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Western Gas Sands Project Status Report

November 30, 1978

Prepared for
U.S. Department of Energy
Bartlesville Energy Technology Center
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Project Manager

Compiled by CER Corporation
Las Vegas, Nevada

Contract EY-76-C-08-0655

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1. SUMMARY

This edition of the WGSP Status Report summarizes the progress during October, 1978 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, NVO/0655-100.

A Technology Implementation Plan (TIP) meeting was held at the CER office in Las Vegas, Nevada, October 16-19 to initiate the implementation phase of the Enhanced Gas Recovery (EGR) working group activities.

A WGSP Logging Program meeting was conducted on October 24, 1978 at CER offices to define the problems associated with logs in tight gas sands.

CER personnel and the project manager attended a two-day course on the fundamentals of core and reservoir analysis in Denver, Colorado, and met with USGS personnel to discuss USGS work on the WGSP.

A meeting was held to discuss a contract for coring a Twin Arrow well on the Douglas Creek Arch, Colorado.

CER Corporation personnel attended the Geological Society of America Annual Meeting held in Toronto, Canada, October 23-27 and a Gas Stimulation Workshop at Sandia Laboratories in Albuquerque, New Mexico, October 11 and 12 to discuss recent mineback experiments conducted at the Nevada Test Site.

Fiscal year 1979 projects initiated by USGS and the Energy Technology Centers and National Laboratories are progressing as scheduled.

The USGS has expanded the boundaries of the Northern Great Plains Province to include the entire states of North and South Dakota.

Mobil Research and Development Corporation fractured zone 8 of the F-31-13G well in Rio Blanco County, Colorado. Colorado Interstate Gas Company poured the concrete pad for the compressor expected to be delivered in December and were laying pipeline between the wells at month end. The Mitchell Energy well, Muse Duke No. 1 was flowing on test at a rate of 2,100 MCFD and preparations proceeded to fracture the well on November 15 with approximately 1,000,000 gal of fluid and 3,000,000 lb of sand. Terra Tek completed laboratory analyses of cores taken from the Mitchell Energy well.

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2. PROJECT MANAGEMENT

2.1 TECHNICAL MONITORING AND EVALUATION

Representatives of DOE, CER, Booz-Allen, Lewin & Associates, TRW, CK GeoEnergy and Commercialization Insights met in Las Vegas October 16-19 to initiate the TIP phase of the EGR Working Group activities. A list of participants appears below.

Charles Atkinson	DOE - NV
Alex Crawley	DOE - HQ
Robert Johansen	DOE - BETC
Conrad Appledorn	CER Corporation
Gerald Luetkehans	CER Corporation
Robert Mann	CER Corporation
John Boyer	Booz-Allen & Hamilton
Frank Gentry	Booz-Allen & Hamilton
Walt Holman	Booz-Allen & Hamilton
Jerry Brashear	Lewin & Associates
Lloyd Elkins	Lewin & Associates (consultant)
William Bailey	TRW
Carroll Knutson	CK GeoEnergy
Charles Ware	Commercialization Insights

Work included an expansion of the initial Strategic Plan and development of a comprehensive tactical plan for the technology development activities necessary to realize the goals of the projects delineated in the Strategic Plan—Volume I for the WGSP. The TIP will function as a monitoring tool for DOE - HQ and budget authorities to determine and evaluate progress. In addition, the TIP will be used by HQ as the primary management tool for the initiation of new projects, redirection of existing projects and the allocation of supplemental funds. Finalization of the TIP is scheduled in October, 1979.

The WGSP Log Program meeting was held at CER offices, October 24, 1978. The purpose of the meeting was to discuss the *WGSP Logging Program Document, August 14, 1978*, and to define the problems inherent with logs in tight gas sands.

The meeting is discussed in greater detail in Section 3.3, "Log Program" of this report.

D. C. Bleakly, H. E. Newman and L. T. Hodges, CER personnel, and C. H. Atkinson, attended a two-day course on core analysis in Denver, Colorado, October 30-31. The course reviewed physical characteristics of reservoir rock, the makeup and mechanics of the fluid content and flow, sampling and preservation procedures, laboratory measurements and equipment, the interpretation of core data, special rock properties and applications.

Following the core analysis course, D. C. Bleakly, H. E. Newman, L. T. Hodges and G. C. Kukal met with Chuck Spencer, Ben Law, Ted Tyler and Louise Kitley to discuss ongoing and future USGS work.

D. C. Bleakly of CER met with Tom Fouch of USGS to discuss ongoing work in the Uinta Basin and the results from this summer's field studies dealing principally with outcrops.

H. E. Newman and G. C. Kukal met with Dudley Rice to review log analysis problems in the Northern Great Plains Province and the recent expansion of the Province to include all of North and South Dakota. (See Section 3.4.2, "Basin Activities - Northern Great Plains Province" for details concerning the expansion.)

Mr. Kukal met with several people while at USGS and brief summaries of each meeting follow:

- C. W. Spencer and G. C. Kukal met to review the USGS input into the WGSP Logging Program. Individual points related to the *Logging Program Document* were considered as well as USGS log analysis tasks.
- Mr. Ching Wu's paper, *Density Neutron Crossplot Analysis for Shaly Gas Sands Using Hand Carried Calculators*, (the abstract of this paper appears in Section 2.2.2 "Articles and Publications" of this report) was reviewed and discussed. Mr. Kukal and Ching Wu also discussed Scientific Software Corporation's (SSC) LOGCALC system, recently purchased by USGS for use in the WGSP. The system will be available for limited use by CER personnel and the upcoming SSC course "Use of Digitized Well Logs" to be attended by G. C. Kukal, will serve as a guide for how CER can best take advantage of the SSC software package.
- A meeting with Dan Gautier of USGS focused on petrographic analysis of the Eagle sandstone in the Northern Great Plains Province.

Chuck Spencer, director of the USGS effort, conducted a tour of the facilities in use in the tight gas program and introduced people involved with the varied aspects of the project to CER. The tour included lineament studies, petrographic analysis, SEM studies (including mini-SEM), X-ray diffraction and fluorescence studies, and thin-section lab techniques. Also explained was the handling of the USGS core library.

C. H. Atkinson, H. E. Newman and D. C. Bleakly met with Gordon Byers of Twin Arrow and Craig Rightmeyer of TRW to discuss coring a Twin Arrow well on the Douglas Creek Arch. No problems were encountered, although more work was required before a contract could be drafted.

L. T. Hodges attended the Geological Society of America Annual Meeting held this year in Toronto, Canada from October 23-27. A paper on the paleoenvironments of the Green River Formation in Wyoming, and several papers on Cretaceous shales and sediments were presented. A number of papers on exploration for oil and gas, and a special symposium on exploration using satellites (LANDSAT) were also presented.

R. L. Mann, CER Corporation, attended a Sandia Laboratories hosted Gas Stimulation Workshop on October 11 and 12, 1978 in Albuquerque, NM. The objective was to allow detailed examination and discussion of the results from recent mineback experiments conducted at the Nevada Test Site. Details of this meeting are presented in Section 5.8.2 "Sandia Laboratories—Mineback, Current Status" of this report.

2.2 TECHNOLOGY TRANSFER

2.2.1 Documentation and Reports

Data compilation continued for the fourth *Quarterly Basin Activities Report*, to include information for the months of July, August and September. The *Status Report, August 31, 1978* has been distributed and *Status Report, September 30, 1978* has been completed and will be released shortly. Financial supplement reports for the end of fiscal year 1978 and October, 1978 have been completed. Both reports will be released shortly. An initial draft of an operations manual has been prepared to assist in the set up and operation of the DOE Well Test Facility. The compiling of material for the WGSP Bibliography continued.

2.2.2 Articles and Publications

As a result of the USGS/CER Corporation meetings in Denver, Colorado, and routine literature search, the following papers were made available to the WGSP file. Abstracts, when available, are included.

Density - Neutron Crossplot Analysis for Shaly Gas Sands Using Hand-Carried Calculators
Ching H. Wu, U.S. Geological Survey and Colorado School of Mines, and
Jack Krug, Petro-Lewis Corporation

Abstract—A program for hand-carried calculators has been developed for shaly gas sand crossplot analysis. This program processes data obtained from a log suite consisting of FDC-CNL-GR and a deep-investigation resistivity log, and prints out values for effective porosity, shale content, and water saturation.

The program uses an analytical method that describes the shaly-sand crossplot technique. This technique is capable of handling cases where the density porosity at the clay point is either positive or negative. The program executes the crossplot analysis accurately and quickly, taking less than 30 seconds for each data point.

*Formation Evaluation and Gas Detection in Shallow,
Low-Permeability Shaly Sands of the Northern Great Plains Province*
Gerald C. Kukal, CER Corporation
to be presented at the SPE Symposium on Low-Permeability Gas Reservoirs,
May 20-22, 1979, Denver, Colorado

Abstract—Montana log, core, and production data are combined with geology in a systematic approach for improved log analysis of shallow Upper Cretaceous gas sands having a high silt-clay content. Qualitative (overlay) techniques are reviewed with emphasis placed upon the normalized Δt — compensated neutron overlay for gas detection. Various log crossplots and log-core crossplots are utilized in the analysis of lithology, formation factor, effective porosity, and permeability.

Several conventional water saturation models are discussed and compared for quantitative saturation analysis. The Total Shale Relation is recommended as the best method for saturation evaluation. Log parameters relating to this equation are generalized and refined.

Suggestions are made for improved log quality of porosity logs and for supplementing present log evaluations by using unconventional logging programs.

*Core Descriptions, Photographs and Core X-ray Analysis of
Portions of the Upper Cretaceous Mesaverde Group, Washakie Basin, Wyoming*
Theodore F. Tyler, USGS, Open File Report 78-708, 1978

Abstract—Eleven cores from the Upper Cretaceous Mesaverde Group in the Washakie Basin, Wyoming were described, photographed, and sampled at the U.S. Geological Survey core library, Denver, Colorado. Core-analysis data and bulk-sample X-ray data are included to supplement the core descriptions.

*Influence of Diagenetic Reactions on Reservoir Properties of the Neslen,
Farrer, and Tuscher Formations, Uinta Basin, Utah*
C. W. Keighin, USGS, under preparation for presentation in
Denver, Colorado, 1979 SPE Symposium

*Mineralogical Analysis of Drill Core Samples From Midlands Gas
Corporation Wells—Federal 0370 No. 1 and 2962 No. 1*
Phillips County, Montana
Dudley Rice, USGS

Abstract—This report records the mineralogy of core samples from two wells in Phillips County, Montana. These wells are located in the Bowdoin gas field in north-central Montana. The gas is produced from low-permeability reservoirs at shallow depths (less than 610 m) over an area of 1554 km.

Fracturing Fluid Rock Interaction of Cotton Valley Lime Formation
U. Ahmed, L. Buchholdt, A. S. Abou-Sayed, Terra Tek

Abstract—Laboratory analyses were performed on cores taken from Mitchell Energy Corporation's Muse-Duke Well No. 1, Limestone County, Texas, to

determine fracturing fluid interaction with the host rock. All tests were conducted at simulated *in situ* conditions of 8,800 psi confining pressure, 6,400 psi pore pressure, 40 percent saturation and 285°F. Three candidate fracturing fluids were evaluated: Versagel; Stratafrac 400; Polaris 60. Tests were carried out to assess, (1) fracturing fluid damage to the rock permeability and (2) clean-up efforts required to return the host rock to its initial permeability. Irrespective of the initial, untreated permeability; post treatment permeability was in the tenths of microdarcies range. Initial permeability of the rock treated with Versagel and Stratafrac 400 was recovered in less than 2 hours. With Polaris 60, post fracture permeability appeared to stabilize at 60 percent of the initial permeability.

