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Western Gas Sands Project Status Report

1 February 1979 - 28 February 1979

Prepared for
U.S. Department of Energy

Bartlesville Energy Technology Center
Charles H. Atkinson
Project Manager

Compiled by CER Corporation
Las Vegas, Nevada

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1. SUMMARY

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

John Sharer of the Gas Research Institute met with C. H. Atkinson and CER personnel in Las Vegas on February 2, to discuss the CER-GRI contract for WGSP supporting research.

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

During February, projects of the National Laboratories and Energy Technology Centers progressed on schedule. Work on fracture conductivity, rock-fluid interaction, and log evaluation and interpretation techniques continued at Bartlesville Energy Technology Center. Lawrence Livermore Laboratory continued experimental and theoretical work on hydraulic fracturing mechanics and analysis of well test data. Sandia Laboratories started a new program using seismic reflection concepts as a means to delineate individual channel sand reservoirs from surface data. M. D. Wood, Inc. will monitor a hydraulic fracture in the Wattenberg gas field using a new type of tiltmeter array.

Field tests and demonstrations progressed as scheduled. The CER Corporation RB-MHF 3 is on an inactive status pending contractual arrangements. The final RB-MHF 3 report is being edited for printing. The DOE Well Test Facility was moved from Vernal, Utah to the Miller No. 1 well in the Wattenberg field, Weld County, Colorado to perform BHP buildup and related tests on both the Sprague No. 1 and Miller No. 1 wells for the Colorado Interstate Gas Company cyclic injection test. The Mitchell Energy Corporation Muse-Duke No. 1 well was flowing 4,100 MCFD. Zone 9 of the Mobil well PCU No. F31-13G flowed 1,800 MCFD in February.

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2. PROJECT MANAGEMENT

2.1 TECHNICAL MONITORING AND EVALUATION

C. H. Atkinson and CER personnel met with John Sharer, Gas Research Institute, in Las Vegas on February 2, 1979 to discuss the CER-GRI contract for WGSP supporting research.

Erich Evered, CER's Assistant Project Manager for the Western Gas Sands Project, attended the Natural Gas Reservoirs Symposium held February 15-16, 1979 at Stanford University. Papers were divided into three areas (basic reservoir parameters, reservoir flow analysis, field case histories), relative to analytical techniques and applications for natural gas reservoirs. Several abstracts with relevance and potential application to the WGSP are printed in Section 2.2.2.

C. H. Atkinson met with Battelle Northwest personnel on February 15, 1979 in Las Vegas to review WGSP activities.

CER Corporation and C. H. Atkinson met with Sandia Laboratories personnel in Las Vegas on February 20, 1979 to discuss Sandia participation in the Western Gas Sands Project.

Intercomp presented a review of the status of their work to CER Corporation and C. H. Atkinson in Las Vegas on February 27, 1979.

2.2 TECHNOLOGY TRANSFER

2.2.1 Documentation and Reports

The Status Report, December 31, 1978 has been distributed. The Fourth Quarterly Basin Activities Report, January 1, 1979, and Status Report, 1 January - 31 January, 1979 have been completed and are in review.

The final report on the CER-managed Government/Industry MHF-3 demonstration well is being edited for printing and will be released in April, 1979.

2.2.2 Articles and Publications

FOAMED AQUEOUS AND NON-AQUEOUS FLUIDS FOR EFFECTIVE GAS RESERVOIR STIMULATION - AN UPDATE

David L. Holcomb, Cardinal Chemical, Inc.

ABSTRACT — Both aqueous and non-aqueous fluids have been foamed to successfully stimulate production from several Mid-Continent gas reservoirs. Foaming agent development has allowed the use of both low quality and high quality foam in condensate, 2 percent KCl water and 3 percent HCl plus 1.2 percent HF systems. Gas reservoirs such as the Morrow, Canyon Sand, Pubbs, Strawn, Crockett Sand, San Miguel, Skinner, etc. have successfully been treated in the Mid-Continent. A new series of specialty foamers has been developed to combat some of the problems of foaming in the presence of, or directly in, hydrocarbon condensate. Techniques and case histories will be discussed to illustrate the effectiveness of foamed stimulation.

GAS POTENTIAL OF THE FRONTIER FORMATION, GREEN RIVER BASIN -- A TECHNOLOGICAL FRONTIER

Jerry R. Bergeson, Consultant, Bergeson and Associates

ABSTRACT — The Frontier formation is related to the deltaic deposition from the Greater LaBarge Platform. Wells drilled for the Frontier have been geologic successes, inasmuch as they have encountered gas-bearing sands. However, extensive engineering analysis is required to determine if the wells can be economically completed. An integrated approach utilizing log and core data, drill stem test analysis, and production histories of nearby wells allows reasonable predictions of future well problems.

2.2.3 Project Data Bank

A wildcat well penetration map showing wells drilled into and through potentially gas-bearing, low-permeability Upper Cretaceous and Tertiary reserves, Great Basin Divide, southwest Wyoming, and three structure maps on the top of the Lance Formation, Almond Formation, and Baxter-Hillard-Steele Formations were added to the project file. Work on the WGSP bibliography continued.

2.3 ASSOCIATED GAS RESEARCH INSTITUTE ACTIVITIES

Successful contract negotiations between CER Corporation and the Gas Research Institute (GRI) were concluded with a contract being let in January, 1979. CER Corporation will coordinate the proposed GRI work with DOE-funded projects in order to increase the efficiency, cost-effectiveness, scope and long-term value of the research.

3. RESOURCE ASSESSMENT

3.1 U.S. GEOLOGICAL SURVEY ACTIVITIES

3.1.1 Greater Green River Basin

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

Petrographic examination of core chips from the Superior-Pac. Crk. Unit well in sec. 27, T. 27 N., R. 103 W., Sublette County, Wyoming continued.

Relationships between pressure, temperature, and organic maturation in the Pacific Creek area, northeastern Green River Basin are being investigated.

Surface samples from the northern Green River Basin are being prepared for heavy mineral analyses.

Work continued on the lineament study of the Washakie and Great Divide Basins.

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

A well penetration map of the Great Divide Basin is ready for review.

An exhibit for the annual AAPG-SEPM meeting in Houston, April, 1979 is being prepared.

3.1.2 Uinta Basin - Piceance Basin

Analysis of X-ray diffraction data from the Mesaverde Group and Tertiary formations in the Westwater Canyon area has begun.

Three cross-sections of Upper Cretaceous and Tertiary rocks in the southern Piceance Basin have been submitted for review as USGS Oil and Gas Charts.

Three cross-sections of Upper Cretaceous and Tertiary rocks in the northern Piceance Basin have been submitted for review prior to publication as USGS Oil and Gas Charts.

Analysis of rock plugs from the Mesaverde Group in the Uinta Basin (Natural Buttes area) for porosity and permeability has continued. All results to date range from 3 to 13 percent porosity and from less than 0.1md to 0.5md to air. These values are obtained from analysis of plugs cut at each change in rock character through producing intervals at Southman Canyon gas field. All plugs in which fractures were noted were omitted from analysis. Only one core sample of 18 studied so far has a permeability to air (at surface pressure) of less than 0.1md.

3.1.3 Northern Great Plains Province

Preparation of a manuscript on the Bowdoin field for SPE continued.

An exhibit for the annual AAPG-SEPM Meeting in April, 1979 is being prepared.

A paper on the reservoir characteristics of the Eagle Sandstone in the Bearpaw Mountain area is in preparation.

Petrographic investigation of shelf sandstones in the Eagle-Telegraph Creek interval of the J. C. Paine well began. Preliminary investigations indicate that high porosity and permeability values recorded from conventional core analysis resulted from the extensive micro-fracture system created by desiccation of clays.

