DOE/METC-86/6034

DOE/METC/83-45

Unconventional Gas Recovery Contractors Meeting

Eastern Gas Shales, Coalbed Methane, Western Gas Sands

Abstracts and Agenda

November 18-19, 1985

Ramada Inn
Morgantown, West Virginia

U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
P.O. Box 880
Morgantown, West Virginia 26507-0880

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UNITED STATES DEPARTMENT OF ENERGY

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SESSION 1.0

EASTERN GAS SHALES

UNCONVENTIONAL GAS RECOVERY
CONTRACTORS MEETING

PROJECT SYNOPSIS

CONTRACT TITLE:	Eastern Gas Shales
CONTRACT NUMBER:	DE-AI21-83MC20422
CONTRACTOR:	U.S. Geological Survey
ADDRESS:	955 National Center
CITY, STATE, ZIP:	Reston, Virgina 22092
TELEPHONE:	(703) 860-6634
PROGRAM MANAGER (CONTRACTOR):	John B. Roen
PRINCIPAL INVESTIGATORS:	John B. Roen Wallace de Witt, Jr. Laure G. Wallace
METC PROJECT MANAGER:	Albert Yost
PERIOD OF PERFORMANCE:	October 1, 1983, to September 30, 1985

ABSTRACT

The project objectives are twofold: (1) to identify and evaluate the hydrocarbon potential of the black, organic-rich shale of Ordovician age in the Appalachian basin; and (2) to determine the source rocks for the hydrocarbons found in Upper Devonian reservior rocks in selected areas of the Appalachian basin.

Significant thicknesses of black Ordovician shales having source rock potential at some point in time have been identified in selected areas of the basin. The maturation level ranges from early diagenetic to the metagenic stage. Should the timing of generation and entrapment be optimal, quantities of hydrocarbons might be identified by drilling suspected traps.

Several oils from Devonian reservoir rocks and Devonian shale extracts have been examined by chromatography. Results suggest that the hydrocarbons found in conventional reservoirs or black shale source rocks of Devonian age were derived from the Devonian black shales. Migration is thought to have occurred continually since generation in a general upward direction. At first, migration occurred through more porous poorly lithified silty sediments and later through fracture systems in the lithified rock sequence.

Future activities include sample collection and analyses and preparation of final reports and illustration for the Ordovician shale evaluation and the Devonian source bed study.

ACCOMPLISHMENTS

Ordovician black shale

Two geological settings based on structural characteristics, maturation levels, and the presence of discrete units of black shale were selected for study.

- Unexplored, structurally complex eastern overthrust belt of Tennessee and Virginia.
- Explored deep downwarped, northwest part of the Appalachian basin.

Fifty-six (56) shale samples have been collected from Tennessee and Virginia in the southern overthrust area and the Pennsylvanian part of the northwest deep basin area.

- Total organic carbon content averages 1% for the shales from the southern area and exceeds the minimum value of 0.5% for source beds.
- The 1% average may only indicate residual carbon resulting from weathering and maturity, hence original carbon content may have been greater.
- Average current hydrocarbon generating potential for southern overthrust area is 0.04 mg of HC/gm of rock. Minimal value from Rock-Eval analysis is $(S_1 + S_2)$ 2 mg/g.

Conodont alternation indices indicates maturation levels range from CAI 1.4 to about CAI 4.

- Southern overthrust area, Tennessee and Virgina CAI 3 to CAI 4: upper catagenic to metagenic dry gas stage.
- Northern deep basin area, New York, Pennsylvania, and Ohio CAI 1.5 to CAI 4: very late diagenetic to metagenic stage, oil to dry gas.

Hydrocarbon potential of Ordovician shales of the southern overthrust area, Tennessee and Virginia.

- Limited to dry gas.
- Dependent on timing, dry gas could be trapped in the structurally buried fractured Ordovician shale sections.
- Possible targets in the Saltville thrust sheet.

Hydrocarbon potential of Ordovician shales in the northern deep basin area, New York, Pennsylvania, and Ohio.

