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Western Gas Sands Project Status Report **MASTER**

1 January - 31 January 1980

Prepared for
U.S. Department of Energy
Bartlesville Energy Technology Center
Las Vegas Field Office

Compiled by CER Corporation
Las Vegas, Nevada

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1. SUMMARY

This edition of the WGSP Status Report summarizes January, 1980, 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, WGSP Status Report, NVO/0655/100.

The USGS continued activities in the four primary areas of interest in the WGSP. Coring and logging of Rainbow Resources No. 1-3 Federal well, Sweetwater County, Wyoming, was completed during January. A site for the Multi-Well Experiment is still being sought.

Bartlesville Energy Technology Center continued support for studies on logging, coring, in situ permeability and rock/fluid interaction. Experiments continued to study frictional effects on crack growth across unbonded interfaces at Lawrence Livermore Laboratory; the Borehole Seismic System continues to map fractures while being created and measure fracture orientation for Sandia Laboratories.

The DOE Well Test Facility has been moved to Wattenberg field to monitor well tests at the Colorado Interstate Gas Company cyclic injection site. Sixteen minifrac tests were conducted at the Nevada Test Site in conjunction with Sandia Mineback program.

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2. PROJECT MANAGEMENT

2.1 TECHNICAL MONITORING AND EVALUATION

D. L. Reese (CER Corporation) met with Mountain Fuel Supply Company, Salt Lake City, Utah, on January 7 to discuss a potential site for the multi-well experiment.

C. H. Atkinson (DOE) attended a meeting of the National Petroleum Council tight gas study group and CK GeoEnergy personnel in Las Vegas, January 8. The discussion concerned modeling lenticular sands for production prediction calculations.

C. H. Atkinson (DOE), G. R. Luetkehans and R. L. Mann (CER Corporation) met with Sandia Laboratories and Institute of Gas Technology personnel in Albuquerque, New Mexico, on January 14 to discuss the WGSP multi-well experiment. They were joined on January 15 by additional CER personnel, and personnel from Bartlesville Energy Technology Center, Lawrence Livermore Laboratory, Los Alamos Scientific Laboratory, Institute of Gas Technology and DOE/HQ to develop activity planning networks for the multi-well experiment. (Refer to Section 3.6 for more information.)

J. E. Evered and D. L. Reese (CER Corporation) attended a Society of Petroleum Engineers (SPE) Four Corners Section meeting on "Fracturing in Tight Gas Dakota Formation" of the San Juan Basin, January 16, in Farmington, New Mexico. Information from this meeting is of potential value to the WGSP.

C. H. Atkinson (DOE) and J. C. Schillo (CER Corporation) visited a Mountain Fuel Supply Company site near Rifle, Colorado, January 22, as a potential site for the multi-well experiment. Environmental personnel from LLL were also at the site for preliminary assessment.

G. R. Luetkehans, J. E. Evered and D. L. Reese (CER Corporation) attended a GRI Project Advisors' meeting at Mountain Fuel Supply Company in Salt Lake City, Utah, January 28.

G. C. Kukal and J. C. Schillo (CER Corporation) attended an SPE meeting on Formation Damage Control on January 28 in Bakersfield, California. This meeting was pertinent to the multi-well experiment.

C. H. Atkinson (DOE) briefed S. Ewing and D. Keene, Exxon Production Research (Houston, Texas) on the WGSP, January 28 and 29, in Las Vegas, Nevada.

2.2 TECHNOLOGY TRANSFER

2.2.1 Documentation Reports

The WGSP section of the DOE Semi-Annual Report of the Unconventional Gas Recovery Program (period ending September, 1979) has been finalized. The WGSP Status Report for October, 1979, has been distributed and work continues on the Quarterly Basin Activities Report for the fourth quarter, 1979. The DOE Well Test Facility Operations Report and the WGSP Coring Program Document are being updated. The WGSP Logging Report is being updated and reviewed. Work continued on the WGSP Greater Green River Basin Review and similar geologic reports for the Piceance and Uinta Basins. An investigation was begun on a new WGSP Status Report format.

2.2.2 Project Data Bank

"Maps Showing Generalized Structure Contours on the Tops of the Wasatch and Green River Formations, Geologic Sections, and Contours of Thickness of the Green River Formation, Southeastern Uinta Basin, Utah and Colorado," by W. F. Holmes, USGS, was added to the WGSP data bank. Updating and cataloging continued on the WGSP bibliography and map filing system.

2.2.3 Articles and Publications

The following article relates to the WGSP and is included in the bibliography. The abstract is included.

*Experimental Determination of Particle-Size
Distributions from Proppant Interactions
With Tight Reservoir Rocks*
by B. A. Baker and H. B. Carroll, Jr.
BETC

A series of laboratory experiments were performed in which a 2 percent KCl solution was pumped through simulated sand-packed fractures between core halves representing three different tight reservoir formations. During these fluid injections, the core assemblies were subjected to typical overburden pressures ranging from 500 to 9,000 psig, and effluent samples of particle-liquid mixtures were collected for analysis with a particle-counting apparatus. These analyses typically include the particle concentrations as well as the means, modes, medians, and size ranges of these mixtures. This data, except for the particle concentrations, was obtained in the form of particle-size distribution curves. The degree of plugging of similar types of hydrocarbon-producing formations experienced in the field can be anticipated and then reduced by proper engineering techniques.

3. RESOURCE ASSESSMENT

3.1 U. S. GEOLOGICAL SURVEY ACTIVITIES

3.1.1 Uinta-Piceance Basins

The following cross sections have been published:

Johnson, R. C., Cross Section A-A' of Upper Cretaceous and Lower Tertiary rocks, Northern Piceance Creek Basin, Colorado. USGS MF-1129A.

Johnson, R. C., Cross Section B-B' of Upper Cretaceous and Lower Tertiary rocks, Northern Piceance Creek Basin, Colorado. USGS MF-1129B.

Johnson, R. C., Cross Section C-C' of Upper Cretaceous and Lower Tertiary rocks, Northern Piceance Creek Basin, Colorado. USGS MF-1129C.

Johnson, R. C., M. P. Granica, and N. C. Dessenberger, Cross Section A-A' of Upper Cretaceous and Lower Tertiary rocks, Southern Piceance Creek Basin, Colorado. USGS MF-1130A.

Johnson, R. C., M. P. Granica, and N. C. Dessenberger, Cross Section B-B' of Upper Cretaceous and Lower Tertiary rocks, Southern Piceance Creek Basin, Colorado. USGS MF-1130B.

Johnson, R. C., M. P. Granica, and N. C. Dessenberger, Cross Section C-C' of Upper Cretaceous and Lower Tertiary rocks, Southern Piceance Basin Creek, Colorado. USGS MF-1130C.

Sedimentologic and mineralogical analysis of surface and subsurface data from Piceance and Uinta Basins is continuing.

Manuscripts are being prepared that report results of currently available studies in the Uinta Basin.

3.1.2 Greater Green River Basin

Work continued on stratigraphic analysis of Greater Green River Basin.

T. Tyler submitted two E-log cross sections (G-G' and H-H') in the Washakie Basin for technical review.

B. E. Law and D. J. Markochick collected Mesaverde core samples from the Rainbow Resources No. 1-3 Pacific Creek Federal well, Sec. 3, T26N, R103W, Sweetwater County, Wyoming, for gas desorption studies.

H. Bucurel redescribed Mesaverde core samples from the Amoco No. 1 Tierney Unit, Sec. 15, T20N, R94W, Sweetwater County, Wyoming. This well is located on the Wamsutter Arch in the Greater Green River Basin.

3.1.3 Northern Great Plains Province

A report was revised entitled "Reservoir geometries in the Shannon Sandstone near the northern Black Hills, Montana and South Dakota," by G. W. Shurr.

Work continued on regional cross section from southeastern Alberta to north-central Montana.

Core samples were analyzed from Joseph J. C. Paine No. 1-9 Aasen well, Little Missouri field, Sec. 9, T129N, R106W, Bowman County, North Dakota.

3.1.4 Schedule Status

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

3.2 CORE PROGRAM

In the Greater Green River Basin, field work commenced December 29 on Rainbow Resources, Inc. No. 1-3 Federal well, Sec. 3, T26N, R103W, Sweetwater County, Wyoming. Two Mesaverde (Ericson Formation) cores were cut by December 31, with full recovery. Coring resumed January 6 when drilling reached 12,630 ft and continued to 12,777.5 ft with 85 percent recovery from the Rock Springs Formation. When drilling reached 13,410 ft, coring again resumed in the Rock Springs Formation until 13,503 ft, with 92 percent recovery. Coring operations were completed on January 17. Core samples were sent to BETC, LLL and Core Laboratories.

3.3 LOGGING PROGRAM

WGSP logging representatives G. C. Kukal and W. J. Brown (CER Corporation) assisted in logging Rainbow Resources No. 1-3 Federal well, Sweetwater County, Wyoming.