Further fracturing fluid/rock interaction tests will be performed with the above mentioned fracturing fluids on core samples from the same well in addition to microscopic examination of the cores.

Transient Pressure Analysis for Fractured Wells

Heber Cinco-L, Stanford University, and
Fernando Samaniego-V., Instituto Mexicano del Petroleo,
Members SPE-AIME, SPE 7490

Abstract—Several methods have been presented in the literature for analyzing transient pressure data of fractured wells. In this work, the limitations and advantages of each of these techniques are discussed. It is shown how different methods may be combined to accomplish a more reliable analysis.

In addition, a new analytical solution is presented for the unsteady-state flow behavior of wells intersecting a vertical fracture of low and intermediate conductivities at small values of time. A graphical technique is provided to analyze pressure data under these conditions. It is shown that a plot of p_{wf} versus $\sqrt[4]{t}$ yields a straight line whose slope depends upon the group $h_f \sqrt{wk_f}$, where h_f , w , and k are the height, width, and permeability of the fracture, respectively. The limitations of this method are discussed.

Detection Within the Wellbore of Seismic Signals Created by Hydraulic Fracturing

Carl Schuster, Sandia Laboratories, SPE 7448, presented at the 53rd Annual
SPE Technical Conference

Abstract—Early in 1978, Sandia Labs participated in massive hydraulic fracture mapping experiments with Amoco in the Wattenburg area. On two of these massive hydraulic fractures in the Sussex formation, a downhole, wall clamped, three-axis geophone was tested. On the first experiment, the system was clamped in the open hole section during the break-down phase. On the second experiment, the system was located in the lubricator during the main fracture and was lowered into place after shut-in.

Breakdown pump for the first experiment was conducted in four phases. The formation was first broken down and shut-in for a quiet period and then three 5,000 gal stages of fluid, without proppant, were pumped with a quiet

period after each. Following the last quiet period, flow back was started and half way through, a shut-in was scheduled for the fifth and last quiet period. During even the smallest flow rates, the noise induced into the geophones was extremely large and masked any other seismic activity. During the quiet periods, several seismic events were observed. These apparently are from two sources: 1) motion associated with permanent movements of the fracture face and 2) high frequency impulsive sources possibly associated with thermal fracturing.

Following the 124,000 gal fracture on the second experiment, the seismic system was lowered into place and clamped into the casing 50 ft above the open hole section that had been fractured. Seismic signals were recorded for approximately six hours after shut-in when the test was terminated. Both types of signals seen on the early experiment also appear to be present after the fracture treatment.

An Overview of the Electrical Potential Method for Determining Fracture Orientation

Carl L. Schuster, Sandia Laboratories,
presented at the 1978 Annual ASCE Meeting

2.2.3 Project Data Bank

Topographical maps of Wyoming are to be received from the USGS, Denver along with an east-west cross section of the Washakie Basin and an east-west cross section of the Green River Basin. Copies of several isolith and sand percentage maps for several Upper Cretaceous Formations are being sent to CER Corporation from USGS.

D. C. Bleakly visited the Utah State Oil and Gas Commission in Salt Lake City, Utah to arrange for photocopying production records. Monthly production figures were pulled for most months back through 1965. The monthly production figures are reported by lease and in several cases a lease will include a number of wells. The Oil and Gas Commission also maintains production records for each well, which can be photocopied if necessary.

3. RESOURCE ASSESSMENT

Geological, geophysical and reservoir evaluation studies are necessary to define and characterize the resource base. The USGS is performing the majority of these studies with support provided by field test data and core acquisition and analysis.

3.1 U. S. GEOLOGICAL SURVEY ACTIVITIES

3.1.1 Greater Green River Basin

The Green River Basin proper outcrop and log cross sections are being reviewed prior to open-filing.

Tentative agreements were made with Champlin Oil and Gas to conduct a geochemical profile on a drilling well in the vicinity of Moxa Arch in western Green River Basin.

Ten samples from the Green River Basin were submitted for palynological examination.

X-ray diffraction analysis of samples taken from the Superior No. 1 Pacific Creek Unit well, Section 27, T27N, R103W, Sublette County, Wyoming were conducted.

Work continued on construction of a cross section network.

B. E. Law and Ching Wu attended the DOE meeting in Las Vegas on a proposed well logging program for core support wells.

3.1.2 Northern Great Plains Province

A talk was presented to the Rocky Mountain Association of Geologists on the natural gas potential of tight reservoirs in the Northern Great Plains Province.

Data on the Bowdoin Field in north-central Montana is being collected for a SPE paper.

Work is progressing on assessing reservoir properties of the Eagle Sandstone at the Tiger Ridge Field in the Bearpaw Mountains area. Gas is produced from conventional reservoirs in the coastal sandstone facies. These reservoirs will be compared with the low-permeability shelf sandstones to the east when core becomes available.

USGS-Denver is working with the Water Resources Division of USGS on the possibility of examining cores through the Pierre Shale in central South Dakota. This will provide an opportunity to evaluate the potential of producing gas from a predominantly shale sequence that may be naturally fractured.

3.1.3 Uinta Basin

A report is being prepared to discuss control of reservoir properties in Upper Cretaceous rocks at Southman Canyon gas field. The paper will be published in SPE volume if accepted.

3.1.4 Piceance Basin

A manuscript is being prepared to discuss stratigraphy as depicted on the cross sections which have previously been released or are in review prior to release. The units involved contain many of the natural gas bearing reservoirs in the Piceance Basin.

3.1.5 Schedule Status

Figure 3-1 is a milestone chart for USGS projects undertaken for FY 1979. Work is progressing as scheduled.

3.2 CORE PROGRAM

Twin Arrow Company has agreed to participate in the WGSP Core Program. Their well C&K 4-14 is located in the Douglas Creek Arch area of Colorado, Section 14, T3S, R101W, in Rio Blanco County, Colorado. The location is approximately 10 miles southwest of the nearest designated core area, however after discussions with USGS personnel, it was decided that coring a portion of the continental Mesaverde section would be useful to the project. Close study of the shallow Mesaverde sands in this locale will give a clearer understanding of diagenetic changes that take place basinward with increasing depth of burial.

The interval chosen for coring in Twin Arrow's C&K 4-14 well was based on close analysis of logs from nearby wells including:

Twin Arrow	C&K 1-13, 1-13x	Sec 13, T3S, R101W
Conoco	Pollock Draw 1	Sec 15, T3S, R101W
Utex Explor	Cathedral 1-A	Sec 20, T3S, R100W
Argo Oil	Government Gates 1	Sec 3, T3S, R101W
Fuelco	Federal 23-1	Sec 23, T3S, R101W
Twin Arrow	C&K 1-12 East Douglas	Sec 12, T3S, R101W

Several wells in the area have had gas shows throughout the proposed interval. Working with Density and E-log cross plots on the 1-13x well, it was determined that three sands in the continental Mesaverde section had approximately a 50 percent gas saturation. These sands are the focus of the coring interest in Well C&K 4-14, one-third mile west.

The core interval includes seven distinct sand zones varying from very clean with 20 percent plus porosity to very shaley with as little as 8 percent porosity. Thin shaley and coaly zones separate the sands.

Figure 3-1 Milestone Chart—USGS

WGSP-USGS	FY-79											
B. NORTHERN GREAT PLAINS PROVINCE	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Preliminary mapping of lineaments from enhanced LANDSAT images for key parts of study area												
Prepare paper for SPE Symposium on Bowdoin Dome area, north-central Montana												
Detailed surface and subsurface mapping of Eagle (Shannon) sandstone on north flank of Black Hills, SE Montana and NW South Dakota												
Prepare paper on the origin of shallow gases												
Petrographic and clay mineralogy studies on outcrop sections and core if available												
Description of selected core in the study area when available												
Prepare abstract and talk on shallow gas potential in eastern Dakotas												
Prepare open-file report on Lake Traverse Section, South Dakota-Minnesota												

WGSP-USGS	FY-79											
B. NORTHERN GREAT PLAINS PROVINCE	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Prepare talk for Potential Gas Committee												
Prepare talk for Rocky Mountain Assoc. Geological												
Analyze gas samples from Suffield Block, Canada for comparison with Northern Great Plains Province												

Figure 3-1 Continued

WGSP-USGS	FY-79											
C. PICEANCE BASIN	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Prepare and release cross section relating rock types, lithofacies, engineering data for rocks between DeBeque and Rifle, Colorado	▼								▼			
Prepare and release cross section in style above for southernmost Piceance Basin										▼		
Cross section as above from Cathedral Bluffs to Rio Blanco area									▼			
Report results of analysis of core from Rio Blanco area							▼					

WGSP-USGS	FY-79											
D. UINTA BASIN	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Prepare and release cross section relating rock types, lithofacies, engineering data for rocks from Wasatch Mountains to southcentral Uinta Basin	▼											
Investigate mineralogy and stratigraphy, and rock properties of core from Southman Canyon region of Uinta Basin												
Analyze data from San Arroyo Wash surface exposures of Cretaceous and Tertiary units of the southeast Uinta Basin. Report results as they become available												
Prepare report on "tight gas" reservoirs in Tertiary rocks of southcentral Uinta Basin. To be published in SPE volume					▼				▼			
Prepare report on diagenetic reactions and controls on Upper Cretaceous gas reservoirs at Southman Canyon Field, to be published in SPE volume		▼							▼			
Core analysis—Upper Cretaceous and Lower Tertiary units, southwest Uinta Basin												

Figure 3-1 Continued

The core interval in C&K 4-14 is tentatively set at 950 to 1,210 ft, which corresponds to a similar depth in wells 1-13 and 1-13x.

Spud in is scheduled for November 18, 1978 with the coring expected to take place from about November 22 through 24.*

During the month, several operators were contacted for possible participation in the WGSP Core Program. In the Piceance Basin the operators were Adolph Coors of Golden, Colorado, Koch Exploration of Denver, Colorado and Dome Petroleum also in Denver. Odessa Natural, Odessa, Texas was contacted about a well they are planning to drill in the Uinta Basin. At month end, the only agreement made was with Twin Arrow.

In the Greater Green River Basin, True Oil Company and Michigan-Wisconsin Pipeline Company were contacted concerning potential core sites in Sweetwater County, Wyoming. DOE is interested in coring parts of the Fort Union, Lance, Lewis and Mesaverde from the well. Pacific Transmission Supply Company was contacted about a well in Sublette County, Wyoming. In this well, DOE is interested in coring parts of the Lower Tertiary and Mesaverde sections. DOE and PTS are working together on this well and may decide to negotiate a coring contract. Davis Oil was contacted to obtain core from their No. 1 Parish Mark Unit well in Sweetwater County, but were not able to participate because of lease obligations.