3.1.4 Schedule Status

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

3.2 CORE PROGRAM

During February, operators were contacted for potential core sites in the four primary areas of interest to the WGSP. Kansas-Nebraska Natural Gas Company and Odessa Natural Corp. were contacted concerning sites in north-central Montana. Ensearch Exploration was contacted with regards to several locations staked in the Southman Canyon - Natural Buttes area of the eastern Uinta Basin. CER maintained contact with Teton Energy throughout the month to discuss the possibility of coring one of three wells being drilled by the company in the Piceance Basin. Northwest Exploration was contacted at month's end concerning a number of locations in the southern portion of the Piceance Basin. Woods Petroleum, Michigan-Wisconsin Pipeline, Dome Petroleum, Kemmerer Coal Co., and Forest Oil were all contacted with reference to core operations in the Greater Green River Basin.

Agreement on one coring contract was reached in February with Smokey Oil for their 3-18 Bluewater Federal well in Sweetwater County, Wyoming.

3.3 LOGGING PROGRAM

Log analysis of the Twin Arrow well C&K 4-14x near Rangely, Colorado continued through the month of February.

3.4 SURVEY OF BASIN ACTIVITIES

Drilling and testing 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. Background information on the core areas is given in the WGSP *Quarterly Basin Activities Report*, April 1, 1978, NVO/0655-05.

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

3.4.1 Greater Green River Basin

Completed wells of interest to the WGSP in the Greater Green River Basin added 18,239 MCFD of new gas. Twenty wells were completed; 12 development wells and 8 wildcats. Development wells were 66 percent successful (8 wells out of 12) and wildcats had 38 percent success. Producing horizons were the Frontier (6,563 MCFD), Mesaverde (2,721 MCFD), Almond (757 MCFD), and Lewis (8,198 MCFD).

Thirteen development wells and 3 wildcats were staked during February, and at month end one had been spudded and was drilling ahead.

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

3.4.2 Northern Great Plains Province

Fifty-six wells were completed in the Northern Great Plains Province in horizons and at locations of interest to the WGSP. Forty-nine of 51 development wells were successful. Four of 5 wildcats completed were discoveries. Total gas production from horizons of interest yielded 12,710 MCFD. Producing zones were the Bow Island, Phillips, and Bowdoin.

Seventeen new locations were staked in February; 10 development wells and 7 wildcats. One wildcat was completed D&A by month end.

Wells of significance to the Western Gas Sands Project are located on Figures 3-3 and 3-4, and listed in Table 3-2.

3.4.3 Piceance Basin

New gas from Upper Cretaceous horizons in the Piceance Basin totaled 4,961 MCFD. The wells produced from the Mancos, undifferentiated (933 MCFD) and Mancos B (4,028 MCFD). Sixteen of eighteen development wells (2 D&A) and one of two wildcats (1 D&A) were productive.

Twenty new wells were reported in February; 11 development sites and 9 wildcats.

Wells of special interest to the WGSP are listed in Table 3-3 and located on Figure 3-5.

3.4.4 Uinta Basin

Twenty-one wells were completed in horizons of interest to the WGSP during February and added 17,025 MCFD of new gas. Twenty development wells were completed with 65 percent success (13 wells of 20), and 1 wildcat was D&A. Producing horizons were the Wasatch (12,271 MCFD), commingled Wasatch/Mesaverde (3,550 MCFD), Green River (1,000 MCFD), and Mancos B (204 MCFD). Six new locations were staked.

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

Figure 3-2

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

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

OPERATOR	WELL NAME	MAP INDEX NO. ¹	LOCATION Sec/T/R	HORIZON ²	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Amoco Production	1 Champlin 242 AMOCO-K	1	w1/4sw 33/20N/93W Echo Springs Field Sweetwater Cty, WY	Mesaverde (10,015)			Located in core area A	
Amoco Production	6 Unit	2	new 9/21N/94W Siberia Ridge Field Sweetwater Cty, WY	Almond (10,438-10,500)	12,250 PB: 10,565	6,500 gal acid	Completed, no cores or tests, located in core area A	350
Davis Oil	1 Picket Lake Unit	3	nwse 24/26N/97W Unnamed Field Sweetwater Cty, WY	Lewis (13,142-13,176)	13,602	232,470 gal emulsion, 294,600 lb sand	Wildcat, completed, no cores, large frac treatment, Lewis discovery—new field	8,198
Davis Oil	1 Parrish Mark Unit	4	nwse 12/26N/109W Wildcat Field Sweetwater Cty, WY	Mesaverde (10,200)	15,872		Wildcat, located in core area B, D&A	

¹ Refer to Figure 3-2

² Horizon - projected depth or producing interval

Figure 3-3

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

Figure 3-4

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

Table 3-2 Summary of Wells - 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
Marmik Oil	16-2 Federal	1	sese 2/5S/51E Wildcat Field Powder River Cty, MT	Shannon (2,800)			Wildcat drilling at 2,353 ft	
Joseph J.C. Paine	1-1306 Strohmén	2	nwse 13/30N/36E Unnamed Field Valley Cty, MT	Bowdoin (1,182-1,222)	1,595		Completed, located in core area C	720
Montana Dakota Utilities	966 Smith	3	nenw 13/31N/43E Bowdoin Field Valley Cty, MT	Bowdoin-Phillips (1,400)			Development well	
Xeno, Inc.	11-23 Battle	4	nesw 23/36N/19E Unnamed Field Blaine Cty, MT	Eagle (1,616-1,622)	1,640		Completed, no core or tests	792
Joseph J.C. Paine	1-1962 Montana Power Federal	5	senw 19/36N/32E Bowdoin Field Phillips Cty, MT	Phillips (1,516-1,538) Bowdoin (1,281-1,333)	1,600 PB: 1,538		Completed, commingled production	623

¹ Refer to Figures 3-3 and 3-4

² Horizon - projected depth or producing interval

Figure 3-5

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

Table 3-3 Summary of Wells - Piceance Basin

OPERATOR	WELL NAME	MAP INDEX NO. ¹	LOCATION Sec/T/R	HORIZON ²	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Chandler & Associates	3-22-1-2 Fork Unit	1	nenw 22/1S/102W North Douglas Creek Rio Blanco Cty, CO	Emery (2,317-2,377)	2,628	Perf (2,317-2,377 90,930 gal water, 230,000 lb sand	Completed, no cores or tests, large frac treatment	1,000
Teton Energy	14-1 Yellow Creek-Federal	2	nene 14/1S/99W Wildcat Field Rio Blanco Cty, CO	Mancos (11,500)			Wildcat located in core area A	
Northwest Exploration	1-Federal	3	sesw 32/11S/93W Wildcat Field Mesa Cty, CO	7,300 ft test			Wildcat located near core area D	

¹ Refer to Figure 3-5

² Horizon - projected depth or producing interval

Figure 3-6

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

Table 3-4 Summary of Wells - Uinta Basin

OPERATOR	WELL NAME	MAP INDEX NO. ¹	LOCATION Sec/T/R	HORIZON ²	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Koch Exploration	Cedar Rim No. 21	1	swne 4/4S/6W Altamont Field Duchesne Cty, UT	Wasatch (7,900)			Located in core area A	
Continental Oil	34-2 Conoco-Mtn. Lion	2	nese 34/8S/21E Ouray Field Uinta Cty, UT	Wasatch (5,953-6,878)	10,227 PB: 8,015	Perf 5,954-6,878 acidized, frac with 185,850 gal water 312,500 lb sand	Completed, no cores or tests, large frac treatment	3,234
CIG Exploration	43-14-10-22 CIGE	3	senw 14/10S/22E Natural Buttes Field Uintah Cty, UT	Wasatch (5,041-5,864) Mesaverde (6,409-7,153)	7,300	Acidized 6,000 gal, 145,095 gal emulsion, 275,000 lb sand	Completed, no or tests, commingled production	750
Coseka Resources	1 Dry Burn	4	nwse 29/13S/25E Unnamed Field Uintah Cty, UT	Mancos B (5,536-5,686)	5,792 PB: 5,699	500 gal acid, 122,600 gal water, 82,000 lb sand	Wildcat completion, no cores or tests, Mancos B discovery-new field. Located in core area D	204

¹ Refer to Figure 3-6

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

Review of the Maurer Engineering pressure core barrel drawings conducted by Larry Russell and Associates of Houston identified a number of areas where design modifications appear to be necessary. These areas were called to the attention of the prospective RFP respondents, and an extension of the closing date to March 5, 1979 was allowed.