- Good hydrocarbon potential based on subsurface extent, thickness, and maturation.

- Total amount hydrocarbons generated is probably a very significant quantity; however, the amount entrapped is dependent on identifiable deep basin structures, stratigraphic traps or a combination of both. Deep well distribution probably not sufficient to identify any plays.

Devonian shale-oil study

Analyses of four oils from Devonian shale wells in Pleasants County, West Virginia, compared with analysis of extractable organic material from the Rhinestreet and Genesee intervals from DOE/West Virginia #7 well in Wetzel County, West Virginia.

- Samples are all similar. As expected the oils are all high gravity, thermally mature oils whose source was the organic detritus in the Devonian gas shales.

- Rock extracts from the Rhinestreet and Genesee intervals from DOE/West Virginia #7 show a strong correlation of gas chromatograms with data from the four Pleasants County samples confirming a Devonian shale source for the oils.

- Carbon isotope ratios of the C_{15+} saturated and aromatic hydrocarbons from the six samples indicates that the oils were derived largely from the marine component of the black-shale sequence. Clustering of the oils in close proximity to the Rhinestreet suggests it, rather than the Genesee, may have been the source unit.

- A similar relationship exists for Pennsylvanian Upper Devonian oils - Bradford oil from the Bradford field (McKean County) and combined Venango and Bradford from the Shippensville pool (Clarion County) - when evaluated against chromatogram of the Brallier shale from DE/Pa-1 McKean County, Pennsylvania. A common source is indicated for all three samples.

PRESENTATIONS

Roen, John B., Paleozoic black shales of the Appalachian basin, International Chemical Congress of Pacific Basin Societies, Abstracts for 1984 meeting.

PROJECT SYNOPSIS

CONTRACT TITLE:	Stress-Ratio/Structure Studies and Testing in the Appalachian Basin
CONTRACT NUMBER:	DE-AC21-83MC 20337
CONTRACTOR	The Trustees of Columbia University in the City of New York
ADDRESS:	Lamont-Doherty Geological Observatory
CITY, STATE, ZIP:	Palisades, New York 10964
TELEPHONE:	(914) 359-2900
PRINCIPAL INVESTIGATORS:	Keith Evans Terry Engelder
METC PROJECT MANAGER:	Albert B. Yost II
PERIOD OF PERFORMANCE:	30 September 1983 - 1 January 1986

ABSTRACT

The objective of the project is to measure in detail vertical and lateral variations in in-situ stress occurring on lateral scales of one to fifty kilometers in a bedded sandstone/shale sequence and to explain their origin. The measurements are being made in existing open-hole completed wells using a wireline-based minifracturing system purposefully modified to permit operation in the 6-8 inch diameter boreholes commonly drilled in the study area.

The first phase of the project addressed the issue of the spatial coherence of in-situ stress on scales of the order of one kilometer. Access was gained to a cluster of three previously untreated 8 inch diameter boreholes each of which present open hole sections extending from the Dunkirk formation through to below the Tully limestone. The wells (Wilkins, Appleton and O'Dell), are located in an approximately straight line extending WSW from the village of South Canisteo in Steuben County, New York, and are separated by distances of 2 km and 1 km respectively. The site was chosen because of the proximity to the extensively cored and tested Eastern Gas Shales Project well NY#1 which penetrates an identical stratigraphic section some 25 km northwest of the site. Bedding in the area is nearly horizontal.

Considerable problems were initially encountered with the development of the downhole tool assembly. These were finally overcome in the spring of 1985 and the system was successfully tested and dispatched to the field in July. Complete borehole seisviewer logs were run in each well to identify intervals free of natural fractures and also to calibrate the L-DGO wireline depth standard against Gearhart post-drilling gamma logs thereby facilitating accurate stratigraphic positioning of the fracturing tools. In addition, a complete log suite was run in the easternmost well (Wilkins Well) through the courtesy of Schlumberger-Doll Research which included, amongst others four-arm dipmeter and long-spaced sonic logs. On the basis of the logging information, seven discrete quartz-rich horizons were identified (referred to hereafter as sands D through K) ranging in thickness between 3 and 20 meters, each of which intersected all

three wells. The sands could be clearly distinguished from the surrounding massive shales in the seisviewer images. No discrete sand sections are found in the Devonian section below the K-sand which lies 20 m above the base of the Rhinestreet formation. A program of stress measurements was designed to reveal any systematic difference in stress state that might exist between the sands (or siltstones) and shales.

