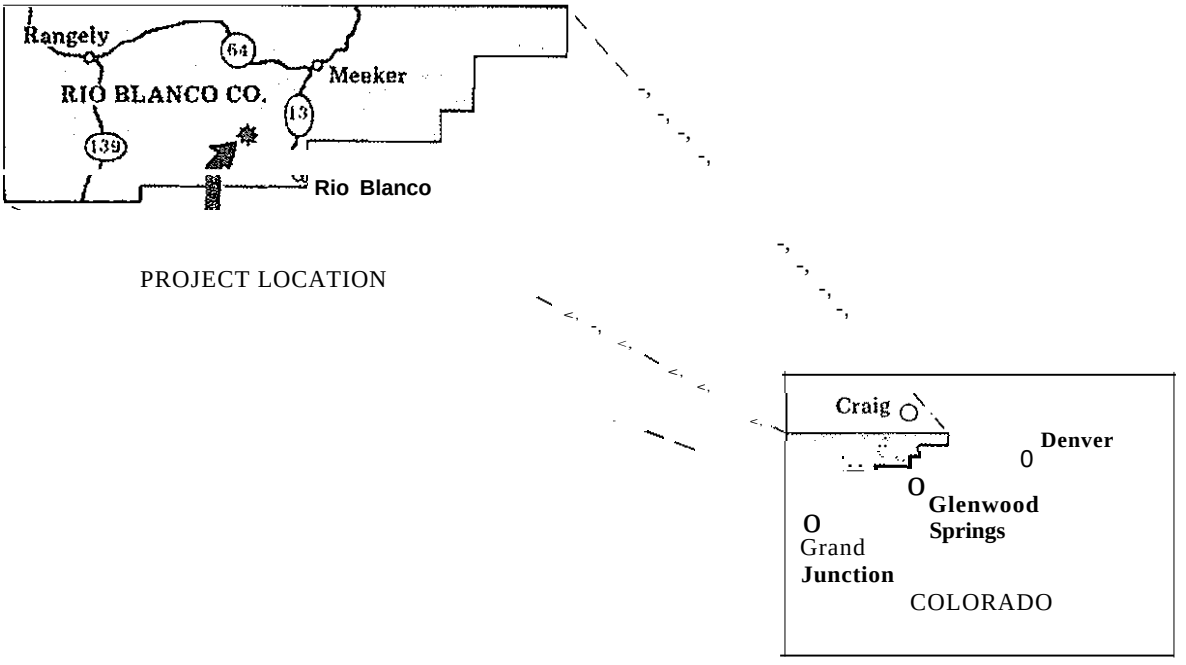
Status: Active

Contract Date:	July 1, 1976	
Anticipated Completion:	June 1st 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.



PROJECT LOCATION

5.7 MOBIL RESEARCH AND DEVELOPMENT CORPORATION

During June 1-4, the skirt on the overshot at about 8,812 ft was cut off using a cutter shoe on wash pipe and the fish was washed-over to the mill at about 8,827 ft. On June 5 the upper 47 ft of fish was recovered leaving parts of the overshot in the hole. This junk was milled up and the fish was washed over during June 5-10. On June 11 the bottom fish was recovered. The remaining sand and junk was milled-up and washed-out down to the retrievable bridge plug at 9,040 ft. An overshot was run to retrieve the plug on June 13. This apparently opened the pressure equalizer valve and allowed the well to flow from below the plug. Attempts to kill the well with 2 percent KCI water failed. As of June 14 the well was blowing strongly to the pit. Before attempting to pull the plug the well will be allowed to flow until the pressure declines enough to permit an easy kill.