The adaptor-sub for the pilot bit drilling tests at Terra Tek has been designed. Fabrication should be completed the second week of April, and drill tests should start at Terra Tek during April.

4.1.1.2 Core Fluid Tests

During February the study of the pseudo plastic flow properties of non-Newtonian power-law fluids in the core/core barrel annulus was completed. Power-law fluids, such as the polymer muds which will be used in low invasion coring, obey the following shear stress/strain rate relationship.

$$T = K \frac{du}{dy}^n, \text{ where } T = \text{shear stress,}$$

du/dy is the rate of strain, K is the characteristic viscosity, and n is an experimentally determined exponent. A simple Newtonian fluid such as water has a value of unity and a constant viscosity K . With a Newtonian fluid, the calculation of the velocity profile and pressure buildup in the core barrel is relatively straightforward. However, experimental data from the Brinadd polymer system "Sanheal" showed the fluid properties to be highly non-Newtonian and a strong function of both temperature and shear rate. In order to calculate the pressure buildup during coring for this type of fluid, the necessary power-law equations were developed and solved numerically using a computer.

The 100 lb/BBL Sanheal mud, which was far too thick to pour, had a pressure buildup of only 31 psi when flowing through the 1/8 in. annulus over the ten ft length of the core. This contrasts favorably with the 60,000 cp Dow-Corning 200 fluid, which had a calculated pressure buildup of 500 psi. Although Sanheal was much thicker at rest than the Dow-Corning 200, its shear-thinning properties greatly reduce the coring pressure buildup and will allow the use of extremely high viscosities in order to minimize filtrate invasion.

Bariod core holder/filtration test equipment has arrived and will be set up as soon as possible. This equipment will be used to optimize particle size distribution of the polymer mud for the three different rock types to be tested. The core holder was shipped with the wrong o-rings, and has delayed the experimental work for at least two weeks. The proper o-rings have been ordered locally and will arrive soon. This additional low invasion coring fluids testing is being carried on under a separate BETC contract.

4.1.1.3 Bit Design and Fabrication

Stainless steel canning for use in the diffusion bonding of StratapaxTM cutters to the first pilot bit body has been received at Sandia. The first diffusion bonded pilot bit should be available for the April Terra Tek drilling tests.

The redesigned tooling for ultrasonic tacking of StratapaxTM cutters to steel studs was reworked to correct fabrication errors. Tack welding of cutters using new tooling will be attempted in the first week of March.

4.1.1.4 Request For Proposals

The final date for receipt of proposals for the joint cost-sharing program for development of an improved pressure coring system is March 5, 1979. A one week extension of the closing date was made to provide time for respondents to include assessment of the specific areas identified by Larry Russell's review of the Maurer design.

Three no-quote responses, from the University of California, San Diego Deep Sea Drilling Project, Di Kor, and American Coldset Corporation, were received by the end of February.

4.1.2 Interface Conductivity Effects on Electric Logging

Duplicate plugs for 8 depths from the Natural Buttes No. 21 well in Uintah County, Utah were prepared for porosity, permeability, and conductivity measurements. Porosity values determined by the Boyle's Law technique appear in Table 4-1. Formation factor and cation exchange capacity (CEC) measurements for these plugs are in progress. An automated sample tumbler was assembled for CEC samples. This equipment will increase the speed and accuracy of CEC tests.

Table 4-1 Porosity of Natural Buttes No. 21

Core Depth, ft	Porosity, percent
4,462.0	2.57
4,468.0	1.75
6,407.0	6.58
6,475.0	10.56
6,499.0	7.26
6,499.5	10.01
7,427.0	8.02
7,427.8	8.62

4.1.3 Logging Techniques and Interpretations

Porosity and matrix density for 48 plugs cut from the Natural Buttes No. 21 well were reported in January. Figure 4-1 shows the matrix density versus porosity as a function of relative porosity. Ten samples have been cut and sent to National Petrographic Service in Houston, Texas for the preparation of oversized thin sections (approximately 22 x 35 mm). These thin sections, cut perpendicular to bedding, will be surface impregnated without coverglasses.

4.1.4 Reservoir Simulation Studies

Type curve plots made from pressure buildup data taken during several tests run on the Mobil well F31-13G show long periods of wellbore storage. The plots show that there is eventually no data that can be used for Horner analysis. Type curve analysis of the data gives values for permeability that appear to be too large.

Flow time prior to a buildup test should be much longer than the buildup time for type curve analysis to be used. This is not the case for tests on the Mobil well. The reason for imposing this condition on type curve analysis is due to the fact that the dimensionless variables used in preparing the curves are calculated for drawdown conditions.

The pressure drop during a drawdown test is given by:

$$\Delta p = p_i - p_{wb} = 141.2 \frac{q B \mu}{k h} [p_D(t_D) + s] \quad (1)$$

$P_D(t_D)$ is a time-dependent dimensionless pressure drop that depends upon the reservoir geometry. Type curves usually are plots of $P_D(t_D)$ as a function of dimensionless time, t_D . The pressure change during a buildup is obtained by applying the superposition principle using Equation 1. This gives:

$$\Delta p = p_i - p_{ws} = 141.2 \frac{q B \mu}{k h} [p_D(t_p + \Delta t)_D - p_D(\Delta t)_D] \quad (2)$$

t_p is the flow time before the well was shut-in and Δt is the buildup time.

A type curve plot of buildup data is made by plotting the logarithm of the pressure change since the well was shut-in against the logarithm of the buildup time. An expression for the pressure change is obtained by subtracting Equation 2 from Equation 1:

$$p_{ws} - p_{wb}(t=0) = 141.2 \frac{q B \mu}{k h} [P_D(t_p)_D - p_D(t_p + \Delta t)_D + p_D(\Delta t)_D + s] \quad (3)$$

$P_{wh}(\Delta t = 0)$ is the flowing pressure just before shut-in. If $P_b(t_p)_D$ and $P_D(t_p + \Delta t)_D$ are eventually equal, Equation 3 is the same as Equation 1 for the drawdown. This happens when t_p is much greater than Δt . When this is not true, the drawdown type curve cannot be used.

Figure 4-2 is a type curve plot of drawdown and buildup data calculated for a low permeability reservoir which contains a constant compressibility liquid. Both curves show the data to be controlled by wellbore storage. In this case, the first two terms of Equation 3 do not cancel each other and the buildup data is shifted to the right of the drawdown data. If the flow time had been long enough to get out of wellbore storage, the two sets of data would coincide. Permeability calculated from type curve analysis of the buildup data would be high.