Commencing January 19, the well was logged as follows:

- Dual Laterolog/Simultaneous Micro-SFL/Caliper/Gamma Ray (logged 13,700 - 11,390 ft; pad closed logged 13,662 - 12,440 ft; repeat section 12,720 - 12,380 ft and 12,890 - 12,756 ft; Mud Log 12,400 - 12,170 ft).

Figure 3-1 Milestone Chart — USGS

WGSP — USGS	FY-80											
B. Northern Great Plains Province	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Petrographic examination of producing low-permeability reservoirs of SE Alberta.												
Write paper on origin of biogenic gas accumulations.												
Construct cross-sections from western Canada to north-central Montana.												
Write paper on depositional environments and geometries of Mosby SS (Greenhorn Fm.) of north-central Montana.												
Regional subsurface study of Niobrara Fm. in North and South Dakota.												
Pilot lineament study of Northern Black Hills.												
Subsurface study of Groat sandstone.												
Regional lineament map.												

WGSP — USGS	FY-80											
C. Piceance Basin	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Report results of core analysis from Rio Blanco area.												
Structure contour map of top of Cretaceous.												
Isopach map of rocks in interval from top of Cretaceous to Rollins sandstone.												
Prepare results of outcrop section of Mesaverde and lower Tertiary sequence at Rifle Gap.												
Continue studies of mineralogy, diagenesis, stratigraphy and sedimentology of cores from Twin Arrow, Mobil and Ralstov Production Company.												

Figure 3-1 Continued

WGSP — USGS	FY-80											
D. Uinta Basin	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Geologic and engineering cross section from Wasatch Plateau to south central Uinta Basin.												▽
Sedimentology, stratigraphy and mineralogy study of Tertiary core from Southman Canyon region												▽
Analyze stratigraphy, sedimentology, and diagenesis of core from Pariette Bench field Tertiary rocks.								▽				
Continue analysis of CIGE NBU No. 21 core as available.												
Prepare analysis of sedimentology, stratigraphy, and mineralogy of Late Cretaceous and lower Tertiary rocks at Price River Canyon.							▽					

Figure 3-1 Continued

- Dual Induction Log - SFL/SP/GR (logged 13,692 - 11,389 ft; repeat section 12,692 - 12,270 ft); Simultaneous BHC Sonic - Caliper (logged 13,665 - 11,389 ft; repeat section 12,745 - 12,270 ft); Variable Density Log (logged 13,664 - 11,389 ft; repeat section 12,856 - 12,337 ft).
- Dipmeter (logged 13,694 - 11,392 ft; repeat section 13,686 - 13,340 ft).
- Formation Density - Caliper/Simultaneous Compensated Neutron/Gamma Ray (logged 13,693 - 11,392 ft; repeat section 12,800 - 12,340 ft; repeat section 13,508 - 13,394 ft.)
- Natural Gamma Spectroscopy (logged 13,641 - 11,390 ft; repeat section 13,573 - 12,364 ft).

Field prints were delivered on location. Cyberlook Log was computed over interval 13,650 - 11,420 ft and the Cyberdip Log was run over 12,850 - 11,850 ft. Logging was completed on January 20.

3.4 SURVEY OF BASIN ACTIVITIES

3.4.1 Greater Green River Basin

During January, 30 wells were reported complete: 14 development wells were producers, 7 wildcat wells were discoveries, and 3 development and 6 wildcat wells were D&A.

The Almond Formation had the largest potential flow of new gas (10,988 MCFD). Other contributing horizons were the Frontier, Mesaverde undifferentiated and the Lewis. Total initial potential flow for the Greater Green River Basin during January was 20,959 MCFD.

Thirty-six new locations were staked by month's end: 23 development and 13 wildcats.

Wells of interest are summarized in Table 3-1, and Figure 3-2 shows the location of the wells and the USGS designated core areas.

3.4.2 Northern Great Plains Province

For the month, 26 wells were reported complete: 11 development wells were producers, 3 wildcat wells were discoveries and 6 of each type well were D&A.

From the 14 wells reported complete, the total initial potential flow of new gas was 6,505 MCFD. (Two IPFs were not available.) The Bow Island Formation was the largest producer with 6,412 MCFD. Other horizons included the Eagle, Shannon and Bow Island/Phillips commingled.

Newly staked wildcat locations outnumbered the development locations this month: 7 wildcat and 6 development wells were reported.

Table 3-2 is a summary of wells of interest and Figure 3-3 shows the locations of the wells.

3.4.3 Piceance Basin

Activity was slow this month in the Piceance Basin: 6 wells were reported complete. Five were producing development wells and one was a wildcat discovery.

Initial potential flow totaled 1,160 MCFD of new gas with the Mancos B contributing most of the total (955 MCFD). Other contributing horizons were the Mancos A and Mancos undifferentiated. (One IPF was not available.)

Ten locations were staked during January: 9 development and 1 wildcat. Most of the newly reported locations were in Mesa County.

Table 3-3 summarizes wells of interest to the WGSP and Figure 3-4 shows the locations of the wells and the USGS designated core areas.

3.4.4 Uinta Basin

During the month, 8 wells were reported complete: 7 development wells were producers and 1 wildcat well was a discovery.

The Mesaverde Group undifferentiated had the largest potential flow of new gas with 1,070 MCFD. Other horizons included the Wasatch, Green River and North Horn. Total initial potential flow for January was 2,515 MCFD.

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

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

OPERATOR	WELL NAME	MAP INDEX NO. ¹	LOCATION Sec/T/R	HORIZON ² ft	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Cotton Petroleum	4 Shallow Creek Unit	1	nwse 31/16N/94W Unnamed Field Sweetwater Cnty, WY	Mesaverde 12,600			Wildcat outpost, reported 1-9-80. Operator reported 4 additional Mesa-verde tests in same locale.	
Amoco Production	1 USA-Amoco-T	2	csw 4/20N/93W Five Mile Gulch Field Sweetwater Cnty, WY	Almond 10,490- 10,624	10,960	331,506 gal emul, 597,000 lb sand; acidized twice w/ total 4,300 gal.	Wildcat outpost extension, comp. 7-23-79. No cores or tests. Located in Core Area A.	699
Burton-Hawks	28-1 Madex	3	w½sw 28/27N/93W Lost Creek Field Fremont Cnty, WY	Fort Union 3,000	2,047	Acidized w/ 250 gal.	Wildcat outpost, comp. 12-20-79 D&A. No cores or tests.	
Pacific Transmission Supply	24-19 Federal	4	sesw 19/33N/114W Unnamed Field Sublette Cnty, WY	Mesaverde 5,206-5,342	11,464 PB: 5,560		Wildcat field discovery - new field, comp. 11-13-79. Participated in WGSP Core Program.	347

¹ Refer to Figure 3-2

² Horizon - projected depth or producing interval

Figure 3-3 Northern Great Plains Province Showing Wells of Interest and 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 ft	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Sodagas Ltd.	1-10 Sodagas-Barrick	1	csw 10/5N/28E Wildcat Field Stanley Cnty, SD	Niobrara 1,200	1,200		Wildcat well, comp. 11-29-79 D&A. Operator had 4 additional D&A wells in county.	
Petrolero Corp.	1-5 Crow Tribal	2	nwnw 5/5N/35E Wildcat Field Treasure Cnty, MT	Shannon 2,270			Wildcat well, reported 12-21-79.	
Sam G. Harrison	21-1 Truman	3	nenw 21/15N/3E Cady Creek Field Harding Cnty, SD	Shannon 1,100	1,100		Wildcat outpost extension, comp. 11-1-79 as SIGW. OWWO: previously comp. 12-74 D&A.	N/A
Milan R. Ayers; American Quasar Petroleum	1 Sheble Ranch	4	nenw 24/30N/6W Unnamed Field Pondera Cnty, MT	2nd Bow Island 1,967-1,976	2,535 PB: 2,048	Fractured	Wildcat field discovery - new field, comp. 7-6-79. No cores or tests.	56

¹ Refer to Figure 3-3

² Horizon - projected depth or producing interval

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 — Piceance Basin

OPERATOR	WELL NAME	MAP INDEX NO. ¹	LOCATION Sec/T/R	HORIZON ² ft	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Twin Arrow	2-28 Continental	1	nws 28/3S/100W Cathedral Field Rio Blanco Cnty,	Mancos A (Castlegate) 3,343-3,360	5,099	50,000 scf nitrogen, 140,000 lb sand; acidized w/300 gal.	Develop. well, comp. 10-17-79. No cores or tests.	215
Coseka Resources	2-T-2 Federal	2	senw 2/5S/103W Evacuation Creek Field Garfield Cnty, CO	Mancos B 4,916-5,018	7,597 PB: 5,211	83,496 gal emul, 196,000 lb sand	Wildcat outpost extension, comp. 11-3-79. No cores or tests.	155
Tenneco Oil	3-14 Haley-USA	3	nws 3/9S/104W Bar X Field Mesa Cnty, CO	2,360 Cretaceous test			Wildcat outpost, reported 1-22-80.	
Adolph Coors	4-17 Ute	4	swsw 17/10S/96W Plateau Field Mesa Cnty, CO	Corcoran 3,120			Develop. well, reported 1-25-80.	

