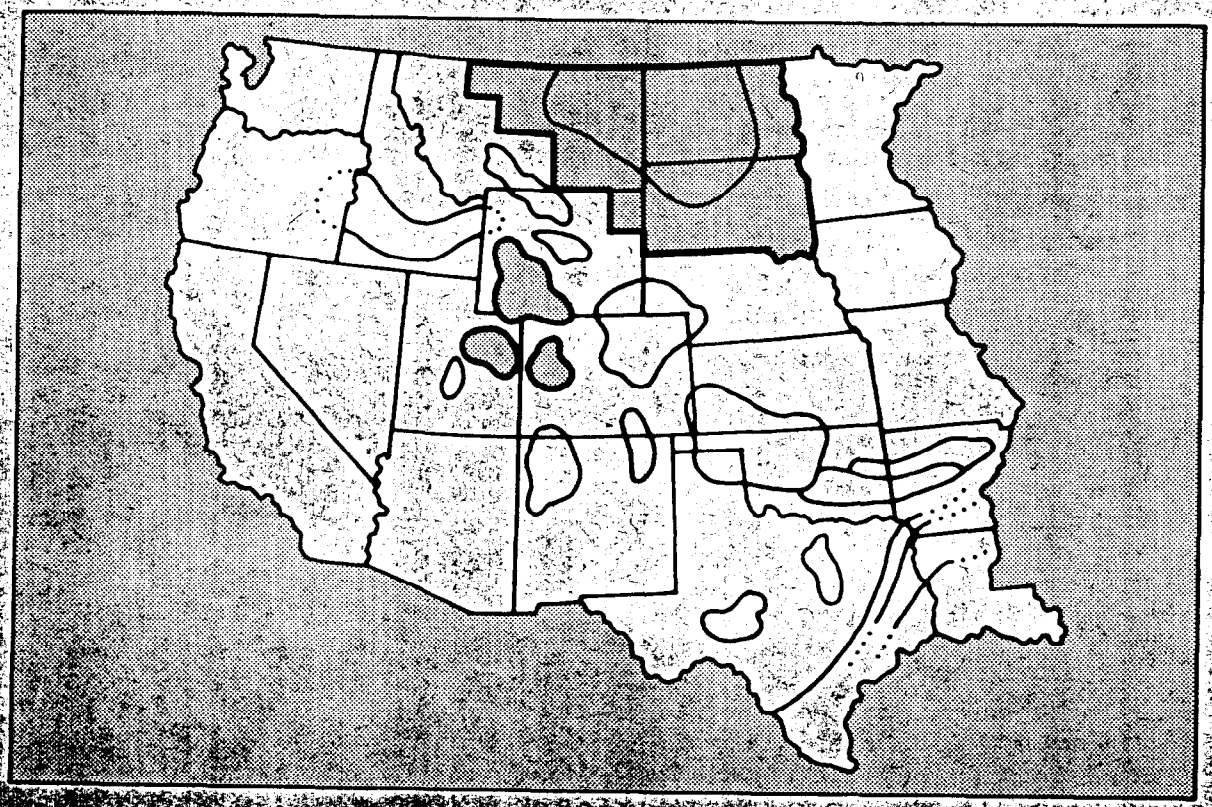
DOE/BG/01569-8

Western Gas Sands Project Status Report



1 May 1979 - 31 May 1979

Prepared for
U.S. Department of Energy

Bartlesville Energy Technology Center
Charles H. Atkinson
Project Manager

Compiled by CER Corporation
Las Vegas, Nevada

Contract DE-AC08-79 BG01569

JGR FILE #02/16/79

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

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

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

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

CONTENTS

		Page
1.	SUMMARY	1
2.	PROJECT MANAGEMENT	3
2.1	Technical Monitoring and Evaluation	3
2.2	Technology Transfer	4
2.3	CK GeoEnergy	5
3.	RESOURCE ASSESSMENT	7
3.1	U.S. Geological Survey Activities	7
3.2	CK GeoEnergy Corporation	8
3.3	Core Program	8
4.	RESEARCH AND DEVELOPMENT BY ENERGY TECHNOLOGY CENTERS AND NATIONAL LABORATORIES	17
4.1	Bartlesville Energy Technology Center	17
4.2	Lawrence Livermore Laboratory	24
4.3	Sandia Laboratories	29
4.4	Gas Research Institute	31
5.	FIELD TESTS AND DEMONSTRATIONS	33
5.1	Background	33
5.2	CER Corporation	36
5.3	Colorado Interstate Gas Company	38
5.4	DOE Well Test Facility	40
5.5	Gas Producing Enterprises, Inc.	42
5.6	Mitchell Energy Corporation	47
5.7	Mobil Research and Development Corporation	49
5.8	Rio Blanco Natural Gas Company	51
5.9	Sandia Laboratories—Mineback	53

FIGURES

		Page
Figure 3-1	Milestone Chart — USGS	9
Figure 3-2	Greater Green River Basin Showing Wells of Interest and USGS Designated Core Areas	12
Figure 3-3	Northern Great Plains Province Showing Wells of Interest	14
Figure 3-4	Detail of USGS Designated Core Areas	14
Figure 3-5	Piceance Basin Showing Wells of Interest and USGS Designated Core Areas	15
Figure 3-6	Uinta Basin Showing Wells of Interest and USGS Designated Core Areas	16
Figure 4-1	Permeabilities of Cores from Pacific Transmission Supply No. 24-19 Federal	21
Figure 4-2	Milestone Chart — BETC	25
Figure 4-3	Milestone Chart — LLL	30
Figure 4-4	Milestone Chart — Sandia	32
Figure 5-1	Flow Rate Performance of Natural Buttes No. 9 well	43
Figure 5-2	Flow Rate Performance of Natural Buttes No. 14 well	43
Figure 5-3	Flow Rate Performance of Natural Buttes No. 18 well	44
Figure 5-4	Flow Rate Performance of Natural Buttes No. 19 well	44
Figure 5-5	Flow Rate Performance of Natural Buttes No. 20 well	45
Figure 5-6	Flow Rate Performance of Natural Buttes No. 22 well	45
Figure 5-7	Results of Exploratory Coring for the Hole No. 6 Formation Interface Experiment	54
Figure 5-8	Location of CFE-2 with Respect to CFE-1 and Hole No. 6	55
Figure 5-9	Milestone Chart — Sandia Mineback	57

TABLES

		Page
Table 3-1	Summary of Wells — Greater Green River Basin	12
Table 3-2	Summary of Wells — Northern Great Plains Province	13
Table 3-3	Summary of Wells — Piceance Basin	15
Table 3-4	Summary of Wells — Uinta Basin	16
Table 4-1	Static Invasion Test Results of Grey Berea and Brown Sandstone	17
Table 4-2	Surface Areas of PCU F31-13G and Natural Buttes No. 21 Cores	19
Table 4-3	X-ray Diffraction Mineral Percentages of the PCU F31-13G Core	19
Table 4-4	Klinkenberg Permeabilities of Cores from Pacific Transmission Supply No. 24-19 Federal	21
Table 4-5	Permeabilities of Pacific Transmission Supply Well No. 24-19 Core	22
Table 4-6	Porosities and Permeabilities of Twin Arrow C&K 4-14 Core	22
Table 5-1	MHF Contract Locations and Frac Data	34

1. SUMMARY

May, 1979 progress of the government-sponsored projects directed toward increasing gas production from 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.

G. C. Kukal (CER Corporation) presented a research paper "Formation Evaluation and Gas Detection in Shallow, Low Permeability Shaly Sand of the Northern Great Plains Province" at the SPE meeting in Denver, Colorado on "Low Permeability Gas Reservoirs," May 21-22.

Work by the USGS toward resource assessment in the four primary study areas continued.

Projects of the National Laboratories and Energy Technology Centers continued during May. Bartlesville Energy Technology Center continued work on fracture conductivity, rock-fluid interaction, and log evaluation and interpretation techniques. Lawrence Livermore Laboratory continued experimental and theoretical work on hydraulic fracturing mechanics and analysis of well test data. Analysis of data obtained from a test of the borehole seismic unit by Sandia Laboratories is continuing. Preliminary design work began on a DOE-financed experimental multi-well fracturing project.

Cyclic gas injection operations were begun by Colorado Interstate Gas Company on the Miller No. 1 well. The Mitchell Energy Corporation Muse-Duke No. 1 well flowed 3,500 MCFD in May. Fishing operations resumed on the Mobil PCU F31-13G well.

2. PROJECT MANAGEMENT

2.1 TECHNICAL MONITORING AND EVALUATION

R. L. Mann, and G. R. Luetkehans, (CER Corporation) met with R. Ottinger, W. Bailey, and H. Aronson (TRW) on May 1 to discuss WGSP-TRW interactions and budgets, and the ongoing data gathering task. The data gathering task is to be completed June 1. Currently, data is being organized for presentation to TRW and will also be added to the WGSP Project files.

R. L. Mann, G. R. Luetkehans, J. E. Evered, H. E. Newman, (CER Corporation) and C. H. Atkinson (DOE) met with B. Carter, N. Vanderborgh and E. B. Nuchols of Los Alamos Scientific Laboratory on May 2 to review LASL's and CER's roles in the WGSP.

R. L. Mann attended a WGSP meeting in Tulsa, Oklahoma on May 7-8 which was called by DOE-Headquarters for an informal industry review of DOE plans for the Unconventional Gas Program. DOE-Headquarters was interested in comments concerning schedules, milestones, costs and relative priorities.

R. L. Mann, G. R. Luetkehans, (CER Corporation) and C. H. Atkinson (DOE) met with H. Stoller of Sandia Laboratories on May 11 to discuss the development of a WGSP multi-well experiment, which would include extensive testing of new tools, technology developments, and fracturing techniques. Basins and locations have not yet been decided upon.

J. E. Evered (CER Corporation) attended the new Gas Reservoir Engineering course presented by H. K. van Poollen & Associates on May 14-18. The course emphasized well testing and pressure transient theory and applications.

R. L. Mann, G. R. Luetkehans, J. Pollock, (CER Corporation) and C. H. Atkinson (DOE) met with H. Carroll (BETC), C. Schuster and D. Northrop (Sandia) on May 18 to discuss aspects of project management of a WGSP multi-well experiment.

R. L. Mann, G. R. Luetkehans, J. E. Evered, C. R. Appledorn, and G. C. Kukal (CER Corporation) attended the SPE meeting, May 21-22, in Denver, Colorado, on "Low Permeability Gas Reservoirs" sponsored by the Society of Petroleum Engineers. This was the first meeting of this type held by the SPE. G. C. Kukal presented a research paper for the meeting entitled "Formation Evaluation and Gas Detection in Shallow, Low Permeability Shaly Sands of the Northern Great Plains Province," SPE 7920.

R. L. Mann, P. T. Branagan, C. R. Appledorn, (CER Corporation) and C. H. Atkinson (DOE) met with C. R. Boardman (CK GeoEnergy), C. Schuster and T. Dobecki (Sandia) on May 24 to discuss seismic work which will be conducted near Vernal, Utah, in conjunction with CK GeoEnergy's outcrop study.

2.2 TECHNOLOGY TRANSFER

2.2.1 Documentation and Reports

Data for the First Quarterly Basin Activities Report, 1979 is being compiled. A report on the activities of the WGSP Logging Program is being revised and updated. An extensive report covering WGSP activities from October, 1978 to March, 1979 was mailed to Morgantown Energy Technology Center as input into the Semi-annual Enhanced Gas Recovery Program report. A draft copy of the WGSP Project Plan Document, FY 1980, is being prepared. Data is being compiled for a draft report on the WGSP Financial Supplement which will include the project's financial status as of June 30, 1979. A geologic review of the Northern Great Plains Province is being prepared by CER personnel.

2.2.2 Articles and Publications

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

EXPERIMENTAL EVALUATION OF FRACTURING FLUID INTERACTION WITH TIGHT RESERVOIR ROCKS AND PROPPED FRACTURES
by U. Ahmed, A. S. Abou-Sayed, and A. H. Jones

Prediction of gas well production after a massive hydraulic fracture (MHF) treatment is essential for economic assessment of the planned stimulation. Present accepted techniques of predicting the increase in production (stimulation ratio) are based on the estimated fracture dimensions, well and reservoir properties. Fracturing fluid damage is not considered.

This study demonstrates that when fracturing fluid damage is included in the stimulation ratio calculations, good agreement with actual post fracturing production can be achieved. Laboratory experiments at simulated in situ conditions (stress, temperature, saturation and fracturing treatment procedure) were performed on actual core samples to assess fracturing fluid damage to both the matrix permeability and propped fracture conductivity; damage was found to be site specific. Laboratory data on cores from unconventional gas reservoirs in both the eastern and western parts of the United States are presented. The observed damage is identified and explained. Specific examples are presented and predicted production compared with post-fracturing flow. Good agreement was obtained.

DEVELOPMENT OF SHALLOW GAS RESERVES IN LOW-PERMEABILITY RESERVOIRS OF LATE CRETACEOUS AGE, BOWDOIN DOME AREA, NORTH-CENTRAL MONTANA
by G. L. Nydegger, D. D. Rice, and C. A. Brown

Natural gas is currently being developed and produced in the Bowdoin Dome area from shallow, low-pressure, low-permeability reservoirs. Reservoirs are dominantly thin, discontinuous, shaly siltstone and sandstone which cannot be distinguished on conventional logs, require stimulation to provide commercial flow rates, and necessitate more sophisticated evaluation methods than conventional reservoirs.

A CASE HISTORY FOR MASSIVE HYDRAULIC FRACTURING THE COTTON VALLEY LIME MATRIX, FALLON AND PERSONVILLE FIELDS — LIMESTONE COUNTY, TEXAS
by H. G. Kozik, B. G. Bailey, and S. A. Holditch

Mitchell Energy Corporation has been actively developing acreage in the Fallon and Personville Fields in Limestone County, Texas. This report summarizes the results of an active stimulation program as evaluated using reservoir production and pressure transient data.

Using standard economic parameters and reservoir permeabilities determined by history matching, a detailed study was made to determine the well spacing and fracture length necessary for optimum development of the Fallon and Personville Fields.

2.2.3 Project Data Bank

Work continued on the WGSP bibliography.

2.3 CK GEOENERGY

A tentative location for the core sampling has been selected. The location will allow the lower part of the continous Tuscher Formation, all of the lenticular Farrer Formation, and the upper part of the Neslen Formation to be drilled with one core hole.

William Pease/Trend Oil Company will allow the use of their location for the drill site and approvals to drill have been checked through the State of Utah and U.S. Bureau of Land Management. A coring contractor has been secured and coring will start on June 5, 1979.

Outcrops on three sides of the location will be mapped to provide a model of the type of material being cored.

Research logging will be conducted as soon as the logging companies can get on site.

CK GeoEnergy attempted to log two Uinta Basin wells belonging to Diamond Shamrock (Rockhouse 4 and 5A). Both attempts were aborted; one because of an obstruction near the bottom of the tubing, and the other because of a broken master valve.

3. RESOURCE ASSESSMENT

3.1 U.S. GEOLOGICAL SURVEY ACTIVITIES

3.1.1 Uinta-Piceance Basins

Petrographic study of selected Cretaceous core samples from the CIGE NB No. 21 well from the Uinta Basin is near completion.

3.1.2 Greater Green River Basin

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

Petrographic examination of core chips from the Superior No. 1 Pacific Creek Unit well in the Green River Basin and from the Tierney Unit wells in the Washakie Basin continued.

Lineament studies of the Washakie and Red Desert (Great Divide) Basins are complete and a final report is being drafted.

Cross-sections through the Washakie and Green River Basins are being prepared.

A draft paper entitled "Preliminary results of organic maturation, temperature, and pressure studies in the Pacific Creek area, Sublette County, Wyoming" was completed by B. E. Law, C. W. Spencer, and N. H. Bostick.

A draft paper entitled "X-ray mineralogy and petrology of thirteen core samples, Upper Cretaceous Mesaverde Group, Washakie Basin, Wyoming" was completed by J. C. Webb and T. F. Tyler.

Core samples from the Tierney No. 1 well, sec. 15, T. 20 N., R. 94W., Washakie Basin, Wyoming were described.

A draft paper entitled "Stratigraphy and depositional history of the intertonguing, Upper Cretaceous Mancos Shale and Mesaverde Group in Moffat, Rio Blanco, and Routt Counties, Colorado" was completed by L. W. Kiteley.

An illustration entitled "Wildcat well penetration map showing wells drilled into and through potentially gas-bearing low-permeability Upper Cretaceous and Tertiary Reservoirs, Great Divide Basin, southwest Wyoming" was published by C. W. Spencer.

CER/DOE were furnished with work maps showing "Wildcat well locations, total depths, and formations at total depth for parts of the Greater Green River Basin".

3.1.3 Northern Great Plains Province

A speech for the May 23, 1979 National Petroleum Council subcommittee meeting on tight gas sands was prepared.

An open-file report entitled "Evaluation of a color-coded Landsat 5/6 ratio image for mapping lithologic differences in western South Dakota" by G. L. Raines, USGS, R. F. Bretz, South Dakota Geological Survey, and G. W. Shurr, USGS, was completed.

Petrographic analysis of the Eagle interval, Joseph J. C. Paine-DOE cored well, north-central Montana, continued.

Research for a paper on the production, accumulation, and resource potential of biogenic gas has begun.

A paper entitled "Reservoir geometry of Eagle equivalent sandstones, southeastern Montana" for the *Mountain Geologist* is being prepared by G. W. Shurr.

3.1.4 Schedule Status

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

3.2 CORE PROGRAM

Chandler and Associates was contacted concerning participation in the WGSP Coring Program for one of their wells in the Piceance Basin. No agreements were reached. Fuel Resources Company was also contacted concerning a location in the White River Dome area of the Piceance Basin. At month end, Fuel Resources decided against drilling the well.