RIO BLANCO COUNTY, COLORADO MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

EY·76·C·08·0677

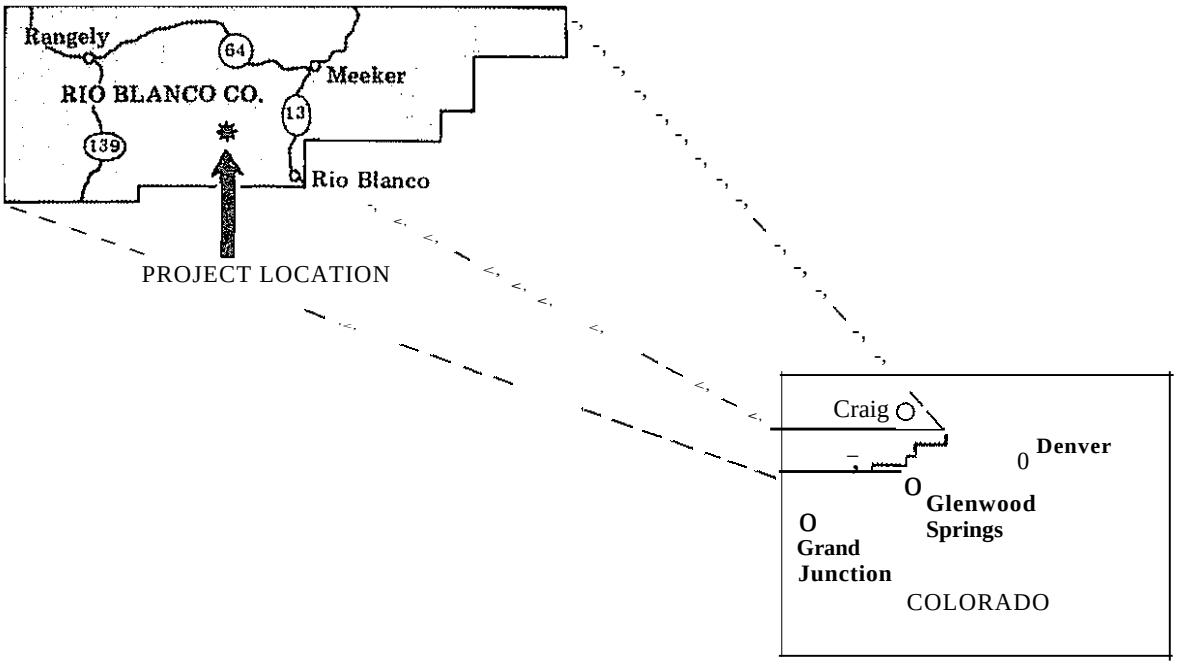
Rio Blanco Natural Gas Company
Denver, Colorado

Status: Active

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

OBJECTIVE

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



5.8 **RIO BLANCO** NATURAL GAS **COMPANY**

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

The final report is in preparation.

NEVADA TEST SITE
NYECOUNTY,NEVADA
MINEBACK TESTING

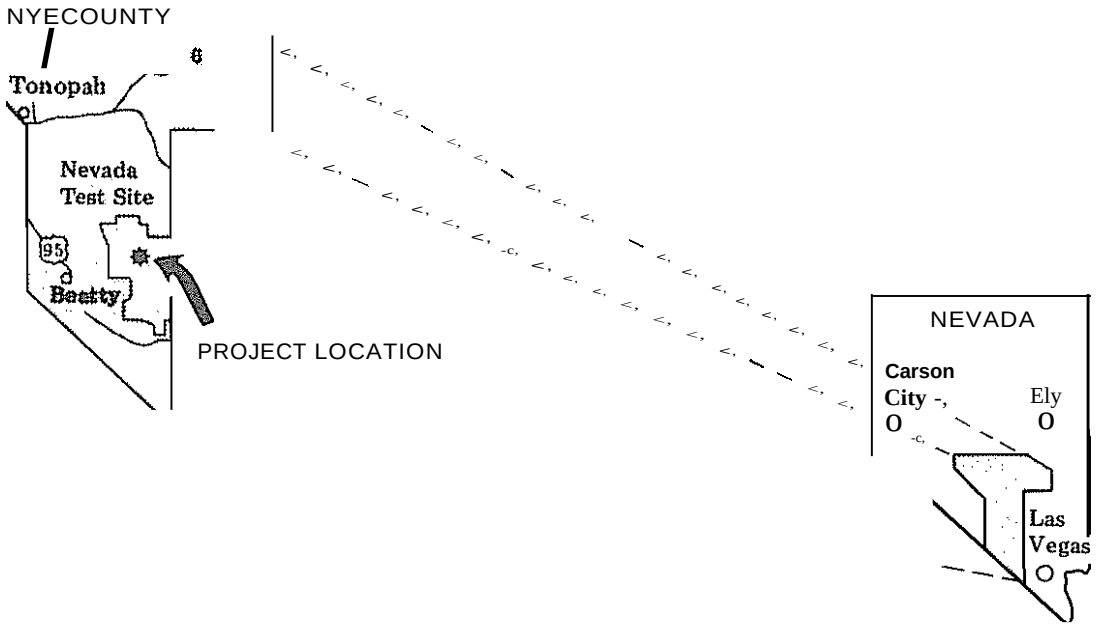
Sandia Laboratories
Albuquerque, New Mexico