¹ Refer to Figure 3-4

² Horizon - projected depth or producing interval

By month's end, 18 new locations were reported: 12 development and 6 wildcat. Most of the newly-staked locations were located in the Natural Buttes Field.

Wells of interest are summarized in Table 3-4, and Figure 3-5 shows the well locations and the USGS designated core areas.

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 — Uinta Basin

OPERATOR	WELL NAME	MAP INDEX NO. ¹	LOCATION Sec/T/R	HORIZON ² ft	FINAL TD	FRACTURE TREATMENT	STATUS	IPF in MCFD
Mapco Production	11X-18F River Bend Unit	1	nesw 18/10S/20E River Bend Field Uintah Cnty, UT	Green River 3,650			Develop. well, reported 12-28-79. Operator has 1 additional Green River test in locale.	
Enserch Exploration	1-12 NSO-Federal	2	nwne 12/10S/23E Southman Canyon Field Uintah Cnty, UT	Mesaverde 6,854-7,857	8,250 PB: 7,978	200,000 gal emul, 460,000 lb sand; acidized w/2,000 gal.	Develop. well, comp. 11-17-79. No cores or tests.	270
Pacific Transmission Supply	33-36 State	3	nwse 36/11S/14E Unnamed Field Duchesne Cnty, UT	North Horn 3,865-4,455	6,383 PB: 6,280	95,000 gal fluid; 77,800 lb sand; acidized 5 times w/total 10,350 gal.	Wildcat field discovery - new field, comp. 11-24-79. No cores.	435
Del-Rio Drilling	30-1A Federal	4	swne 30/14S/20E Flat Rock Field Uintah Cnty, UT	Wasatch 4,400			Wildcat outpost, reported 12-28-79. Located in Core Area D.	

¹ Refer to Figure 3-5

² Horizon - projected depth or producing interval

Figure 3-6 Milestone Chart — Multi-Well Experiment

3.5 C K GEOENERGY

Field work is continuing for contracts No. DE-AC08-79BC10005 (Development of Techniques for Optimizing Selection and Completion of Western Tight Gas Sands) and a final report is in preparation for contract No. ET-78-C-08-1601 (Reservoir Characteristics in Uinta Basin Gas Wells).

3.6 MULTI-WELL EXPERIMENT

A site for the experiment has not yet been obtained. A potential Mountain Fuel Supply Company site near Divide Creek may be unacceptable because the Mesaverde section appears to be wet or in the transition zone. Additional sites in the southeast portion of the Piceance Basin are being explored.

A planning meeting was held during the month to initiate a network plan for the experiment. Activity networks, showing estimated time and responsibility, were developed for site acquisition, drilling, core handling and analyses, logging, well testing, and stress testing. The activities leading to the completion of the first well and confirmation of the site are well defined; however, subsequent activities require further definition. Drawn networks and computer printouts resulting from the meeting were available by the end of the month.

Figure 3-6 is a milestone chart depicting the progress of the multi-well experiment.

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

4.1 BARTLESVILLE ENERGY TECHNOLOGY CENTER

4.1.1 Improved Pressure Coring System — Sandia Laboratories

4.1.1.1 Core Retriever Design and Test

The improved double O-ring seat seal for the ball valve was effective in improving pressurized core recovery during field testing. It is being included by DOWDCO Pressure Coring Incorporated (PCI) in all new and reworked ball valve assemblies.

The check valve in the flushing head continues to be useful in field operations.

4.1.1.2 Core Fluid Tests

The low-invasion fluid has been useful in obtaining better pressure cores. Even though it is an added expense, users are requesting it. Reports from Shell's petrophysicists indicate that it provides additional core handling benefits during core analysis.

Viscosity tests of the low invasion fluid up to 350°F indicated that base mud and particulate mud decomposed and had viscosities as low as 10 to 15 cp. However, mud containing an MgO additive had a viscosity of approximately 80 cp. The MgO mud also regained significant viscosity upon cooling after the tests, while the other muds did not. These results confirm that the low invasion fluid remains usable at temperatures up to 300°F if the MgO additive is present in small amounts.

Work scheduled includes evaluation of calcium bromide as a replacement for calcium chloride as the freezing point depressant. This might further improve the core handling characteristics of the low invasion fluid.

4.1.1.3 Bit Design and Fabrication

The Sandia redesigned bits with improved hydraulics are being fabricated and will be available for testing in April. These one- and two-piece core bits will be equipped with diamond compax cutters diffusion-bonded to steel studs. This will permit the field replacement of damaged cutters to rebuild the core bits for reuse.

4.1.1.4 Polycrystalline Diamond Core Bit Tests

PDC core bits have gained wide acceptance in pressure coring operations and are being requested by users. DOWDCO has adapted the PDC core bits to standard core barrels and is now offering this service to their customers.

4.1.2 Logging Studies

4.1.2.1 Interface Conductivity Effects on Electric Logging

Influences of Shale Conductivities on the Electrical Conductivity of Low-Permeability Rocks.¹

Many of the wells now being drilled in the tight western gas sands are using potassium-based drilling muds to help stabilize encountered clays. It is possible that the potassium and sodium ions may behave differently in electric logging. Models to explain the conductivity of shaly formations^{2,3,4} have been centered on the use of sodium brine.

In Figure 4-1, the shale conductivity, C_x , has been plotted against the cation exchange capacity, Q_v , for the potassium and sodium counterions using the Dual-Water (DW) model of Clavier, et al². Values for the parameters used in this model are given in Table 4-1. β is the counterion equivalent conductance and Vq is the product of the specific clay-area coefficient and the distance of the counterions from the clay surface (see reference 2). The differences between the potassium and sodium counterions are small (especially at higher temperatures) even though the equivalent conductance of the potassium ion is almost 50 percent greater than that of the sodium ion at 25° C in bulk water.

In Table 4-1, the value of B_0 (the counterion equivalent conductance) for the model proposed by Waxman and Smits³ has been included. Based on the new data for the potassium counterion (and no *a priori* knowledge of the counterion equivalent conductance), there appears to be little discernable difference between the two models.

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

Most of the 323 water samples available from wells in the Uinta Basin were taken in the 1960s and early 70s during drill stem tests or swabbing tests as the wells were drilled or completed. Due to the presence of unknown quantities of drilling fluid filtrate in these samples, reliable R_w data cannot be expected. Only 22 samples were obtained from wells on production, for which it could be safely assumed that drilling fluid filtrate was no longer a contaminant.

¹ Volk, L. J., C. J. Raible and H. B. Carroll, "Influence of Shale Conductivities on the Electrical Conductivity of Low-Permeability Rocks," accepted for publication in the Journal of Petroleum Technology.

² Clavier, C., G. Coates and J. Dumanoir, "The Theoretical and Experimental Bases for the 'Dual Water' Model for the Interpretation of Shaly Sands," presented as Paper SPE-6859 at SPE 52nd Annual Fall Conference, Denver, Colorado, October 9-12, 1977.

³ Waxman, M. H. and L. J. M. Smits, "Electrical Conductivities in Oil-Bearing Shaly Sands," Society Petroleum Engineers Journal (June 1978), 107-122.

⁴ Waxman, M. H. and E. C. Thomas, "Electrical Conductivities in Shaly Sands — I. The Relation Between Hydrocarbon Saturation and Resistivity Index; II. The Temperature Coefficient of Electrical Conductivity," Journal Petroleum Technology (February 1974), 213-225.

Figure 4-1 C_x versus Q_v for the Sodium and Potassium counterions at 23 degrees C and 75 degrees C from the Dual-Water Model. Curves for the Sodium counterion are based on Clavier, et al (Reference 2)

Table 4-1 Summary of Parameters for the Dual-Water and Waxman-Smits Models

	Sodium ^b		Potassium	
	25°C	75°C	25°C	75°C
B_o	0.0383 ^a	—	0.034	0.076
$[(\text{cm}^2)(\text{meq}^{-1})(\text{ohm}^{-1})]$			(0.0008)	(0.021)
β	0.0205	0.063	0.0285	0.067
$[(\text{cm}^2)(\text{meq}^{-1})(\text{ohm}^{-1})]$			(0.0007)	(0.020)
V_q	0.28	0.22	0.295	0.202
$[\text{cm}^2/\text{meq}]$	0.30 ^c		(—)	(0.008)

Note: Values in parenthesis under Potassium column are standard deviations

^a From Waxman and Thomas (reference 4)

^b From Clavier, et al (reference 2)

^c From Clavier, et al - determined by curve fitting

To conclude this project successfully, more reliable samples must be taken and analyzed. Since most oil or gas wells ultimately produce some formation water, operators in the field will be asked to collect produced water samples and submit them for analysis. A list of operators is being prepared for that purpose.