Figure 4-3 is a type curve plot of drawdown and buildup data calculated for a tight gas well. Both curves show the data to be dominated by wellbore storage. The shift between the two sets of data is much greater than shown in Figure 4-1. This is due to gas compressibility changing with pressure. The early time drawdown pressures are high, thus giving a low gas compressibility. Since the reservoir is tight, the drawdown pressure at the end of the flow period is low. The early time buildup pressures are low resulting in a longer storage period.

Permeability calculated by type curve analysis of the buildup data would be too large.

Prefrac data on zones 5, 6, and 7 have been analyzed assuming no fracture prior to fracturing. The results to date show that all zones appear to be fractured. Work on these zones continues.

The post frac test of zone 3 is presently being analyzed. It appears that the zone is fractured and has a significant skin value.

4.1.5 Rock Fluid Interaction

An experiment was conducted to simulate the effect of pumping a gel through a propped fracture. Fine diameter sand particles, which simulated crushed proppant and core face materials, were mixed with a partially degraded 40 lb gel in 2 percent KCl solution. The mixture had about 90,000 particles per ml with a mean diameter of 5.35 microns. The gel-particle mixture was injected through a 10 in. length, 1-1/2 in. diameter Mesaverde core split lengthwise, and packed with 40-60 mesh sand to form a 0.1 in. fracture.

With an 8,000 psig overburden pressure imposed on the core, a constant volume pump was used to inject the mixture through the simulated fracture at a rate of 2.5 mls/min. After 28 min the injection pressure increased to 270 psig and after 60 min the pressure increased to 990 psig. Aliquots of the core effluent indicated a decrease in particle number with an increase in particle diameter. Due to pump pressure limitations the experiment was concluded with the fracture plugging. The data indicates that proppant pores and fracture were plugged due to the particle mixture and gel residue.

Figure 4-2 Type Curve Plot for a Low Permeability Reservoir which contains a Constant Compressibility Liquid

Figure 4-3 Type Curve Plot for Tight Gas Well

Permeabilities of seven adjacent plugs from a uniform core interval from the Mobil PCU F31-13G well were measured for data consistency between plugs. Although replicate measurements for a single plug were reasonably consistent, permeability variation between different plugs was excessive for a core interval with uniform lithologic appearances as shown in Table 4-2. The data suggest a problem of gas leakages between the core and Hassler sleeve. Additional plugs of larger diameter were prepared for additional tests to study the problem of blow-by on low permeability cores.

Table 4-2 Permeability Values of Adjacent Plugs in a Uniform Core Interval (Mobil PCU F31-13G)

Plug Number	Permeability (md)
A	.050
B	.078
C	.075
D	.097
E	.073
F	.102

4.1.6 Measurement of Formation Characteristics for Western Tight Sands

High pore pressure tests have commenced on No. 7011 and No. 9957. These tests were conducted holding the overburden or effective stress at 100 psia. Due to a late discovered problem with calibration of the differential pressure transducer recorder, large differences between Klinkenberg extrapolated permeabilities and 10g/l NaCl brine permeabilities, results are being sorted out, particularly since the high pressure effect upon gas slippage has been noted.

Table 4-3 and Figures 4-4, 4-5, and 4-6 show determination of K_{rg} on previous and newly cut plugs for No. 8498A, No. 9998A, and a redetermination of No. 9957. The table and figures also show Corey approximations. The closeness of fit for No. 8498A to No. 8498 and No. 9998A to No. 9998 is good. The discrepancy between previously determined No. 9957 and the present data probably results from a systematic offset in weighing the core, resulting in a systematic shift. The Corey equation values shown apply for both curves if the second No. 9957 run is shifted over. This high value measured for the initial conditions was after the core had been dried in a vacuum oven at a temperature of 115° C which was 25° C higher than previous dryings. When the core was resaturated and dried again at 90° C, the original initial permeability was found. This may be due to clays giving up water at increasing temperatures. Runs of 10g/l NaCl solution through No. 9957 for Klinkenberg tests show that No. 9957 has a large number of fines in the pore spaces. Flow in one direction would quickly decrease. When flow was reversed, it would

Figure 4-4 and 4-5 Effects of Water Saturation on Gas Permeability

Figure 4-6 Effects of Water Saturation on Gas Permeability

Table 4-3 Effect of Water Saturation on Gas Permeability

8498	S_w (%)	0	14.18	24.82	34.04	47.52	61.70
	K_{eg1} (md)	2.76×10^{-2}	2.23×10^{-2}	2.05×10^{-2}	1.53×10^{-2}	8.88×10^{-3}	4.67×10^{-3}
	K_{eg2} (md)	—	2.15×10^{-2}	1.66×10^{-2}	1.25×10^{-2}	7.08×10^{-3}	2.55×10^{-3}
8498A	S_w (%)	0	22.63	32.12	39.42	47.45	52.55
	K_{eg1} (md)	2.73×10^{-2}	1.95×10^{-2}	1.38×10^{-2}	1.17×10^{-2}	9.86×10^{-3}	6.70×10^{-3}
	K_{eg2} (md)	—	1.76×10^{-2}	1.34×10^{-2}	9.19×10^{-3}	7.11×10^{-3}	5.30×10^{-3}
9998	S_w (%)	0	26.45	39.35	54.19		
	K_{eg1} (md)	3.15×10^{-2}	2.60×10^{-2}	1.91×10^{-2}	1.15×10^{-2}		
	K_{eg1} (md)	—	2.25×10^{-2}	1.51×10^{-2}	7.66×10^{-3}		
9998A	S_w (%)	0	18.52	26.54	33.33	38.27	
	K_{eg1} (md)	3.77×10^{-2}	2.94×10^{-2}	2.45×10^{-2}	2.24×10^{-2}	1.79×10^{-2}	
	K_{eg2} (md)	—	2.72×10^{-2}	2.25×10^{-2}	1.85×10^{-2}	1.57×10^{-2}	
9967 (1)	S_w (%)	0	24.2	35.4	43.4	55.1	62.6
	K_{eg1} (md)	1.10×10^{-1}	5.7×10^{-2}	4.5×10^{-2}	2.8×10^{-2}	8.2×10^{-3}	1.3×10^{-3}
	K_{eg2} (md)	—	5.97×10^{-2}	3.85×10^{-2}	2.54×10^{-2}	1.02×10^{-2}	3.6×10^{-3}
9957 (2)	S_w (%)	0	27.09	36.45	40.89	49.75	70.44
	K_{eg1} (md)	1.46×10^{-1}	8.35×10^{-2}	6.09×10^{-2}	5.10×10^{-2}	3.99×10^{-2}	2.45×10^{-3}
	K_{eg2} (md)	—	7.16×10^{-2}	4.87×10^{-2}	3.89×10^{-2}	2.19×10^{-2}	—

Note: K_{eg1} — Measured relative permeability.

K_{eg2} — Relative permeabilities calculated using Corey equation.

The parameters in the equation were assigned the following values:

8493	and 8498A :	$m = 1.1$	$S_{gc} = 0.25$	$S_{wc} = 0$
9998	and 9998A :	$m = 1.1$	$S_{gc} = 0.20$	$S_{wc} = 0$
9957 (1)	and 9957 (2):	$m = 1.3$	$S_{gc} = 0.30$	$S_{wc} = 0$

increase to a maximum value and then begin decreasing, indicating fines were dislodged and then began resealing pores. Two oscillations showed that the flow reached the same maximum value before decreasing irrespective of flow direction. Cores of similar initial gas permeability exhibited different brine permeabilities, therefore brine flows will be retested.

4.1.7 Schedule Status

Figure 4-7 is a milestone chart showing the status of BETC WGSP activities.