A total of 22 stress tests were conducted in the Appleton well and 43 in the Wilkins. At the time of writing fieldwork was still in progress on the O'Dell well. There has been little time for analysis of data and consideration of its implications and hence only provisional results arising from shut-in pressure variations of induced fracture geometry will be presented.

The results show that shut-in pressures for the section above the three deepest Rhinestreet sands (H, J and K) lie close to or slightly above the estimated lithostat. The majority of these fractures were determined to be vertical and hence we conclude that the ratio of least horizontal to vertical stress in this section lies in the range 1.05 to 1.10. The stress state within and below the 120 m section containing Sands H, J and K is more complicated. Least horizontal stress in these sands is systematically higher (≈15%) than the surrounding shales which trend to sub-lithostatic. Below the D-sand the least horizontal stress drops dramatically. In the Wilkins well, the fracture gradient drops from 1.15 in the K-sand to 0.8 in the Cashaqua shale over a vertical distance of less than 10 m. Below the transition, the shut-in pressure gradient is about the same as the lithostat although the sub-lithostatic offset persists to the limit of our measurements at 1050 m. The same correlation between measured stress and stratigraphy is observed in both holes completed to date, and the measured stresses correlate closely in magnitude when a topographic correction is made for the difference in elevation of the two holes.

Although the majority of the induced fractures in the Appleton well were determined to be sub-vertical of north-east preferred orientation, two purely horizontal fractures and "mixed" cases were detected. Given the somewhat modest difference between the overburden and least horizontal stress in the upper Rhinestreet section where horizontal fracture nucleation at the wellbore is implied, it would seem that the natural strength anistropy of the material played a significant role in the initiation of the fracture. We consider it likely that commercial scale hydraulic fracture treatments administered at depths shallower than the K-sand would result in the development of horizontal fractures at most some short distance from the borehole.

The results for inferred maximum principal horizontal stress are not available at the time of writing. A study was undertaken of fracture re-opening pressure. It is well known that re-opening pressure, whose correct estimation is crucial to the estimation of maximum horizontal stress, t.ends to lower values on successive pump cycles during a typical stress measurement. Approximately thirty stress tested intervals were re-occupied a day or more after the tests were conducted when the pore pressure in the fracture and surrounding rock has reached hydrostatic equilibrium with the borehole fluid pressure. This is the true re-opening pressure assumed by the theory. Significant differences between "undrained" re-opening pressures measured during the stress tests and "drained" re-opening pressure measured later were found.

Accomplishments

1) A wireline minifrac stress measurement system capable of operation in boreholes up to 8 inches in diameter has been developed and successfully fielded.

2) A cluster of three open-hole completed wells a kilometer or so apart have been stress tested to 1050 m in depth. An extremely high density of measurements were made in order to reveal clear correltions between in-situ horizontal stress and lithology. The same correlations were found in the two wells in which measurements have been completed. Measurements of the third is on-going at the time of writing.

3) An investigation of the stability of fracture re-opening pressure and its relationship to the "drained" state of the induced fracture has been performed.