4.1.3 In Situ Permeability

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

The effective gas permeability of core No. 5210.3 from the Pacific Transmission Supply No. 24-19 Federal well, T19S, R114W, Sublette County, Wyoming, and core No. 8498 from the Mobil PCU No. F31-13G well, Rio Blanco County, Colorado, was measured as a function of water saturation. The effect of mean pore pressure on effective permeability was simultaneously evaluated. The results are shown in Figures 4-2 and 4-3, respectively. As in the case of cores No. 5172, 5205 and 5220, a decrease in partial water saturation was accompanied by an increase in the slope of the Klinkenberg plot. For core No. 5210.3, two sets of data are shown for 0 percent saturation. One was determined before saturation and one was determined after drying. The two lines shown were obtained by a linear regression analysis and the slopes were determined from the same. The partial water saturation values and the slopes of the lines for the two cores are tabulated in Tables 4-2 and 4-3, respectively.

From the line relating effective gas permeability and reciprocal mean pore pressure, effective permeability values corresponding to a mean pore pressure of 34.7 psia were estimated. Figure 4-4 plots effective gas permeability as a function of partial water saturation for core No. 8498. Also shown in the figure are the results of earlier measurements on the same core. The permeability reduction characteristics are different, probably due to the various cycles the core has been subjected to, as reported in the December Status Report.

Experiments were conducted to establish the combined effects of high net confining pressure and partial water saturation on gas slippage. Core No. 5172 from the PTS No. 24-19 well was partially saturated to 43.2 percent water saturation, and effective gas permeability was measured as a function of mean pore pressure and net confining pressure. The results are shown in Figure 4-5 and in Table 4-4. The slope of the Klinkenberg plot decreased from 0.37 (md) (psi) at 120 psi net confining pressure to 0.17 (md) (psi) at a net confining pressure of 2,600 psi. It should be noted that the slope measured at a net confining pressure of 120 psi is lower than the value estimated for the same core in November. The data are being reexamined. It is qualitatively clear that the gas slippage effect is reduced at high net confining pressures for both dry and partially saturated cores.

Data in Table 4-5 (plotted in Figure 4-6) show the results of similar measurements for core No. 5205 from the same well. The core was 19.8 percent saturated. The slope of the Klinkenberg plot decreased from 2.61 (md) (psi) at a net confining pressure of 120 psi to 1.59 (md) (psi) at 2,600 psi.

Figure 4-2 Effect of Partial Water Saturation on Gas Slippage Effect

Figure 4-3 Effect of Partial Water Saturation on Gas Slippage Effect

Table 4-2 Partial Water Saturation Values for PTS No. 24-19 Federal Well

Core No. 5210.3			
Water Saturation, percent	Slope of Klinkenberg Plot, (md) (psi)	Intercept K_{∞}, md	Klinkenberg Constant b, atm
35.5	0.47	0.061	0.53
21.5	1.53	0.109	0.96
10.8	2.32	0.116	1.36
0	1.87	0.176	0.72
	2.45	0.175	0.95

Table 4-3 Partial Water Saturation Values for Mobil PCU No. F31-13G Well

Core No. 8498			
Water Saturation, percent	Slope of Klinkenberg Plot, (md) (psi)	Intercept K_{∞}, md	Klinkenberg Constant b, atm
56.3	0.13	0.0009	9.28
39.4	0.21	0.0032	4.37
29.4	0.22	0.0071	2.14
22.7	0.70	0.0068	6.94
0	0.89	0.0069	8.77

Figure 4-4 Effect of Partial Water Saturation on Effective Gas Permeability

4.1.4 Advanced Logging Techniques and Interpretations

4.1.4.1 Dielectric Constant Measurement for Formation Evaluation

A calibration procedure for the dielectric constant measurement system has been developed: the dielectric constant of a dry sample is accurately measured and then placed in the newly designed sample holder. This design allows the sample to be saturated with fluids before dielectric measurements are made. Measurement errors due to the frequency response of the capacitance and conductance standards were also identified and methods for correction were developed.

Studies of the Bruggeman⁵, Hanai⁶ and Sillars⁷ methods of modeling the dielectric constant of heterogeneous materials has begun. A computer analysis based on the works of Hanai and Wobschall⁸ shows that frequency dispersion effects of formation rock may be modeled in terms of reservoir parameters. Work in this area is continuing.

⁵ Bruggeman, D. A. G. (1935) Annln Phys. 24,636.

⁶ Hanai, T., "Electrical Properties of Emulsions," Chapter 5 in Emulsion Science, Philip Sherman Ed., 1968, Academic Press, London & New York.

⁷ Sillars, R. W., "The properties of a Dielectric Containing Semi-conducting Particals of Various Shapes," Journal of Institute of Electrical Engineers (London) p. 378-394, 1937, vol. 80.

⁸ Wobschall, D., "A Theory of the Complex Permittivity of Soil Containing Water: The Semidisperse Model" IEEE Transactions on Geoscience Electronics, p. 49-58, January 1977, vol. GE-15, No. 1.

Figure 4-5 Effect of Net Confining Pressure on Gas Permeability of a Partially Saturated Core

Table 4-4 Measurement of Effective Gas Permeability as a Function of Mean Pore Pressure and Net Confining Pressure for PTS No. 24-19 Well

Core No. 5172			
Water Saturation: 43.2 percent			
Net Confining Pressure, psi	Slope of Klinkenberg Plot, (md) (psi)	Intercept K_{∞} , md	Klinkenberg Constant b, atm
120	0.366	0.0283	0.88
1,000	0.251	0.0167	0.86
2,000	0.205	0.0101	1.38
2,600	0.172	0.0097	1.20

Table 4-5 Measurement of Effective Gas Permeability as a Function of Mean Pore Pressure and Net Confining Pressure for PTS No. 24-19 Well

Core No. 5205

Water Saturation: 19.8 percent

Net Confining Pressure, psi	Slope of Klinkenberg Plot, (md) (psi)	Intercept K_{∞} , md	Klinkenberg Constant b, atm
120	2.61	0.130	1.36
1,000	1.58	0.107	1.00
2,000	1.60	0.085	1.28
2,600	1.59	0.086	1.25

Figure 4-6 Effect of Net Confining Pressure on Gas Permeability of a Partially Saturated Core

Table 4-6 Capacitance and Dissipation Factors for Synthetic Al₂O₃ Samples

Sample No.	Thickness in Inches	Average C, pico Farad (pF)	Dissipation Factor
1	.545	20.62	.0790
2	.427	25.26	.0634
3	.526	21.32	.0751
4	.597	18.87	.0790
5	.529	21.82	.0747
6	.660	16.89	.0570
7	.524	21.21	.0705
8	.686	16.25	.0593
9	.525	20.40	.0596
10	.604	18.75	.0745
11	.467	24.37	.0712
12	1.100	12.48	.0814
13	.488	23.58	.0688
14	.781	14.61	.0728
15	.420	24.17	.0444
16	.695	16.47	.0697
17	.550	20.45	.0696
18	.529	22.23	.0891
19	.530	22.07	.0774
20	.542	20.94	.0715

4.1.4.2 Developments and Applications of a Wide Band Laboratory Dielectric Constant Measurement System — Colorado School of Mines

The pulsing capability of the laser has been integrated into the sandstone thermal conductivity measurement system and is now operational. Sandstone sample preparation for the laser experiment is underway.

The General Radio 1615-A Capacitance Bridge has been used to measure the capacitances and dissipation factors for a series of synthetic samples (Al₂O₃). Results are shown in Table 4-6. All samples have a diameter of 2.258 in. and all measurements were at 1.0 KHz.

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

When evaluating the sonic log, Schlumberger has assumed a matrix travel time of 52.6 microseconds/foot. Core analysis has shown that the zones under examination have varying amounts of shale, which should increase the matrix travel time. Using laboratory measured porosities and sonic log travel times, actual matrix travel times were calculated. Each zone is shown in Table 4-7. These values range from 53.2 to 69.3 microseconds per foot.

Table 4-7 Calculated Matrix Travel Times

Zone	Plug Porosity* percent	Matrix Travel Time* microseconds/ft
A	3.90	55.8
B	4.26	57.4
C	5.28	66.5
D	5.31	63.3
E	7.86	59.8
F	7.23	69.3
G	4.27	58.9
H	4.06	64.4
I	8.66	53.2
J	2.46	65.9
K	5.65	62.3

* Average for zone

To confirm that matrix travel times are greater than 52.6 microseconds/foot assumed by Schlumberger, permission has been granted by the Texas A&M Department of Geophysics to use an acoustic tool for the measurement of matrix travel times. The acoustic tool is equipped with a pressure vessel enabling travel times to be measured at reservoir pressure. Once the travel times are known, porosities can be calculated directly from the sonic log. Precise matrix travel times measured on a regional basis will increase the sonic log effectiveness. Porosities derived from the sonic log will provide a cross check for the porosities measured in the laboratory by the saturation method.