Status: Active

Principal Investigator: D. A Northrop

OBJECTIVE

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



5.9 SANDIA LABORATORIES MINEBACK

5.9.1 Summary of Past Activities

The exploratory coring program to determine the overall shape of the Hole NO.6 fractures continued and the second hole of the Interface Test Series (CFE-2) was fractured in four zones in May.

5.9.2 Hydraulic Fracturing Containment Experiments

5.9.2.1 Formation Interface Fracture Experiment (Hole No.6)

Exploratory coring of the Hole No.6 Formation Interface fractures continued in June. Corehole EV6-24, which should have intersected the fractures about 190 ft below the interface, failed to detect any evidence of a fracture at that depth. The location where the fracture plane should have been intersected is shown in Figure 5-7. This places a lower bound on the fracture system. Coring will continue in July.

5.9.22 Interface Test Series

Mineback of the fractures created in the second hole (CFE-2) of the Interface Test Series was initiated in June. Two of the zones (35 ft and 70 ft) were fractured at 4 gpm and two zones (20 ft and 50 ft) at 2 gpm to test the effect of flow rate on the containment of a hydraulic fracture at a material property interface. Mineback of the first two zones (20 ft and 35 ft) showed that the created fractures were extremely small (4 ft x 8 ft) and did not reach the interface; this was typical of the size of a fracture created with about 2 gal of fluid rather than the 50 gal that were pumped.

Operational difficulties, such as failure of the back packer to pressurize, or other mechanical problems, were suspected and, therefore, two additional fractures at 61 ft and 83 ft were created. In one of the zones (83 ft in the original hole as shown in Figure 5-8),150 gal of blue dyed water was injected at 4 gpm. In the second zone (61 ft in the original hole) 50 gal of blue dyed water was injected at 8 gprn,

Table 5-2 CFE-2 Fracturing Data

Zone	Flow		Breakdown			Recycle			Full Pump		
(ft)	Q (gpm)	Pc (psi)	P_f (psi)	P_{isi} (psi)	VoL (gal)	P_f (psi)	P_{isi} (psi)	VoL (gal)	P_f (psi)	P_{isi} (psi)	VoL (gal)
70	4		1,010	930	7.9	1,120	1,050	5.8	1,120	1,050	36.3
50	2		1,200	1,160	9.7	1,150		3.1	1,275		37.2
35	4		1,060	855	7.6	1,000	840	3.9	980	870	38.5
20	2		700	575	68	640	580	2.5	840	810	40.7
83	4		1,000	740	8.1	900	720	5.1	750	700	137.0
61	8		1,070	950	8.4	1,070	970	7.6	1,100	1,025	36.0