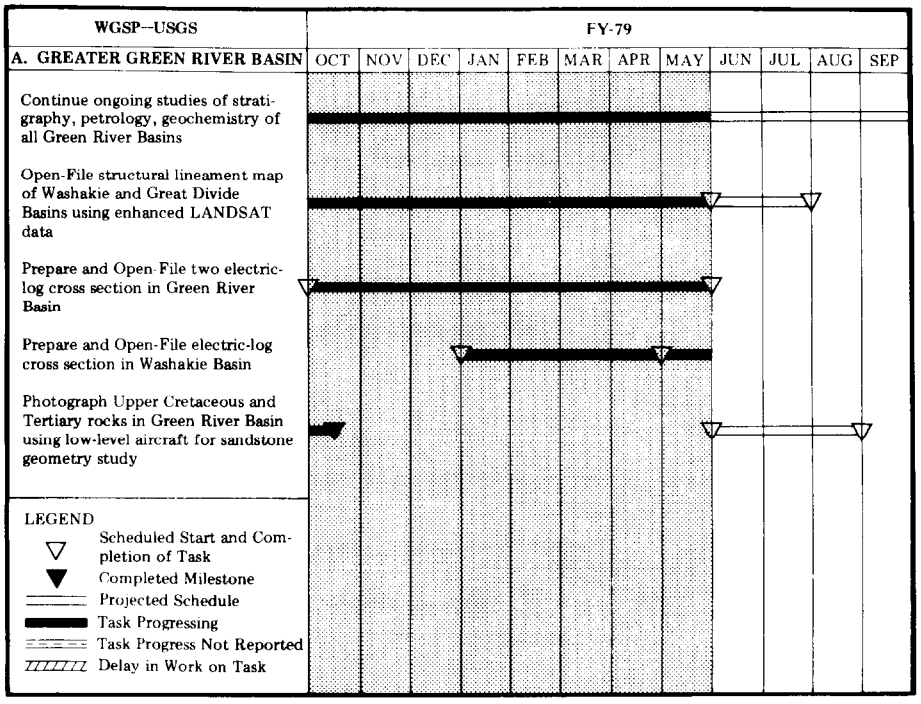
3.3 SURVEY OF BASIN ACTIVITIES

3.3.1 Greater Green River Basin

In the Greater Green River Basin, 24,964 MCFD of new gas was added from completed wells of interest. Producing horizons were the Frontier, Mesaverde and Lewis. Twenty-four wells were completed: 7 wildcats and 17 development wells. Thirteen of seventeen development wells and 5 of 7 wildcats were successful.

Twelve wildcats and 36 development wells were staked (one which was completed by month's end).

Wells of interest to the Western Gas Sands Project are listed in Table 3-1 and shown on Figure 3-2.



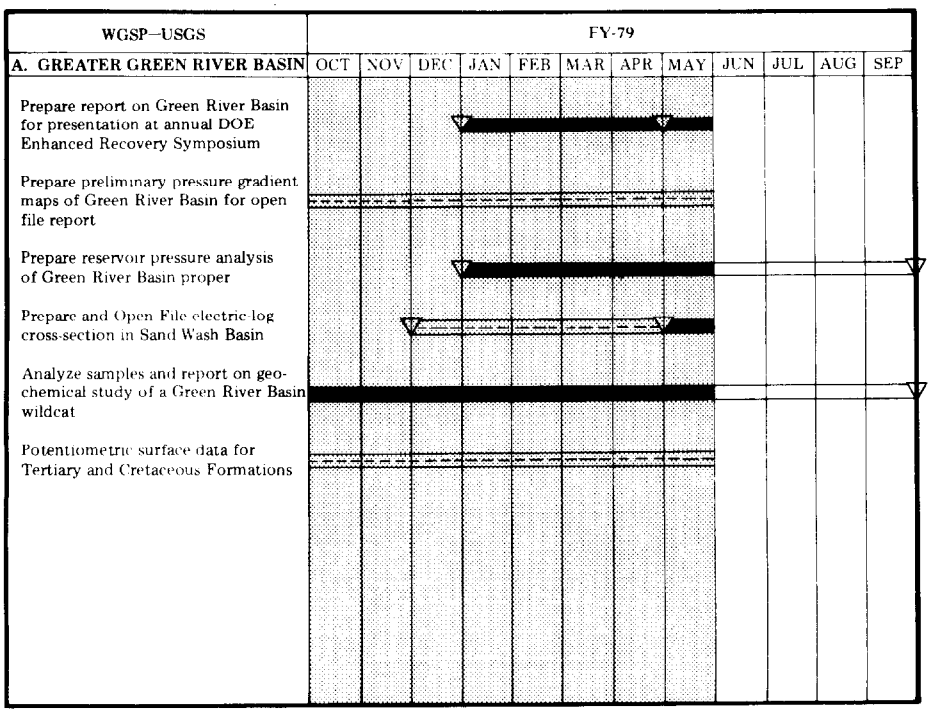
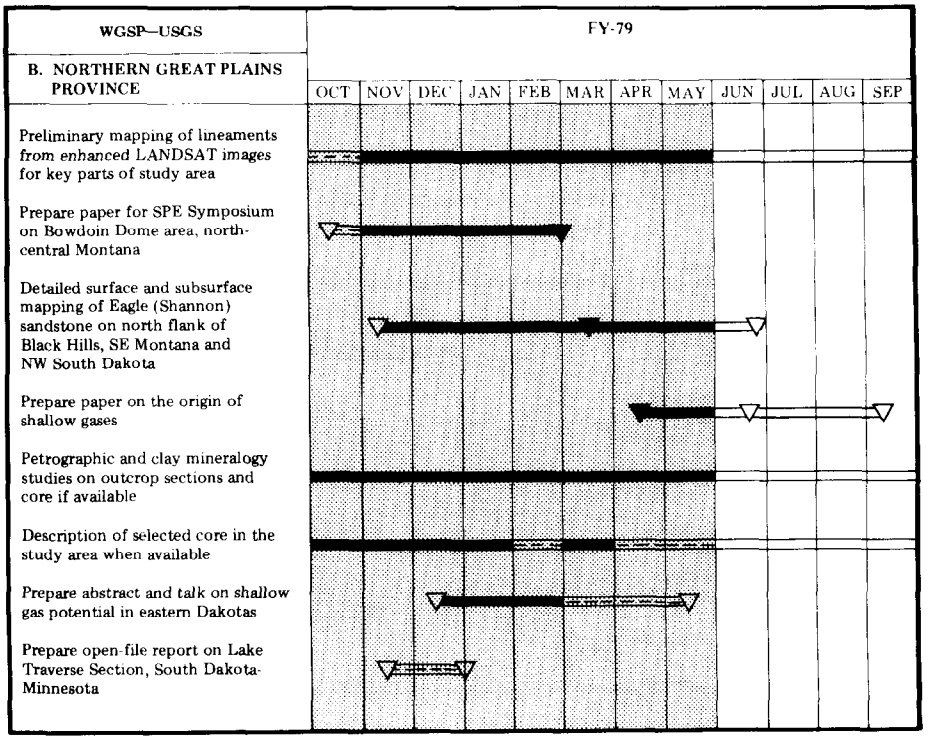


Figure 3-1 Milestone Chart -- USGS



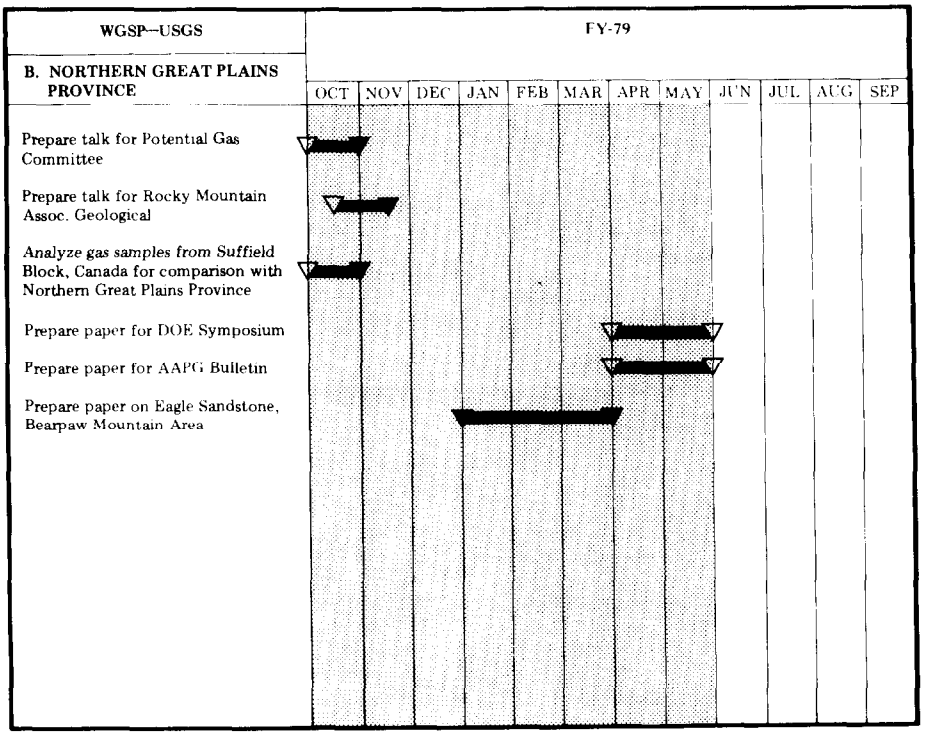
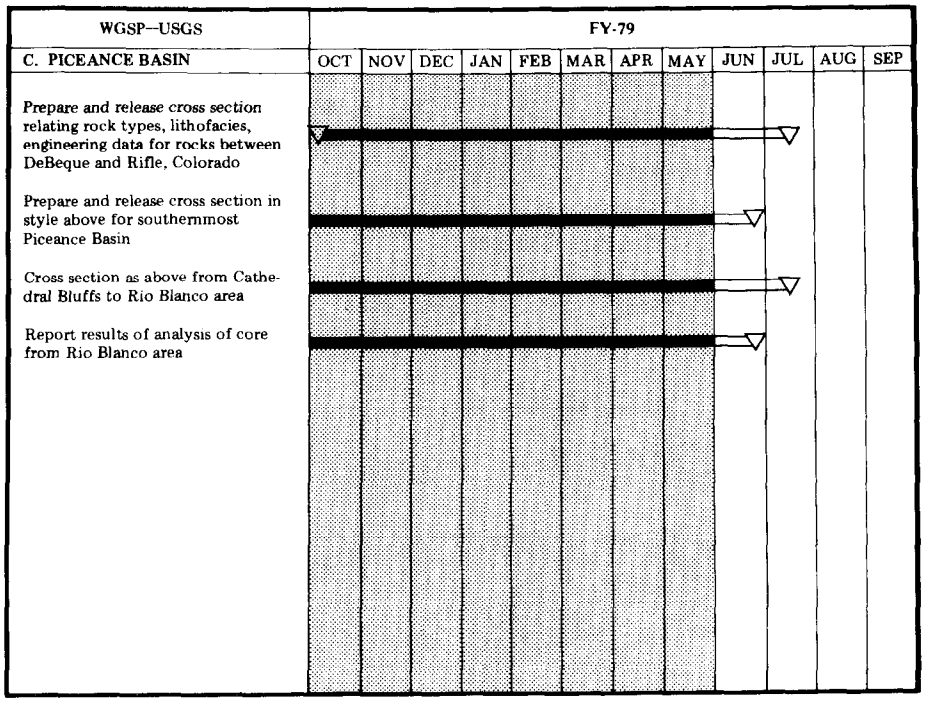


Figure 3-1 Continued



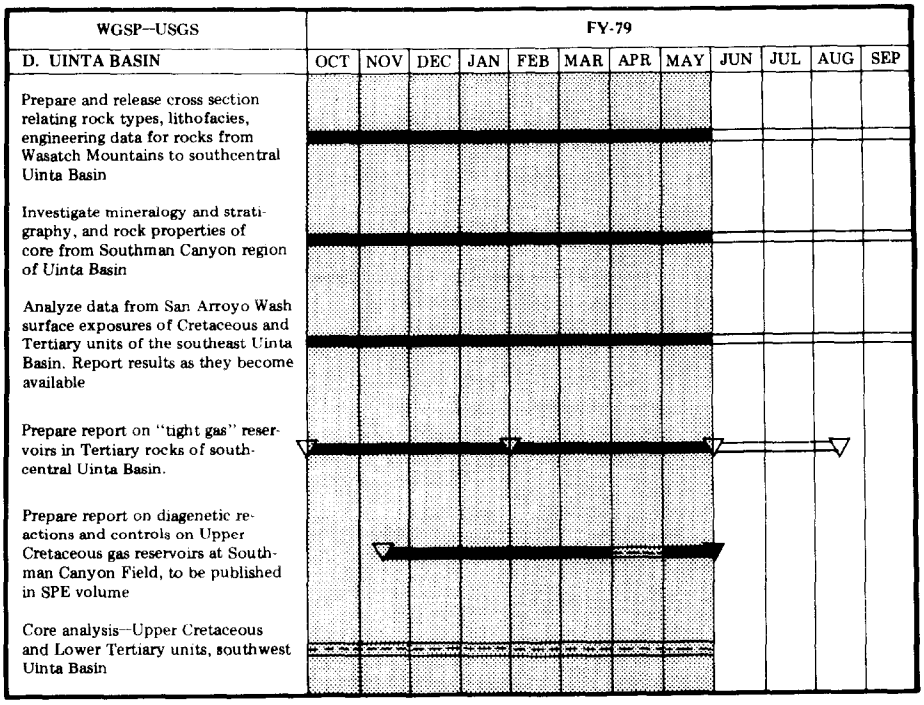


Figure 3-1 Continued

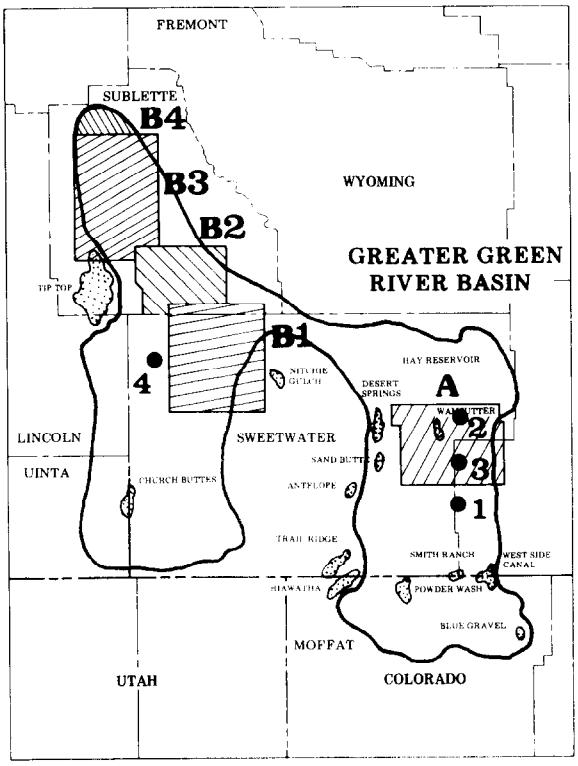


Figure 3-2

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.[1]	LOCATION Sec/T/R	HORIZON[2] ft	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Kemmerer Coal	9-1 Barrel Springs Unit II	1	nese 9/16N/93W Barrel Springs Carbon Cty, WY	Mesaverde (11,490)			Development well. Operator has 4 other Mesaverde tests in this locale.	
Amoco Production	1 Champlin-254 Amoco-C	2	csw 21/20N/93W Wildcat Field Sweetwater Cty, WY	Mesaverde (10,460)			Wildcat location. Operator has 6 other Mesaverde tests in list area.	
Sinclair Oil	2-1 Gryn-berg-Federal	3	cne 2/14N/92W Blue Gap Carbon Cty, WY	Mesaverde (7,290-7,899)	8,150 PB: 8,052	Acidized	Completed development well, operator has 2 additional Mesa-verde tests in this locale.	1,710
Davis Oil	3 Horn Canyon Unit	4	swnw 9/24N/110W Unnamed Field Sweetwater Cty, WY	Frontier (10,602-10,620)	11,760	3,000 gal Condensate 8,400 gal.	Wildcat exten-tion field.	238 3BC

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

3.3.2 Northern Great Plains Province

Thirty development wells (5 D&A) and five wildcats (4 D&A) were completed in the Northern Great Plains Province during May. The Bowdoin, Blackleaf, Bow Island, Eagle, Greenhorn, Phillips and Niobrara yielded 7,733 MCFD of new gas.

Eight wildcats and fifteen development wells were staked, and 3 wildcats and 1 development well were D&A by month's end.

Wells of interest to the WGSP are listed in Table 3-2 and located on Figures 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] ft	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Joseph J. C. Paine & Associates	1 Assen	1	nwse 9/129N/106W Little Missouri Bowman Cty, ND	Eagle (1,151-1,161)	1,235 PB: 1,198		Completed development well.	18
Joseph J. C. Paine & Associates	1-0807 Strommen	2	senw 8/30N/37E Unnamed Field Valley Cty, MT	Bowdoin (1,120-1,170)	1,425 PB: 1,220		Completed development well. Operator has 13 additional wells (12 Bowdoin and 1 Eagle) in the area.	2
Grace Petroleum	4-7x MLINAR	3	swne 4/34N/7E Unnamed Field Liberty Cty, MT	2nd Bow Island (2,096-2,106)	2,235		Wildcat completion. Bow Island Discovery-New Field.	630

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

3.3.3 Piceance Basin

New gas for May totaled 2,838 MCFD and was produced from the Mancos horizon. Eight development wells and 3 wildcats were completed.

Eleven wells were staked during May (2 wildcats and 9 development wells).

Special wells are shown on Figure 3-5 and listed in Table 3-3.

3.3.4 Uinta Basin

Four completed development wells produced 9,700 MCFD of new gas from the Wasatch Formation (2 IPFs for producing horizons were not available from Petroleum Information).

Thirteen development wells and 3 wildcats were staked during May.