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

The objective of this project is to determine the feasibility of developing a wireline tool using acoustic techniques to measure the stress field from a borehole. Work to date has used the phenomenon of acoustic double refraction (ADR) to evaluate rock properties and to measure in situ stress. This includes development of a laboratory data acquisition system, and an initial analysis of measurement sensitivity data quality requirements.

The goal of the first phase of the laboratory work is to evaluate the ADR technique under conditions of uniaxial stress, using face-to-face and same-face transducer geometries. The work was divided into eight sub-tasks:

- learn about the ADR effect and do a literature survey;
- decide on a data acquisition and analysis method;
- assemble the experimental hardware;
- write the software for the data acquisition computer;
- write the software for preliminary data analysis;

- test and make necessary adjustments;
- measure ADR using the face-to-face geometry under uniaxial stress (0.1 MPa confining pressure):
 - a. Westerly granite,
 - b. Nugget sandstone, and
 - c. typical reservoir rock to be determined; and
- measure ADR using the same-face geometry under uniaxial stress and the same materials as above.

The first five steps have been accomplished.

Indications are that the experimental approach is sound and will not require significant changes. Since the ADR work is the first project to use the minicomputer data acquisition system (built for the Nuclear Test Containment Program), the usual difficulties have arisen. They are expected to continue until the system is de-bugged. A new approach has been suggested which uses a continuous wave method to measure the change in the absolute sound speed to follow changes in the stress field. Preliminary measurements have shown that this method is sensitive, and it is currently under evaluation.

Besides developing an accurate data acquisition system, there is a bench set-up where qualitative experiments can rapidly be made. This is to evaluate alternative measurement approaches and demonstrate that the stress effect on velocity can be measured in the laboratory.

4.1.5 Rock-Fluid Interaction

4.1.5.1 Drilling Mud Particle Size Distribution

Three drilling mud samples were analyzed for particle-size distribution. All three samples were diluted with 2 percent KCl solutions to reduce the total number of particle counts per ml to approximately 100,000. Thus, the resulting statistical parameters all could be compared on the same population basis. The values shown in Table 4-8 are quite similar. Drilling Mud No. PTS 3-10A Federal (11,557 ft) appears to have lower values for nearly all the parameters calculated. The biggest differences occur in the parameters which were calculated on a volume basis.

4.1.5.2 Determine Feasibility of Fabricating Light Weight Proppants for Application in Gas and Oil Well Stimulation — Terra Tek, Inc.

The basic proppant geometry to be considered is an assembly of perfect spheres with a uniform characteristic diameter. While the usual mesh specification will actually give a distribution of diameters, the first consideration will not admit this possibility. The characteristic diameter of the usual 20-40 mesh sieve will be taken as midway between these spacings, approximately .6 mm. The spheres themselves will be solid, hollow, or a two-layered sphere with a light-weight core.

Table 4-8 Measured Statistical Parameters for Three Different Drilling Mud Samples and the 2 Percent KCl Solution Used to Dilute Them

Total Particle Counts per ml		Mean	Mode (microns)	Med.	S.D.
(2 Percent KCl Solution Used with Drilling Mud Samples)					
1,245	Pop	1.89	1.41	1.64	1.50
	Vol	10.74	18.50	13.34	2.71
(Drilling Mud Sample: Well No. PTS 3-10A Federal (11,557 ft) in 2 Percent KCl Solution)					
101,003	Pop	2.63	1.41	2.31	1.75
	Vol	8.42	7.16	7.86	1.95
(Drilling Mud Sample: Well No. PTS 22-12 Federal (11,730 ft) in 2 Percent KCl Solution)					
100,531	Pop	2.55	1.41	2.21	1.77
	Vol	10.90	15.22	11.94	1.91
(Drilling Mud Sample: Well No. PTS 22-12 Federal (12,200 ft) in 2 Percent KCl Solution)					
102,779	Pop	2.49	1.41	2.07	1.80
	Vol	11.09	16.24	11.94	1.86

The first order approximation problem to be solved for pressure loading is the contact of spheres. The elastic stress distribution near the contact zone is a well-known solution available in Timoshenko and Goodies⁹, known as the Hertz contact problem. The size of the contact zone is determined by the elastic material properties and the magnitude of the force. It is known that tensile stresses occur outside of and adjacent to the contact zone. These tensile stresses are typically presumed to initiate failure in indentation tests of brittle materials.

It is possible that a theoretical solution is available or can be developed for the interior stresses away from the contact zone, at least for the solid sphere. Accordingly, a literature search will either obtain this solution or identify a readily implemented theoretical solution technique. However, the two-layered sphere and probably the hollow sphere will likely require a numerical analysis. While finite element programs are readily available and can be used (note that the problem is axisymmetric), an alternate numerical solution using the Boundary Integral Equation^{10,11} numerical method is currently being worked on. This method has cost/accuracy advantages, particularly for problems with high stress gradients. Equation development and computer programming of this approach are currently underway.

⁹ Timoshenko, S. P., and J. N. Goodies, *Theory of Elasticity*, 3rd Edition, McGraw-Hill (1970).

¹⁰ Rizzo, F. J., "An Integral Equation Approach to Boundary value Problems of Classical Elastostatics," *Quarterly of Applied Mathematics*, 25, 83-95 (1967).

¹¹ Cruse, T. A. and F. J. Rizzo, eds., *Boundary-Integral Equation Method: Computational Applications in Applied Mechanics*, ASME AMD - vol. 11 (1975).

The diametral loading of the solid sphere can be considered as the three-dimensional analog of the plane problem of diametral loading of a circular disc. This latter problem is well known, and is termed the "Brazil Test" for tensile strength in rock mechanics. The interior stresses in the disc consist of compression in the direction of the load and an induced tension normal to this direction. Although the numbers will be different in the present spherical case, it is likely that the character of the stresses will be similar.

The strength properties of the candidate materials to determine failure loads, (and the pressures and temperatures at which permeability is reduced) are given in Table 4-9. Increased temperature tends to reduce the strength values. Data on temperature effects on strength are being assembled from the literature.

An additional effect must be considered in the strength analysis: the apparent strength of brittle materials depends on both size and stress gradient effects. Since the small size and high stress gradients are significant features in the proppant sphere loading, these effects should be considered. A literature review of this aspect of the strength analysis is also underway.

4.1.6 Schedule Status

A milestone chart, showing BETC's WGSP progress, is in Figure 4-7.

4.2 GAS RESEARCH INSTITUTE

A proposal by CER Corporation to develop a geologic and engineering data base for the tight sands basins and conduct geologic studies of the secondary basins has been submitted to GRI headquarters.

4.2.1 Evaluation of Seismic Data for Detailed Stratigraphic Studies of Lenticular Sands

Final surveying was completed and computer processing of the seismic data commenced during the month. An extensive discussion of this experiment was presented at the Project Advisors' meeting on January 28 in Salt Lake City, Utah.

4.2.2 Coring and Logging of Rainbow Resources, Inc. No. 1-3 Federal Well

Field work commenced December 29 on this project in Sweetwater County, Wyoming, funded jointly by GRI and the operator. Coring operations concluded January 17, (see Section 3.2) and logging took place January 19-20 (see Section 3.3). A total of 310 ft of Mesaverde core was recovered from the 339 ft cut (91 percent recovery). Core samples were cut intermittently from 12,398 to 13,503 ft.

The bulk of the core recovered was shipped to Core Laboratories, Inc. in Casper, Wyoming, for commercial core analysis. Certain whole core samples were sent to BETC and LLL, and chip samples were shipped to Sandia Laboratories for special analysis and experiments.

Table 4-9 Properties of Ceramics

Materials	Compressive Strength, psi	Specific Heat @200 C, BTU	Thermal Conductivity	Thermal Expansion	Melting Temp.	Density	Young's Modulus	Poisson's Ratio	Tensile Strength, psi
Alumina	425,000	.24	24.0 BTU/at 200 C	4.40×10^{-6}	2,049 C	$3.97 \text{ kg/cm}^3 \times 10^{-3}$	5.4×10^6	.220	38,000
Beryllia	225,000	.30	.06 C/cm	9.20×10^{-6}	1,500 C	$3.00 \text{ kg/cm}^3 \times 10^{-3}$	4.6×10^6	.300	25,000
Mullite	100,000		.09 C/cm	5.00×10^{-6}	1,850 C	3.10 g/cm^3	$.5 \times 10^6$		13,000
Steatite	100,000						14.0×10^6		10,000
Zirconia	120,000	.30	.0057 C/cm	7.50×10^{-6}	2,700 C	5.43 g/cm^3	25.0×10^6	.324	15,000
Cordierite	50,000		.0055 C/cm	3.00×10^{-6}	1,471 C	2.51 g/cm^3	17.0×10^6	.210	50,000
Silicon carbide	20,000		.493 C/cm	4.80×10^{-6}		3.218 g/cm^3	70.0×10^6	.190	
Silicon nitride	90,000		.033 C/cm	2.85×10^{-6}	1,870 C	3.00 g/cm^3	35.0×10^6	.270	
Titanium boride		.30	40.0 BTU/at 200 C	4.80×10^{-6}	3,227 C	4.52 g/cc	70.0×10^6	.100	
Zirconium boride					2,249 C	3.63 g/cc			
Boron carbide	40,000	.25	70.0 BTU/at 200 C	2.40×10^{-6}	2,427 C	2.52 g/cc	6.5×10^6	.210	
Boron nitride	16,000	.30	18.0 BTU/at 200 C	1.00×10^{-6}	2,704 C	2.28 g/cc	16.0×10^6	.230	8,000
Magnesium oxide	120,000	.28	24.0 BTU/at 200 C	6.45×10^{-6}	2,852 C	3.57 g/cc	38.0×10^6	.180	18,000
Zirconium oxide	300,000	.14	1.2 BTU/at 200 C	4.16×10^{-6}	2,765 C	5.56 g/cc	15.0×10^6	.260	21,000
Silicon dioxide	100,000	.20	3.5 BTU/at 200 C	9.40×10^{-6}	1,063 C	2.65 g/cc	10.7×10^6	.170	10,000
Titanium dioxide		.20	3.0 BTU/at 200 C	4.90×10^{-6}	1,837 C	4.25 g/cc			
Sialon			1.5 BTU/at 200 C	1.50×10^{-6}	1,760 C	3.20 g/cc	properties similar to silicon nitride		