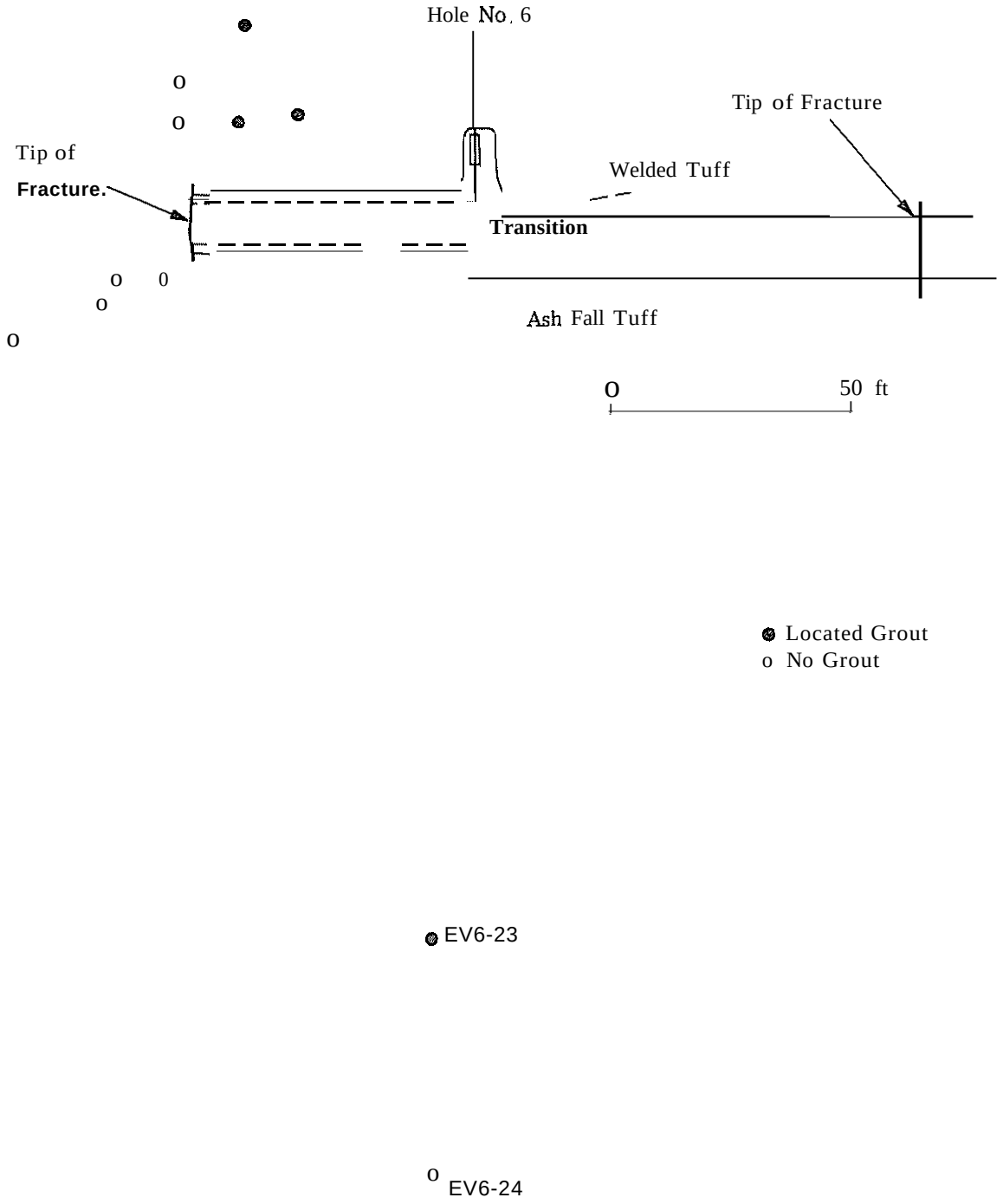


Figure 5-7 Results of Exploratory Coring for the Hole No. 6 Formation Interface Experiment