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

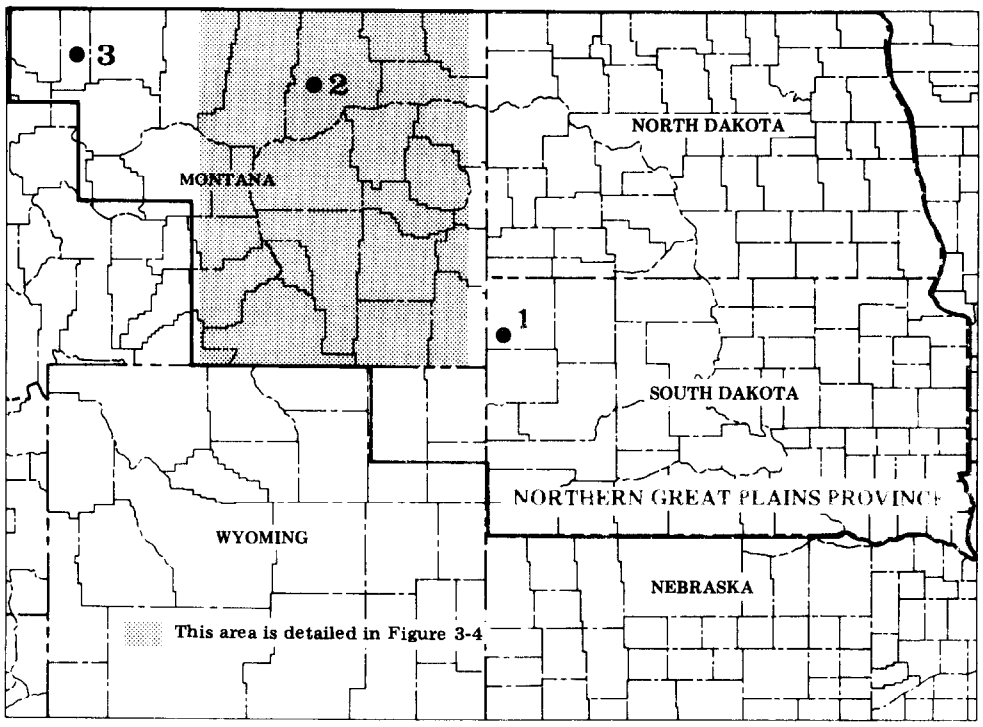


Figure 3-3

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

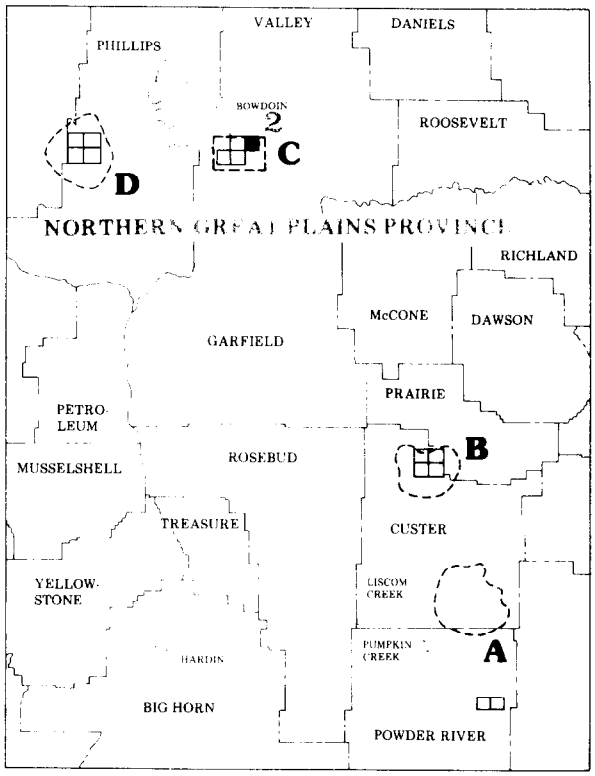


Figure 3-4

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)

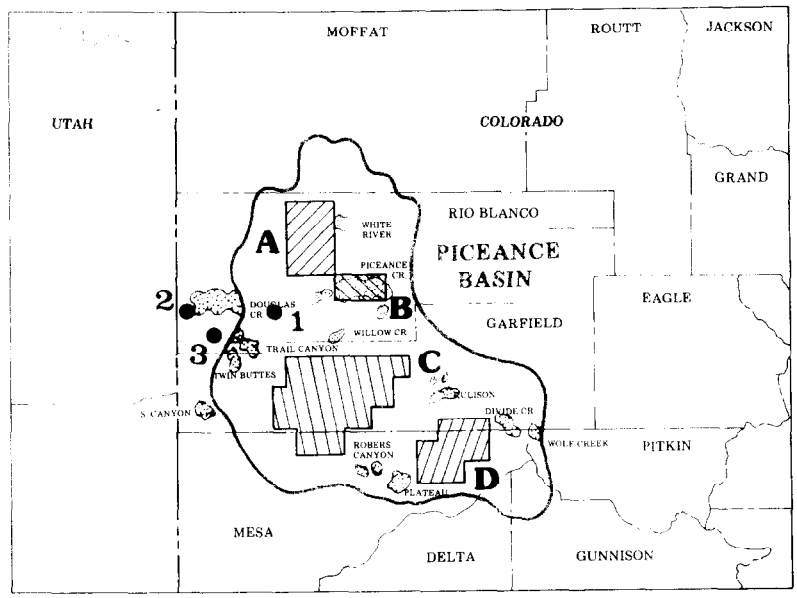


Table 3-3 Summary of Wells — Piceance Basin

OPERATOR	WELL NAME	MAP INDEX NO.[1]	LOCATION Sec/T/R	HORIZON[2] ft	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Fuel Resources Development	B-10-3-101-S Federal	1	nwne 10/3S/101W Cathedral Field Rio Blanco Cty, CO	Emery (2,700)			Development well. Operator has 7 other Emery tests in this locale.	
Coseka Resources	19-G-13 Taiga Federal	2	swne 13/3S/104W Unnamed Field Rio Blanco Cty, CO	Mancos (3,742-4,201)	4,302 PB: 4,247	75,000 gal water 255,000 lb sand	Wildcat completion. Mancos Discovery-New Field.	53
Joseph B. Gould	33-17 Gould	3	nene 33/2S/103W Lower Horse Draw Rio Blanco Cty, CO	Mancos (2,988-3,158)	3,290		Development well completed as SIGW. No cores or tests.	

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

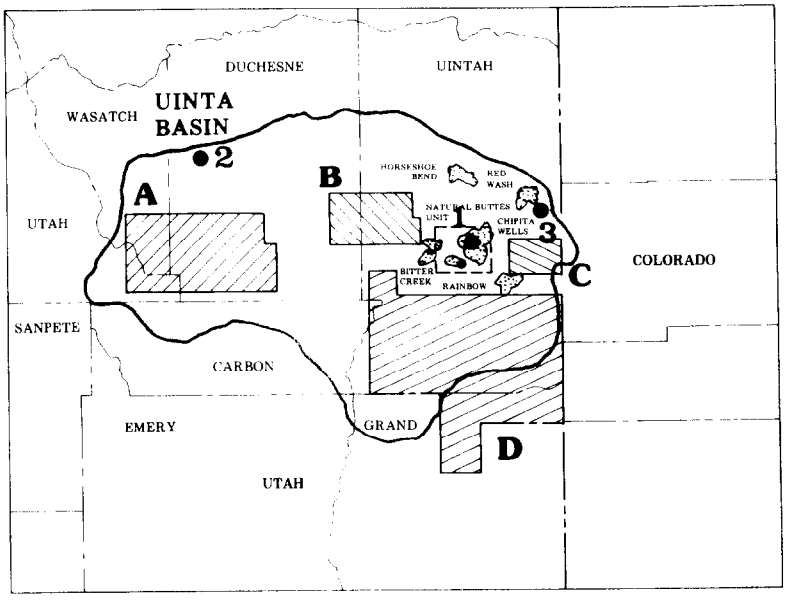


Figure 3-6

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 Sec/T/R	HORIZON[2] ft	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
CIG Exploration	46-21-9-21 CIGE	1	nene 21/9S/21E Natural Buttes Field Uintah Cty, UT	Wasatch (5,173-7,190)	7,350 PB: 7,307	3,500 gal acid, 154,200 gal emul. 250,000 lb sand	Completed development well.	2,500
Gulf Oil	4-22-1A Skitzy Canyon-Ute	2	nwnw 22/4S/6W Unnamed Field Duchesne Cty, UT	Wasatch (5,800)			Development well.	
Carmack Drilling	1-Dunlap-Federal	3	swsw 8/6S/24E Wildcat Field Uintah Cty, UT	Mancos (1,000)			Wildcat.	

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

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

4.1 BARTLESVILLE ENERGY TECHNOLOGY CENTER

4.1.1 Improved Pressure Coring System

4.1.1.1 Core Retriever Design

Modifications proposed by Diamond Oil Well Drilling Company (DOWDCO) have been approved. Modifications will consist of an adapter sub to attach the Sandia core bit assembly and channel the drilling fluid through the main bit body, addition of an inner barrel piston, and rework of the flushing head assembly to isolate the low invasion fluid in the inner core barrel. These modifications will enable field testing of the Sandia two-piece bit design on the DOWDCO pressure core barrel. Fabrication of parts for the modification of three core barrels for field tests will be completed in June.

Shell Oil Company will probably run the non-invading fluid and new Stratapax bit during 1,000 ft of pressure coring in the Wasson Field operations during June, July, August, and September, 1979.

4.1.1.2 Core Fluid Tests

During May, static invasion tests were conducted on various particle size distribution polymer muds (See Table 4-1). Five commercially available grades of $CaCO_3$ bridging particles were added in 25 lb/BBL concentration to a base mud consisting of 5 lb/BBL HEC polymer in low-freezing 30 percent $CaCl_2$ brine. The muds were tested for API filtrate loss at 100 psi/72°F and 500 psi/200°F, and were tested for invasion into Grey Berea and Brown sandstone with a 3,000 psi hydrostatic loading and a 500 psi differential pressure. The results (cc fluid loss in 30 min) are summarized below.

Table 4-1 Static Invasion Test Results of Grey Berea and Brown Sandstone

Additive	Grey Berea		Brown Sandstone		API Filtrate	
	1 Min	30 Min	1 Min	30 Min	100 psi/72°F	500 psi/200°F
Wate	21.0	38.2	17.0	27.6	8.4	24.0
Safeseal	0.5	3.7	4.0	15.9	1.4	11.6
Safeseal-X	5.0	8.3	17.0	22.9	3.2	11.0
Sluggit	1.5	7.1	7.0	11.9	2.0	14.4
Sluggit-max	8.2	12.3	5.5	10.2	4.2	18.4

Particle size distributions of five grades of $CaCO_3$ have been measured using a sedigraph. The sedigraph measures the particle absorption of tungsten generated X-rays and calculates the particle size by using Stoke's law for particle settling. The data indicated that the optimum particle size distribution for minimizing invasion and fluid loss was greatly affected by the presence of the polymer. Safeseal, which was superior in reducing invasion, had the "wrong" size distribution to effectively minimize invasion.

Work is planned to verify the results for dynamic invasion under simulated drilling conditions, and the necessary dynamic test equipment is being designed. This equipment will circulate viscous mud under high temperature and pressure while scraping the core face to remove the filter cake.

4.1.1.3 Bit Design and Fabrication

Six 2-½ in. pilot core bit bodies have been fabricated. Diffusion bonding of the diamond compax (Stratapax) cutters to these bodies has been delayed due to a failure experience in the autoclave canning which is required for this attachment. This problem is being investigated and brazing of the cutters is being pursued as an alternate interim attachment method. No delay in field testing is anticipated.

Design of the 6-½ in. bit body is complete with fabrication scheduled in June.

Diffusion bonding of the diamond compax cutters and trimmers to the steel studs for the 6-½ in. bit bodies is scheduled in June. Steel studs are on hand for use in these bits.

A laboratory test of a 3 in. pilot bit with cutters attached by low temperature brazing, but similar in design to the 2-½ in. pressure core barrel bit, was run using low invasion mud for chip removal and cooling. The mud was extruded by the core entering the drill tube similar to that anticipated in the pressure core barrel assembly. Mud compressibility due to entrained air caused the barrel to plug from lack of mud flow across the cutter faces. A second test is planned as soon as de-aerated mud becomes available and the cutters which failed due to faulty brazing can be re-attached.

4.1.2 Interface Conductivity Effects on Electric Logging

Surface area measurements to determine the most representative specific surface areas on cores from the Mobil PCU F31-13G and Natural Buttes CIGE No. 21 wells continued. Presently, cores are crushed, sieved and dried for several days prior to analysis, and then degassed with argon at 100° C for 40 min prior to analysis. This procedure gives surface area values which are repeatable and consistent. Values obtained by this method are shown in Table 4-2.

Samples from the Mobil PCU F31-13G well were analyzed for mineral and clay composition by x-ray diffraction. Table 4-3 summarizes the mineral analysis of the PCU F31-13G samples.

Table 4-2 Surface Areas of PCU F31-13G and Natural Buttes No. 21 Cores

Well	Depth in ft	Measured surface areas (m^2/g)
CIGE No. 21	4,462	4.8
CIGE No. 21	4,468	4.4
CIGE No. 21	6,407	3.3
CIGE No. 21	6,475	1.4
CIGE No. 21	6,499	2.9
CIGE No. 21	6,499.5	2.1
CIGE No. 21	7,427	3.0
CIGE No. 21	7,427.8	5.0
PCU F31-13G	8,498	3.9
PCU F31-13G	9,946	4.0
PCU F31-13G	9,957	3.4
PCU F31-13G	9,998	3.7

Table 4-3 X-ray Diffraction Mineral Percentages of the PCU F31-13G Core

	Depth (ft)			
Mineral	8,498	9,946	9,957	9,998
Quartz	55	50	84	68
Feldspar	6	3	4	8
Calcite	18	3	3	3
Dolomite	2	22	2	5
Siderite	—	—	—	2
Kaolinite	6	6	trace	—
Chlorite	3	3	trace	—
Illite	8	11	7	12
Glanconite	—	trace	trace	trace
Mixed layer illite/mont-morillonite	2	2	trace	2

The cation exchange capacity (CEC) has been determined for several core plugs from the Natural Buttes No. 21 and Mobil PCU F31-13G wells. Samples from the Natural Buttes well are from the 6,400 ft to 7,500 ft interval. The CEC range was from 0.010 to 0.027 meq/g. There was good correlation between increasing the CEC and surface area, giving a value of 180 m^2 of surface area per meq CEC.

Four Mobil core samples had higher average CEC values, ranging from 0.021 to 0.034 meq/g. Mineral analysis indicated about the same total clay content as for the Natural Buttes core although the clays were expected to yield higher CEC values. Correlation between surface area and CEC values was poor. This could have been due to the relatively high calcium content as shown in Table 4-3.

4.1.3 Reservoir Simulation Studies

Pre-fracture pressure buildup data taken on zones 8 and 9 of the Mobil well PCU F31-13G have been analyzed. Analysis showed these zones to be fractured prior to massive hydraulic fracturing. This may have been due to natural fractures existing in the reservoir or to fractures created during perforation breakdown. Other zones tested in this well also appeared to be fractured prior to MHF.

The effective gas permeability of the matrix rock in zone 8 is 0.0134 md and that of zone 9 is 0.0154 md. The test data indicate a reservoir pressure for zone 8 of 2,825 psia and 2,905 psia for zone 9. This is anomalous since zone 8 is the deeper of the two zones.

Analysis of the post MHF pressure drawdown data from zone 5 continued. Tests were run directly following the fracturing operation. The well was still producing fracturing fluid during the test. This resulted in large rate and pressure fluctuations which made it difficult to obtain accurate information on fracture characteristics.

4.1.4 In Situ Permeability

Klinkenberg permeabilities were measured at low overburden pressures for cores from the Pacific Transmission Supply No. 24-19 Federal well. Two different methods of applying confining pressures showed that small changes in external or rubber sleeve sealing pressure caused a difference in extrapolated Klinkenberg permeabilities. Figure 4-1 shows gas permeability determinations for two cores. The lines with greater slope were run with confining pressures of 100 psi above the inlet gas pressure. Lines with less slope were run at a constant overburden pressure. For the curve produced by increasing overburden pressure, the effect of gas or pore pressure produced a net average confining pressure which increased with increased inlet pressure. At a constant overburden pressure the net average confining pressure decreased as the inlet gas pressure was increased. This relatively small change in net confining pressure could cause a significant difference in curve slope and extrapolated Klinkenberg permeabilities for some cores. Table 4-4 contains values obtained by the two methods for cores from the Pacific Transmission Supply well, No. 24-19 Federal.

4.1.5 Measurement of Formation Characteristics for Western Tight Sands

4.1.5.1 Pressure Dependence of Single-Phase Permeability

Fluid tests have been conducted using methyl alcohol in an attempt to determine the permeability of cores without gas slippage effects. This low viscosity fluid was extracted from the cores without damaging clays and permitted sufficiently high flow rates at low differential pressures. At high differential pressures across the core, clay fines can be separated from the pore surface and moved to pore throats, causing blockage, or the fines may be forced out of the rock. In both situations, the permeability of the core changes with the tortuosity of the pores. No quantitative evaluation has yet been made to assess the degree to which the technique can change the original core properties.

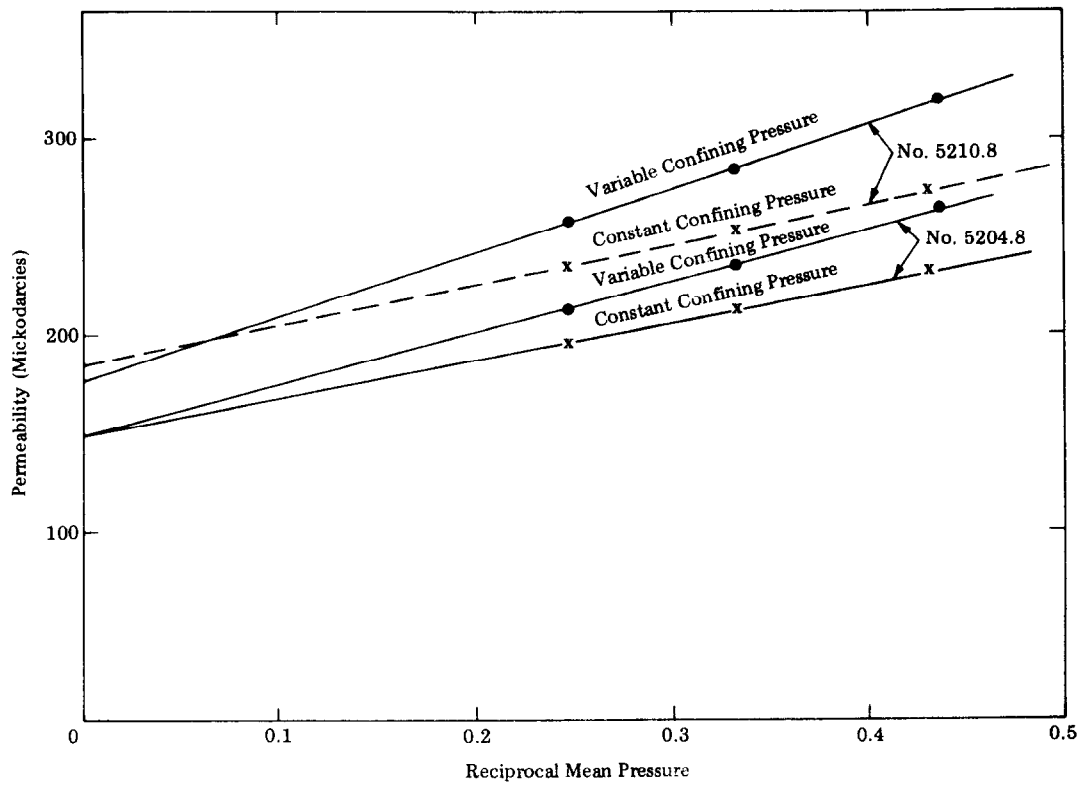


Figure 4-1 Permeability of Cores from Pacific Transmission Supply No. 24-19 Federal

Table 4-4 Klinkenberg Permeabilities of Cores from Pacific Transmission Supply No. 24-19 Federal

Depth (ft)	Constant O.B. pressure (225 lbs) microdarcies	Variables O.B. pressure mircrodarcies
5,120.7 A	26.	30.
5,120.7 B	22.	23.
5,122.7 A	448.	—
5,122.7 B	415.	415.
5,172.3 A	133.*	—
5,172.3 B	729.*	831.
5,196.5 A	116.	93.
5,204.8 A	148.	148.
5,210.8 B	185.	177.
5,217.8 A	820.	777.
5,219.1 A	1,202.	1,170.
5,220.4 B	709.	735.
5,220.7 B	1,390.	1,258.
5,221.4 B	647.	563.