WGSP — BETC	FY-80											
RESOURCE ASSESSMENT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
FORMATION EVALUATION												
IMPROVED PRESSURE CORING SYSTEM												
Core Retriever Design & Test												
Core Fluid Testing												
Bit Design & Fabrication												
Bit Tests												
IN SITU PERMEABILITY												
Measurement of Formation Characteristics												
LEGEND												
▽ Scheduled Start and Completion of Task												
▼ Completed Milestone												
▬ Projected Schedule												
▬ Task Progressing												
▬ Task Progress Not Reported												
▬ Delay in Work on Task												

WGSP — BETC	FY-80											
RESOURCE ASSESSMENT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
IN SITU PERMEABILITY (Continued)												
Permeability of Interbedding Material Measurement												
Development of Standardized Core Analysis												
ADVANCED LOGGING TECHNIQUES AND INTERPRETATION												
Measurement of Interface Conductivity Effects on Electric Logging												
Dielectric Constant Measurements												
Mapping and Contouring Water Resistivities Study												
Study of Sonic, Neutron and Density Logging of Low Permeability Gas Sands												

Figure 4-7 Milestone Chart — BETC

WGSP — BETC	FY-80											
RESOURCE ASSESSMENT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
STIMULATION MECHANICS & METHODS												
RESERVOIR MODELING AND STIMULATION												
Perform Analysis of MHF Test Data and Engineering Studies												
ROCK-FLUID INTERACTION												
Physical Measurements												
PROPPANT AND PROPPANT TRANSPORT												
Evaluation of Particle Transport in Proppant Beds												
Evaluation of Proppant Embedment in Tight Gas Sands												
Study of Proppant Settling												
Light Weight Proppant Feasibility Study												

WGSP — BETC	FY-80											
RESOURCE ASSESSMENT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
ROCK MECHANICS												
IN SITU STRESS												
Development of Wire-Line In Situ Stress Tool												
Study on Measurement of Stress in Cores												

Figure 4-7 Continued

4.3 LAWRENCE LIVERMORE LABORATORY

4.3.1 Theoretical Analysis

Theoretical calculations are being used to analyze some aspects of hydraulic fracture penetration through a frictional interface. Comparison of these results with laboratory experiments will determine how the critical frictional levels result in stress concentrations that allow fracture penetration of the interface. In previous status reports it was shown that due to frictional slip, the stress intensity factor changes as a pressurized crack approaches an interface. These calculations were performed with relatively coarse grids, which did not allow sufficient detail to evaluate stress concentration effects across the interface. The current calculations use a finer grid.

Two-dimensional models are being developed to analyze the effect on hydraulic fracturing of overpressure in the productive formation. It has been suggested that overpressure can help induce a hydraulically driven fracture to propagate into the surrounding non-productive layers.

LLL's time dependent finite element model has been expanded so material density can be varied. A change in density across an interface results in impedance mismatch that affects elastic wave propagation. This, in turn, affects the likelihood of crack extension across an interface.

4.3.2 Experimental Program

4.3.2.1 Frictional Effects on Crack Growth Across Interfaces

During January, more rock samples were prepared for further experiments to study frictional effects on crack growth across unbonded interfaces. Experiments using blocks of Indiana limestone were performed to assess the effect of a lubricated strip on an otherwise smooth, dry, unbonded interface. The experiment consisted of the standard three block sandwich used in previous experiments, in which the fracturing fluid is injected into the interior block of the sandwich. In all experiments, the effect of lubricating a one-inch strip with the Hi-Temp C-100 Anti-Ball Lubricant significantly affected the crack penetration across the interface. In one experiment in which the crack penetrated both the dry and lubricated interfaces, the crack directly crossed the dry interface. However, when the crack intersected the lubricated strip on the opposite interface, it appeared to jump sideways and enter the adjacent block in the unlubricated region (see Figure 4-8). This result is preliminary and more experiments are needed to further study this phenomenon.

4.3.2.2 Rock Mechanics Measurements

The plumbing of the high pressure system for simultaneous measurements of ultrasonic velocity in multiple directions at confining pressures up to 1.0 GPa is complete and waiting testing. Specimens of Mesaverde shale have been prepared for Brazil tests, pressure-volume tests, and failure envelope tests. More of this material has been requested from the USGS as there are insufficient samples for complete tests. Mesaverde sandstone specimens have been jacketed and strain-gaged for pressure-volume tests which will be performed in February.

Figure 4-8 Hydraulic Fracturing-Interface Experiment with Lubricated Strip on one Interface

4.3.3 Geology and Geophysics

The manuscript and drawings have been completed for a document titled "A Review of the Mechanics and Occurrence of Natural Fractures in Rock as Applied to the Development of the Tight Western Gas Sands," which summarizes several months' work. An abstract titled "The Evolution and Stress History of the Low Permeability Upper Cretaceous Gas Reservoirs in the Rocky Mountains" has been accepted for presentation at the June AAPG meeting in Denver.

4.3.4 Schedule Status

Figure 4-9 depicts LLL's WGSP progress in a milestone chart.

Figure 4-9 Milestone Chart — LLL

4.4 LOS ALAMOS SCIENTIFIC LABORATORY

4.4.1 Nuclear Magnetic Resonance Studies

Transmitter and receiver electronics were overhauled due to periods of intermittent operation. The transmitter electronics evidently had suffered several internal arcs. The probable cause was determined to be the output transformers, which were subsequently redesigned and rebuilt. A consequent "jitter" in the pulse length was also eliminated, lending stability to the system. In addition, receiver noise was reduced by replacing several noisy components. This new system has been used to observe spin-echo NMR signals from the homogeneous field region surrounding the simulated wellbore position. They are considerably easier to observe than the free induction decay signals previously utilized.

Remote NMR signals have been obtained from simulated reservoir rock in a downhole configuration. The reservoir was simulated by surrounding the borehole with glycerol-saturated sea sand. The distribution of sand was approximately:

- 33 percent between 32 and 42 mesh;
- 33 percent between 42 and 60 mesh; and
- 33 percent between 60 and 80 mesh.

Porosity for this distribution of glycerol-saturated sand was measured to be approximately 50 percent. Preliminary data are now being analyzed with further experiments planned.

4.4.2 Schedule Status

Figure 4-10 is a milestone chart depicting LASL's progress within the WGSP.

4.5 SANDIA LABORATORIES

4.5.1 EGR Instrumentation and Characterization

4.5.1.1 Hydraulic Fracture Characterization

Shell Oil Hydrofracture Experiment

The Shell Oil test site, located on Lake Texoma (Texas), is scheduled for two massive hydraulic fractures at depths of 5,700 and 5,500 ft. The first test (5,700 ft) is scheduled for the last week of February. Fielding and checkout of the Surface Electrical Potential System (SEPS) will begin before the test.

The borehole seismic system will also be used in this experiment. One system will be installed in an offset well during the fracturing to map the fracture while being created. A system will also be used in the frac well during breakdown to measure fracture orientation.