In Montana, Erico Resources of Denver was contacted about coring a well in Valley County, Montana. The sections of interest are in the Upper Cretaceous. Joseph J. C. Paine was also contacted for a potential site (Eagle) in the northern Bowdoin Dome area of Montana, as well as for a site (Judith River and Eagle) in the southeast part of the Cedar Creek Anticline, North Dakota.

3.3 LOGGING PROGRAM

The WGSP Logging Program meeting was held at CER offices, October 24, 1978. A list of those in attendance appears below:

Gerald Kukal	CER Corporation	Las Vegas, NV
Robert Mann	CER Corporation	Las Vegas, NV
Harry Newman	CER Corporation	Las Vegas, NV
Charles Atkinson	DOE -BETC/NV	Las Vegas, NV
Herb Carroll	DOE -BETC	Bartlesville, OK
Robert Clarke	DOE -NV	Las Vegas, NV
Elena Clark	Intercomp	Houston, TX
Joe Hearst	Lawrence Livermore Lab.	Livermore, CA
Merle Hanson	Lawrence Livermore Lab.	Livermore, CA
Jasper Jackson	Los Alamos Scientific Lab.	Los Alamos, NM
Nick Vanderborgh	Los Alamos Scientific Lab.	Los Alamos, NM

*Well cored on December 1 - 5, 1978

W. F. Baldwin
Tom Dobecki
Peter Lysne
Carl Schuster
Ben Law
Ching Wu

Mobil Research
Sandia Laboratories
Sandia Laboratories
Sandia Laboratories
U.S. Geological Survey
U.S. Geological Survey

Dallas, TX
Albuquerque, NM
Albuquerque, NM
Albuquerque, NM
Denver, CO
Denver, CO

The purpose of the meeting was to discuss the WGSP Logging Program document, August 14, 1978 and define the problems that exist with logs in tight gas sands. Also discussed was the need to identify which reservoir parameters require better definition, and whether logging problems should be approached with existing tools, improved existing tools, or with the development of new tools. The research laboratories identified areas for their research and delineated research tasks. These tasks will be summarized in a revision to the WGSP Logging Program which is to be released in December.

An HP 67 calculator program has been prepared for use in WGSP log analysis.

The Twin Arrow well, C&K 4-14 will be a part of the logging program. The well will be drilled with air-mist and a 7-7/8 in. drill bit. At the time of logging, the hole will be partially filled or totally filled with native water and with as much as 2 percent KCl. The estimated resistivity of the mud filtrate is 0.3 and the estimated water resistivity (Mesa-verde) is equal to 1.0. The well will be drilled to a total depth of 2,100 ft which is the base of the Castlegate Member of the Mancos Formation. The open hole logs to be run are: Dual Laterolog with gamma and SP, R_{xo} Log (Microlaterolog, μ SFL, or Proximity), Dual Induction Laterolog 8, Sonic BHC with gamma and caliper, Density log with caliper and gamma, Gamma Ray, Compensated Neutron, Spectral Gamma and Sidewall Cores.

3.4 SURVEY OF BASIN ACTIVITIES

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

3.4.1 Greater Green River Basin

During October thirteen development wells and four wildcats were completed in horizons of interest to the WGSP. Twelve development and three wildcats were on stream and a development and a wildcat well were completed D&A. Producing horizons were the Fort Union (628 MCFD), Lewis (12,306 MCFD), commingled Almond/Lance (877 MCFD), Mesaverde (3,190 MCFD) and the Frontier (1,291 MCFD). Total production for the month was 18,292 MCFD.

Forty-seven new wells with application to the WGSP were staked during October. Twenty-five wells were located in proven fields and 22 were in wildcat areas. Three of these wells were spudded and are drilling ahead at month end. Recent wells of interest are summarized in Table 3-1 and located on Figure 3-2.

*Figure 3-2
Greater Green River Basin Showing
Wells of Interest and USGS Designated Core Areas (refer to Table 3-1)*

3.4.2 Northern Great Plains Province

The USGS has expanded the boundaries of the Northern Great Plains Province, effective October 1, 1978, to include the entire states of North and South Dakota. USGS in Denver has delineated the following reasons for this expansion.

- Chalks in the Greenhorn, Carlile and Niobrara Formations are developed over a large part of these states and are potential tight reservoirs. Active exploration for these chalks, particularly in the Niobrara, is occurring in Colorado, Kansas, and Nebraska and the interest is extending to the Dakotas where similar reservoirs exist.
- Previous and ongoing work by the USGS and South Dakota Geological Survey has shown that shales in the Pierre Shale and associated units are, in some places, extremely organic-rich and naturally fractured. Therefore the natural gas potential of these naturally fractured shales should be tested. Potential gas production, similar to that from the Devonian shales in the Appalachian Basin could be established using comparable technology.

Table 3-1 Summary of Wells of Interest—Greater Green River Basin

OPERATOR	WELL NAME	MAP INDEX NO. ¹	LOCATION Sec/T/R	HORIZON ²	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Chandler & Assoc.	15-22 McWilliams	1	SWSE 22/ 8N/90W North Craig Field Moffat Cty, Colorado	Fort Union (1,120- 1,122) Lewis (2,491- 2,628)	3,030 PB 2,640	60,000 gal 70,000 lb sand	Completed, commingled production	628 1,232
Texas Oil & Gas	1 Windmill Draw	2	NWSE 14/15N/94W Unnamed Field Sweetwater Cty, Wyoming	Almond (11,556- 11,606)	12,575 PB 11,800	Acidized— 4,000 gal, 178,500 gal emulsion, 253,250 lb sand	Completed	877
Amoco Production	1 Bog Field WI Unit	3	NESW 3/22N/91W Wildcat Field Sweetwater Cty, Wyoming	Mesaverde	15,832	Acidized— 2,168 gal	Completed, D&A deep test near core site A	
Amoco Production	1 Champlin 438 Amoco-A	4	CSE 5/22N/96W Red Desert Field Sweetwater Cty, Wyoming	Cretaceous	13,040	Perfed 9,536- 9,650, 10,217-10,255, 10,940-10,962	Completed, D&A near core site A	
Energetics Inc	32-3 Federal	5	SWNE 3/25N/110W Wildcat Field Sweetwater Cty, Wyoming	Morrison (11,665)			Located, near core site B1 and B2	
Woods Petroleum	2 Lost Valley Unit	6	NWSE 22/25N/99W Wildcat Field Sweetwater Cty, Wyoming	Baxter (13,000)			Located	

¹ Refer to Figure 3-2

² Horizon - projected depth or producing interval

- Shelf sandstones of Late Cretaceous age and derived from the Sioux Uplift in southeastern South Dakota are developed throughout central and eastern South Dakota. These shelf sandstones are identical to those developed in Montana and are potential tight, gas-bearing reservoirs.

Activity in the Province continues to be concentrated in the northern counties of Montana. Thirty-four wells applicable to the WGSP were completed during the month of October. Twenty-two were located in proven gas fields in northern Montana and twelve were wildcats. Wildcat wells were only 17 percent successful, while development wells were 50 percent successful. The producing formations were the Eagle, Phillips, Bowdoin, Greenhorn and Bow Island. Total amount of gas produced was about 10,800 MCFD.

Thirty new wells were staked in the Upper Cretaceous Sands of the Northern Great Plains Province; seventeen development and thirteen wildcat wells. At month end six had been spudded and were drilling ahead, three were completed D&A and one had reached total depth.

Activity relevant to the WGSP in North and South Dakota is limited at this time. Jerry McCutchin is active in the West Short Pine Hills Field, Harding County, South Dakota, and has plans to drill six or seven wells in the field area next year. Unichem International is evaluating the Niobrara Sand in south-central North Dakota. This well is located in Sioux County where the Niobrara will be tested through production casing due to inconclusive logs. Joseph J. C. Paine and Associates plan to drill three Judith River-Eagle wells in Bowman County, North Dakota. The wells are scheduled to test the Eagle at about 2,000 ft. Refer to Figure 3-3 and Table 3-2 for a listing and approximate location of recent wells of interest to the WGSP.

In the southern part of Montana, the Water Resources Division of the USGS is preparing to set 9-5/8 in. casing, apparently through the Madison, at a deep water evaluation well, located 10 miles northeast of Billings, Montana in Yellowstone County. Twenty-four cores over 30 ft intervals between the Telegraph Creek (Cretaceous) and Cambrian are scheduled to be taken. J. E. Shackleford has a shallow test planned in Dawson County, Montana. This Dawson County wildcat well was previously drilled by Apache Corporation to 10,400 ft in 1976. A stratigraphic test is planned by Orlyn Terry in Carter County, Montana; the projected depth was not reported.

3.4.3 Piceance Basin

Wells completed during October in the Upper Cretaceous zones of the Piceance Basin produced 5,993 MCFD of gas. Nine wells were completed of which six were located in proven gas fields and three were wildcat locations with 33 percent success. The producing horizons and locations were the Wasatch and Douglas Creek zones in Piceance Creek Field, Rio Blanco County, the Mancos and Mancos B in the Cathedral Field, Rio Blanco County, and commingled Rollins/Cozzette/Corcoran in Plateau Field, Mesa County.

Figure 3-3 Northern Great Plains Province Showing Wells of Interest and USGS Designated Core Areas A, B, C and D (refer to Table 3-2)

Table 3-2 Summary of Wells of Interest—Northern Great Plains Province*

OPERATOR	WELL NAME	MAP INDEX NO. ¹	LOCATION Sec/T/R	HORIZON ²	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Jerry McCutchin, Jr.	1 State- Placid	1	16/15N/ 3E Wildcat Field Harding Cty South Dakota	Shannon (1,300)			Located	
Benson Mineral Group	1-20 Williams	2	20/34N/18E Wildcat Field Blaine Cty, Montana	Greenhorn	2,404		Completed	
Unichem International	1 Jacobs	3	7/129N/85W Wildcat Field Sioux Cty, North Dakota	Deadwood (7,200)			@ 7,168, running logs to evaluate the Pierre at 1,660 ft and Niobrara at 2,100 ft	
Erico Resources	18-1 Mcintyre	4	18/29N/41E Wildcat Field Valley Cty, Montana	Winnipeg (8,350)			Located	
Tricentrol United States	4-3 US	5	4/30N/18E Tiger Ridge Field Blaine Cty, Montana	Eagle (1,442-	1,700 PB 1,570	15,000 lb sand	Completed	400
J.E. Shackel- ford	1-16 State	6	16/16N/55E Wildcat Field Dawson Cty, Montana	1,083 ft test			Located	
Orlyn Terry	36-16 Montana State	7	36/ 7S/58E Carter Cty, Montana	Strati- graphic test			Located	
Falcon- Colorado Exploration	1-19 Federal	8	19/32N/35E Swanson Creek Field Phillips Cty, Montana	Bowdoin (740-760) Phillips (934-944)	1,350	14,300 gal water, 40,000 lb sand 14,439 gal water, 40,000 lb sand	Completed	293
Joseph J. C. Paine & Associates	1-0562 Anderson	9	5/36N/32E Unnamed Field Phillips Cty, Montana	Bowdoin (1,352- 1,393)	1,650 PB 1,450	13,356 gal water, 40,000 lb sand	Completed	3,586

¹ Refer to Figure 3-3

² Horizon - projected depth or producing interval

Twenty-four new wells were staked during the month; ten wildcats and fourteen development wells. At month end two had been spudded and were drilling ahead and one well had been drilled to total depth. The new activity was concentrated in the North Douglas Creek Field, Rio Blanco County, where Chandler and Associates staked seven Mancos tests and in the Piceance Creek Field, Rio Blanco County, where the Wasatch was the major objective.