* Thin coal beds

Table 4-5 shows permeabilities at 120 psia net confining pressure; the permeabilities were determined using both NaCl solution (15 g/ℓ) and methyl alcohol.

The permeabilities which were determined using brine were significantly less than the permeabilities which were determined using extrapolated gas data. Jones and Owens[1] observed that salt solutions with concentrations of 60,000 ppm cause permeability reductions similar to those observed here. Subsequent use of fresh water caused only a minor further decrease in permeability, indicating that the salt solution had been nearly as damaging to the core as fresh water would have been. Jones and Owens proposed that this may possibly be due to immobile or "solid" water held to clay surfaces due to electrostatic effects. Similar low permeabilities have been found for methyl alcohol which may be the result of damage of the core or similar immobilization of the alcohol near clay surfaces.

Table 4-5 Permeabilities of Pacific Transmission Supply Well No. 24-19 Core

	Permeability (md)	
Core Depth (ft)	NaCl Solution (15g/ℓ)	Methyl Alcohol
8,498	.0014	.0030
9,957	.0057	.0052

4.1.5.2 Effect of Core Saturation History on Relative Permeability to Gas and to Water

Welge-type unsteady state relative permeability curves can be obtained only at high differential pressures across the core because of high capillary pressures. An expression for relating flow out of the downstream end to permeability and relative permeability must first be obtained since these high differential pressures produce a large net confining pressure gradient. The general nature of this expression involves integration of flow for an infinitesimal length where the permeability at that point is determined by an equation describing the pressure dependence of permeability as a function of net confining pressure. An expression to evaluate unsteady state measurements is being formulated. This will be compared with the liquid phase stationary method measurements.

Laboratory equipment has been set up at Los Alamos Scientific Laboratory to measure permeability and porosity of cores as a function of water saturation. Only one set of samples from the Twin Arrow well in the Piceance Basin of Colorado has been examined to date. Porosity and permeability measurements in a radially confined simulated in situ mode have been tested. Table 4-6 gives the results of these measurements on two selected samples:

Table 4-6 Porosities and Permeabilities of Twin Arrow C&K 4-14 Core

DEPTH (ft)	POROSITY	PERMEABILITY (wet)	PERMEABILITY (dry)
1,010	*	> .00001 md	~ .000013 md
1,014	*	> .00001 md	~ .03 - .04 md

* Due to the conditions of the samples upon delivery, it was impossible to make accurate porosity measurements.

[1] Jones, F. O. and W. W. Owens. "Laboratory Study of Low Permeability Gas Sands", SPE 7551 presented at 1979 SPE Symposium on Low Permeability Gas Reservoirs, May 20-22, 1979, Denver, Colorado.

4.1.6 Advanced Electromagnetic Logging Techniques

Experiments in electromagnetic logging techniques performed at Sandia Laboratories yield information concerning the resistivity, dielectric constant and magnetic permeability of formation materials. A major part of the Sandia logging effort is to relate these electrical parameters to reservoir parameters such as porosity, gas to water ratios, and fluid flow permeabilities. In regard to this goal, recent efforts by BETC have been directed toward relating the dielectric and resistive properties of sandstones saturated with saline water to pore volumes and shapes.

Data have been published on the electrical impedance of saturated sandstones in the 1.5 kHz to 1.8 kHz range. Success has been achieved in fitting these data with a model based on a Maxwell-Wagner-Sillars dispersive dielectric coupled with a nondispersive resistivity given by Archie's Law. While the present model qualitatively represents available data, a quantitative model will require a distribution function describing pore shapes. With such a function, the rock matrix is much better described than if only the porosity is known. For example, a continuum of pore-volume pore-surface areas may be modeled thereby paving the way for fluid permeability determinations through the use of a generalized Kozeny Equation. Furthermore, extensions of the model to a three-component system could yield hydrocarbon-water ratios for pore fluids.

4.1.7 Fracture Modeling

A flow chart has been drawn for a Monte Carlo program to calculate the propagation of a vertical fracture as it encounters inhomogeneities of a given distribution. Initially the medium will be taken to be uniformly inhomogeneous (vertical containment can be incorporated later).

A 2D solution for a penny-shaped fracture expanding in a homogeneous medium is found by solving simultaneously the Carter equation and the Sneddon width equation to find fracture radius and width. The equations are used to find the times and fracture volumes when the fracture tip arrives at equally spaced radial intervals.

The propagating crack is divided into a number of sectors, eight initially, but increasing as the fracture expands, to form a fairly uniform grid in (r, θ) space. Inhomogeneities are impressed on this grid.

Propagation of the fracture tip in each sector can now be determined by comparing the pressure (p) in the fracture (calculated using rheological models) with σ_{min} selected from a given normal distribution. If $p > \sigma_{min}$ the sector expands.

Using the model calculation of an average pressure fluctuation, $\delta p/p$ will be related to the spectrum of inhomogeneities. Hopefully these bottom-hole pressure variations will provide important information on the fracturing process as it happens. Pressure variations may be used to estimate the spectrum of inhomogeneities by employing models like the Monte Carlo.

4.1.8 Schedule Status

Figure 4-2 is a milestone chart depicting May progress of BETC projects.

4.2 LAWRENCE LIVERMORE LABORATORY

4.2.1 Theoretical Analysis

The dynamic finite element studies to date have been limited to events up to the time when a bilaterally propagating crack reached an interface. Three subsequent possibilities will be investigated. First, the crack will stop at the interface and local events will be followed as the elastic body waves disperse. Secondly, the crack will continue propagating by penetrating the adjacent material or by cracking along the interface. Thirdly, the crack will stop at the interface and, if displacement overshoot is large enough, the crack will begin extension across or along the interface.

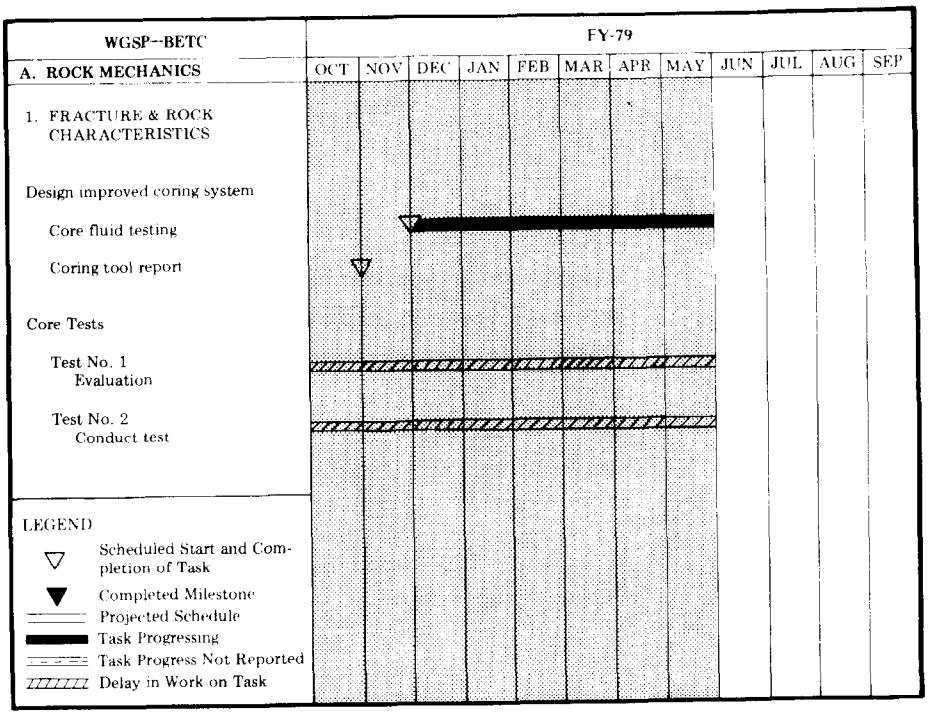
During May, coding modifications were begun to analyze a crack which stops at the interface. Body wave reflections from the far interface are the primary problem in this study. These waves can be delayed somewhat by increasing the cracking speed, but realistic cracking speeds are limited by the shear wave velocity. Preliminary results indicate that the amount of overshoot in the displacements perpendicular to the crack of points near the crack is not large.

4.2.2 Experimental Program

Friction experiments continued on the Nugget sandstone and Indiana limestone. Roughening of the sliding surfaces by sandblasting increased the coefficient of friction approximately 11 percent for sandstone and 18 percent for limestone above the values of smooth surfaces. Saturating rocks with water produces about a 40 percent increase in the coefficient of friction in the limestone with smooth surfaces. Saturation produces about a 24 percent decrease in the coefficient of friction in the sandstone with smooth surfaces.

A new pressure intensifier has been ordered to perform hydraulic fracture experiments. This intensifier has a fluid capacity of 180 cc as compared to the 20 cc intensifier used at present. It will operate in a two-stage system being driven by 1,000 psi compressed nitrogen with a 10 to 1 pressure magnification ratio. This system will permit a wider range in the rate at which the fracturing fluid can be pressurized, and the larger volume capacity will permit fracturing of porous rocks without having to stop and refill the intensifier with oil from a reservoir during the performance of an experiment.

The uniaxial stress compressive loading experiments to measure the failure envelope of Mesaverde shale from Rio Blanco County, Colorado, have been completed. Jacketing of the Colorado Mesaverde shale and sandstone specimens for the pressure-volume study has begun. Preparation has also begun of specimens of the Mesaverde sandstone and shale from Sublette County, Wyoming, for mechanical property tests.



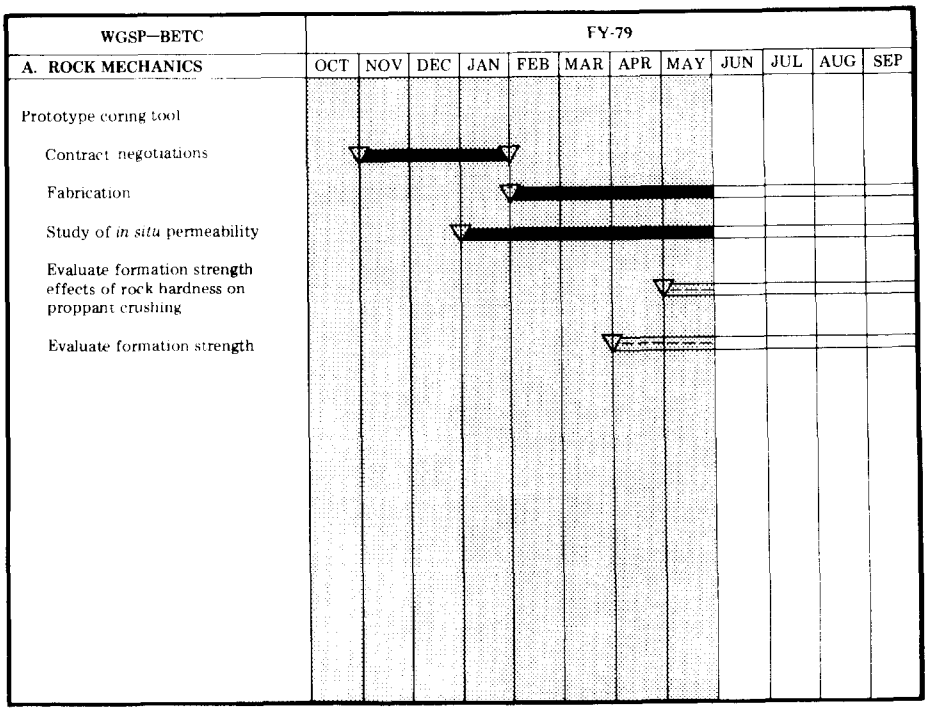
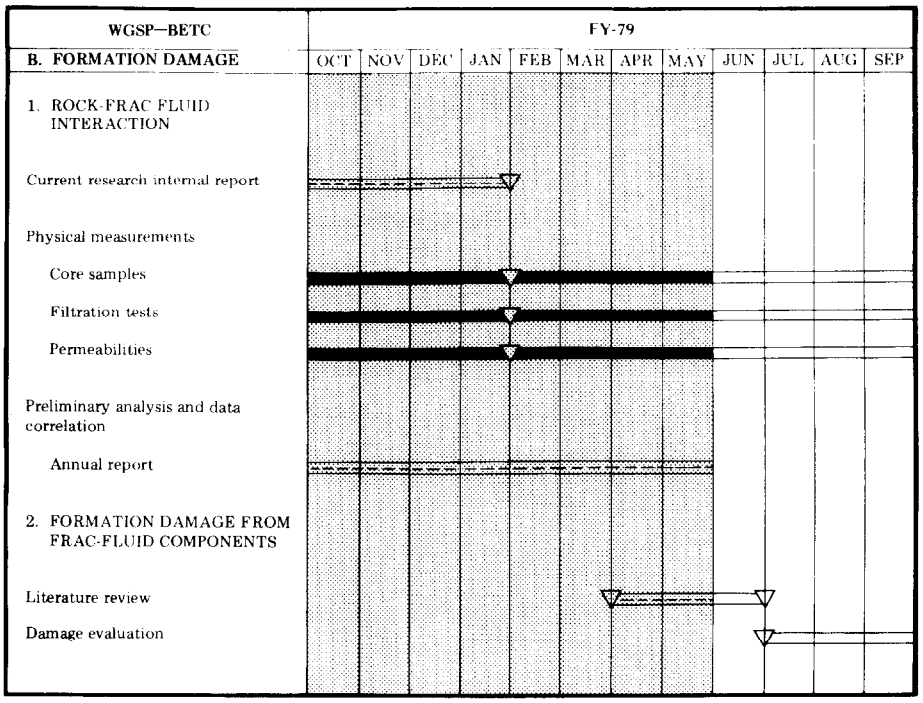


Figure 4-2 Milestone Chart — BETC



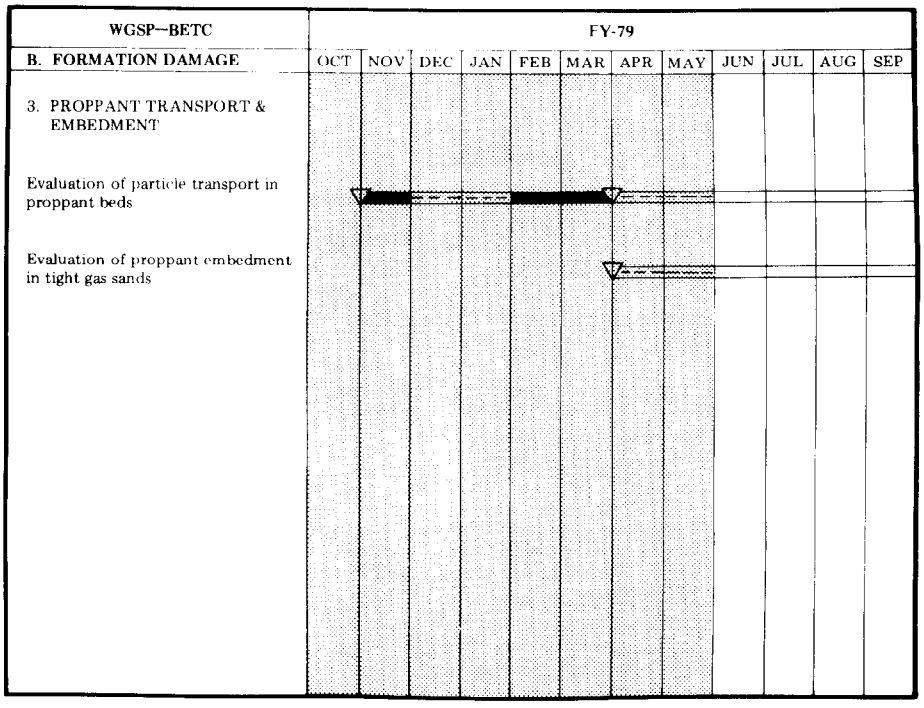
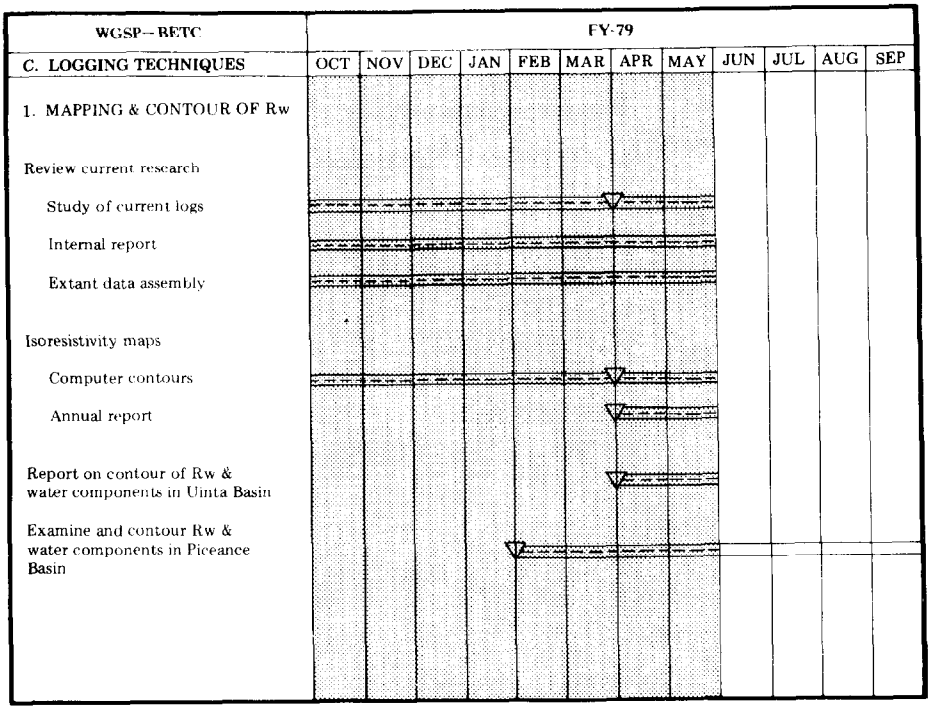