Figure 4-7 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												

Figure 4-7 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 4-7 Continued

Figure 4-7 Continued

4.2 LAWRENCE LIVERMORE LABORATORY

4.2.1 Theoretical Analysis

Analysis was initiated to determine the characteristics of a dynamically expanding pressurized crack that was approaching perpendicular to an interface. Except for one calculation, which corresponded to an isotropic material, the interface separates two materials of differing elastic moduli but identical densities. For every case, the crack propagated at $.4C_p$ (where C_p is the dilatational wave speed) in a material typified by the Lamé constant $\mu = \rho\lambda = 0.3 \text{ Mbar}$. Several calculations were made with each calculation corresponding to a unique set of values for the elastic constants of the adjoining material. Some calculations were performed where the adjoining material was stiffer than the material that contained the crack and some where the adjoining material was more flexible.

The results show significant differences when compared to each other. Parallel displacements (displacements parallel to the crack and perpendicular to the interface) of a point along the crack diverge slightly when the first reflected dilatational waves arrive from the interface. These displacements tend to diverge at a greater rate later on. The perpendicular displacements also diverge, but much later than the arrival time of the reflected dilatational wave. Reflections of elastic waves from the interface must cause this divergence but the onset of divergence does not immediately correspond to the first reflected wave arrival time for either dilatational or shear waves. This situation is further complicated by the crack tip passing by the point in question.

Further calculations will be made, particularly for the extreme case where the interface is a free boundary. Comparison of the displacements near the crack for several cases of differing elastic constants will be made following these calculations.

4.2.2 Experimental Program

Friction experiments of the type described in the January status report have continued. The materials studied have been the same as those used in the interface fracture experiments, i.e., Nugget sandstone, Indiana limestone and PMMA. In the experiments on the rocks both smooth surfaces and surfaces roughened by sandblasting have been used. Water saturated rock specimens have also been used. Many experiments have been performed and many more are planned in order to obtain a large statistical sample because of the variability in rocks. Data analysis is presently in progress.

Some preliminary experiments have been reported in which the effects of intermediate fluid pressure loading rates on hydraulic fractures have been studied¹. Intermediate loading rates are several orders of magnitude lower than those generated by explosives but several orders of magnitude greater than those produced in conventional hydrofracture loading. These intermediate loading rate experiments have continued using water, kerosene and glycerol as fracturing fluids. These experiments are still in the development stage. However, they have indicated a tensile strength dependence on strain rate, and illustrated that the LLL strain rate apparatus can be used to investigate the strength-strain rate effect in a region of interest to hydrofracturing of which very little is currently known.

Core samples were received from a 5,200 ft depth in the Mesaverde Group in Sublette County, Wyoming. X-ray diffraction analysis has been done to study the composition of these samples and of samples from the Mesaverde Group in Rio Blanco County, Colorado. Bulk and grain density measurements and Brazil test tensile strength measurements have also been completed on samples from Rio Blanco County, Colorado.

4.2.3 Schedule Status

Figure 4-8 is a milestone chart depicting the status of LLL projects through February, 1979.

- ¹ Hanson, M. E., et al., LLL Gas Stimulation Program Quarterly Progress Report July through September 1978, Lawrence Livermore Laboratory, UCRL 50036-78-3, November 6, 1978.

4.3 SANDIA LABORATORIES

4.3.1 EGR Instrumentation and Diagnostic Program

4.3.1.1 Hydraulic Fracture Characterization

The current generator in SEPS was modified to increase the pulse risetime. One area of consideration is that of the distributed capacity between the downhole current probe cable and well casing, allowing significant high frequency content current injection at and near the surface. Increased pulse risetime will work against this possible effect. Risetimes in the range of 30-50 milliseconds can be achieved against a downhole current probe-sink well loop impedance of approximately 70 ohms. Increased pulse risetime is accomplished, however, at the expense of current injection magnitude.

At the receiving end of SEPS, long highpass time constants between the pick-up probe and the instrumentation input seem to be most effective against the effects of the transient voltage spikes on the leading and trailing edges of the millivolt level data potentials. This was determined experimentally using an input signal similar to that encountered in the field. These time constants (70 seconds) limit the sampling rate due to the time required for the instrumentation to settle after being switched from calibration to a data probe. One approach being explored is that of a 2-dimension time constant, a short one (0.2 seconds) during the settling period, and a long one during the data acquisition interval.

Information content in the tail of the seismic signals from the Gordon Turkey Farms and UPRR experiments is under investigation. It is felt that the periodic signal is fracture-related but it is not fully understood and could be mechanical resonance in the seismic unit.

In order to investigate this portion of the signal, an experiment is being planned at NTS. The experiment consists of inducing various types of seismic signals (i.e., impact, spark, sine wave, etc.) and observing the wave forms on both the borehole seismic unit and a triaxial geophone package in close proximity to the borehole unit. Separation of mechanical resonances and elastic ground motion should be accomplished.

Figure 4-8 Milestone Chart-LLL

A system has been designed for electrical testing of the Edo Western hydrophone at pressures up to 10,000 psi. The system was set up for a test and electrical measurements (for reference) made at ambient pressure. However, when the pressure was increased on the hydrophone unit, the electrical wire feed-thru connector from the pressure container failed and further testing could not be made. A new design for the feed-thru is now being fabricated and the hydrophone electrical test will commence when the improved feed-thru connector is available.

The required change in the component layout for the amplifier mixer-line driver printed circuit board has been completed. The board has been fabricated, the circuit components assembled, tested, and is functioning properly.

4.3.1.2 Advanced Borehole Logging

To model the response of an induction probe consisting of a transmitter coil and one or more receiver coils situated in a borehole, Maxwell's equations and the equations that describe the electrical properties of earth materials must be solved simultaneously. These latter constitutive equations are complicated since parameters such as the dielectric "constant" are frequency dependent. Measurement and correlation of frequency dependence with porosity, pore fluid salinity, and, perhaps, fluid flow permeability is sought.

With reference to the modeling work of J. H. Moran and K. S. Kunz (Geophys. 27 829, 1962), the electrical properties of the earth follow from the complex voltage induced in the receiver coils and are proportional to:

$$\text{Phase 1 } \sigma + \omega \epsilon''(\omega)$$

$$\text{Phase 2 } \omega \epsilon'(\omega).$$

In these relations, the conductivity, σ , is the assumed constant, ω is the angular frequency, and ϵ' and ϵ'' are the components of the complex dielectric permittivity. For many earth materials, $\epsilon''(\omega)$ is approximately proportional to ω^{-1} and $\sigma \gg \omega \epsilon''(\omega)$. Consequently, Phase 1 information is not very useful in the determination of dielectric data. Phase 2 information does yield dielectric information. However, in practice, this phase includes another term dealing with the free-space couplings between the transmitter and receiver coils. By proper design of the receiver coils, this relatively large coupling term may be nulled. Thermal expansion effects may disrupt the null giving a false signal. Nevertheless, a probe based on this concept is a possibility.

Another possibility follows from the usage of pulsed rather than steady-state driving currents. For such measurements, the constitutive relations must include transient effects. One formulation that has proven useful is based on the Duhamel or hysteretic integral of the form

$$D(t) = \epsilon_{\infty} E(t) + \frac{(\epsilon - \epsilon_{\infty})}{\tau} \int_0^t \exp\left(-\frac{t-t'}{\tau}\right) E(t') dt' ,$$

where D and E are the time-dependent displacements and fields and the constants ϵ_∞ , ϵ and τ are, respectively, the instantaneous and relaxed permittivities and the relaxation time.