Table 3-3 is a summary of recent wells of interest to the WGSP and Figure 3-4 shows the well locations.

3.4.4 Uinta Basin

Only three wells were completed in the Uinta Basin with application to the WGSP during October. All three were Mesaverde producers and located in the Natural Buttes Field, Uintah County, Utah.

Eighteen new wells were staked during the month. Eleven of these were CIG Exploration wells located in the Natural Buttes Field and scheduled to test the Wasatch. There were also a couple of confidential tests in the Cedar Rim Field of Duchesne County, and two wildcat wells, one located in core area D and the other in core area A.

Table 3-4 summarizes recent wells of interest to the WGSP and Figure 3-5 shows each well location within the basin.

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

Table 3-3 Summary of Wells of Interest—Piceance Basin

OPERATOR	WELL NAME	MAP INDEX NO. ¹	LOCATION Sec/T/R	HORIZON ²	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Koch Exploration	1 Federal	1	NWNW 13/ 8S/99W Wildcat Field Mesa Cty, Colorado	Dakota (6,800)			Located	
Norris Oil	13-3 Finch	2	NWNE 13/10S/96W Plateau Field Mesa Cty, Colorado	Rollins (3,310-3,354) Cozzette (3,640-3,657) Corcoran (3,784-3,863)	4,008	3,128 gal water, 517,000 lb sand	Commingled 1,734 completion	
Fuel Resources Development	23-1 Federal	3	NENE 23/ 3S/101W Cathedral Field Rio Blanco Cty, Colorado	Mancos B (3,572-3,799)	4,105 PB 3,910	73,400 gal 195,000 lb sand	Completed	199
Northwest Exploration	2 Clough	4	SESW 21/ 6S/94W Rulison Field Garfield Cty, Colorado	8,700 ft test			Located	

¹ Refer to Figure 3-4

² Horizon - projected depth or producing interval

Figure 3-5
*Uinta Basin Showing
 Wells of Interest and
 USGS Designated Core
 Areas (refer to Table
 3-4)*

Table 3-4 Summary of Wells of Interest—Uinta Basin

OPERATOR	WELL NAME	MAP INDEX NO. ¹	LOCATION Sec/T/R	HORIZON ²	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
W.A. Moncrief	8-1 Pender	1	SESW 8/ 2S/ 4W Wildcat Field Duchesne Cty Utah	Confidential test			Located	
Gas Producing	22 Natural Buttes Unit	2	SENE 18/10S/22E Natural Buttes Field Uintah Cty, Utah	Mesaverde (6,838-8,550)	8,622 PB 8,615	Acidized- 3,500 gal, 490,758 gal emulsion, 1,151,000 lb sand	Completed	697
Pacific Transmission Supply	44-3 Federal	3	SESE 3/14S/20E Wildcat Field Uintah Cty, Utah	Mancos (7,000)			Located	

¹ Refer to Figure 3-5

² Horizon - projected depth or producing interval

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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

The completed Maurer engineering design is being used as part of the request for proposals being mailed to prospective industrial partners.

The purpose of the RFP is to solicit proposals based on the Maurer engineering design, modifications to this design, or any new design that incorporates the improvements in pressure coring that are the basis for the Maurer design. The proposals are to be for a joint industry and DOE cost-sharing development program to fabricate and field test an improved pressure coring system to be reported as a new task in FY 79.

4.1.1.2 Coring Fluid Selection

The water-based SANHEAL is still recommended for use with the new pressure coring system at this time, but continuing studies may identify other options.

4.1.1.3 Bit Design

The computer program for the 8-1/2 in. full body bit has been completed and the 9 in. diameter 9310 material is on hand. Fabrication of the 8-1/2 in. bits will start as soon as time becomes available on the numerically controlled five axis machine. Pilot bit bodies are completed and awaiting diffusion bonding of the stratapax cutters.

4.1.2 Interface Conductivity Effects on Electric Logging

Resistivity measurements are continuing on core plugs from the Mesaverde formation. The following is a summary of data obtained from several plugs:

Table 4-1 Summary of Core Measurements

Formation Depth, ft	Measured Formation Factor "F"	Permeability (k)		Porosity (ϕ)	Cementation Factor (M)
		Gas, micro- darcies	Liquid, micro- darcies		
7,300	114	67.0	3.7	0.114	2.44
7,530	295	43.8	5.6	0.072	2.16
7,553	226	77.5	5.2	0.092	2.27
7,900	172	26.5	3.1	0.085	2.09
8,066	178	35.0	2.4	0.096	2.22

Cores from Mobils' Piceance Creek Well were received and plugs will be tested as time permits.

Surface area measurements of several core samples are being made. Continuous flow equipment patterned after Nelson and Eagerton for surface area determination was checked with known surface area standards. In order to use this equipment, core samples must be crushed. Tests are underway to determine the effect of sample crushing.

An apparatus for determining the cation exchange capacity (CEC) of clay-containing core samples was assembled. Due to the time involved in the procedure and the anticipated number of samples, an automated CEC device was required. The most involved portion is the auto titration procedure, however, after sample preparation, CEC determination should require minimal attention.

4.1.3 Logging Techniques and Interpretations

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

Study of the series of logs from Paine No. 1-0296 well in Montana with accompanying core data showed that, with two exceptions, the core data agreed with the porosity determined from the sonic log.

This analysis assumed a matrix density of between 2.65 and 2.68 gram/cc or travel time of 55.5 to 51.2 μ sec/ft. A slight variance of the matrix density for each area is necessary to obtain the porosity described in the core analysis. The density log consistently provides a porosity lower than that obtained in core analysis results.

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

A logging task force was formed in February, 1978, and was chartered to investigate the state-of-the-art in commercial geophysical logs as well as logging research to determine which areas of concentration might be most beneficial to natural gas reservoir applications. Numerous months of literature search, theory development, and interviews with production and research personnel from the petroleum industry, academic community, and logging service organizations, indicates that the areas of NMR and electromagnetics would provide the most benefit. In addition, continuing research and development of existing Sandia borehole neutronics programs is encouraged with petroleum applications in mind. A working relationship with Chevron Oil Field Research Laboratories for NMR study of western gas sand formations has been developed, and a program for developing the pertinent electromagnetic theory linked to lab measurements has been initiated.

4.1.4 Reservoir Stimulation Studies

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

Heber Cinco-L. and Fernando Samaniego-V. presented a paper titled *Transient Pressure Analysis for Fractured Well* at the Fall meeting of the SPE in Houston. The abstract of this paper appears in Section 2.2.2, "Articles and Publications" of this report. Four flow periods were defined. The first is linear flow from the fracture only. The second is bilinear flow. The third is for linear flow from the matrix alone and the fourth is for radial flow from the matrix.

The slope during the first flow period should be a straight line on a log ΔP versus Δt or type curve plot with a value of 0.5. The second period should be a straight line of a slope of 0.25 on a type curve plot. The third flow period should have a slope of 0.5 on a type curve plot and the fourth should bend over.

The various flow periods may be present on any test or may be non-existent on any one test depending on the parameters of the reservoir. The first flow period may be masked by storage effects, etc. The buildup tests for zone 1 and zone 3 of the Mobil well F31-13G show a slope of about 0.25 for the pre-frac tests. This slope was previously recognized and noted but the reason was unknown. It appears that zones 1 and 3 of the F31-13G well have natural fractures or that they were created during drilling or completion operations. Figure 4-1 is the type curve for zone 3 pre-frac build-up. It appears that the first two flow periods may be present. Seen on Figure 4-2, the first slope, notation 1, is a 0.5 slope and the second slope, notation 2, is a 0.27 slope. It appears that the third slope is not present. Cinco, et al states that this is true if $k_{fw}/(kx_f)$ is <1.6 . The nomenclature above is:

- K_f = fracture permeability, md.
- w = fracture width, ft.
- k = formation permeability, md.
- x_f = fracture half-length, ft.

Figure 4-1 Type Curve Plot for Mobil Well F31-13G, Zone 3 Build-Up

Figure 4-2 Type Curve Plot for Mobil Well F31-13G, Zone 3 Build-Up with Slopes Defined

Previous work was performed assuming that the reservoir was not fractured prior to the MHF treatment. This now appears to be in error and zones 1 and 3 were fractured during the pre-frac tests.

The pre-frac test was analyzed using the method described by Cinco, et al for the bilinear flow period. A plot of $\Delta m(p)$ versus ${}^4\Delta t$ is given on Figure 4-3. The slope of the line is $270 \times 10^6 \text{ psi}^2 / (\text{cp hr}^{1/4})$. From the Horner plot, the permeability is 0.019 md. The Horner plot of the actual build-up data is given on Figure 4-4. From the slope of $\Delta m(p)$ versus ${}^4\Delta t$ the following equation holds:

$$h_f \sqrt{k_{fw}} \quad k^{1/4} = \frac{-15709 \quad q \quad P_{sc} T}{T_{sc} (\phi \mu C_t)^{1/4} m_{bf}}$$

Where the nomenclature is (with values used):

h_f	=	fracture height, ft (61 ft)
q	=	rate MCF/D (700 MCF/D)
P_{sc}	=	standard pressure, psi (14.65 psi)
T	=	reservoir temperature, °R (675° R)
T_{sc}	=	standard temperature, °R (520° R)
ϕ	=	reservoir porosity, (0.036)
C_t	=	system compressibility, psi^{-1} ($1.74 \times 10^{-4} \text{ psi}^{-1}$)
m_{bf}	=	slope of $\Delta m(p)$ versus ${}^4\Delta t$ $\frac{\text{psi}^2}{\text{cp hr}^{1/4}}$ ($270 \times 10^6 \frac{\text{psi}^2}{\text{cp hr}^{1/4}}$)

$$\text{or} \quad k_{fw} \sqrt{k} = 0.4140$$

$$\text{so} \quad k_{fw} = \frac{0.4140}{\sqrt{k}}$$

Figure 4-3 $\Delta m(p)$ versus $\sqrt[4]{\Delta t}$ for Mobil Well F31-13G, Zone 3, Pre-Frac Build-Up

Figure 4-4 Horner Plot of Mobil Well F31-13G, Pre-Frac, Build-Up

With this value as a starting point, several runs were attempted using values for wellbore storage fixed by the defined wellbore geometry. The run which gave the best result is shown in Figure 4-5 and is compared to the actual data on Figure 4-6. It can be seen from the figure that the curves match well at long times but the initial data appears to be in error. If the wellbore storage value is increased, the two curves should match, but there is no reason to assume the storage value is off very far, although it may be low. The important point is that the bilinear flow period appears to match.

The matrix permeability was increased to 0.0215 md. because the storage effects or rate effects on the build-up were still present. The analysis of a Horner plot of the simulated data will give a lower value of matrix permeability than actually used. The Horner plot of the simulated data is shown on Figure 4-7.

Zone 1 (type curve is given in *September 30, 1978 Status Report, NVO/0655-112*) pre-frac build-up has the same features as the zone 3 except the first flow period cannot be seen. It appears that the bilinear flow period lasts almost during the full test period for zone 1.