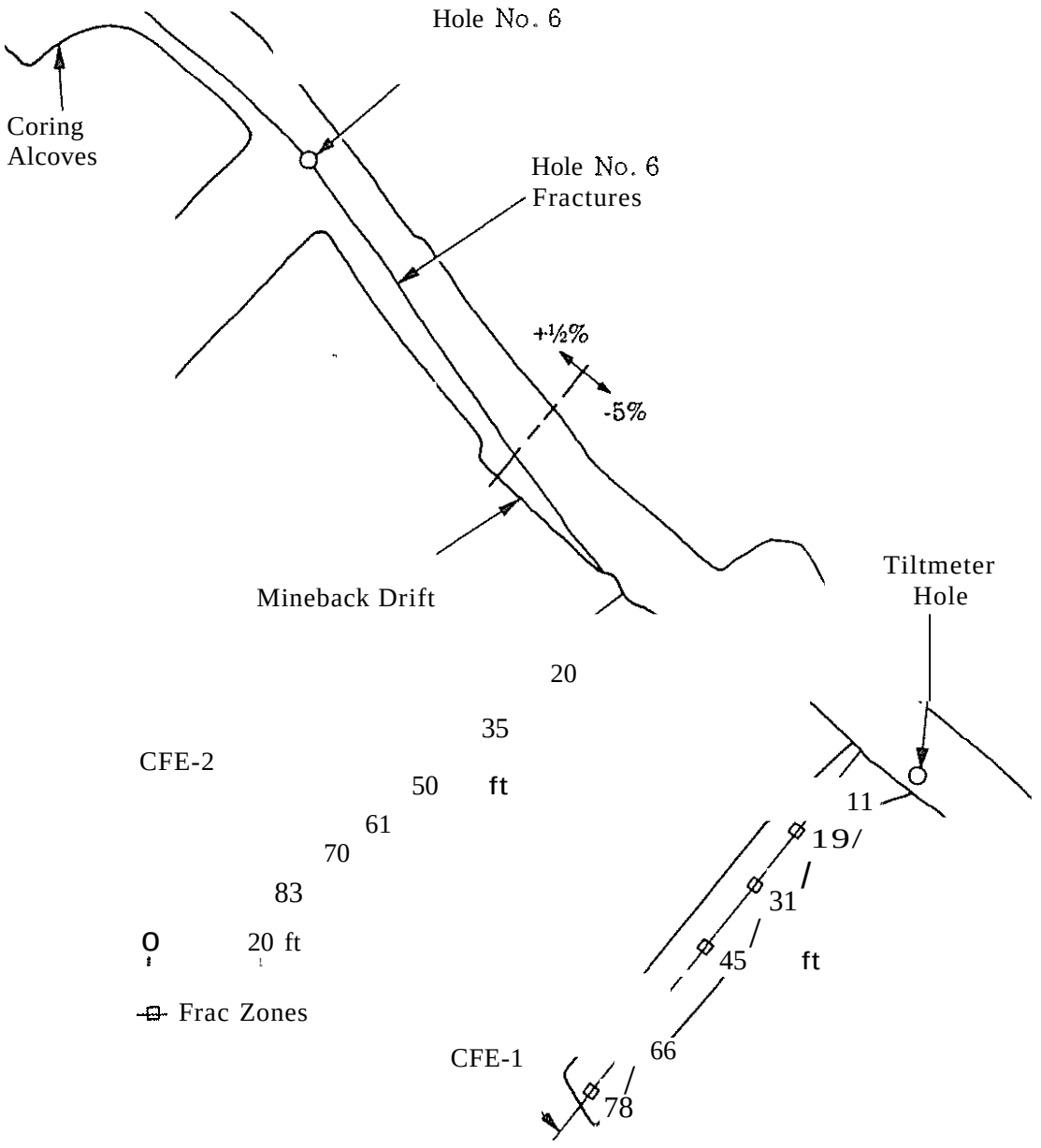


Figure 5-8 *Interface Test Series Experiment Locations*

The pressure data from all six fractures conducted in CFE-2 are listed in Table 5-2. The core obtained from CFE-2 showed very little fracturing, yet no breakdown peaks were observed. The fracturing pressures in this region were nearly twice that of CFE-1 which was only 40 ft away. Mineback of the final four zones will occur in July.