4.3.2.1 Modeling and Analysis

A rock mechanics/fracture mechanics model was formulated in January that described the character and size of the micro-crack zone at a crack tip in rock. Work this month was extended to include a description of the orientation of the micro-cracks within the zone and effects of an anisotropic in situ stress state.

The microcrack zone is described by defining the boundary near a crack tip for which the maximum tensile stresses are greater than some value, σ_u . If the in situ stress state is hydrostatic then this boundary is defined by

$$r = \frac{1}{2\pi} \left(\frac{K_{Ic}}{\sigma_u + \bar{\sigma}} \right)^2 \cos \frac{\theta}{2} \left(1 + \sin \frac{\theta}{2} \right)^2 \quad (1)$$

r, θ are polar coordinates from the crack tip,

K_{Ic} is fracture toughness,

σ_u is ultimate stress, and

$\bar{\sigma}$ is hydrostatic stress.

At each point within this zone, orientation of the maximum tensile stress can be determined and this then will give the most probable orientation of microcracks at each point. The equation that defines these orientations, α , is

$$\alpha = \frac{1}{2} \left(\frac{3\theta}{2} + \frac{\pi}{2} \right) \quad (2)$$

This equation is depicted in Figure 4-9 by short lines within the microcrack zone which represent microcracks.

Figure 4-9 Damage Zone in a Crack Tip in Rock
(Short Lines are Perpendicular to Tensile
Stress and Indicate Probable Orientation
of Microcracks)

Figure 4-10 Microcrack Zone as a Function of In Situ Stress
Anisotropy, β

The description of this microcrack zone becomes more complicated when the in situ stress state is not hydrostatic. The solution process is similar to that followed for Equation 1.

$$r = \frac{1}{2\pi} \left(\frac{K_{Ic}}{\sigma_u + \bar{\sigma}} \right)^2 \left(\cos \frac{\theta}{2} \frac{1 + \beta \sin \frac{\theta}{2} \sin \frac{3\theta}{2} + \sqrt{\left(1 + \beta \sin \frac{\theta}{2} \sin \frac{3\theta}{2}\right)^2 - \left(1 - \beta^2\right) \cos^2 \frac{\theta}{2}}}{1 - \beta^2} \right)^2 \quad (3)$$

$$\text{and } \beta = \frac{\sigma_{\pi} - \sigma_{\perp}}{2(\sigma_u + \bar{\sigma})}$$

where

σ_{π} is the in situ stress parallel to the crack,

$\sigma_{\perp}$ is the in situ stress perpendicular to the crack,

$\bar{\sigma}$ is the mean stress $\left(\frac{\sigma_{\pi} + \sigma_{\perp}}{2} \right)$, and

β is degree of in situ stress anisotropy, $0 < \beta < 1$.

Physically, this constitutive relation means the present value of D is related to the present and all past values of e ; past values being forgotten exponentially. It may be noted that a customary form of $\epsilon'(\omega)$ and $\epsilon''(\omega)$ follows from $E = E_0 e^{-1/\omega\tau}$ and $t \gg \tau$. For $t < \tau$, transient terms are present.

Presently, vector and scalar potentials are being formulated using Duhamel integrals to represent the dielectric, magnetic and ohmic properties of matter. These potentials will serve as the basis for initial modeling of a pulsed induction probe. This modeling is sufficiently accurate to test the feasibility of such a probe. However, if feasibility is demonstrated, hysteretic integrals involving a spectrum of relaxation times will be required to properly model the electrical properties of the earth.

Since hydraulic fractures are generally perpendicular to the least principal stress, σ_1 is considered a principal stress and $\sigma_1 < \sigma_2$. Equation 3 reduces to Equation 1 for $\beta = 0$. Equation 3 can be non-dimensionalized and is plotted in Figure 4-10 for various values of β .

This equation can now be used to determine the size and shape of microcrack zones at hydraulic fracture tips. This information is very useful in understanding the characteristics of fracture growth for hydraulic fractures in rock.

Preliminary studies of the fluid mechanics of fracturing model show that the system of equations, which must be solved by an iterative technique, does not readily converge. Furthermore, the time dependent terms, which dominate at small times, add another degree of complexity so that it is difficult to start a calculation from zero time (zero fracture length). The behavior of the system of equations and convergence techniques are presently being investigated.

Photomicrographs of some microfractures observed in thin sections cut within 1 cm of the grouted hydrofrac No. 6 are now available. A brief memo on the results of the petrographic analysis of the sections is forthcoming. Hydraulically induced microfractures have not been identified in the sections examined.

4.3.2.2 Formation Mapping

This new program is an outgrowth of discussions held at the Borehole Logging Program meeting in October, 1978, wherein concern was raised over the present inability to delineate and map individual sand channel reservoirs typical of the Mesaverde Group. T. L. Dobecki (Sandia) proposed at this meeting that state-of-the-art seismic reflection concepts (seismic stratigraphy, 3-D seismic) might be a means of delineating sand channels from surface derived data. Since that time, he has been compiling applicable case histories and conducting interviews with experts in the fields of seismic reflection surveying and Cretaceous stratigraphy in the Utah, Colorado, and Wyoming area. The results of this preliminary investigation were presented in a briefing for CER and DOE personnel held at CER, Las Vegas, on February 20. Sandia representatives were C. L. Schuster and T. L. Dobecki. It was decided that a limited seismic program should be performed and that a coordinated effort with C. K. GeoEnergy Corp., who is performing statistical analyses of primary sedimentary structures in channel sands in outcrop, would be mutually beneficial. Discussions at C. K. GeoEnergy on February 21 pointed out at least three possible areas which may be appropriate for the proposed seismic study. These are near Rangely, Colorado, De Beque, Colorado, and Green River, Utah. The latter site is preferred, as this is the site of intense analysis by C. K. GeoEnergy with USGS cooperation. Future activities, based on the results of these meetings, will include site visits, compilation of available geologic/geophysical data applicable to the sites, and determining instrumental, procedural, and processing specifications to be met by prospective seismic contractors.

4.3.3 Schedule Status

Figure 4-11 is a milestone chart showing the status of Sandia's WGSP activities.

Figure 4-11 Milestone Chart—Sandia

4.4 M. D. WOOD, Inc., TILTMETER

4.4.1 Current Status

M. D. Wood, Inc. (MDWI) hosted Carl Schuster of Sandia Laboratories and Mike Smith of Amoco Research on February 9, 1979 to review recent work and plan future experiments. An outcome of the meeting was additional independent confirmation of the determination of fracture azimuths that have been done in past work. An experiment was planned to support the hydraulic fracturing research in the Sandia Mineback Project at the Nevada Test Site. Tiltmeters will be located in the floor of a tunnel near the site where 4 small (40 in. diameter) hydraulic fractures will be produced. Gradients of tilt will be measured along one fracture radius and then compared to theoretical predictions to learn more about in situ ground response and refine techniques for determining fracture boundaries.

4.4.2 Future Plans

M. D. Wood, Inc. will monitor the formation of a hydraulic fracture in the Wattenberg gas field, Colorado. A new type of tiltmeter array, designed by MDWI, will be used to accurately determine lengths of deep vertical fractures.

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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 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. A draft copy of the RB-MHF 3 final report is being edited for printing.