4.1.4.2 Future Work

Data analysis will continue. It appears that some zones are fractured prior to MHF treatments. The analysis of the post MHF data will be re-analyzed with this in mind.

4.1.5 Rock-Fluid Interaction

Particle size distribution and numbers from 40-60 mesh sand placed 0.2 in. thick between two core halves have been obtained. A 10 in. long x 1½ in. diameter Berea core was cut in half and reassembled with 0.2 in. fracture, packed with 40-60 mesh sand. The assembled high-pressure core apparatus was arranged with the simulated fracture in the vertical position, then a 2 percent KCl solution pumped through the pack. The overburden pressure was increased in 1,000 psi increments starting at 1,000 psi and continuing up to 6,000 psi. Samples of the passing fluid were examined and the particles counted and sized. Generally, as the overburden pressure was increased the proppant particles were fractured and traveled in the 2 percent KCl solution. Table 4-2 shows the particle size and concentration in the effluent 2 percent KCl solution.

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

Initial results from the study of overburden pressure on gas permeability for several cores have correlated well with past data.

4.1.6 Schedule Status

Figure 4-8 is a milestone chart depicting the progress of projects undertaken by BETC for FY 1979

Figure 4-5 Type Curve Plot, Mobil Well F31-13G, Zone 3, Pre-Frac, Build-Up

Figure 4-6 Type Curve, Mobil Well F31-13G, Pre-Frac Build-Up, Simulated and Observed Data

Figure 4-7 Horner Plot of Simulated Data for Zone 3 Pre-Frac, Build-Up Mobil F31-13G

Table 4-2 Particle Size Distribution in Simulated Frac Fluid

SAMPLE NO.	OVERBURDEN PRESSURE (psi)	MAXIMUM COUNTS per ml	PARTICLE SIZE IN MICRONS		
			Mean	Mode	Range
1	1,000	27,000	2.1	1.8	1.6-- 6.8
2	2,000	13,000	2.7	1.8	1.6 - 6.2
3	3,000	62,000	2.5	1.8	1.6 - 6.3
4	4,000	53,000	2.2	1.8	1.6 - 5.5
5	5,000	53,000	2.2	1.8	1.6 - 5.8
6	6,000	57,000	2.4	1.8	1.6 - 7.8

Figure 4-8 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 internal report												
Physical measurements												
Core samples												
Filtration tests												
Permeabilities												
Preliminary analysis and data correlation												
Annual report												
2. FORMATION DAMAGE FROM FRAC-FLUID COMPONENTS												
Literature review												
Damage evaluation												

WGSP-BETC	FY-79											
B. FORMATION DAMAGE	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
3. PROPPANT TRANSPORT & EMBEDMENT												
Evaluation of particle transport in proppant beds												
Evaluation of proppant embedment in tight gas sands												

Figuro 4-8 Continued

WGSP-BETC	FY-79											
C. LOGGING TECHNIQUES	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1. MAPPING & CONTOUR OF R _w												
Review current research												
Study of current logs												
Internal report												
Extant data assembly												
Isoresistivity maps												
Computer contours												
Annual report												
Report on contour of R _w & water components in Uinta Basin												
Examine and contour R _w & 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 EVALUATION												
Effects of interface conductivity on electric logging												
Physical measurements												
Core preparation & selection												
Resistivity												
Data correlations												
Conductivities from Rink & Shopper equation												
Permeabilities												
Report												
Study of Logging Techniques												
Neutron log data evaluation												
Acoustic log data evaluation												

Figure 4-8 Continued

Figure 4-R Continued

4.2 LAWRENCE LIVERMORE LABORATORY

4.2.1 Theoretical Analysis and Model Development—Results

4.2.1.1 Interface Calculations

The preliminary model to include the effects of friction on an interface has been developed, written in Fortran, and is currently being debugged. For comparison with the forthcoming calculations with a frictional interface, a series of calculations for a crack approaching a well bonded interface between two materials has been completed. The materials on either side of the interface were defined having identical Poisson's ratios with different Young's moduli. The medium around the pressurized fracture was assumed to be impermeable and the pressure in the crack was taken as constant. Two sets of calculations were performed, one with the pressurized crack in the lower modulus material and the higher modulus material across the interface and the other set of calculations had the material moduli interchanged. The calculations were performed in two dimensions for plane strain. Figure 4-9 shows the geometry of the problem. The distance, ξ , of the fracture tip to the interface has been non-dimensionalized with respect to the crack length.

Figure 4-9 Geometry of Problems with Cracks Approaching Bonded Interface Between Two Materials Having Moduli E_1, ν_1 and E_2, ν_2

Figures 4-10 and 4-11 show the maximum principal axis of strain resulting from a pressurized crack in the layered medium. One fracture tip is at $\xi = 0.4$ from the interface for both figures. Figure 4-10 shows the case where the fracture is embedded in the lower modulus material. On Figure 4-11, the fracture is embedded in the higher modulus material. It illustrates that the change in material properties significantly effects the orientation of the principal strains, especially directly in front of the crack tip.

The strain normal to the interface and the shear strain along the interface for several positions of the crack with respect to the interface have been calculated and plotted. These strain values are computed in the coordinates of the interface. Since finite element techniques were used to calculate the elastic field, these strain values were computed on either side of the interface. Each curve on these plots is for one position, ξ , of the crack tip from the interface as a function of position η along the interface (see Figure 4-9 for the geometry). Figures 4-12, 4-13, 4-14 and 4-15 display these normal and shear strain values for the case when $E_1 = 10$ GPa and $E_2 = 50$ GPa. The pressure in the crack was 30 MPa. Figures 4-12 and 4-13 show the normal and shear strains just to the left of the interface while Figures 4-14 and 4-15 show similar strain functions just to the right of the interface. Observations show that the normal strains become more compressive as the fracture tip nears the interface. Also, as the fracture tip approaches the interface, the point of maximum compressive normal strain and maximum shear strain tends to approach the line $\eta = 0$ (line extended from the fracture axis to the interface). The normal strain plots also indicate that the presence of the fracture tends to increase the normal strain at the interface directly ahead of the fracture tip. Also, as the tip approaches the interface, the normal strain at $\eta = 0$ becomes more and more tensile. This could give rise to a reduction in the frictional stresses in this region.

For this case where the pressurized crack is in the lower modulus material, the resulting normal and shearing strains are larger on the lower modulus side of the interface than on the higher modulus side.

Figures 4-16 and 4-17 show similar strain values for the case where $E_1 = 50$ GPa and $E_2 = 10$ GPa. In this case $\nu_1 = \nu_2 = 0.25$. The pressure in the crack was 30 MPa. The normal and shear strain on these plots are computed in the interface coordinates. Figures 4-16 and 4-17 show the normal and shear strain along and just to the left of the interface while Figures 4-18 and 4-19 show similar strain functions along and just to the right of the interface (the geometry of the problems are shown on Figure 4-9). For this material configuration the general remarks discussed previously tend to be relevant, however, the normal strain becomes positive on the left of the interface directly ahead of the crack tip but remains compressive to the right of the interface in this region.

4.2.1.2 Lens Calculations

To determine the stress perturbations caused by the presence of lenses the following problems were analyzed with an LLL numerical model. Three geometries of lenses embedded in a homogeneous material are shown in Figures 4-20, 4-21 and 4-22. In each geometry Poisson's ratio for both materials is 0.35 and Young's modulus (E) for the lenses (10 GPa) is half that of the surrounding material (20 GPa) for the first calculation (Case 1). For the second calculation the Young's moduli were reversed (Case 2). A constant normal stress (σ_0) is applied in the negative y direction along $y = 0$. Since the distances and displacements in the problem will scale, the distances are given in terms of the

Figure 4-10 Axis of Maximum Principal Strain for the case $E_1 = 10$ GPa and $E_2 = 50$ GPa. Interface is shown as Solid Line. Fracture is Schematically shown as ELLIPSE.

Figure 4-11 Axis of Maximum Principal Strain for the Case $E_1 = 50$ GPa and $E_2 = 10$ GPa. Interface is shown as Solid Line. Fracture is Schematically shown as ELLIPSE.

Figure 4-12 Normal Strain to Left of Interface as a Function of Distance Along the Interface for Various Distances of the Fracture Tip from the Interface. $E_1 = 10$ GPa and $E_2 = 50$ GPa.

Figure 4-13 Shear Strain to Left of Interface for Various Distances of Fracture Tip from the Interface, $E_1 = 10$ GPa and $E_2 = 50$ GPa

Figure 4-14 Normal Strain to Right of Interface as a Function of Distance Along the Interface for Various Distances of Fracture Tip from the Interface $E_1 = 10$ GPa and $E_2 = 50$ GPa.

Figure 4-15 Shear Strain to the Right of Interface as a Function of Distance Along the Interface for Various Distances of Fracture Tip from the Interface. $E_1 = 10$ GPa and $E_2 = 50$ GPa.

Figure 4-16 Normal Strain to Left of Interface as a Function of Distance Along the Interface for Various Distances of Fracture Tip from the Interface. $E_1 = 50$ GPa and $E_2 = 10$ GPa.

Figure 4-17 Shear Strain to Left of Interface as a Function of Distance Along the Interface for Various Distances of Fracture Tip from the Interface. $E_1 = 50$ GPa and $E_2 = 10$ GPa.

Figure 4-18 Normal Strain to Right of Interface as a Function of Distance Along the Interface for Various Distances of Fracture Tip from the Interface. $E_1 = 50$ GPa and $E_2 = 10$ GPa.

Figure 4-19 Shear Strain to Right of Interface as a Function of Distance Along the Interface for Various Distances of Fracture Tip from the Interface. $E_1 = 50$ GPa and $E_2 = 10$ GPa.

Figure 4-20 The Single Lens Geometry

Figure 4-21 Geometry of Vertically Triple Lenses Stacked

Figure 4-22 Geometry of Horizontally Arranged Triple Lenses

lens thickness ℓ . Two-dimensional plane strain is considered so that the lens and the material is assumed to extend infinitely in the z direction. Furthermore, displacement in the x direction at $x = \pm 40 \ell$ was not allowed.

The normal stress in the y direction (σ_y) along the lines labeled BB and B'B' in Figure 4-20 is shown in Figure 4-23 for Case 1 ($E_{\text{lens}} = 10$ GPa, elsewhere $E = 20$ GPa). This calculation was reported in the status report of October 31, 1978. The stresses along the two lines are identical due to problem symmetry. Stress is nondimensionalized by dividing by the applied stress. Increasing σ_y/σ_0 corresponds to increasing compression. From Figure 4-23 compression is greatest along the lens and least about 2ℓ above and about 2ℓ below the lens. It would be expected that a horizontal fracture entering from outside the area of the lens would tend to cross line BB or B'B' at one of these two points of least compression. Figure 4-24 is a plot of stress along BB for the same single lens geometry with $E_{\text{lens}} = 20$ GPa and elsewhere $E = 10$ GPa (Case 2). Here the least compression is right along the side of the lens. It is likely that a fracture approaching the lens would be drawn toward the lens for this case.

Figures 4-25 (Case 1) and 4-26 (Case 2) are plots of horizontal stress along the lines AA or A'A' in Figure 4-20. Again, increasing stress corresponds to increasing compression. The stress along line A'A' does not differ appreciably from the stress along AA. Inelastic deformation was not allowed in this analysis. Consequently, some of the severe character in the curve near the lens would be smoothed somewhat if plastic deformation occurred. In Figure 4-25 the least compression occurs above and below the center of the lens. One would expect a vertical hydrofracture to intersect the lens near its center for this case. In Figure 4-26 the least compression is about 2ℓ outside the extremities of the lens.