This region apparently has unusually large in situ stress variations which may be due to the effect of the overlaying welded tuff. There is some indication that a significant portion of the stress variation is due to a large vertical stress gradient just below the interface. The gradient is so steep that the fractures in CFE-1 broke up through the interface (elastic modulus about 5 times greater) rather than propagate against the gradient.

Mineback has been completed on three 8 lb explosive experiments which were fired in April, This work uncovered unexpected detail, For example, dye thought to be pumped, post event, into the RS8 cavity actually entered the formation through a break in the pipe about 0.5 m from the cavity. Mineback data on these events is being reduced.

Data from the January 1,000 Ib H.E. event has been compiled and a report is being written. Active gages in this experiment recorded peak dynamic and residual stresses. Three kinds of gages measured a residual stress of 0.2 to 0.25 kilobars, four meters from the charge center. Also, post-event pressurization work showed direct evidence of the residual field.

5.9.3 Modeling and Analysis

Evidence from various mineback experiments performed at NTS indicates that the minimum principal in situ stress is the dominant parameter which dictates the geometry of a hydraulic fracture. It has been widely accepted that a hydraulic fracture generally orients itself perpendicular to the least principal stress, but the direction of fracture growth, including the question of fracture containment at an interface, is primarily governed by the spatial variation in the least principal stress. Other parameters such as material properties, pump rate, and fluid viscosity may at times play an important role in fracture growth, especially when the variation in the least principal stress is slight. However, these stress variations appear to be typically large enough to dominate the resulting behavior. The supporting evidence for these claims is now being assembled for a report.

A technique for the convergence of the system of equations governing the fluid mechanics of hydraulic fracturing has been obtained. This technique simultaneously solves the complete width equation (determines the width distribution for a given pressure distribution), the continuity equation and the momentum equation by iterating on the pressure distribution in the fracture and the fracture length at each time step. Efforts will now be initiated to debug the program, determine convergence characteristics, and check the results.