Figure 4-2 Continued



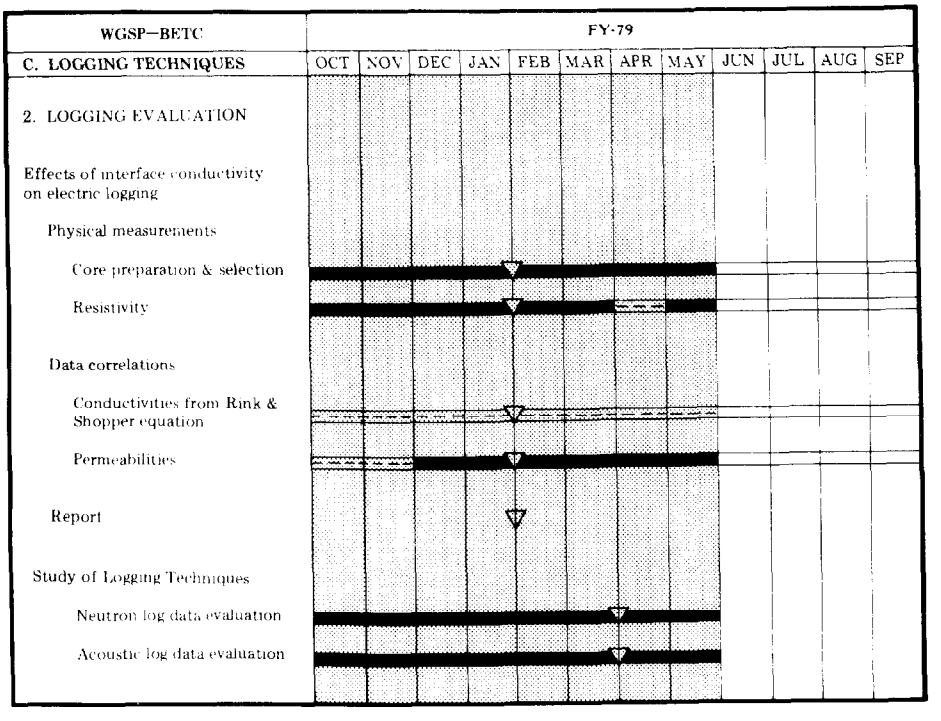
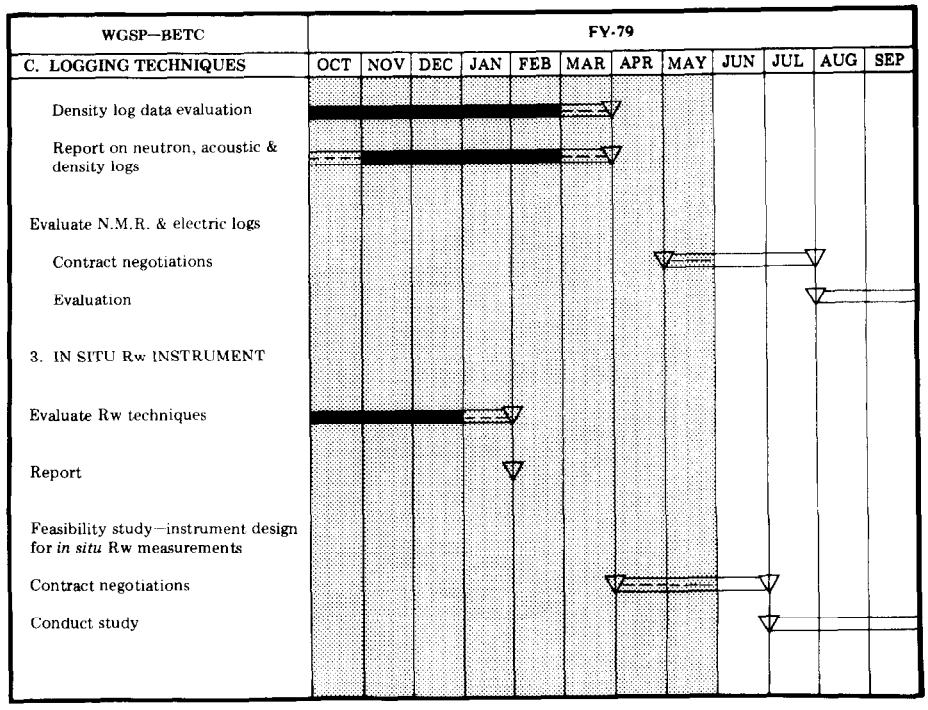


Figure 4-2 Continued



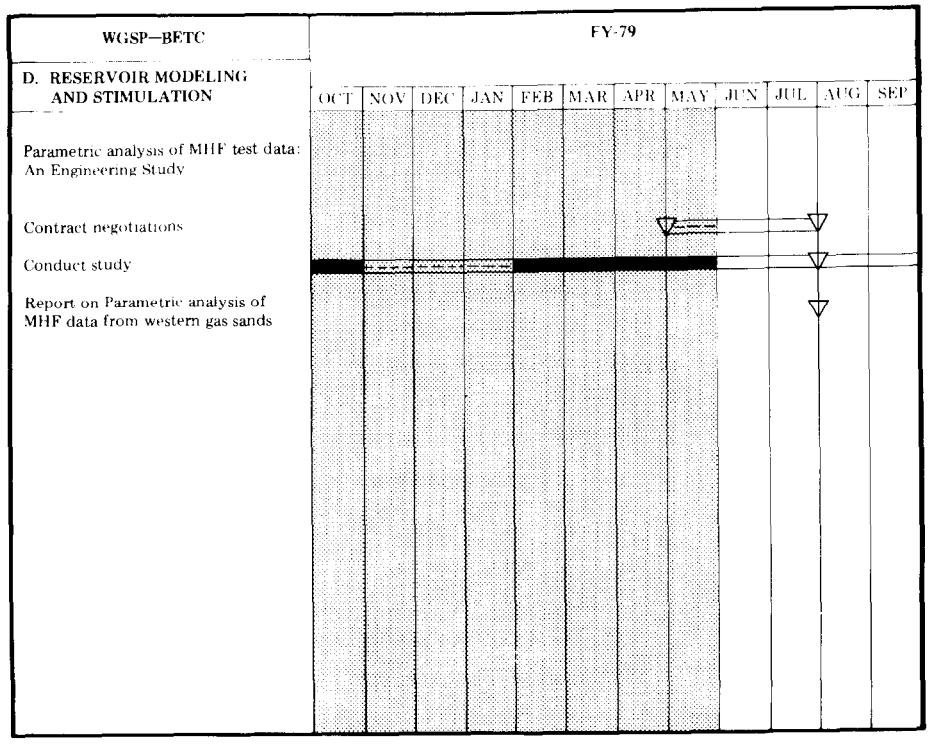


Figure 4-2 Continued

4.2.3 Log Analysis and Geology

A report has been completed on the logging evaluation of the Piceance Basin well (Twin Arrow, Inc., C&K 4-14, with some general logging observations. Log and core data from the Bowdoin Dome (Montana) of the Northern Great Plains Province have been assembled for evaluation and cross-plots. Density, neutron, and sonic porosity logs are available. High shale or clay content appears to distort gamma ray vs. sonic cross-plots so that porosities are greatly overstated.

4.2.4 Schedule Status

Figure 4-3 is a milestone chart depicting LLL project status through May, 1979.

4.3 SANDIA LABORATORIES

4.3.1 EGR Instrumentation and Diagnostic Program

4.3.1.1 Hydraulic Fracture Characterization

Analysis of data obtained from the seismic evaluation test of the borehole seismic unit at the Nevada Test Site is continuing. Selected events have been digitized and the onset of the seismic signal has been examined. It has been determined that mechanical resonances do not interfere with the unit's ability to determine the azimuthal direction to the seismic source. However, signals arriving at an angle greater than approximately 55° from the horizontal may produce large errors due to the low amplitude of the P-wave signal. This was found to be true for the system grouted in the tuff.

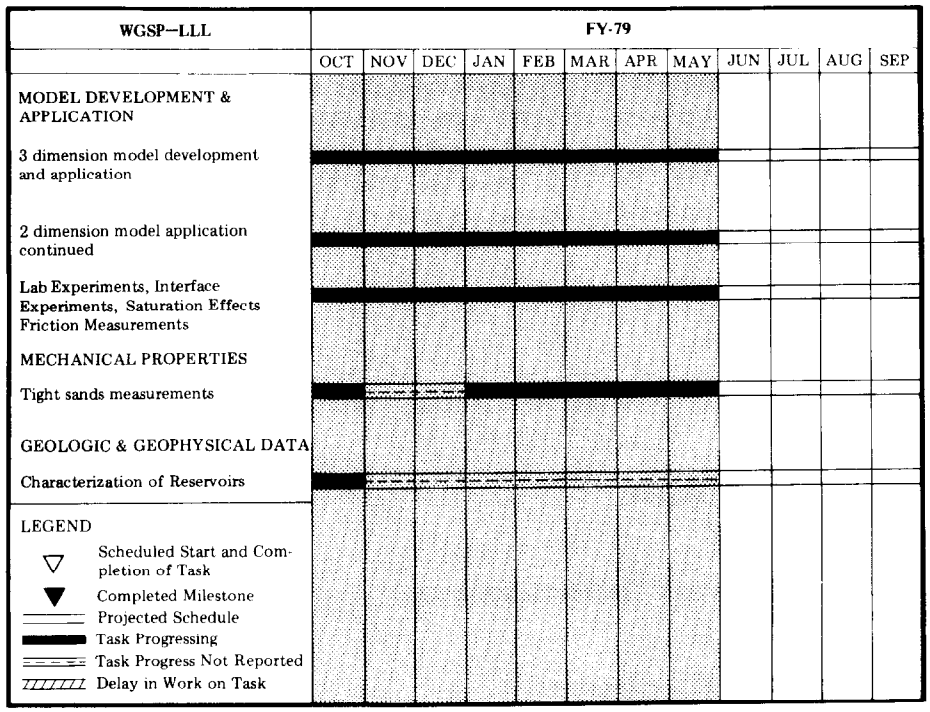
The S-wave onset is also detectable and apparently responsible for inducing the resonant ringing in the borehole seismic unit.

Further examination of the data is necessary to determine the accuracy of measuring the vertical angle to the seismic source and accuracy of predicting distance to the source.

4.3.1.2 Borehole Hydrophone System

Electrical testing to 10,000 psi of the Edo Western hydrophones has been completed. The data collected indicate that all the hydrophones do operate up to 10,000 psi and that the sensitivity is reduced at high pressures. Quantitative results on the reduction of sensitivity are difficult to determine because of poor acoustic coupling and resonance in the testing system. The complete 30 ft hydrophone system has been assembled and tested in the laboratory. It is functioning properly and preparations are being made for downhole testing.

Six hydrophone units fabricated by a second supplier will be shipped to Sandia Laboratories by June 15, 1979.



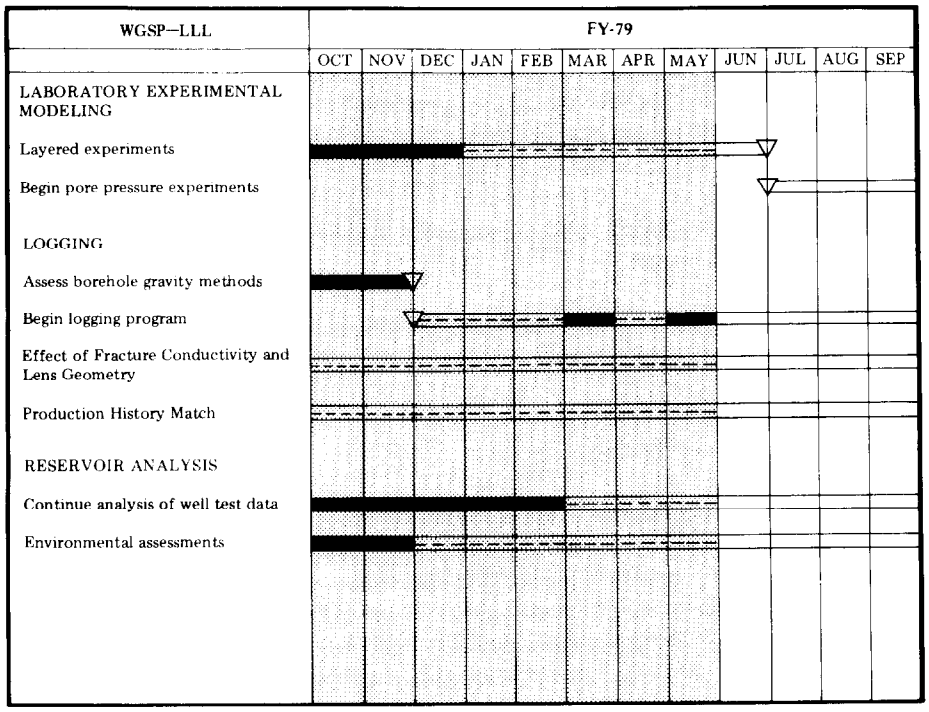


Figure 4-3 Milestone Chart — LLL

4.3.1.3 Formation Mapping

On May 24, C. L. Schuster and T. L. Dobecki of Sandia met with C. H. Atkinson (DOE), R. L. Mann and C. R. Appledorn (CER), and C. Boardman (C K GeoEnergy) at CER Corporation in Las Vegas, Nevada, to discuss the results of the preliminary site investigations and to develop a plan for the proposed seismic surveys. It was agreed that, although the topographic relief at site No. 1 presents formidable data acquisition problems, the sites are ideally suited to establishing the viability of state-of-the-art seismics in the context of channel sand exploration. Based on the results of this meeting, Sandia has prepared a specifications document for CER Corporation to follow in engaging a seismic contractor for the proposed survey.

C. Knutson (C K GeoEnergy) has been discussing the proposed drilling/seismic program with the Bureau of Land Management (Moab office), and no access problems are foreseen. He has also been working with Sandia in trying to obtain well logs in the area from state and private log files.

4.3.2 Schedule Status

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

4.4 GAS RESEARCH INSTITUTE ACTIVITIES

Synopses of potential projects have been prepared, and priorities for these projects established. These synopses were submitted to the Project Manager as an appendix to the Field Evaluation of Reservoir Fracturing, First Quarterly Report, February 1 to April 30, 1979 a draft copy of which has been submitted for review. The potential projects are as follows:

- Develop a data base for the Ouachita, Arkoma, and Val Verde Basins,
- Evaluation of seismic data for detailed stratigraphic studies of lenticular sands,
- Hydraulic fracture and testing of the Rio Blanco Natural Gas Company Government 397-1 well,
- Cost-shared, close-spaced multi-well assessment and stimulation testing in the Northern Great Plains Province.
- Core, log, fracture, and test a well in the Madden Unit, Wind River Basin, Wyoming,
- Cooperative work with DOE in a number of basins for which RFP's were being considered,
- Cooperation with industry research organizations who will not work under government contracts,

Final proposals have been received from Rio Blanco Natural Gas Company and Sandia Laboratories. The Rio Blanco Natural Gas Company proposal entails hydraulic fracturing, using high strength proppants, of the Government 397-1 well Rio Blanco County, Colorado. The Sandia proposal asks for support to develop seismic stratigraphic modeling of lenticular sands in the Mesaverde Group of the eastern Uinta Basin, Utah. Both proposals will be included in a Project Plan that is in preparation.

A meeting was held in Denver, Colorado on May 22, 1979, to discuss the Rio Blanco Natural Gas Company proposal. BETC and Dowell agreed to obtain samples of Mesaverde cores from the Rio Blanco area in order to run fracture conductivity, fracture closure, proppant strength, and regained permeability tests for the zones of interest in the proposed fracture treatment of the Government 397-1 well.

Preliminary design work has begun on a DOE-financed experimental multi-well fracturing project for the Uinta or Piceance Basin. Areas of possible GRI-DOE cooperation in the conduct of this long-term (three or more years) effort will be identified.

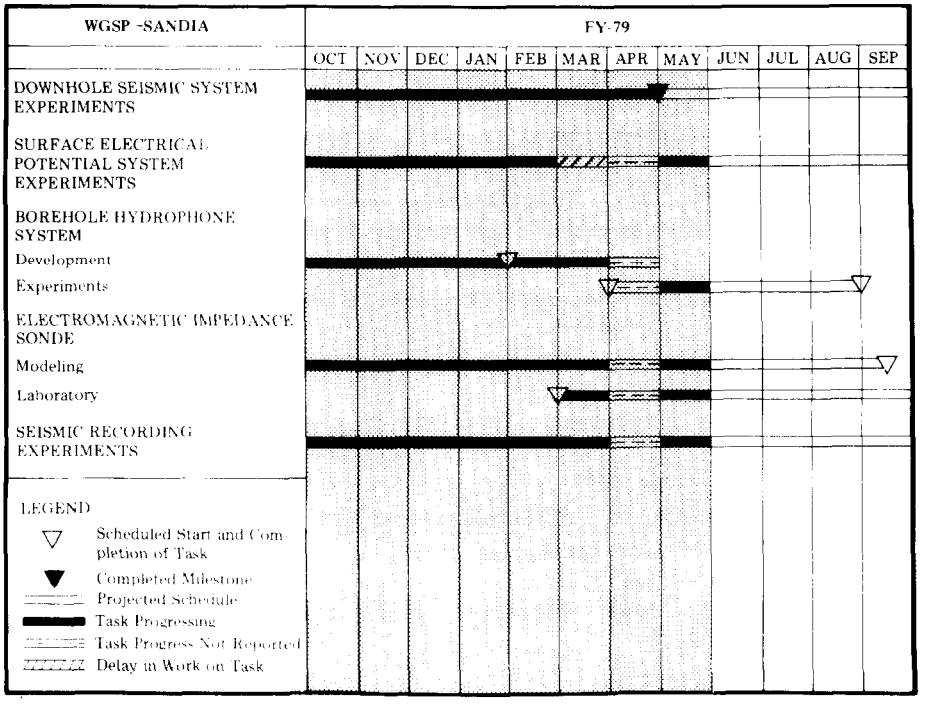


Figure 4-4 Milestone Chart — Sandia

5. FIELD TESTS AND DEMONSTRATIONS

5.1 BACKGROUND

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 arrangement to perform additional tests, and for final disposition of the well. The 3 volume final report on the RB-MHF 3 was distributed in April.