Figures 4-27 (Case 1) and 4-28 (Case 2) show vertical stress along the lines BB or B'B' in Figure 4-21. In Figure 4-27 compression is greatest along the sides of the lenses. An approaching horizontal hydrofracture should tend to avoid the lens while for Case 2 (Figure 4-28) the fracture should be drawn to one of the lenses.

Figures 4-29 (Case 1) and 4-30 (Case 2) are plots of horizontal stress along the lines AA or A'A' in Figure 4-22. Least compression in Figure 4-29 is above and below the center of the lenses while in Figure 4-30 least compression is between or outside the lenses. A vertical hydrofracture approaching the lenses should intersect the lenses for Case 1 and should avoid the lenses for Case 2.

When a lens has a larger modulus than the surrounding material, these analyses indicate that a horizontal fracture would be drawn toward the lens. Conversely, the stress field around the lens would tend to impede the growth of a vertical fracture toward the lens. The results of crack growth near interfaces must also be taken into account to determine whether the fracture will penetrate a lens.

4.2.2 Experimental Program

4.2.2.1 Crack Growth Across Interfaces

Last month LLL reported on experiments in which hydraulic fractures were driven across unbonded interfaces from dry Indiana limestone into water saturated Indiana limestone.

Figure 4-23 Normal Stress in the y Direction Along the Lines BB or B'B' in Figure 4-20. Increasing Stress Corresponds to Increasing Compression. For Case 1: Young's Modulus in the Lens is 10 GPa; Young's Modulus of the Surrounding Material is 20 GPa.

Figure 4-24 Normal Stress in the y Direction Along the Lines BB and B'B' in Figure 4-20. Increasing Stress Corresponds to Increasing Compression. For Case 2: $E_{\text{lens}} = 20$ GPa and elsewhere $E = 10$ GPa.

Figure 4-25 Normal Stress in the x Direction Along the Lines AA or A'A' in Figure 4-20 for Case 1. Increasing Stress Corresponds to Increasing Compression.

Figure 4-26 Normal Stress in the x Direction Along the Lines AA or A'A' in Figure 4-20 for Case 2.

Figure 4-27 Normal Stress in the y Direction Along the Lines BB or B'B' in Figure 4-21 for Case 1

Figure 4-28 Normal Stress in the y Direction Along the Lines BB or B'B' in Figure 4-21 for Case 2

Figure 4-29 Normal Stress in the x Direction for Lines AA or A'A' in Figure 4-22 for Case 1

Figure 4-30 Normal Stress in the x Direction for Lines AA or A'A' in Figure 4-22 for Case 2

It was found that the threshold stress load across the interface for cracks to cross was lowered from about 650 psi to about 500 psi by saturation. The effect of the water in the interface might be expected to be that of a lubricant which would reduce the shear or frictional force transmitted across the interface at a given normal load. Such an effect would make it more difficult to grow a crack across that interface. The result that the crack will cross into the saturated material at a lower normal load across the interface suggests that the material properties of the saturated material which govern its acceptance of a crack may be sufficiently altered so that they more than compensate for the lubrication effect of the water. Since tensile strength is felt to be one of the important material properties, Brazil tests were performed to measure the tensile strength of the saturated limestone. The results indicated a tensile strength of 19 ± 3 bars as compared to about 50 bars for dry limestone. This dramatic decrease in tensile strength may account for the lowering of the threshold stress for cracks to cross the interface.

4.2.2.2 Rock Properties

During the month of October, design was completed for a hot-gas permeability apparatus for rock specimens at pressures up to 50 MPa and temperatures up to 250°C. Most apparatus parts have been ordered. Design has also been completed for a high pressure vessel for measuring ultrasonic velocities in six directions on one rock specimen. This vessel is being constructed. With this vessel the elastic constant tensor of a transversely isotropic rock as a function of confining pressure up to 1.0 GPa can be determined. This vessel can be easily altered for moderate temperature operation if such measurements are desired.

4.2.3 Related WGSP Activities

On October 11 and 12 LLL attended a meeting at Sandia Laboratories in Albuquerque to discuss mineback work on the interface experiments being conducted at the Nevada Test Site. On October 24, LLL attended a meeting held at CER Corporation in Las Vegas to help formulate the logging program for the WGSP.

4.2.4 Schedule Status

Figure 4-31 is a milestone chart of LLL FY 1979 activities.

4.3 SANDIA LABORATORIES

4.3.1 EGR Instrumentation and Diagnostic Program

4.3.1.1 Hydraulic Fracture Characterization

Sandia will begin participation in a follow-on set of experiments in the AMOCO Wattenberg Field, north of Denver, beginning the week of November 6. A series of three gas wells are planned in the Muddy "J" Sands, approximately 8,000 ft deep.

Figure 4-31 Milestone Chart-LLL

A breakdown procedure experiment is planned for all three wells. Sandia's instrumentation is to include the downhole three axis wallclamp geophone and the HP high resolution recording pressure gauge. The geophone has been instrumented with high temperature geophones in preparation for the high formation temperature.

Present planning calls for the Surface Electrical Potential System (SEPS) to be installed on the first and third wells during the full fracture experiment. Residential congestion around well No. 2 makes the installation of the SEPS impractical. Additional instrumentation during the full fracture will include the HP recording pressure gauge and the surface tilt-meter. Fracture fluid pressure and flow data from the service company transducer will also be recorded by SEPS instrumentation.

The first well for the SEPS installation will be Gorden Turkey Farm D-1. This well has a depth of 7,972 ft and is uncased at the fracture interface. Current from the SEPS will be injected at this level via the downhole current probe. Previous attempts at this procedure have resulted in current pulser failure. Hardware checkout at this point indicates that this problem has been corrected. The surface electrical potential will be recorded at radii of 1,200 and 2,400 ft. Two current sink wells, approximately 90 degrees apart, will be used.

4.3.1.2 Advanced Borehole Logging Program

Sandia attended the Western Gas Sands Logging Program meeting held at CER Corporation offices in Las Vegas. The meeting's objective was to bring together participants in the Logging Program to develop a working plan for geophysical logging research and development as regards tight western gas sand reservoirs.

The Sandia program concerns three areas; nuclear magnetic resonance (NMR), electromagnetic theory (EM), and borehole neutronics. These three areas were developed as a direct output of investigations carried out by a Sandia Logging Task Force whose conclusions are summarized in the following section. The NMR aspect of Sandia's program will involve evaluation of the applications of NMR techniques to low-permeability formations through laboratory testing and development of empirical relationships. Advanced instrument development for NMR measurements is part of the program given by Los Alamos Scientific Laboratories. The electromagnetic theory program involves development of the physical theory of time-dependent, borehole EM response of geologic formations leading to a series of laboratory measurements and, ultimately, tool development. The Sandia contribution to the overall borehole neutronic effort will be in the areas of new tube development and spectral gamma analysis.

4.3.1.3 Conclusions of Sandia Logging Task Force

A logging task force formed in February, 1978, was chartered to investigate the state-of-the-art in commercial geophysical logs as well as logging research to determine which areas of concentration might be most beneficial to natural gas reservoir applications. Numerous months of literature search, theory development, and interviews with production and research personnel from the petroleum industry, academic community, and logging service organizations, indicated that the areas of NMR and electromagnetics would provide

most benefit. In addition, continued research and development of existing Sandia borehole neutronics programs is encouraged with petroleum applications in mind. A working relationship with Chevron Oil Field Research Laboratories for NMR study of western gas sand formations has been developed, and a program for developing the pertinent electromagnetic theory linked to lab measurements has been initiated. These developments form the basis for the Sandia program described in the previous section.

4.3.1.4 Other Program Activities

David A Northrop met with Dr. Phil Randolph and Dr. Leo Rogers of the Institute of Gas Technology in Chicago on October 19, 1978. The purpose of the meeting was to examine IGT data on *in situ* stress variations (to be compared with those observed at NTS) and to explore IGT participation in program activities.

Carl L. Schuster presented a paper titled *Detection Within the Wellbore of Seismic Signals Created by Hydraulic Fracturing* (SPE 7448) at the 53rd Annual SPE Technical Conference. The abstract of this paper appears in Section 2.2.2, "Articles and Publications" of this report.

Mr. Schuster also presented a paper titled *An Overview of the Electrical Potential Method for Determining Fracture Orientation* at the 1978 Annual ASCE Meeting.

4.3.2 Schedule Status

Figure 4-32 is a milestone chart of the FY 1979 Sandia activities.

Figure 4-32 Milestone Chart—Sandia

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5. FIELD TESTS AND DEMONSTRATIONS

5.1 BACKGROUND

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

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

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

Table 5-1 MHF Contract Locations and Frac Data

COMPANY, BASIN	LOCATION	WELL	INTERVAL	FRAC. DATE	FRAC.	FLUID INJECTED
	T / R / Sec		Feet		TREATMENT	
					Lbs of Sand	10 ³ Gal
AUSTRAL Piceance, Mesaverde	7S, 94W, S3 Garfield Co. Colorado	Federal 3-94	5,170- 6,333	8-25-76	1,140,000	542 Gel Gel H O
CONSORTIUM MANAGED BY CER CORPORATION Piceance, Mesaverde	3S, 98W, S11 Rio Blanco Co. Colorado	RB-MHF-3	8,048- 8,078	10-23-74	400,000	117 Gel
			7,760- 7,864	5- 2-75	880,000	285 Gel
			5,925- 6,016	5- 4-76	815,000	400 Gel
			5,851- 5,869	11- 3-76	448,000	228 Gel
GAS PRODUCING ENTERPRISES, INC. Uinta, Wasatch and Mesaverde	10S, 22E, S10 Uintah County Utah	Natural Buttes No. 18	6,490- 8,952	9-22-76	1,480,000	745 Gel
	10S, 21E, S21 Uintah County Utah	Natural Buttes No. 19	8,900- 9,664	9-21-76	424,000	280 Gel
			7,224- 8,676	9-28-76	784,000	364 Gel
	9S, 21E, S22 Uintah County Utah	Natural Buttes No. 14	6,646- 8,004	3-15-77	1,098,000	544 Gel
	9S, 21E, S28 Uintah County Utah	Natural Buttes No. 20	8,498- 9,476	6-22-77	826,000	322 Gel
	10S, 22E, S18 Uintah County Utah	Natural Buttes No. 22	6,858- 8,550	11-21-77	1,091,000	479 Gel
	9S, 21E, S19 Uintah County Utah	Natural Buttes No. 9	5,661- 8,934	3-27-78	554,000	349 Gel
	10S, 21E, S29 Uintah County Utah	Natural Buttes No. 2	7,251- 8,774	8- 8-78	1,965,000	722 Gel
	10S, 22E, S7 Uintah County 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 County Texas	Ferguson A-1	5,957- 6,794	9-10-76	506,000	139 Foam 198 Emul
EL PASO NATL. GAS Northern Green River, Fort Union	30N, 108W, S5 Sublette Co. Wyoming	Pinedale Unit No. 5	10,950-11,180	7- 2-75	518,000	183 Emul 8 Gel
			10,120-10,790	10-20-75	1,422,000	459 Gel
MOBIL Piceance, Mesaverde	2S, 97W, S13 Rio Blanco Co. Colorado	F-31-13G	10,549-10,680	6-22-77	580,000	316 Gel
			9,432- 9,538	8-24-77	600,000	260 Gel
			8,163- 8,650	7- 6-78	660,000	288 Gel
			7,704- 7,794	9- 7-78	218,000	120 Gel
PACIFIC TRANSMISSION Uinta, Mesaverde	8S, 23E, S25 Uintah County	Federal 23-25	NO FRACS PERFORMED			
RIO BLANCO NATL. GAS Piceance, Mesaverde	4S, 98W, S4 Rio Blanco Co. Colorado	Federal 498-4-1	6,150- 6,312	10-22-76	766,000	276 Gel
			5,376- 5,960	11-30-77	243,000+ 22,500 Beads	164 Gel
WESTCO Uinta, Mesaverde	10S, 19E, S34 Uintah County	Home Fed. No. 1	7,826- 9,437	12-21-76	500,000	412 Gel
			10,014-10,202	10- 1-76	600,000	248 Gel