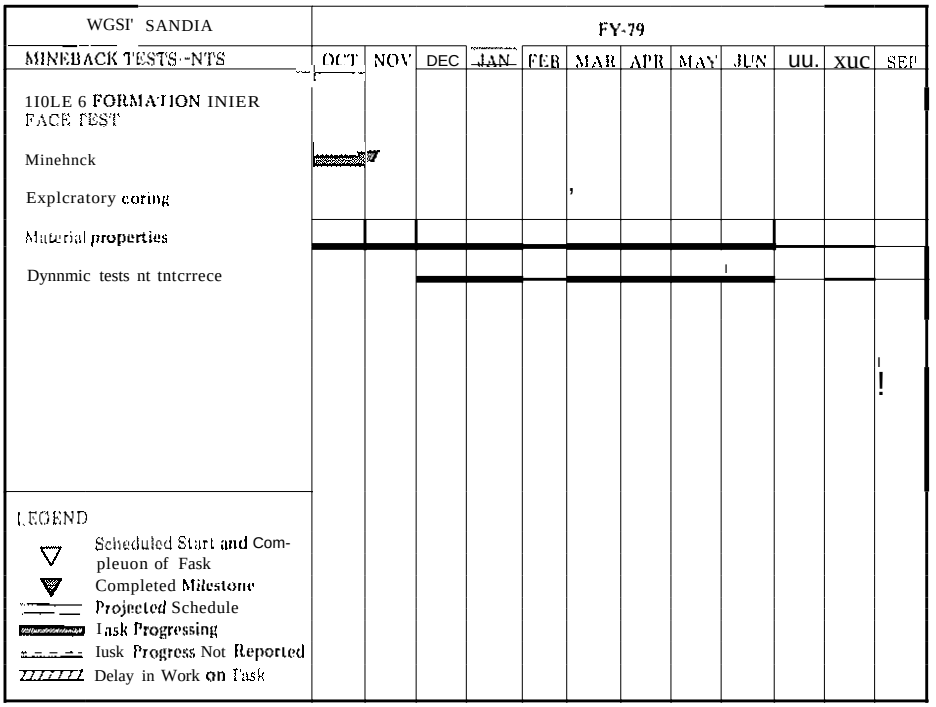
5.9.4 Multi-Well Experiment

A Multi-Well Experiment has been conceived as part of the Western Gas Sands Project. Its objectives are to obtain a comprehensive geologic characterization of a lenticular, low permeability reservoir in the western United States, and to apply and evaluate state-of-the-art and developing technology for the recovery of natural gas from these reservoirs. Sandia Laboratories and CER Corporation will technically direct the experiment under the auspices of C. H. Atkinson, Manager for the Western Gas Sands Project. An industry group will aid in the overall technical guidance of the experiment. Six tasks have been formulated: analysis and evaluation, laboratory testing, field drilling program, stimulation program, production testing, and field diagnostics. This is a research-oriented project and will be conducted to obtain the maximum amount of technical information. Present plans call for drilling of the first well in 1979, a second, offset well in 1980, and conducting a 3-4 year stimulation program in 1981-1984.

An initial statement of work was prepared during June and approval of the concept was obtained at the Unconventional Gas Recovery Project Review meeting in Morgantown, West Virginia on June 12-14, 1979. Procedures for funding have been initiated. The first meeting of the industry advisory group has been scheduled for July 19, 1979 in Dallas, Texas; site selection and detailed task definition are on the agenda.

5.9.5 Schedule Status

Figure 5-9 is a milestone chart depicting Sandia mine back progress.



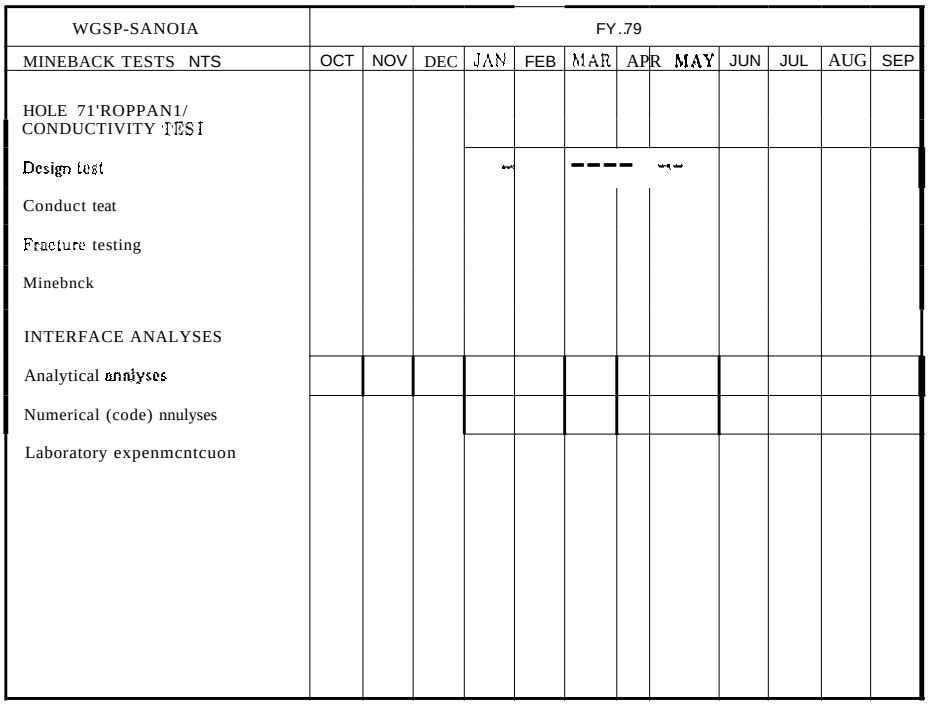


Figure 5-9 Milestone Chart -Sandia Mine back