WGSP — LASL	FY-80											
REMOTE CHARACTERIZATION OF FLUID SATURATIONS	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
PERMEABILITY AND POROSITY DETERMINATIONS ON CORE SAMPLES												
GEOLOGICAL STUDIES: Correlation Studies between Log Suites, Core Sections, and Lab Measurements.												
LEGEND												
▽ Scheduled Start and Completion of Task												
▼ Completed Milestone												
===== Projected Schedule												
===== Task Progressing												
===== Task Progress Not Reported												
===== Delay in Work on Task												

WGSP—LASL	FY-80											
REMOTE CHARACTERIZATIONS OF FLUID SATURATIONS	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
NUCLEAR MAGNETIC RESONANCE STUDIES												
THEORETICAL STUDIES												
Toroidal Magnetic Field												
Signal Detection												
Reservoir Fluid Characteristics by NMR												
LABORATORY STUDIES												
Feasibility of Remote NMR Detection												
Remote Detection of NMR in Focused Toroidal Magnetic Field												
Remote NMR Signal Detection Improvements												
Reservoir Fluid NMR Characteristics												

Figure 4-10 Milestone Chart — LASL

Figure 4-10 Continued

Amoco Cotton Valley Experiment

In November, 1979, Amoco's Burnett Brothers gas well No. 12 was fractured with clear fluid, with the borehole seismic system clamped at 9,490 ft (the top of the fracture zone). To examine the feasibility of determining orientation of the seismic system using explosives, four surface charges were detonated and the signals recorded. The first shot was 5 lbs of explosive at a bearing of $257^{\circ} 40'$ and a distance of 9,000 ft from the well. The second shot was 15 lbs at 9,000 ft with bearing of $305^{\circ} 20'$ and $356^{\circ} 15'$.

Using these known locations of the seismic source, it was determined that the seismic unit was located with the axis of one of the horizontal geophones at a bearing of 301° , 298° , 303° and 297° for the seismic shots. With a spread of only six degrees from the four shots, it is felt that this is a very usable technique for determining orientation.

Between the explosive shots, seismic data were recorded for determining fracture orientation. Because of extremely high background noise, only nineteen signals of sufficient amplitude were received that could be analyzed. These signals indicate a fracture plane whose direction is probably between N 30° E and N 70° E. A plot of this data is shown in Figure 4-11.

4.5.1.2 Electromagnetic Logging

An experimental program has been developed to study the dielectric properties of rock samples as a function of frequency. Initially, the region of experimental interest will be in the approximate range of 1-100 MHz, which is the region of maximum dispersion of the real

Figure 4-11 Seismic Data From Burnett Brothers No. 12 Well

and imaginary parts of the dielectric constant. In this regime, two distinct experimental techniques can be used together, which would indicate the accuracy of the experimental results. The first method is a standard bridge technique: the real and imaginary parts of the dielectric constant of the rock sample are found by using a variable resistor and capacitor to balance the bridge. The second method determines the dielectric properties of the rock sample by measuring the attenuation and phase shift of an applied sinusoidal signal of given frequency through the rock.

Equipment, such as bridges, signal generators and other related items, has been carefully examined to begin setting up a laboratory for the dielectric measurements.

4.5.1.3 Borehole Resistivity System

The problem of determining a one-dimensional radial resistivity profile from potential measurements is currently under study. The solution of this problem would enable the resistivity profile surrounding a wellbore to be determined from potential measurements within the wellbore. The one-dimensional nature of the solution would limit consideration to nonlayered, vertically homogeneous media surrounding the wellbore. Therefore, this problem is regarded as preliminary to the two-dimensional inverse problem. The numerical solution to the one-dimensional forward problem (calculation of potentials

from an assumed resistivity profile) is straightforward and has been used in the interpretation of potential data through an iterative curve matching procedure. The inverse problem (calculation of resistivity profile from known potentials) for the corresponding geometry of a circular current source located on the surface of the earth, with the resistivity stratified in the vertical direction, is being studied.

4.5.1.4 High Resolution Seismic Formation Mapping

Processing of seismic shot data obtained at the Bryson Canyon site began in January. Initial evaluation of the data shows that the maximum useful bandwidth of the seismic data extends up to approximately 100-120 Hz. This is encouraging, as prior model studies have demonstrated the need for this range of frequencies to resolve some of the typical lens thicknesses (~ 25 ft). An analysis of shot-generated noise on records shows that ground roll is not always present, but when it is, it is dominantly 30-40 Hz and less. This is also encouraging. The dominant noise source, however, is the air blast which may eliminate or disrupt recording of reflections from an estimated 1,000-3,000 ft depth interval. The survey was designed to concentrate on the upper 1,000 ft, so this was an expected consequence. A preliminary (Brute) stack record among a single traverse is given in Figure 4-12. This crude stack is not corrected and is only a quick look at reflection possibilities. There are several line-ups or events which correlate for some distance. A look at a synthetic seismogram generated from the CK GeoEnergy borehole (Figure 4-13) shows possibilities of several reflections from the sand section and a good reflection from the 8-ft coal seam. The overall character of the Brute stack and general similarity to the synthetic are also encouraging. Further processing is continuing, and a final evaluation at this site should be complete by early March.

Plans for laying out survey points at Site No. 2 (Horse Point Site) have been developed. Field activities for this site are dependent on snow conditions as this site is some 1,600 ft higher in elevation.

4.5.2 Schedule Status

Sandia WGSP progress is depicted in Figure 4-14, a milestone chart.

Figure 4-12 Brute CDP Stack of Traverse 2 Seismic Data — Bryson Canyon Site

Figure 4-13 Synthetic Seismogram — Bryson Canyon Site

Figure 4-14 Milestone Chart — Sandia

WGSP — SANDIA	FY-80											
EGR — INSTRUMENTATION DIAGNOSTICS	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
FORMATION EVALUATION												
ELECTROMAGNETIC IMPEDENCE SONDE												
Feasibility Study												
Electrical Description												
Geological Description												
Prototype Development												
ELECTROPOTENTIAL SONDE												
Feasibility Study												
Parametric Description												
Prototype Development												

Figure 4-14 Continued

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5. FIELD TESTS AND DEMONSTRATIONS

5.1 BACKGROUND

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

- A dry gas injection experiment in the Wattenberg Field, Colorado, by Colorado Interstate Gas Company,
- MHF demonstrations by Gas Producing Enterprises in the Uinta Basin, Utah,
- MHF treatment of the Cotton Valley Limestone Formation in Limestone County, Texas, by Mitchell Energy Corporation,
- A mineback testing program by Sandia Laboratories.

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

Table 5-1 MHF Contract Location and Frac Data

Company Basin & Formation	Location T/R/Sec	Well	Interval Fractured ft	Fracture Date	Fracture Treatment Lb of Sand	Injected Fluid 10 ³ Gal	Production Rates MCFD		Ratio
							Before	After	
AUSTRAL Piceance, Mesaverde	7S/94W/Sec 3 Garfield Cty, Colorado	Federal 3-94	6,198-6,333 5,170-5,630	8-13-76 8-25-76	420,000 720,000	226 Gel 316 Gel	35	62	1.8
CONSORTIUM MANAGED BY CER CORPORATION Piceance, Mesaverde	3S/98W/Sec 11 Rio Blanco Cty, Colorado	RB-MHF-3	8,048-8,078	10-23-74	400,000	117 Gel	60	60	—
			7,760-7,864	05-02-75	880,000	285 Gel	—	40	—
			5,925-6,016	04-04-76	815,000	400 Gel	42	160	3.8
			5,851-5,869	11-03-76	448,000	228 Gel	57	70	1.2
DALLAS PRODUCTION Fort Worth, Bend Cong.	Ben D. Smith Survey A-779 Wise Cty, Texas	Ferguson A-1	5,957-6,794	09-16-76	506,000	139 Foam 198 Emul	40	15	—
EL PASO NATURAL GAS Northern Green River, Fort Union	30N/108W/Sec 5 Sublette Cty, Wyoming	Pinedale Unit No. 5	10,950-11,180	07-02-75	518,000	183 Emul 8 Gel	150	340	2.3
			10,120-10,790	10-20-75	1,422,000	459 Gel	—	150	—
GAS PRODUCING ENTERPRISES, INC. Uinta, Wasatch and Mesaverde	10S/22E/Sec 10 Uintah Cty, Utah	Natural Buttes No. 18	6,490-8,952	09-22-76	1,480,000	745 Gel	—	1,400	—
	10S/21E/Sec 21 Uintah Cty, Utah	Natural Buttes No. 19	8,909-9,664	09-21-76	424,000	280 Gel	—	166	—
			7,224-8,676	09-28-76	784,000	364 Gel	—	—	—
	9S/21E/Sec 22 Uintah Cty, Utah	Natural Buttes No. 14	6,646-8,004	03-15-77	1,093,000	544 Gel	38	800	21.0
	9S/21E/Sec 28 Uintah Cty, Utah	Natural Buttes No. 20	8,498-9,476	06-22-77	826,000	322 Gel	75	1,200	16.0
	10S/22E/Sec 18 Uintah Cty, Utah	Natural Buttes No. 22	6,838-8,550	11-21-77	1,151,000	499 Gel	—	700	—
	9S/22E/Sec 19 Uintah Cty, Utah	Natural Buttes No. 9	5,661-8,934	03-27-78	554,000	349 Gel	140	540	3.9
	10S/21E/Sec 29 Uintah Cty, Utah	CIGE No. 2	9,237-9,653	06-22-78	170,500	203 Gel	—	Water	—
			7,251-8,774	08-08-78	1,965,000	722 Gel	—	Water	—
MITCHELL ENERGY Cotton Valley, Limestone Trend	2S/97W/Sec 13 Rio Blanco Cty, Colorado	F31-13G	10,549-10,680	06-22-77	580,000	316 Gel	300	800	2.7
			9,392-9,538	08-24-77	600,000	260 Gel	700	2,600	3.7
			8,765-8,972	05-10-78	388,000	150 Gel	479	430	—
			8,163-8,650	07-06-78	660,000	288 Gel	—	360	—
			7,704-7,794	09-07-78	218,000	120 Gel	—	180	—
			7,324-7,476	11-15-78	700,000	365 Gel	1,000	2,000	2.0
PACIFIC TRANSMISSION Uinta, Mesaverde	8S/23E/Sec 25 Uintah Cty, Utah	Federal 23-25	NO FRACTURES PERFORMED						
RIO BLANCO NATURAL GAS Piceance, Mesaverde	4S/98W/Sec 4 Rio Blanco Cty, Colorado	Federal 498-4-1	6,150-6,312	10-22-76	766,000	276 Gel	57	130	2.3
			5,376-5,960	11-30-77	243,000+ 22,500 Beads	164 Gel	80	350	4.4
WESTCO Uinta, Mesaverde	10S/19E/Sec 34 Uintah Cty, Utah	Home Fed. No. 1	10,014-10,202	12-21-76	500,000	248 Gel	33	155	4.7
			7,826-9,437	10-01-76	600,000	412 Gel	40	Water	—