RIO BLANCO MASSIVE HYDRAULIC FRACTURING EXPERIMENT

EY-76-C-08-0623

CER Corporation
Las Vegas, Nevada

Status: Awaiting Advisory
Committee Decision

Interagency Agreement Date: June 19, 1974
Anticipated Completion Date: December 31, 1978

Project Cost (estimated):	DOE	\$1,975,000
	Industry	1,630,000
	Total	\$3,605,000

Principal Investigator: G. R. Luetkehans
Technical Advisor for DOE: C. H. Atkinson

OBJECTIVE

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

5.2 CER CORPORATION

5.2.1 Summary of Past Activities

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

5.2.2 Current Status

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

WATTENBERG FIELD

EY-77-C-08-1514

Colorado Interstate Gas Company
Colorado Springs, Colorado

Status: Active

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

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

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

OBJECTIVE

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

5.3 COLORADO INTERSTATE GAS COMPANY

5.3.1 Scope of Work

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

5.3.2 Current Status

A special compressor has been ordered with delivery expected in December, 1978. The concrete pad for the compressor has been poured, and presently the pipeline is being laid between the wells. One additional month is required for completion of site preparation and BHP buildup, and the first cyclic injection-withdrawal is expected to begin around February 1, 1979.

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.

5.4 GAS PRODUCING ENTERPRISES, INC.

5.4.1 Summary of Past Activities

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

5.4.2 Current Status

Natural Buttes Unit Wells No. 9, 14, 18, 19, 20 and 22 were flowing to sales during October. Production data for these wells appears in Figures 5-1 through 5-6.

Natural Buttes 21, perforated (7,565 - 7,568 ft) on October 13, is being flow tested to the pit. The well made a small amount of water, and gas too small to measure after a breakdown with 1,000 gal of acid.

Natural Buttes Unit No. 2 is presently shut in waiting on field proration, and Natural Buttes Unit 23, stimulated on October 4, 1978, is shut in waiting for pipeline connection permit from the Federal Energy Regulatory Commission.

Natural Buttes Unit 23 was stimulated with the following treatment:

- 90,000 lb of 100 mesh sand
- 135,000 lb of 40-60 mesh sand
- 205,000 lb of 20-40 mesh sand
- 40,000 lb of 10-20 mesh sand
- 240,000 gal of gel plus 4,000 gal of 2 percent KCl water

Future work includes continued analysis of the Natural Buttes Unit 21 core by Terra Tek, and continued production testing of open perms at 7,563 - 7,570 ft. If the perforations continue to produce only water then a cast iron bridge plug will be set and movement up the hole to the next interval will commence.

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	<u>1,074,550</u>
	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.

5.5 MITCHELL ENERGY CORPORATION

5.5.1 Summary of Past Activities

The Mitchell Energy Corporation Muse Duke No. 1 well flowed on a test at a rate of 2,034 MCFD through a 7/64 in. choke at a flowing tubing pressure of 4,289 psi. On September 27, the Cotton Valley Lime was perforated with 15 shots and each perforation was balled out. The formation was acidized with 15 percent HCl through the perforations. Bids for the massive fracture treatment were sent to several companies.

5.5.2 Current Status

The well is presently flowing on test at a rate of 2,100 MCF of gas with 3 BBL of water per day through a 14/64 in. choke with a flowing tubing pressure of 1,850 psi. Figure 5-7 shows the flowing tubing pressure and rates of the initial testing period. Preparations are being made to fracture the well on November 15, with approximately 1,000,000 gal of fluid and 3,000,000 lb of sand.

Since last reported, initial pressure transient tests have been conducted on the Cotton Valley Lime. The field recordings of the pressures and rates for the pressure transient tests were sent to CER Corporation and are available for inspection. Tandem Amerada pressure bombs were run for both the two-rate and buildup tests, conducted over a five-day period. However, and as evidenced by the intermittently abrupt pressure changes at varying time frequencies, the bombs' gauges were sticking during both of the tests. Therefore, only the pressure inflections were utilized in the evaluations.

If at each change, the bombs read either the correct bottomhole pressure, or a constant proportion thereof, then a slope indicative of the formation's productive capacity should be obtained on the buildup plots. These pressure points as well as the other pertinent transient data were sent to CER Corporation for the buildup and two-rate tests, respectively.

The attached Figure 5-8 is the conventional "Horner" plot for the 16,350 lb gauge, while Figure 5-9 is for the 15,000 lb gauge. In addition, the bottomhole tubing pressure difference plot (Figure 5-10), and the "log-log" plot of pressure changes versus time after shut in (Figure 5-11) for the 15,000 lb gauge were prepared for verification of the slopes, and for better delineations of the types of flows. Shown by these latter two figures, the start of the proper straight lines on the "Horner" plots is after a shut in time of approximately 40 hours. Thus, the pseudo-radial equations should be applicable subsequently to this time.

It should be noted on Figures 5-8 and 5-9, that an initial slope variance of only 5 psi-cycle was obtained. Thus, it was concluded that a plot of the above mentioned pressure reflections would yield reliable slopes. This is further substantiated by the fact that the quantitative evaluation did yield reservoir parameters that are very reasonable for the area. These parameters are tabulated on Table 5-2 for the 15,000 lb gauge. The corresponding values for the two-rate test are also shown on this in this table.

Figure 5-7 Flowing Tubing Pressure and Rates of Initial Testing Period

Figure 5-8 Conventional Horner Plot for 16,350 lb Gauge

Figure 5-9 Conventional Horner Plot for 15,000 lb Gauge

Figure 5-10 Bottomhole Tubing Pressure Difference Plot

Figure 5-11 Log-Log Plot of Pressure Changes versus Time After Shut in for the 15,000 lb Gauge

Table 5-2 Reservoir Parameters

PARAMETER	BUILDUP VALUE	TWO-RATE VALUE
Slope, M	110 Psi/Cycle	(-120 Psi/Cycle)
Productive Capacity, Kgh	9.4 Md-Ft	8.7 Md-Ft
Relative Gas Permeability, Kg	0.4 Md	0.3 Md.
Skin Factor, S	(-5.3)	+0.4
Pressure Loss/Improvement, ΔP Skin	(-510 Psia)	+20 Psia
Productivity Index, P.I.	1.3 MCFPD/Psi	—
Radius of Pressure Investigation, γ_d	960 Ft. or 66 Ac.	210 Ft. or 3 Ac.
Infinite Reservoir Pressure, P^*	6,485 Psia	—
Flowing Bottomhole Pressure, $P_f/P_f(t)$	6,193 Psia	6,043 Psia
Infinite Less Flowing Pressure, $P^* - P_f$	292 Psi	—
Stabilized Flow Rates - R_1 R_2	— 379 MCFPD	818 MCFPD 379 MCFPD

Figure 5-12 Conventional Plot for the Two-Rate Test

The conventional plot, the flowing bottomhole tubing pressure difference plot, and the "log-log" plot of pressure changes for this test are shown as Figures 5-12 thru 5-14, respectively. The excellent agreement of the calculated productive capacities and resultant relative gas permeabilities should be noted (Table 5-2). This further validates the fact that the correct slopes were used.

It should also be noted that the last three pressure points on Figure 5-8 (16,350 lb gauge) yielded a slope of 430 psi-cycle, or an increase of 3.7 times the initial slope. However, as no slope changes were encountered on the "Horner" plot for the 15,000 lb gauge (Figure 5-9), nor on the two-rate test (Figure 5-12), and due to the abruptness of the pressure reflections, this increased slope is attributed to erroneous pressure recordings in lieu of a barrier, a lateral permeability variation, and/or cross flow.

In summary, the productive capacity is 9.4 md ft; the relative gas permeability is 0.4 md, the skin factor is -5.3; and the productivity index is 1.3 MCFD/psi.

Terra Tek's laboratory experiments with cores taken from the Mitchell Energy well were completed and the results summarized in the report, *Fracturing Fluid Rock Interaction of Cotton Valley Lime Formation* by U. Ahmed, L. Buchholdt and A. S. Abou-Sayed. The abstract of this report appears in Section 2.2.2, "Articles and Publications", of this report.

Terra Tek, to experimentally determine the effect of different fracturing fluids on the host rock, took core samples from Mitchell Energy Corporation Muse-Duke Well No. 1. All samples were one-inch diameter by one-inch long, with the axes normal to the core axis. First, permeability at atmospheric conditions for core at *in situ* saturation (40 percent) was determined. Upon subjecting the samples to *in situ* pressures (8,800 psia confining pressure, 6,400 psia pore pressure) and temperature (285°F) permeability was again measured. While maintaining the confining pressure, pore pressure and temperature, fracturing fluid was flowed across one face of the sample for four hours at an injection pressure of 8,700 psia. These parameters simulated the field conditions. Twelve hours shut in time was allowed to assure that the fracture fluid was completely broken before backflow. On termination of shut in, permeability measurements were taken to determine the amount of damage.

Clean-up was simulated by introducing 6,400 psi nitrogen at the sample back face and reducing pressure at the fracture face. The following shows the schedule used.

PRESSURE REDUCTION AT FRACTURE FACE psi	DURATION OF NITROGEN BACKFLOW hrs	REMARKS
500	3	Monitor permeability until 100% damage was recovered or move on to the next step if damage recovery stabilized
1,000	2	Same as above
1,500	2	Same as above
2,000	2	Monitor permeability until 100% damage was recovered or stop test if damage re- covery stabilizes.

Figure 5-13 Flowing Bottomhole Tubing Pressure Difference Plot

Figure 5-14 Log-Log Plot of Pressure Changes for the Two-Rate Test

The three different fracturing fluids evaluated were, Stratafrac 400, Versagel and Polaris 60. All the fluids were premixed by the individual companies.

The damage and clean up data on the cores are presented in Table 5-3 and Figure 5-15 and 5-16. The initial *in situ* permeabilities of the samples interacted by Stratafrac 400 and Versagel were in the neighborhood of 25 μ d, whereas the sample interacted by Polaris 60 was much higher (83 μ d). The damaged permeability of all the samples at initiation of clean up were in the tenths of micro-darcy range, irrespective of the initial permeability of the sample and fluid used. There was no evidence of the fracturing fluid flowing totally through the sample.