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

Table 5-1 MHF Contract Locations and Frac Data

COMPANY, BASIN & FORMATION	LOCATION T/R/Sec	WELL	INTERVAL FRACTURED ft	FRAC DATE	FRAC TREATMENT Lb of Sand	INJECTED FLUID 10^3 Gal
AUSTRAL Piceance, Mesaverde	7S/94W, Sec 3 Garfield Cty Colorado	Federal 3-94	5,170- 6,333	8-25-76	1,140,000	542 Gel Gel H O
CONSORTIUM MANAGED BY CER CORPORATION Piceance, Mesaverde	3S/98W, Sec 11 Rio Blanco Cty Colorado	RB-MHF-3	8,048- 8,078 7,760- 7,864 5,925- 6,016 5,851- 5,869	10-25-74 5- 2-76 5- 4-76 11- 3-76	400,000 880,000 815,000 448,000	117 Gel 285 Gel 400 Gel 228 Gel
GAS PRODUCING ENTERPRISES, INC. Uinta, Wasatch and Mesaverde	10S/22E/Sec 10 Uintah Cty Utah	Natural Buttes No. 18	6,490- 8,952	9-22-76	1,480,000	745 Gel
	10S/21E/Sec 21 Uintah Cty Utah	Natural Buttes No. 19	8,909- 9,664 7,224- 8,676	9-21-76 9-28-76	424,000 784,000	280 Gel 364 Gel
	9S/21E/Sec 22 Uintah Cty Utah	Natural Buttes No. 14	6,646- 8,004	3-15-77	1,093,000	544 Gel
	9S/21E/Sec 28 Uintah Cty Utah	Natural Buttes No. 20	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	1,091,000	479 Gel
	9S/21E/Sec 19 Uintah Cty Utah	Natural Buttes No. 9	5,661- 8,934	3-27-78	554,000	349 Gel
	10S/21E/Sec 29 Uintah Cty Utah	Natural Buttes No. 2	7,251- 8,774	8- 8-78	1,965,000	722 Gel
	10S/22E/Sec 7 Uintah Cty Utah	Natural Buttes No. 23	5,080- 6,294	10- 4-78	440,000	240 Gel
DALLAS PRODUCTION Fort Worth, Bend Cong.	Ben D. Smith Survey A-779 Wise Cty Texas	Ferguson A-1	5,957- 6,794	9-10-76	506,000	139 Foam 198 Emul
EL PASO NATL. GAS Northern Green River, Fort Union	30N/108W/Sec 5 Sublette Cty Wyoming	Pinedale Unit No. 5	10,950-11,180 10,120-10,790	7- 2-75 5- 6-75	518,000 1,422,000	183 Emul 8 Gel 459 Gel
MITCHELL ENERGY Cotton Valley, Limestone Trend	Limestone Cty Texas	Muse-Duke No. 1	11,220-11,430	11-15-78	2,800,000	891 Gel
MOBIL Piceance, Mesaverde	2S/97W/Sec 13 Rio Blanco Cty Colorado	F-31-13G	10,549-10,680 9,392- 9,538 8,765- 8,972 8,163- 8,650 7,704- 7,794 7,324- 7,476	6-22-77 8-24-77 5-10-78 7- 6-78 9- 7-78 11-15-78	580,000 600,000 388,000 660,000 218,000 700,000	316 Gel 260 Gel 150 Gel 288 Gel 120 Gel 365 Gel
PACIFIC TRANSMISSION Uinta, Mesaverde	8S/23E/Sec 25 Uintah Cty Utah	Federal 23-25	NO FRACS PERFORMED			
RIO BLANCO NATL. GAS Piceance, Mesaverde	4S/98W/Sec 4 Rio Blanco Cty Colorado	Federal 498-4-1	6,150- 6,312 5,376- 5,960	10-22-76 11-30-77	766,000 243,000+ 22,500 Beads	276 Gel 164 Gel
WESTCO Uinta, Mesaverde	10S/19E/Sec 34 Uintah Cty Utah	Home Fed No. 1	7,826- 9,437 10,014-10,202	12-21-76 10- 1-76	500,000 600,000	412 Gel 248 Gel

RIO BLANCO MASSIVE HYDRAULIC FRACTURING EXPERIMENT

EY-76-C-08-0623

CER Corporation
Las Vegas, Nevada

Status: Awaiting Advisory Committee Decision

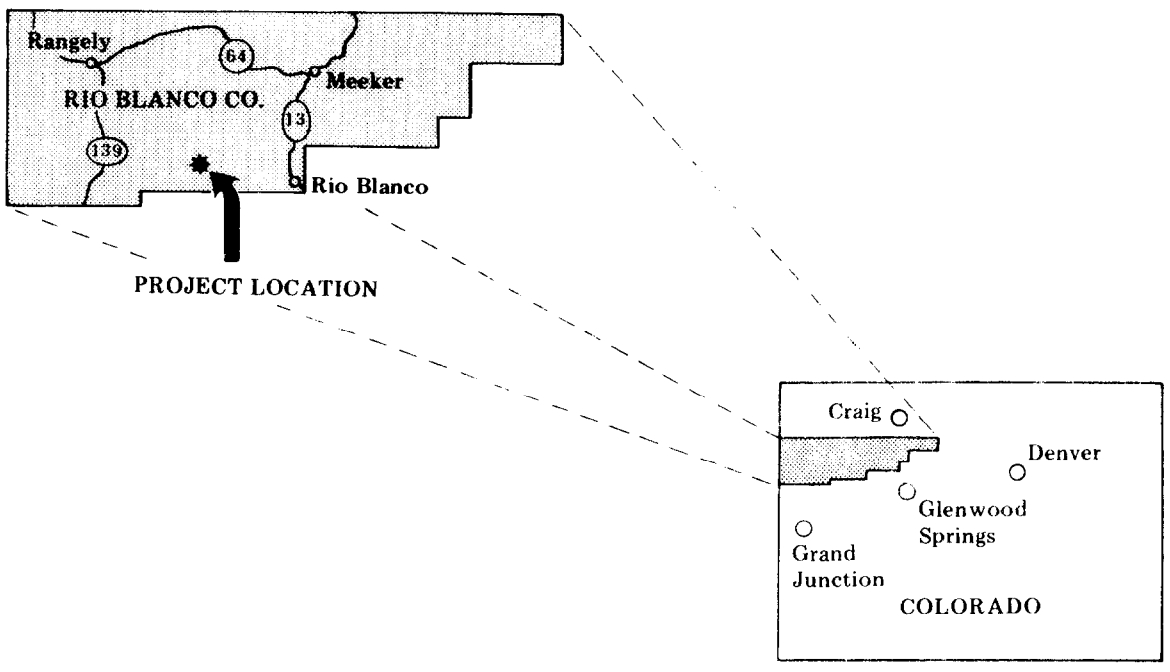
Interagency Agreement Date: June 19, 1974
Anticipated Completion Date: July 1, 1979

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 MHF treatments and extended the term of the contract.

Field activities 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 was released in April.

WATTENBERG FIELD — EY-77-C-08-1514

Colorado Interstate Gas Company
Colorado Springs, Colorado

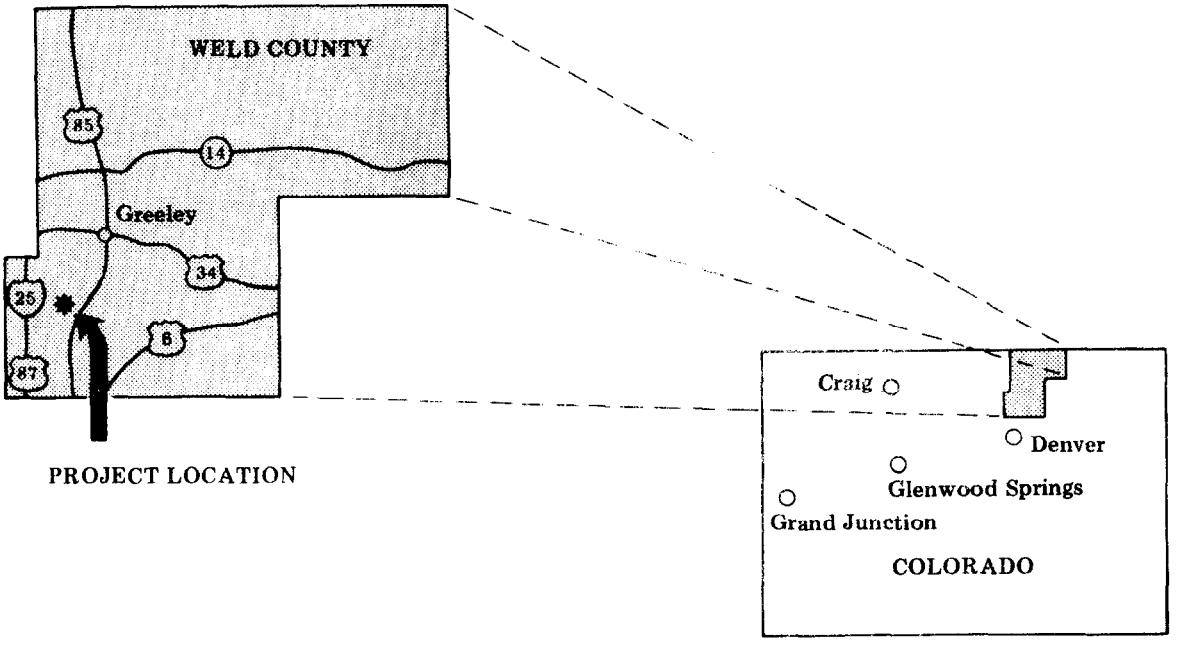
Status: Active

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

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

OBJECTIVE

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



5.3 COLORADO INTERSTATE GAS COMPANY

DOE and Colorado Interstate Gas Company (CIG) entered into Contract No. EY-77-C-08-1514 on September 1, 1977. The experiment will determine if productivity of wells completed in low-permeabilty 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.

The final bottom-hole pressure for the Miller No. 1 well was 1,088 psi and the Sprague No. 1 well was 1,050 psi. The pressure bomb was removed from the Sprague No. 1 well on May 13, 1979.

An attempt was made to begin gas cycling operations on May 16. The Miller No. 1 well was put on production May 17, at which time the compressor shut down due to lack of pressure because the regulator on CIG's line failed to open. Bottom-hole pressure was 406 psi when the Miller No. 1 well stopped producing. The wellhead pressure at the Sprague No. 1 well as measured at the compressor discharge was about 1,300 lb. The dew point of the gas being injected into the Sprague No. 1 well was measured at the discharge of the dehydrator and amounted to 4.5 lb per million cubic feet. An additional problem was incurred when the producer's separator failed and the system was flooded with liquid hydrocarbons. It was difficult to maintain inlet pressure to the compressor between 80 and 200 lb because of the speed at which the pressuere at the Miller No. 1 well dropped.

It is planned to add a back-pressure regulator on the inlet side of the compressor in order to have better pressure control. Several small leaks have developed and will be repaired.

DOE WELL TEST FACILITY

EY-76-C-08-0623

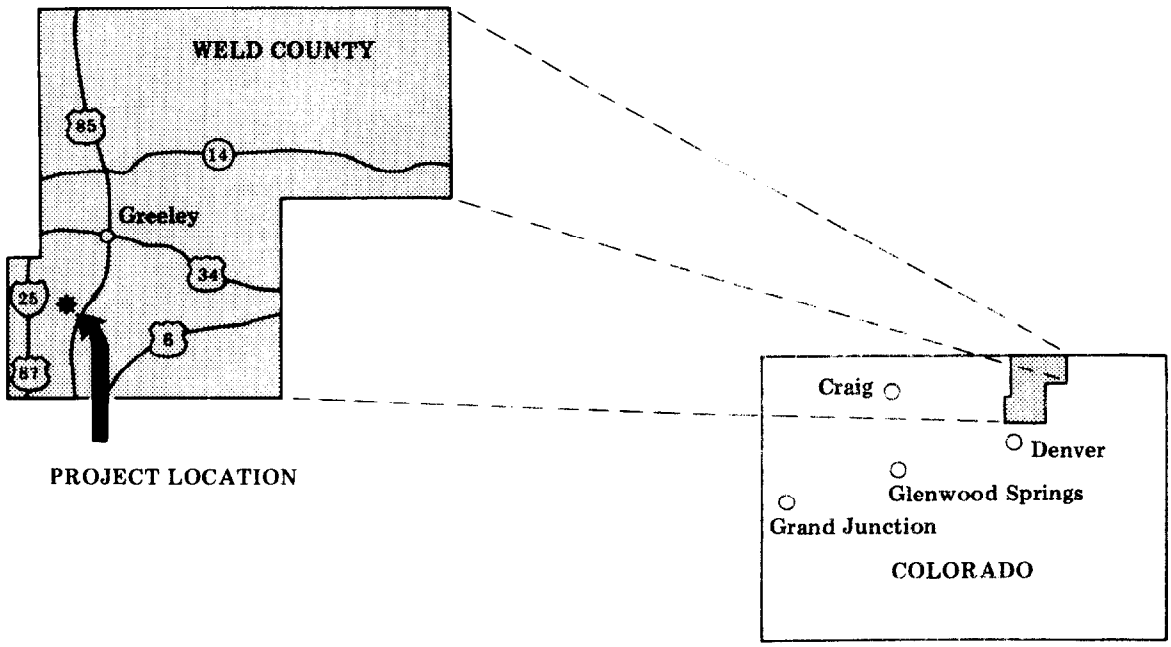
CER Corporation
Las Vegas, Nevada

Status: Equipment checkout and test proceeding

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

OBJECTIVE

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



5.4 DOE WELL TEST FACILITY

The cyclic gas injection project of Colorado Interstate Gas Company was halted since the valving and piping to supply the pipeline gas to the compressor had not been installed. Changes in field operations must be made in order to maintain adequate field records.

Arrangements were made to install a temporary radio telephone in the trailer and pickup truck from Industrial Communications Company of Vernal, Utah.

For possible production tests in conjunction with reservoir evaluation work by CK Geo-Energy Corporation, Belco wells in Section 3, 14, 25 and 26, T9S, R22E were inspected and the following was determined:

- The well in Section 3 is not accessible to the 10 x 50 ft trailer.
- Two wells exist in Section 14.
- All wells are producing with the exception of the well in Section 25 which is an ideal well to work on. However, no well completion data is available at this time.

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

EY-76-C-08-0681

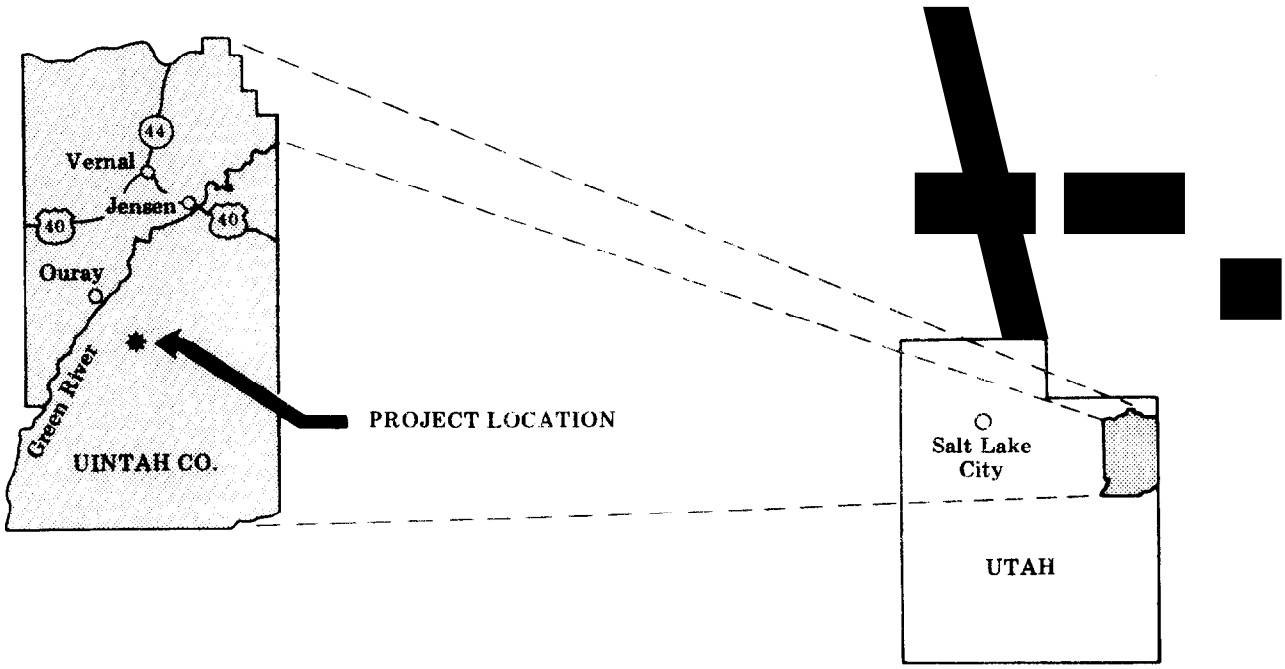
Gas Producing Enterprises, Inc.
Subsidiary of Coastal States Gas Co.
Houston, Texas

Status: Active

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

OBJECTIVE

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



5.5 GAS PRODUCING ENTERPRISES, INC.

The GPE wells, Natural Buttes Units 9, 14, 18 and 19 have been flowing to sales. Natural Buttes Unit No. 20 and No. 21 were shut in, and Natural Buttes Unit No. 22 flooded out. Figures 5-1 through 5-6 show production figures.