RIO BLANCO MASSIVE HYDRAULIC FRACTURING EXPERIMENT

DE - AC08 - 76RA00623

CER Corporation
Las Vegas, Nevada

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

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

DOE Contract No. DE-AC08-76RA00623 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 terms of the contract.

Field activities on the RB-MHF 3 well have been suspended. CER Corporation is transferring the MHF well to an operator who will attempt to complete the well, commingle the previously fractured zones, test the well and provide the data to the industrial participants and DOE.

The transfer has been completed.

WATTENBERG FIELD

DE - AC08 - 77ET12046

Colorado Interstate Gas Company
Colorado Springs, Colorado

Status: Active

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

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

Principal Investigator: David Wilson
Technical Project Officer for DOE: C. H. Atkinson

OBJECTIVE

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

5.3 COLORADO INTERSTATE GAS COMPANY

The DOE test trailer arrived on location at the Miller No. 1 well on January 10. Both the Miller No. 1 and Sprague No. 1 wells were shut in and all cycling operations were halted on January 12. Both wells began drawdown in preparation for measurement of BHP on January 18. Initial pressure at the Miller was approximately 1,600 psi when drawdown began.

Some problems were encountered with channeling in the dehydrators in the cycle prior to shut in, which means that some wet gas was injected.

Methanol drip tanks were installed, but since that was after the wells were shut in, it is not known if they will eliminate or prevent line freezing problems.

Figure 5-1 shows the production and injection volumes and associated pressures of these wells up to the January 13 shut-in.

Figure 5-1 Production and Injection Volumes and Associated Pressure of CIG Miller No. 1 and Sprague No. 1 Wells

DOE WELL TEST FACILITY

DE-AC08-79-BG01569

CER Corporation
Las Vegas, Nevada

Status: Operational

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.

5.4 DOE WELL TEST FACILITY

The DOE Well Test Facility was transported to CIG's Miller No. 1 well, Wattenberg field, Weld County, Colorado. The facility acquired bottom hole pressure and flow rate data for a drawdown test that commenced January 18. The well flowed for 12 days and was subsequently shut-in on January 30. A total of 5,387 MCF of gas was produced for an average flow rate of 450 MCFD. A sampling of the data collected is presented in Table 5-2.

The facility is currently monitoring the buildup portion of the drawdown test that will continue for the next few months. Cable Engineering is currently acquiring bottomhole pressure data on the Sprague No. 1.

The Miller No. 1 and the Sprague No. 1 are the two principal wells for the cyclic dry gas injection and dewatering experiment jointly being conducted by CIG and DOE.

Table 5-2 Miller No. 1 Drawdown Test Data

Date	Cumulative Flow Time (hours)	Flow Rate (MCFD)	Bottomhole Pressure (psia)
1/18	0	487	1,580
1/19	26	299	1,383
1/20	57	311	1,314
1/21	75	489	1,180
1/22	104	529	980
1/23	125	842	658
1/24	151	694	210
1/25	176	550	160
1/26	202	475	152
1/27	217	458	147
1/28	251	433	166
1/29	271	315	144
1/30	287	280	139

NATURAL BUTTES UNIT, UINTAH COUNTY, DE-AC08-76 ET 12060 UTAH MASSIVE HYDRAULIC FRACTURING DEMONSTRATION

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

Status: Active

Contract Date: July 1, 1976
Anticipated Completion: March 31, 1980

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

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

OBJECTIVE

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

5.5 GAS PRODUCING ENTERPRISES, INC.

The GPE wells, Natural Buttes Unit Nos. 9, 14, 18 and 20, flowed to sales during January, with a total production of 47,409 MCF. Natural Buttes Units Nos. 19, 21 and 22 were shut in. (No. 21 is temporarily abandoned in the Mesaverde horizon and No. 22 is being reworked because of excessive water production). Figures 5-2 through 5-7 show the production figures of these wells since the fracture jobs were performed.

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

DE - AC08 - 78ET12150

Mitchell Energy Corporation
Houston, Texas

Status: Active

Contract Date:

March 15, 1978

Anticipated Completion:

April 30, 1979 (Extension being processed)

Total Project Cost (estimated):

DOE \$ 553,771

Industry 1,074,550

Total \$1,628,321

Principal Investigator:

F. D. Covey

Technical Project Officer for DOE:

C. H. Atkinson

OBJECTIVE

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

5.6 MITCHELL ENERGY CORPORATION

The draft of the final report is due by mid-March.

**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.

5.7 SANDIA — MINEBACK

5.7.1 Hydraulic Fracturing Containment Experiments

5.7.1.1 Hole No. 6 Formation Interface Fracture Experiment

Twenty-six coreholes have been completed to date, including EV6-30 and EV6-31, which were completed in January. Their locations are shown in Figure 5-8, which clearly denotes that the fractures propagated mostly downward. They apparently did not propagate very far up into the ashfall tuff which overlies the welded tuff zone.

5.7.1.2 Interface Test Series

In January, 16 minifrac tests were conducted in separate holes to obtain the vertical distribution of the in situ stress in a limited area. The results of these tests are shown in Figure 5-9. The difference in in situ stress between the lower ashfall tuff and the welded tuff above the interface can clearly be seen; however, the stress peaks are not as pronounced as in other areas. This verifies that stress peaks are real phenomena associated with the vertical stress gradient, although the magnitude of the stresses may change considerably over a distance of tens of feet.

5.7.1.3 Rock Mechanics

Variations in material properties of rocks throughout a geologic section will greatly modify, on a local scale, the regional horizontal stress (σ_H) and overburden stress (σ_V). Finite element calculations can readily simulate the local stress variations if the material properties and the regional stresses are known. However, the regional stresses are rarely known in other than broad qualitative terms, yet the local stresses and material properties in a well can be accurately measured. A generalized inversion routine has been developed which infers the regional stresses from the material properties and local (in situ) stress data. The predicted regional stresses might then be used to determine in situ stress in other nearby wells without performing costly stress measurements. Because the data set is usually limited in size, the problem is underdetermined and the regional stress solution is not unique. But there is usually some information about the probable range of the regional stress state. A method has been adopted which finds the best fitting solution lying within "soft" *a priori* constraints. Results from an attempt to fit in situ stress data from the NTS are shown in Figure 5-10. When σ_H was constrained to lie within the range 0 to 1,000 psi, the fit to the data was not good. The rapid increase in compressional horizontal stress immediately below the welded/ashfall tuff interface is readily explained by the model, but the subsequent rapid decrease with depth remains unexplained. Even when the range of σ_H is greatly increased ($\pm 10,000$ psi), the data do not fit.

A finite element thermo-elastic calculation was performed to determine if cooling and contraction after deposition of a hot welded tuff could cause significant local stress changes in underlying rock. Results indicate that cooling produces tension in the welded tuff and compression below it. Figure 5-11 shows that the thermally-induced stress peak occurs below the stress peak caused by regional stresses. Including this effect in the inversion calculation with temperature change and regional stress as unknowns, still failed to substantially improve the fit to the NTS in situ stress data.

Figure 5-8 Results of Exploratory Coring of Hole No. 6

5.7.2 Schedule Status

The progress of the Sandia-mineback projects within the WGSP is plotted in Figure 5-12, a milestone chart.

Figure 5-9 In Situ Stresses Near Interface

Boundary conditions for the finite element calculation. The inclusion simulates a welded tuff with a Young's modulus 5 times that of the surrounding matrix of ashfall tuff.

Figure 5-10 Attempted to Fit to NTS In Situ Stress Data

Figure 5-11 In Situ Stress Effects Caused by Cooling of a Welded Tuff

Figure 5-12 Milestone Chart — Sandia Mineback