A differential pressure of 500 psi was adequate for the clean up of the samples damaged by Stratafrac 400 and Versagel. The sample damaged by Polaris 60 cleaned up about 50 percent on a 500 psi differential pressure. Permeability appeared to stabilize at this level even after 3 hours of backflow. After increasing the differential up to 2,000 psi, there was a 10 percent increase in damage recovery.

Figure 5-17 shows the sample assembly for the test set up. The sample is placed in a pressure vessel and the pore-pressure inlet and outlet are connected to external fittings through the base plug. With this geometry, the sample can be subjected to hydrostatic loading or triaxial compression prior to testing. Pore-pressure in the sample can be set at any value less than the confining pressure, and the desired backflow pressure can be applied.

Table 5-3 Fracturing Fluid/Rock Interaction

FRAC FLUID	PERM AT ATMOSPHERIC CONDITION, K_a μ d	PERM AT IN SITU CONDITIONS, BEFORE FRAC FLUID FLOW, K_b μ d	PERM AFTER FRAC FLUID FLOW, K_s μ d	TIME OF NITROGEN BACKFLOW hrs				FINAL PERM K_f μ d	RECOVERY FRACTION K/K_i Δp of				ESTIMATED 100% RECOVERY TIME, hrs
				500	1000	1500	2000		500	1000	1500	2000	
Strata- frac 400	159	23	0.2	2	-	-	-	22	0.96	-	-	-	2.2
Versagell	991	31	0.3	1.5	-	-	-	25	0.81	-	-	-	1.7
Polaris 60	811	83	0.1	3	0.5	-	0.5	48	0.49	0.54	-	0.58	Inconclusive

Figure 5-15 Change in Permeability During Damage and Clean Up

Figure 5-16 Trend of Permeability Fraction During Damage and Clean Up

Figure 5-17 Fracturing Fluid Interaction Sample Assembly

PICEANCE CREEK FIELD, COLORADO, MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

EY-76-C-08-0678

Mobil Research and Development Corporation
Dallas, Texas

Status: Active

Contract Date: July 1, 1976
Anticipated Completion: December 31, 1978

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

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

OBJECTIVE

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

5.6 MOBIL RESEARCH AND DEVELOPMENT

5.6.1 Summary of Past Activities

Zone 8 was fractured on September 7, 1978. The most severe treating pressure to date was encountered while pumping the treatment. Initial ISIP was 800 psi, after pumping 3,000 gal of pad. Initial (static) treating pressure measured on the tubing, while pumping the gel was 900 psi. Pressure increased rapidly to about 3,400 psi when sand-out occurred after pumping 218,000 lb of 20-40 mesh sand in 120,000 gal of gel at 15 bpm. Table 5-4 is a summary of the Mobil well completion information and Figure 5-18 illustrates the treated zones 6, 7 and 8.

5.6.2 Description of Technical Progress

Most of October was spent in completing preparations for perforating and testing Zone 9. Following remedial cementing on Zone 9, the upper perfs failed to hold pressure. These perfs were successfully squeezed on October 10. The cement retainer was drilled on October 12 and a bond log run. Poor bonding was observed between Zone 9 and the bottom set of perfs at 7,510 ft. Bond was improved by the squeeze. After drilling out cement, attempts were started to move the bridge plug to above the lower cementing perfs. After several days of effort, the plug was jarred loose on October 25. While coming out of the hole with the plug, pressure built up below it and blew the plug and retrieving tools out of the hole. No one was hurt and the well was quickly brought under control. Only modest physical damage was incurred. A drillable plug was set below the zone on October 30.

The zone was perforated between 7,324 - 7,476 ft with 77 shots (one shot per two feet) on October 31 through November 1. After perforating, the well flowed at 650 psi wellhead pressure through a 3/4 in. choke. Figure 5-18 shows the intervals treated and Table 5-4 is a summary of completion information.

5.6.3 Future Plans

Zone 9 will be broken down with 2 percent KCl water and ball sealers, flowed for three days and shut-in for pressure buildup. If suitable for MHF, the zone will be fractured with 700,000 lbs of 20-40 mesh sand carried by 365,000 gal of gel at 60 bpm.

Note: After breakdown on November 1-2, the well flowed 2 MMCF gas plus 70 BBL water/day declining to 1 MMCF/day gas plus 500 BBL water/day in three days. The frac is scheduled for November 15.

Figure 5-18 Mobil F31-13G Well Showing Sands Fractured

Figure 5-18 Continued

Table 5-4 PCU No. 31-13G Completion Information

Zone	No.	Perfs Interval	PBTD, ft.	Tubing	Packer	Gas Gravity	Temp.* °F	Porosity	Pressure Transient Tests	
									Before Frac	After Frac
1	46	10,549-10,680	10,730	2-3/8 @ 10,450	None	N.A.	235		PBU	PBU
2	10	10,186-10,196	10,530			N.A.	230		None	Not Fractured
	2	10,202-10,204								
	4	10,255-10,261								
	10	10,415-10,427								
	3	10,472-10,476								
3	18	9,392-9,432	9,600	2-7/8 @ 9,120	9,120	0.678	215		PBU	PBU
	16	9,517-9,538								
4A	33	9,254-9,320	9,370	2-3/8 @ 9,150	None	N.A.	212		PBU	Not Fractured
4B	32	9,086-9,124	9,210	2-3/8 @ 8,980	None	N.A.	209		PBU	Not Fractured
5	5	8,765-8,773	9,040	2-3/8 @ 8,625	None	0.669	205		PBU	PDD
	11	8,790-8,810								
	5	8,826-8,834								
	9	8,914-8,930								
	10	8,954-8,972								
6	10	8,443-8,463	8,725	2-3/8 @ 8,300	None	Zones 6 and 7 combined	199		PBU	Pressure drawdown (PDD) test was run
	6	8,472-8,482								
	12	8,506-8,528								
	19	8,614-8,650								
7	10	8,163-8,181	8,425	2-3/8 @ 8,050	None	after frac 0.668	194		PBU	Zones 6 and 7 combined after frac
	9	8,210-8,226								
	9	8,250-8,266								
	4	8,279-8,285								
	4	8,349-8,355								
	4	8,366-8,372								
8	27	7,704-7,736	7,812	2-3/8 @ 7,675	7,675	N.A.	191		PBU	
	27	7,776-7,794								

Average porosity for all of these zones is about 9% with an average water saturation of about 60%.

*From temperature logs run over various intervals at different times, the geothermal temperature gradient through the Mesaverde averaged about 1.75°F/100 ft.

Note: Casing is 7 in., 26 lb set at 10,800 ft.

**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.

5.7 RIO BLANCO NATURAL GAS COMPANY

5.7.1 Summary of Past Activities

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

5.7.2 Current Status

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

NEVADA TEST SITE NYE COUNTY, NEVADA MINEBACK TESTING

Sandia Laboratories
Albuquerque, New Mexico

Status: Active

Principal Investigator:

D. A. Northrop

OBJECTIVE

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

5.8 SANDIA LABORATORIES—MINEBACK

5.8.1 Summary of Past Activities

The primary activity in September was the continued evaluation of the Hole No. 6 Formation Interface Fracture Experiment; the problem of hydraulic fracture containment by mineback analysis of two grout-filled fractures propagated above and below a geologic interface of hard welded volcanic tuff overlaying a soft bedded ashfall tuff. The lower zone (ashfall tuff) was treated with 5,000 gal of green grout, followed by 4,000 gal of black grout, and the upper fracture (welded tuff) was propagated with 5,000 gal of blue grout.

5.8.2 Current Status

Efforts continued throughout October to delineate the Hole No. 6 Formation Interface Experiment fractures. This experiment was designed to examine the containment of a hydraulic fracture at a geologic interface by propagating fractures above and below an ashfall tuff—welded tuff (upper formation) interface and mining back the fractures for direct observation and testing of material properties and *in situ* stresses. The entire length of the fractures at the interface were mined back and it was found that the lower fracture, which was initiated in the ashfall tuff, broke through the interface everywhere it contacted it even though the modulus of the welded tuff is an order of magnitude greater than the modulus of the ashfall tuff.

After the mineback of the interface was completed, and exploratory coring program was begun to determine the extent of the fractures. Ten holes were previously cored; during October, two additional holes were cored downward to locate the lower edge of the fracture. Grout was found in hole EV6 No. 11 at approximately 70 ft below the interface and it was somewhat stranded; the thickest strand was 5-6 mm thick. In EV6 No. 12, grout was found about 100 ft below the interface. Here, however, the fracture was about 2 mm thick and a number of hairline strands were in evidence. These depths, along with previous coring results, indicate a total fracture height of at least 140 ft, a value which is close to the 150 ft fracture length observed at the interface. Further coring will be undertaken to determine the upper extremities of the fractures and the shape of the fractures about the wellbore.

Analysis of the problem of a pressurized crack approaching a smeared interface is being addressed from three directions—closed-form analysis, computer code calculations, and experimental studies. The closed-form analysis of this continuum mechanics problem is being handled primarily on contract to Tom Cook at the Southwest Research Institute. The basic approach taken is to use transform techniques to derive appropriate integral equations which are solved numerically. This approach is similar to that used previously by Cook for the problem of a crack approaching a distinct interface. This month, the problem setup was formulated, integral equations derived in transform space and “solved” by means of residues. In the solution process, however, several governing equations were not completely satisfied. A solution is near but its validity needs to be confirmed.

Code calculations on this problem were begun initially using the CHILES code. While this code is excellent for crack problems using enriched elements near the crack tip, problems arose in applying pressure loading to the crack surfaces near the tip. A modified code, similar to the CHILES code called APES is now running on the Sandia computers. This code also uses enriched elements but has additional features such as extra nodal points and the capability for pressure loading the crack tip. Initial check out work is complete and a few simple calculations have been made on the problem of a crack approaching an interface.

Experimental studies have only progressed as far as discussions with rock mechanics personnel. The receipt of a university proposal which deals with fracture behavior of concrete specimens made in such a way as to result in a varying Young's modulus through the specimen will model the smeared interface.

Sandia Laboratories hosted a Gas Stimulation Workshop on October 11 and 12, 1978, in Albuquerque, NM. The objective of the meeting was to allow detailed examination and discussion of the results from recent mineback experiments conducted at the Nevada Test Site. Discussion centered on three topics: (1) Hole No. 5 proppant distribution experiment, (2) Hole No. 6 formation interface experiment, and (3) a proposed fracture conductivity-proppant distribution experiment. Attendees included A. B. Waters and A. Daneshy (Halliburton), M. Feves and J. Elbel (Dowell), P. Randolph (IGT), R. Saucier (Shell), R. Veatch (Amoco), Z. Shuck (WVU/METC), G. Fingleton (SAI), M. Hanson (LLL), R. Mann (CER), H. Wahl (Conoco), and eight of Sandia's personnel. Specific guidance was received on further evaluation of the Hole 5 and 6 experiments and these ideas will be incorporated into project plans. The objectives of the proposed experiment were approved. The workshop was well received and an informal advisory group was initiated, which will act at similar meetings in the future.

5.8.3 Schedule Status

Figure 5-19 is a milestone chart depicting the schedule for activities within Sandia's Mineback program.

Figure 5-19 Milestone Chart—Sandia (Mineback)