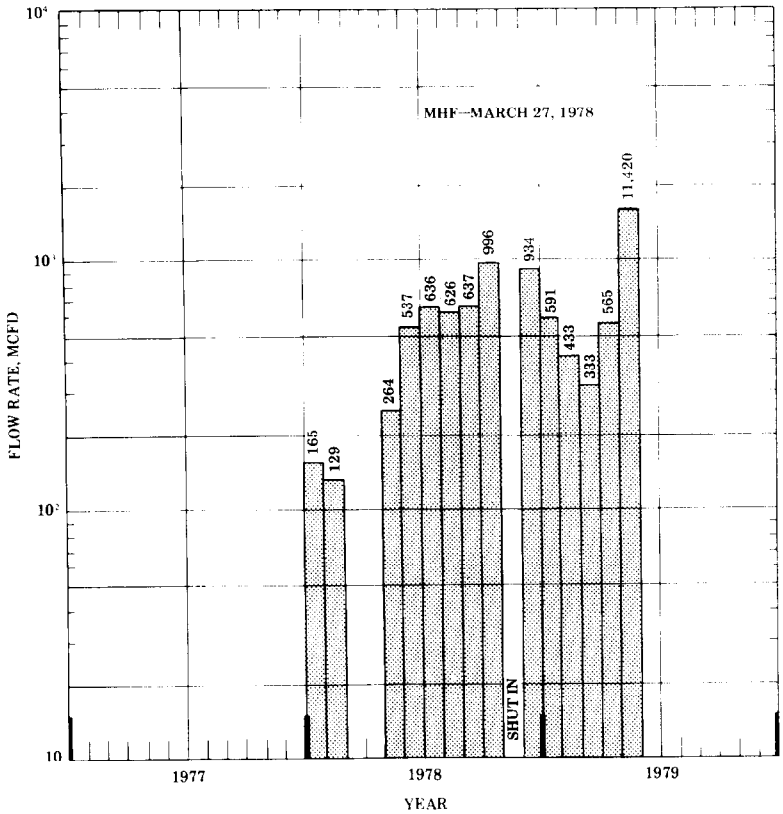


Figure 5-1
Flow Rate Performance of Natural Buttes No. 9 Well

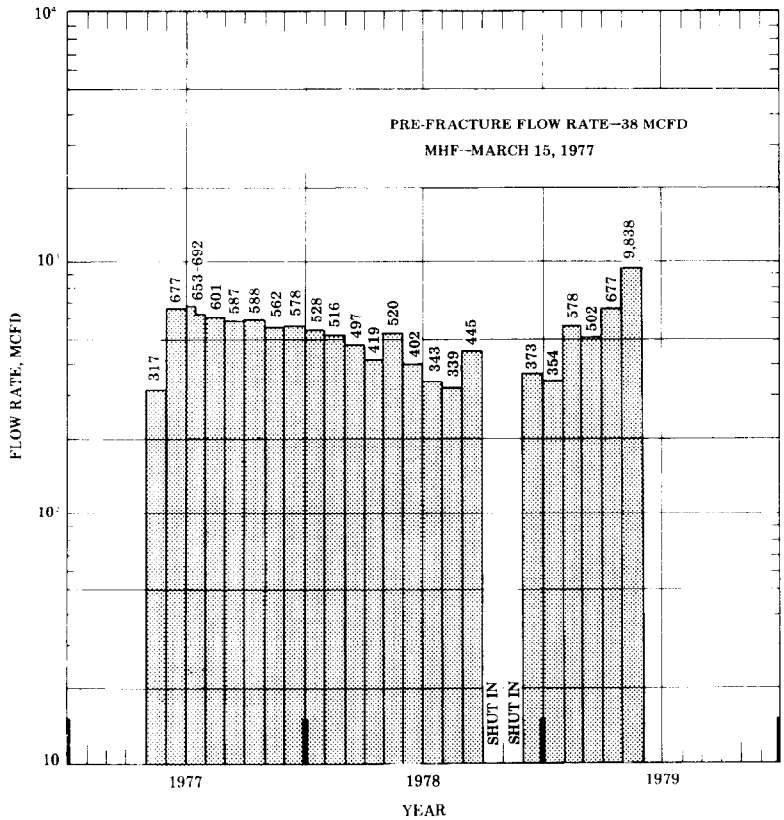
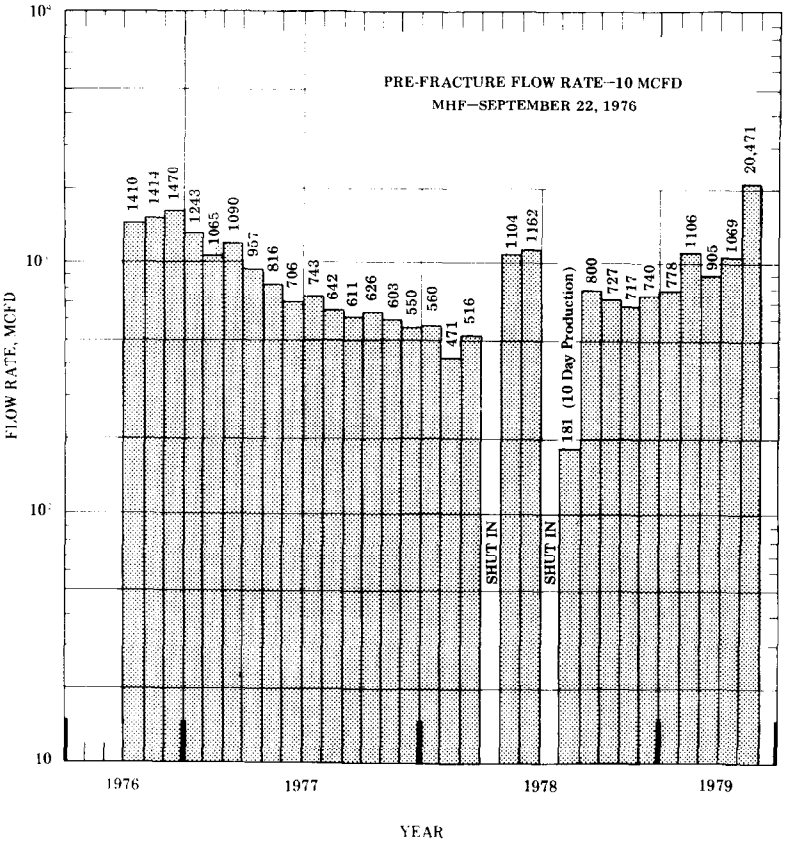


Figure 5-2
Flow Rate Performance of Natural Buttes No. 14 Well

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



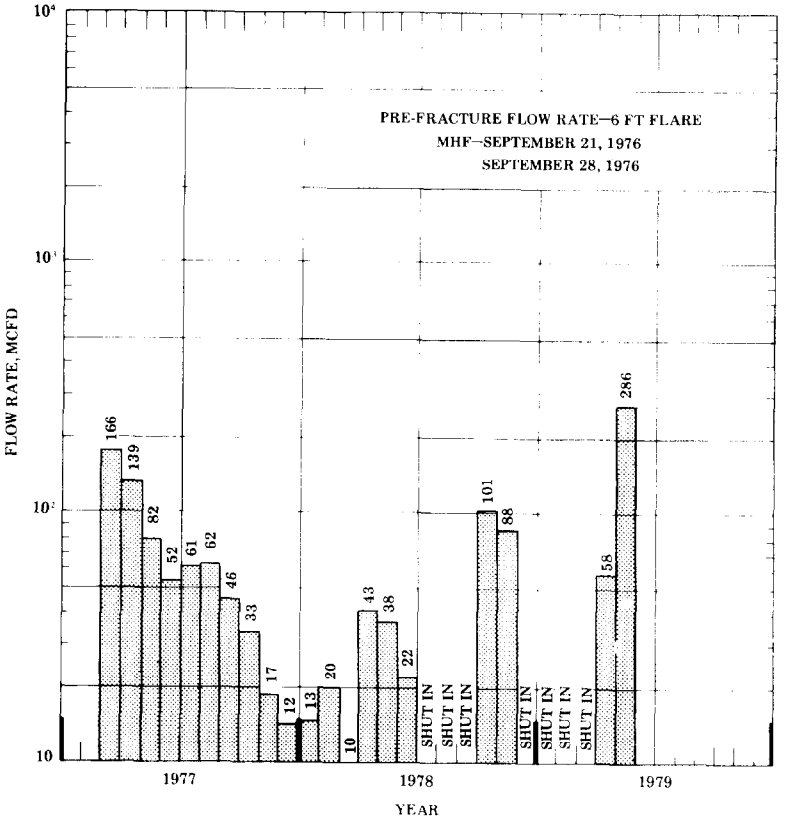


Figure 5-4
Flow Rate Performance of Natural Buttes No. 19 Well

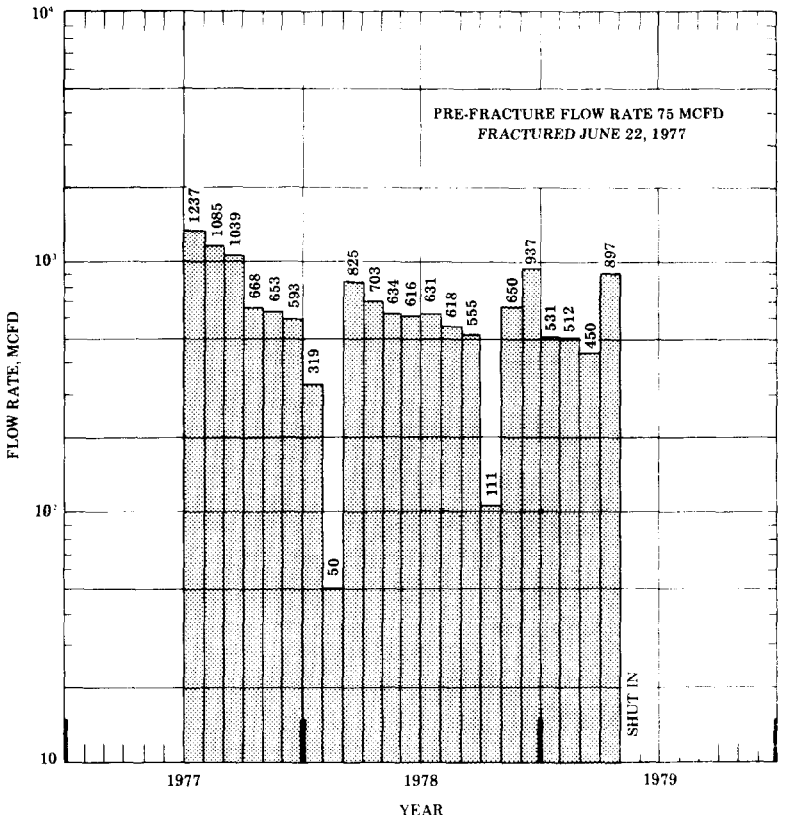


Figure 5-5
Flow Rate Performance of Natural Buttes No. 20 Well

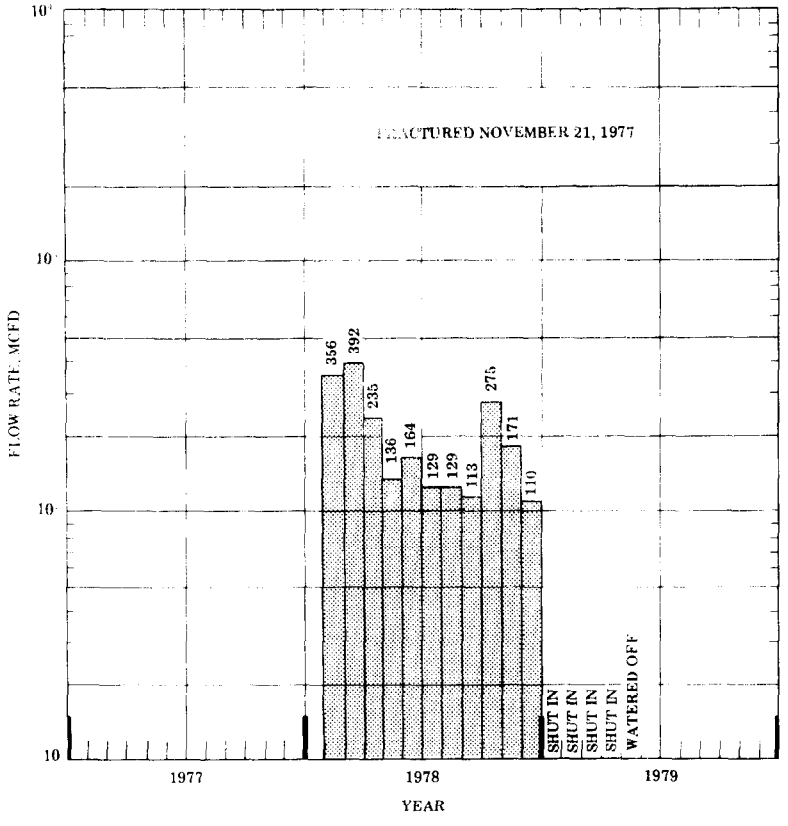


Figure 5-6
Flow Rate Performance of Natural Buttes No. 22 Well

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

EF-78-C-08-1547

Mitchell Energy Corporation
Houston, Texas

Status: Active

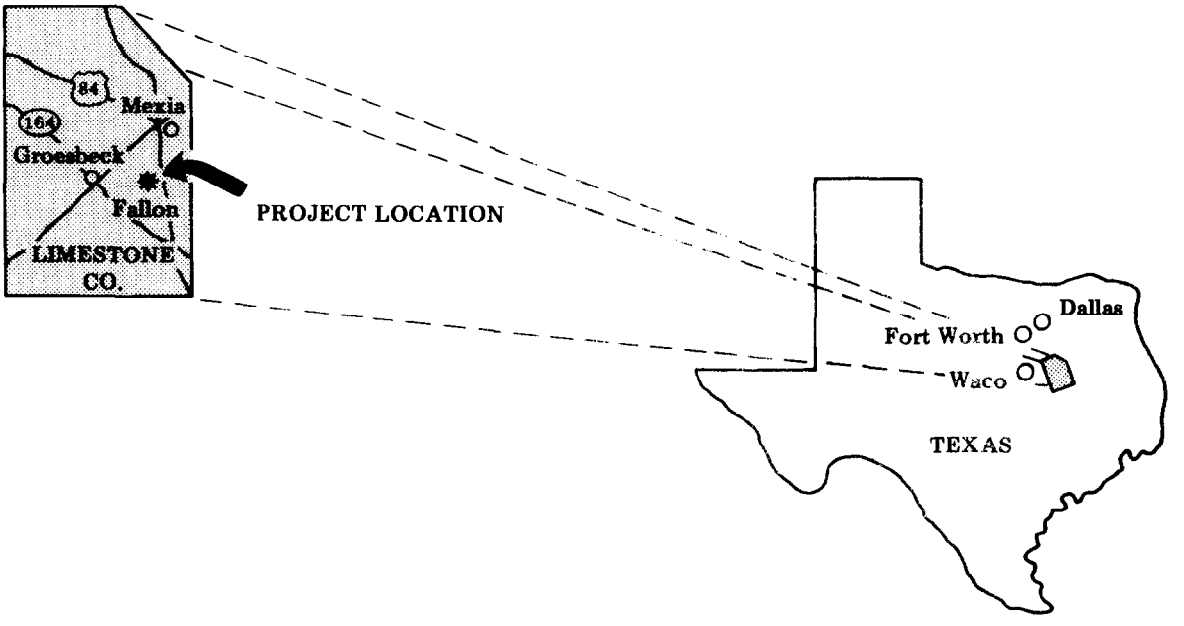
Contract Date:	March 15, 1978
Anticipated Completion:	April 30, 1979

Total Project Cost (estimated):	DOE	$ 553,771
	Industry	1,074,550
	Total	$1,628,321

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

OBJECTIVE

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



5.6 MITCHELL ENERGY CORPORATION

The Mitchell Energy Corporation Muse-Duke No. 1 well flowed 3,500 MCFD and 19 BBL of frac water through a 24/64 in. choke with a flowing tubing pressure of 1,000 psi. To date, production performance has been as expected.

No additional work or testing was performed in May and shut-in of the well to complete the scheduled post pressure transient tests had not occurred.

PICEANCE CREEK FIELD, COLORADO, MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

EY-76-C-08-0678

Mobil Research and Development Corporation
Dallas, Texas

Status: Active

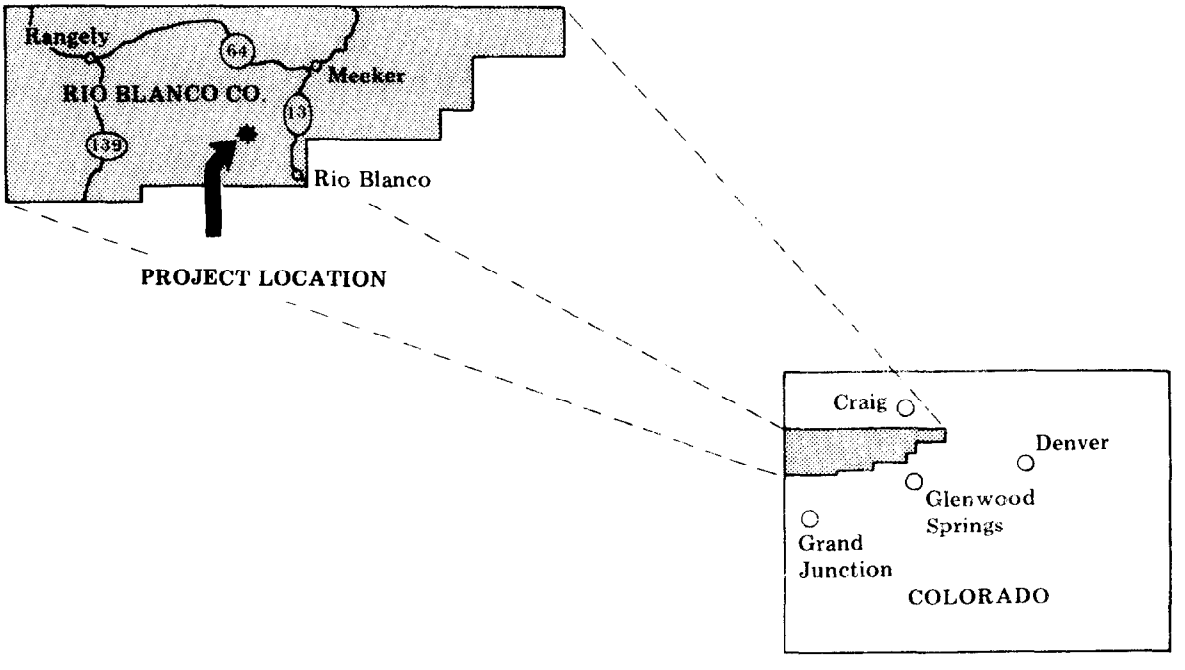
Contract Date:	July 1, 1976
Anticipated Completion:	June 1st 1979

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.



5.7 MOBIL RESEARCH AND DEVELOPMENT CORPORATION

Fishing operations resumed on the PCU F31-13G well on May 7. The well was blown to the pit for several hours until sand cut out the choke. Casing pressure was 2,050 psi initially and declined to 1,350 psi when the well was killed with 2 percent KCl water. During May 7-11, a tight spot in the casing at 7,351 ft was worked out with a 6-1/8 in. swage.

Wash pipe was run over the fish down to the 5-3/4 in. OD overshot at about 8,812 ft. At that point, several attempts to recover all or part of the fish failed. A 1-3/4 in. OD Dia-Log wireline-operated wash pipe was then run through the fish to remove the sand fill which was blocking access to the interior of the fish. This operation began on May 15 and appeared to be succeeding until the wash pipe became stuck in the fish on May 17. During the period May 18-31, attempts to recover the small and large fish failed.

RIO BLANCO COUNTY, COLORADO MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

EY-76-C-08-0677

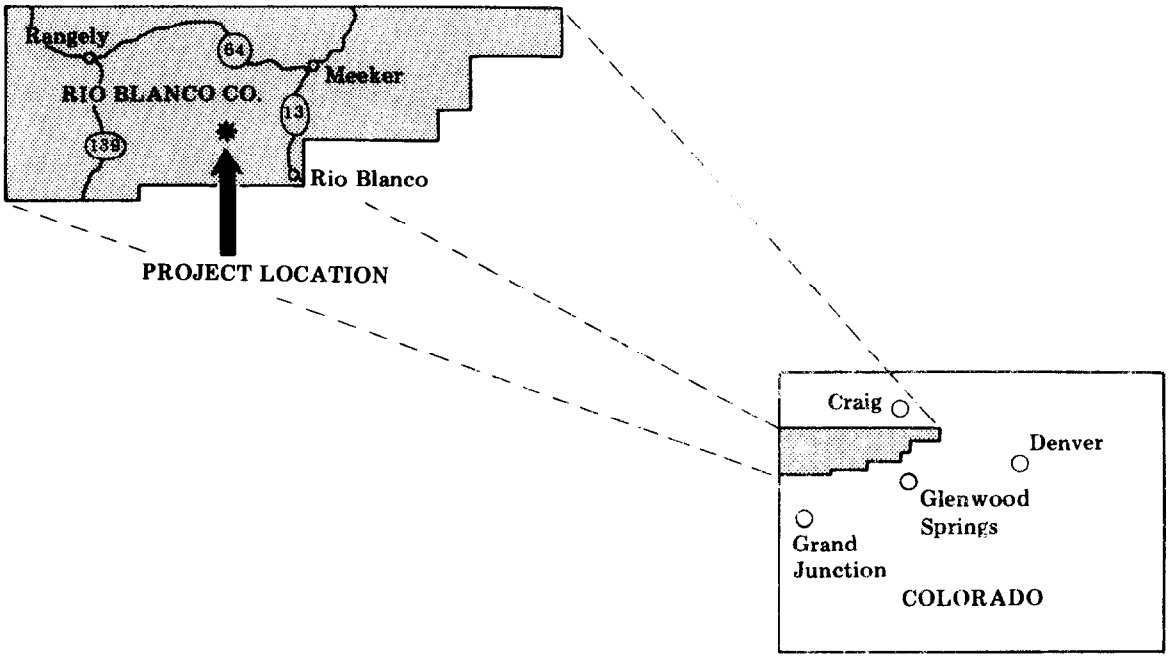
Rio Blanco Natural Gas Company
Denver, Colorado

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 being prepared.