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 T/R/Sec	WELL	INTERVAL FRACTURED ft	FRAC DATE	FRAC TREATMENT Lb of Sand	INJECTED FLUID 10 ³ Gal
AUSTRAL Piceance, Mesaverde	7S/94W, Sec 3 Garfield Cty Colorado	Federal 3-94	5,170- 6,333	8-25-76	1,140,000	542 Gel Gel H O
CONSORTIUM MANAGED BY CER CORPORATION Piceance, Mesaverde	3S/98W, Sec 11 Rio Blanco Cty Colorado	RB-MHF-3	8,048- 8,078 7,760- 7,864 5,925- 6,016 5,851- 5,869	10-23-74 5- 2-75 5- 4-76 11- 3-76	400,000 880,080 815,000 448,000	117 Gel 285 Gel 400 Gel 228 Gel
GAS PRODUCING ENTERPRISES, INC. Uinta, Wasatch and Mesaverde	10S/22E/Sec 10 Uintah Cty Utah	Natural Buttes No. 18	6,490- 8,952	9-22-76	1,480,000	745 Gel
	10S/21E/Sec 21 Uintah Cty Utah	Natural Buttes No. 19	8,909- 9,664 7,224- 8,676	9-21-76 9-28-76	424,000 784,000	280 Gel 364 Gel
	9S/21E/Sec 22 Uintah Cty Utah	Natural Buttes No. 14	6,646- 8,004	3-15-77	1,093,000	544 Gel
	9S/21E/Sec 28 Uintah Cty Utah	Natural Buttes No. 20	8,498- 9,476	6-22-77	826,000	322 Gel
	10S/22E/Sec 18 Uintah Cty Utah	Natural Buttes No. 22	6,858- 8,550	11-21-77	1,091,000	479 Gel
	9S/21E/Sec 19 Uintah Cty Utah	Natural Buttes No. 9	5,661- 8,934	3-27-78	554,000	349 Gel
	10S/21E/Sec 29 Uintah Cty Utah	Natural Buttes No. 2	7,251- 8,774	8- 8-78	1,965,000	722 Gel
	10S/22E/Sec 7 Uintah Cty Utah	Natural Buttes No. 23	5,080- 6,294	10- 4-78	440,000	240 Gel
DALLAS PRODUCTION Fort Worth, Bend Cong.	Ben D. Smith Survey A-779 Wise Cty Texas	Ferguson A-1	5,957- 6,794	9-10-76	506,000	139 Foam 198 Emul
EL PASO NATL. GAS Norther Green River, Fort Union	30N/108W/Sec 5 Sublette Cty Wyoming	Pinedale Unit No. 5	10,950-11,180 10,120-10,790	7- 2-75 10-20-75	518,000 1,422,000	183 Emul 8 Gel 459 Gel
MITCHELL ENERGY Cotton Valley, Limestone Trend	Limestone Cty Texas	Muse-Duke No. 1	11,220-11,430	11-15-78	2,800,000	891 Gel
MOBIL Piceance, Mesaverde	2S/97W/Sec 13 Rio Blanco Cty Colorado	F-31-13G	10,549-10,680 9,392- 9,538 8,765- 8,972 8,163- 8,650 7,704- 7,794 7,324- 7,476	6-22-77 8-24-77 5-10-78 7- 6-78 9- 7-78 11-15-78	580,000 600,000 388,000 660,000 218,000 700,000	316 Gel 260 Gel 160 Gel 288 Gel 120 Gel 365 Gel
PACIFIC TRANSMISSION Uinta, Mesaverde	8S/23E/Sec 25 Uintah Cty Utah	Federal 23-25	NO FRACS PERFORMED			
RIO BLANCO NATL. GAS Piceance, Mesaverde	4S/98W/Sec 4 Rio Blanco Cty Colorado	Federal 498-4-1	6,150- 6,312 5,376- 5,960	10-22-76 11-30-77	766,000 243,000+ 22,500 Beads	276 Gel 164 Gel
WESTCO Uinta, Mesaverde	10S/19E/Sec 34 Uintah Cty Utah	Home Fed No. 1	7,826- 9,437 10,014-10,202	12-21-76 10- 1-76	500,000 600,000	412 Gel 248 Gel

RIO BLANCO MASSIVE HYDRAULIC FRACTURING EXPERIMENT

EY-76-C-08-0623

CER Corporation
Las Vegas, Nevada

Status: Awaiting Advisory
Committee Decision

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

Project Cost (estimated):	DOE	\$1,975,000
	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

CER Corporation was awarded DOE contract EY-76-C-08-0623 in March, 1974 which provided for the drilling of a new well and two MHF treatments. Two additional MHF treatments and an extended term of contract to July 1, 1979 were added to modify the original contract.

5.2.2 Current Status

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

A final report on the RB-MHF 3 is being prepared for printing and will be distributed in late April.

DOE WELL TEST FACILITY

EY-76-C-08-0623

CER Corporation
Las Vegas, Nevada

Status: Equipment checkout
and test proceeding

Principal Investigator:
Technical Advisor for DOE:

R. L. Mann
C. H. Atkinson

OBJECTIVE

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

5.3 DOE WELL TEST FACILITY

5.3.1 Background

CER's support contract includes the operation of a well test facility at various locations selected by DOE. A 10 ft x 50 ft instrument and winch trailer, a two-ton truck equipped with a hydraulically controlled telescoping 50 ft mast, and two trailer-mounted 30 kw and 90 kw electric generators comprise the facility.

5.3.2 Current Status

During the later part of February, the DOE Well Test Facility was moved from Vernal, Utah to the Miller No. 1 well in the Wattenberg field, Weld County, Colorado. The facility will be used to perform bottom hole pressure buildup and related tests on both the Sprague No. 1 and Miller No. 1 wells in support of the Joint DOE/CIG Cyclic Dry Gas Project.

Completion records and addendums revealed that although the Miller No. 1 well still contained the original 2-3/8 in. completion tubing, the 2-3/8 in. tubing had been pulled from the Sprague No. 1 well and replaced with 1-1/4 in. tubing. Since all of the facility's bottom hole tools are in excess of 1-1/4 in. diameter, a wire line service was contracted by CIG to perform the BHP buildup test on the Sprague No. 1 well.

Sinker bars were run in the Miller No. 1 well and encountered a soft obstruction at 7,820 ft. Completion records indicate that TD is 8,029 ft. with perforations at varying intervals from 7,891 - 7,929 ft, and a Baker F packer set at 7,880 ft. The well owners' (Machii-Ross) production foreman stated that an unsuccessful attempt was made to pull the 2-3/8 in. tubing from the Miller No. 1 well in 1974 but the packer would not release. Pressure data gathered at the wellhead indicated that communication exists between the tubing and casing. CIG cleaned out the Miller No. 1 well with nitrogen.

The H.P. pressure transducer and G.O. temperature tool were serviced and calibrated in preparation for use in the Miller No. 1 well. The computer and electrical systems were checked and made operational.

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.

5.4 COLORADO INTERSTATE GAS COMPANY

5.4.1 Scope of Work

On September 1, 1977 Colorado Interstate Gas Company and DOE entered into contract No. EY-77-C-08-1514 to determine if the productivity of wells completed in low-permeability gas reservoirs could be improved by cyclic injection of dry natural gas to reduce the interstitial water saturation. Cyclic injection of dry natural gas could improve productivity by dehydrating matrix clays and by removal of formation damage adjacent to the surfaces of induced fractures.

5.4.2 Current Status

A 2 in. pipeline has been laid between the Sprague No. 1 and Miller No. 1 (see Figure 5-1), wells.

Three Rolo dry bed dehydrators have been obtained. One dehydrator will be installed at each of the wells involved, and a third will be installed on the suction side of the compressor at the Sprague No. 1 well site.

An Ajax "DPC-160/H2" compressor has been delivered by Cooper Energy Services to CIG's East Denver control facility. A concrete pad has been poured for installation of the compressor at the Sprague No. 1 site in March.