NEVADA TEST SITE
NYE COUNTY, NEVADA
MINEBACK TESTING

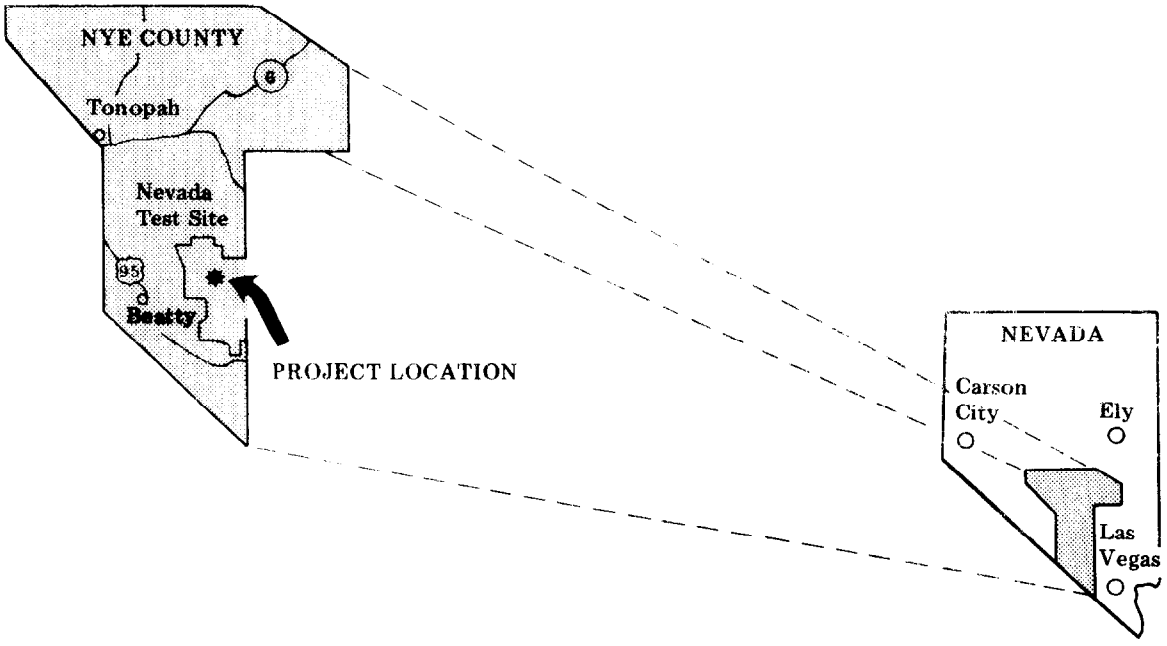
Sandia Laboratories
Albuquerque, New Mexico

Status: Active

Principal Investigator: D. A. Northrop

OBJECTIVE

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



5.9 SANDIA LABORATORIES MINEBACK

5.9.1 Summary of Past Activities

Exploratory coring of the Hole No. 6 experiment was restarted in April. Six zones of the first horizontal experimental hole (CFE-1) were fractured, and mined back in April to examine the behavior of the fractures at the interface. Results of the mineback showed that all six fractures broke through the interfaces without change in orientation or behavior.

5.9.2 Current Status

5.9.2.1 Hydraulic Fracturing Containment Experiments

The exploratory coring program to determine the overall shape of the Hole No. 6 fractures continued in May. As shown in Figure 5-7, EV6-23 located gray grout about 140 ft below the interface. The thickness of the fracture is about 5 mm at this point so that the fracture is still quite prominent. Another hole, EV6-24, will be directed 50 ft below EV6-23 to try to locate the lower extremity of this fracture. It appears that a sizable proportion of the grout went downward, but it is not certain whether this was due to the effect of the grout's density, the interface, or the in situ stress distribution.

The second hole of the Interface Test Series (designated CFE-2) was fractured in four zones during May. Two of the zones were fractured at 4 gpm and the other two at 2 gpm (the first hole, CFE-1, was fractured at 8 gpm) to test the effect of the flow rate on the containment of a hydraulic fracture at a material property interface. The location of CFE-2 with respect to CFE-1 and the Hole No. 6 fractures is shown in Figure 5-8. The hole was drilled at $+9^{o}$ to keep it relatively close to the interface which has a dip of $\sim 11^{o}$. The zone at 70 ft is projected to be about 8.5 ft below the interface and the zone at 20 ft is about 5 ft below the interface. Although there were no observed fractured zones in the core, not a single breakdown peak was obtained during fracturing. The pressures were also abnormally high for this region. The fracturing pressures from Hole No. 6 were 400-700 psi, 500-700 psi from CFE-1, but in CFE-2 they were approximately 1,100, 1,400, 1,000 and 700 psi for the 70, 50, 25 and 20 ft zones, respectively. Mineback and analysis of the fracturing will begin in June.

5.9.2.2 Modeling and Analysis

Several alternative approaches were discussed on stress analysis of a crack approaching an interface and a more realistic failure criterion for this problem emerged. The criterion was based on a critical stress level at the crack tip, averaged over the length of the microcrack zone as predicted by Sandia's microcrack model. This criterion can be applied to discrete and smeared interfaces, and may apply to unbonded as well as bonded interfaces.

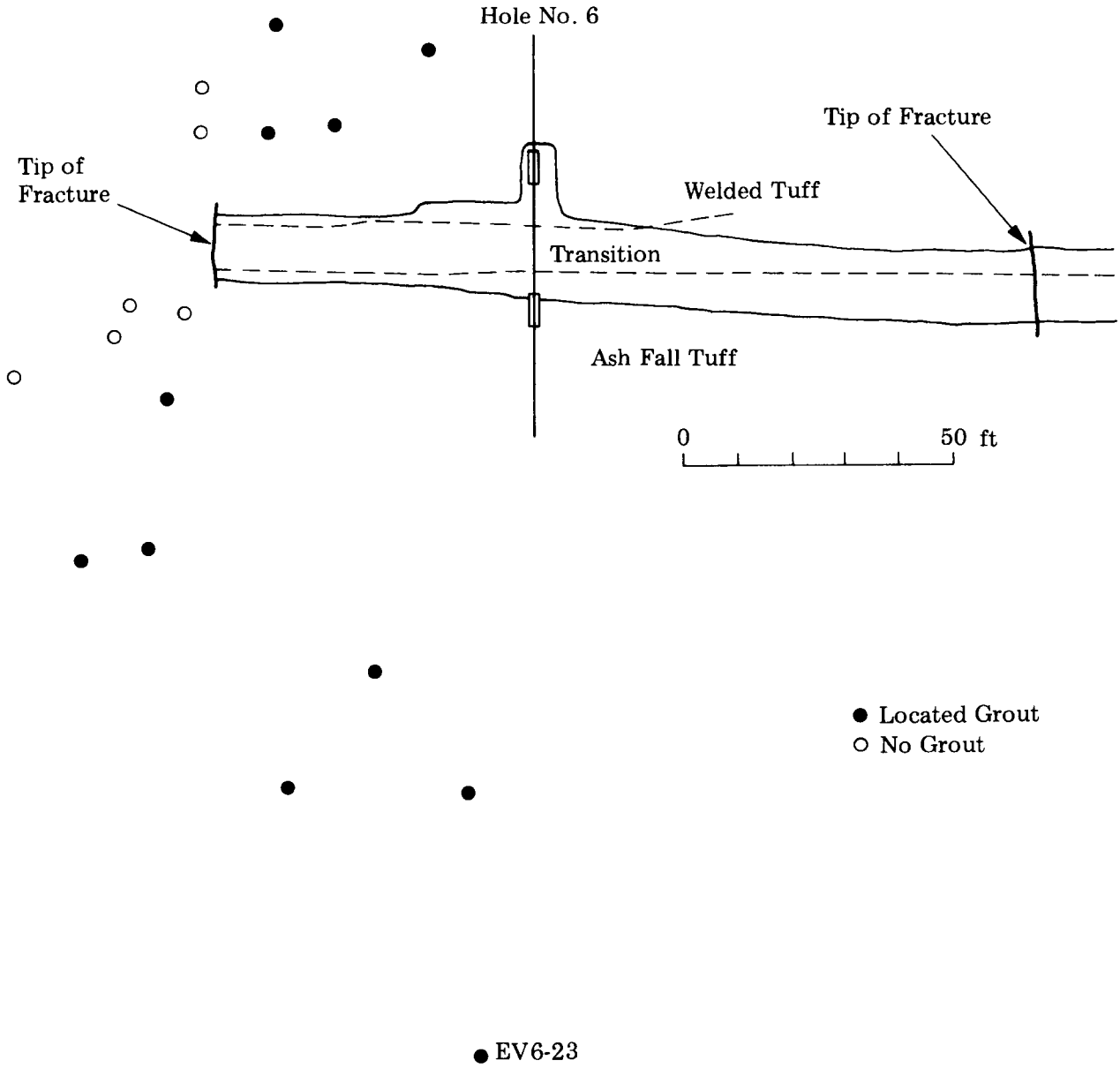


Figure 5-7 Results of Exploratory Coring for the Hole No. 6 Formation Interface Experiment

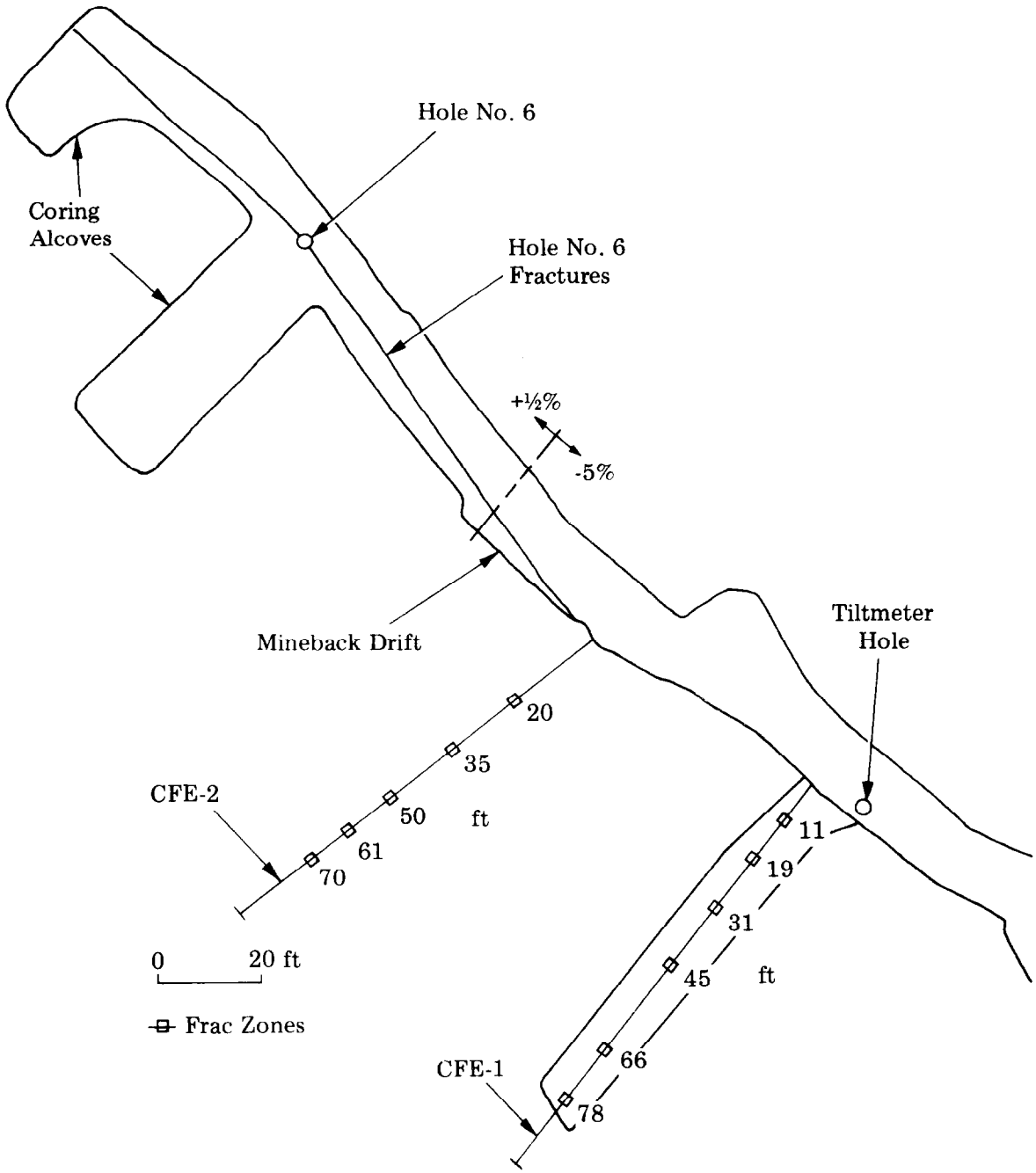


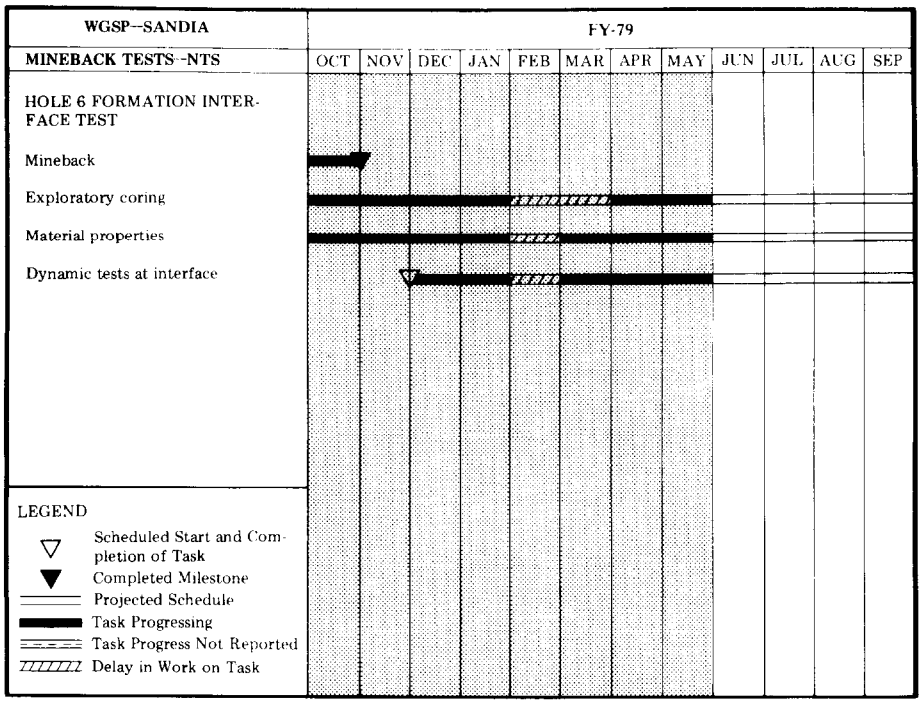
Figure 5-8 Location of CFE-2 with respect to CFE-1 and Hole No. 6

Calculations based on this approach are needed, followed by verification with experiments. These experiments include the mineback experiments at the Nevada Test Site (Hole No. 6 and Crack'r Frac), published laboratory investigations, and experiments being conducted presently on concrete and rock samples by Dr. Ingraffea at Cornell University. Dr. Ingraffea's experiments are being conducted by contract to Sandia and this month's progress included check out of the testing equipment and special setup for these tests. Dry run specimens of rock and concrete also were fabricated.

A suitable method of convergence for the solution of the system of equations of the fluid dynamics of fracturing has still not been constructed. The dynamic terms are the source of the problem since the system of equations converges readily when they are omitted and the flow through a stationary crack is considered. Since the dynamic terms are dominant only for relatively short times (they may be important over a fairly long time frame, but not to the extent that they control the problem for short times) the problem is essentially one of starting the calculations. With longer times, the solution should converge easily.

5.9.3 Schedule Status

Figure 5-9 is a milestone chart of Sandia mineback progress.



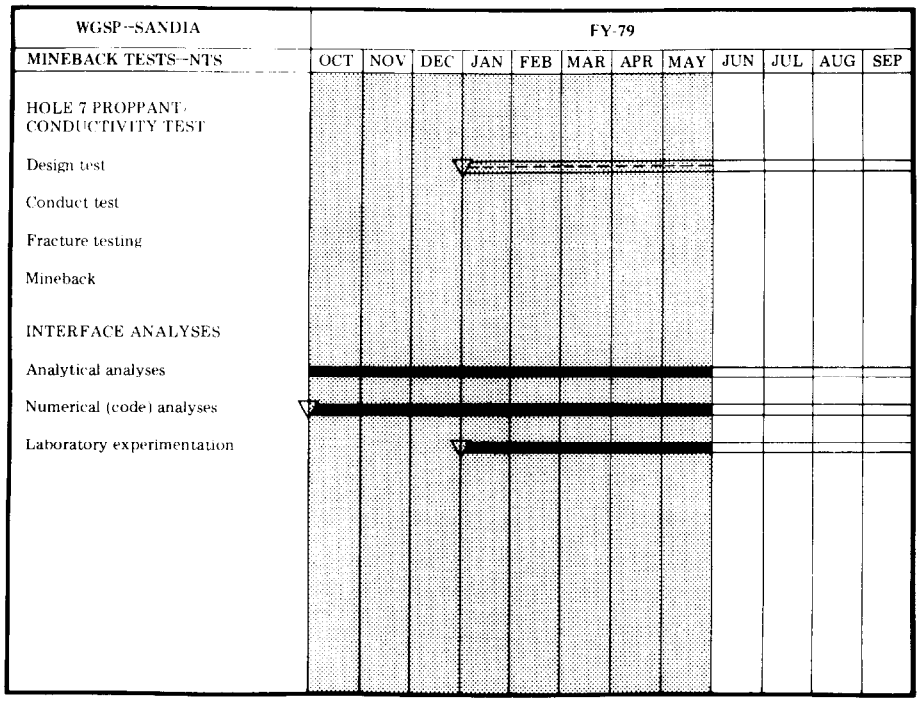


Figure 5-9 Milestone Chart — Sandia Mineback