The DOE test trailer was moved to the Miller No. 1 site to measure the BHP buildup. The test trailer, operated by employees of CER Corporation, is equipped to run the bottom hole pressure gauge, record the data, and determine the productive capacity (Kh) of the producing formation prior to cyclic injection. The information will be obtained with a Hewlett-Packard BHP gauge for a period of approximately 60 days.

When running sinker bars prior to running the bottom hole pressure gauge, CIG was unable to reach the bottom (estimated at 7,891 ft) and got only to 7,820 ft. It was thought frac sand had been carried into the well bore. Cleanout will be attempted.

A wire line service company ran a 1 in. diameter sinker bar into the Sprague No. 1 well and bottomed at 7,974 ft. Records indicate that this well has a total depth of 8,036 ft with perforations between 7,979 ft and 7,988 ft. A pressure bomb with a 144-hour clock will be used to obtain BHP readings in the Sprague well.

Figure 5-1 Layout of Miller No. 1 Well Area

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

EY-76-C-08-0681

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

Status: Active

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

Total Project Cost (estimated):	DOE	\$2,827,000
	Industry (prior costs)	1,881,000
	Industry (new costs)	3,051,000
	Total	\$7,759,000

Principal Investigator: W. E. Spencer
Technical Project Officer for DOE: C. H. Atkinson

OBJECTIVE

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

5.5 GAS PRODUCING ENTERPRISES, INC.

During February, the GPE wells, Natural Buttes Units 9, 14, 18, and 20 flowed to sales. Natural Buttes Units 19 and 22 were shut in. Table 5-2 is a summary of MHF treatments performed on GPE wells to date. Figures 5-2 to 5-7 show production figures.

Table 5-2 Summary of MHF Treatments

Well	No. of Zones Perf.	Net Ft. of Pay	Net Ft. Per Zone	Average		% Sd	Type of Fluid	Frac Job Size Gal of Gel	Lb of Proppant	Calc. Frac Length ft	Est. 1st Year Avg. Prod. Rate
				ϕ	SW						MCFD
Natural Buttes No. 18 DOE	18	224	12.5	10.0	48	88.0	Versa Frac	695,000	1,480,000	882	1,200
Natural Buttes No. 19 DOE	19	194	10.2	9.5	47	87.0	40# Guar Gum	655,000	1,237,000	950	60
Natural Buttes No. 14 DOE	15	271	18.0	9.9	49	65.0	YF4-PSD	544,000	1,082,000	879	600
Natural Buttes No. 20 DOE	8	65	8.1	9.9	44	88.5	YF4-PSD	309,000	826,000	1,150	800
Natural Buttes No. 22 DOE	24	196	8.1	12.0	45	85.0	YF4-PSD	478,758	1,091,000		
Natural Buttes No. 9 DOE	(35)	779*	22.0*	Unkn	Unkn	Unkn	40# Guar Gum	314,000	553,000		
Stage 1 CIGE 2-29-10-21 DOE	10	91	9.1	10.0	40	80.0	MY-T-GEL III	195,000	170,500		
Stage 2	12	181	15.1	11.3	42	85.0	MY-T-GEL III	805,230	1,956,000		
CIGE 23-7-10-22 DOE	10	156	15.6	9.0	60	78.0	YF4-PSD	240,000	470,000		

*Using GR as only indication of net sand which more closely equals gross sand.

Figure 5-2
Flow Rate Performance of
Natural Buttes No. 9 Well

Figure 5-3
Flow Rate Performance of
Natural Buttes No. 14 Well

Figure 5-4
Flow Rate Performance of
Natural Buttes No. 18 Well

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

Figure 5-6
Flow Rate Performance of
Natural Buttes No. 20 Well

Figure 5-7
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.

5.6 MICHELL ENERGY CORPORATION

In February, the M.E.C. Muse-Duke No. 1 was flowing 4,100 MCFD with 20 BBL of frac water through a 22/64 in. choke with a flowing tubing pressure of 1,575 psi. Flow rates and pressures are still dropping, but at a slower rate.

Due to the gas demand, the scheduled pressure transient tests and clean-out work have not been completed.

PICEANCE CREEK FIELD, COLORADO, MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

EY-76-C-08-0678

Mobil Research and Development Corporation
Dallas, Texas

Status: Active

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

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

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

OBJECTIVE

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

5.7 MOBIL RESEARCH AND DEVELOPMENT CORPORATION

5.7.1 Current Status

During February 1-14, Zone 9 flowed at approximately 1.8 MMCFD with 18 BBL condensate.

Work to remove two casing plugs from the well began on February 14. The top plug was drilled out but parts of the plug fell to bottom where they landed on a sand fill at 8,444 ft. Efforts to recover this material by circulating, running a junk basket and drilling were unsuccessful as of February 28.

5.7.2 Future Plans

The well will be put on production as soon as clean-out operations are completed.

RIO BLANCO COUNTY, COLORADO MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

EY-76-C-08-0677

Rio Blanco Natural Gas Company
Denver, Colorado

Status: Active

Contract Date: August 1, 1976
Anticipated Completion: December 15, 1978

Total Project Cost (estimated):	DOE	\$ 410,000
	Contractor	593,000
	Total	\$1,003,000

Principal Investigator: Robert E. Chancellor
Technical Project Officer for DOE: C. H. Atkinson

OBJECTIVE

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

5.8 RIO BLANCO NATURAL GAS COMPANY

Due to persistent water production, gas flow continued to be restricted in February.

A final report is expected to be completed and released in the near future.

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 mine-back for direct observation and evaluation.

5.9 SANDIA LABORATORIES - MINEBACK

5.9.1 Summary of Past Activities

Efforts in January centered around formulating a rock mechanics/fracture mechanics model that would describe the character of the microcrack zone at the crack tip in rock, and evaluation of the Hole No. 6 Formation Interface Experiment.

5.9.2 Current Status

No further work was performed during February on the Formation Interface Fracture Experiment.

The Interface Test Series is a set of small hydraulic fracture experiments that will be conducted to determine the effect of pump rate on the containment of a fracture at a geologic interface. This test will be delayed until the end of March in order for M. D. Wood, Inc. to install 3 tiltmeters in the tunnel to monitor the progress of the fractures and to investigate their applicability to tunnel fracturing experiments.

Nuclear containment studies, financed by DOE's Division of Military Applications, are investigating aspects of the containment of underground nuclear explosions. With a series of small (8 to 1,000 lb) high explosive experiments, the residual stress field that remains after the passage of the dynamic effects of the explosion is being studied. These residual stress fields are created when explosives are detonated in geologic media; thus gas stimulation techniques that utilize explosives will generate these effects.

Preliminary data from the gauges installed on the 1,000 lb event (RS-3) detonated in January have been examined. A cavity gas pressure of 7,500 psi was measured after detonation. In addition, the residual stress field at 13 to 14 ft from the charge center was measured. Five gauge records show an average residual stress 0.25 kilobar. This stress level agrees well with a code calculation value of 0.20 kilobar. Mineback on this 1,000 lb shot has begun.

In February, hydrofrac measurements were performed in two holes (HF29 and 30) in an area for possible future experiments. In this technique, the pressures measured at the termination of pumping is believed to be close to the minimum in situ stress. Sandia measured 540 psi at this location. The pressures required to break out of the packed off interval in the hole allowed calculation of one other in situ stress. For this case (HF29 and 30) the other stress is approximately vertical with a calculated value of 1,250 psi. The hydrofrac was performed with dyed water and mineback will reveal fracture direction and the in situ stress orientation.

5.9.3 Schedule Status

Figure 5-8 is a milestone chart of Sandia mineback progress.

Figure 5-8 Milestone Chart—Sandia (Mineback)