UNCONVENTIONAL GAS RECOVERY
CONTRACTORS MEETING

PROJECT SYNOPSIS

IN-HOUSE RESEARCH TITLE: Eastern Gas Shales Systems Analysis: Lineaments versus Production

METC PROJECT MANAGER: James C. Mercer

PRINCIPAL INVESTIGATORS: James C. Mercer

ABSTRACT

Users of lineament maps to locate well sites for shale gas production have had a history that has resulted in a lack of confidence in the approach. One of the objectives of this special project was to determine how lineaments affect Devonian shale gas production in three areas of different tectonic stress within the Appalachian Basin. A second objective was to compare and contrast the maps provided by three experienced lineament mappers to establish if any of the various techniques used to identify lineaments are also effective at locating subsurface fractures. Natural fractures allow the migration and storage of reservoir fluids and are thought to be of utmost importance when producing hydrocarbons from tight formations such as the Devonian shale. Surface expressions of these naturally fractured zones are thought to be a means of selecting favorable well sites when incorporated with subsurface studies. In an effort to determine how lineaments and producing gas wells are related in areas where the natural fracture system could be described as high, intermediate, and sparse, three target sites for study were defined. The three areas of study are southwestern West Virginia; Meigs County, Ohio; and Floyd County, Kentucky. Although the research effort is ongoing, some tentative conclusions can be made. It is evident that there are vast differences between the maps that were provided by the three investigators for each of the study areas. Dissimilarity was somewhat expected due to the scale differences in detection devices used by the mappers but even the lineaments identified by LANDSAT images, which all three mappers used, showed alarming differences in length, orientation and number. Although the primary analysis is incomplete, the results of the preliminary analysis indicate that none of the lineament variables, regardless of the mapper, showed strong correlations with gas production.

ACCOMPLISHMENTS

The alarming dissimilarity between lineament maps of the same areas is seen as a profound result for it is difficult to correlate the effects of lineaments on production if the position and even the presence of some of the lineaments are in doubt. The fact that very few of the lineament variables showed correlations with production is significant. More accurate methods are required to identify and pinpoint lineaments. In addition, ground truth verification methods such as geochemical studies and earth resistivity profiling surveys may be necessary to verify the presence of fracture zones.

ARTICLES AND PRESENTATIONS

Pratt, S., E. Robey, R. Wojewodka, 1985. Eastern Gas Shales Lineament Analysis, Results of the Geostatistical Analysis for the First Study Area: Southwestern West Virginia. Internal Report to DOE/METC.

Pratt, S., E. Robey, R. Wojewodka, 1985. Eastern Gas Shales Lineament Analysis, Results of the Geostatistical Analysis for the Second Study Area: Meigs County, Ohio. Internal Report to DOE/METC.

UNCONVENTIONAL GAS RECOVERY
CONTRACTORS MEETING

PROJECT SYNOPSIS

IN-HOUSE RESEARCH TITLE: Eastern Gas Shales Reservoir Tester Instrumentation Development

METC PROJECT MANAGER: A. B. Yost

PRINCIPAL INVESTIGATORS: L. O. Lawson
G. E. Fasching

ABSTRACT

Gas wells in Devonian shale and other typically tight sands of the Appalachian Basin are often low producers from a single interval but are economically viable due to multiple interval production. Production well testing is desirable to evaluate reserve capacity, to provide data for emphasizing more productive intervals in well completions, and to diagnose production problems such as premature and abrupt production decline. Data used by Government, universities, and industry today are usually the total initial open-well flows and measurements from the combined, multiple producing regions of the wellbore. Open flow data is of limited value for interval-specific research purposes. The diagnostic technique under development will determine, for isolated intervals, the interval production characteristics and vertical interference characteristics from measured flow rates at controlled back pressures using a downhole wireline tool.

The objective of the work being performed by the Instrumentation Sciences Branch at the Morgantown Energy Technology Center during the 1985 fiscal year has been to design the control, power, data acquisition, and communication systems for the Downhole Reservoir Tester (DRT). The purpose of the DRT is to isolate selected gas producing intervals from within cased or uncased wells, to conduct controlled pressure and flow measurements, and to retrieve uncommingled samples. Hydraulically operated straddle packers are to be used to isolate the test intervals. Electric motors are to power the pumps and valves within the tool. Computers on the surface perform remote control and data logging functions.

ACCOMPLISHMENTS

The communication and data acquisition systems were designed to provide two-way communication of commands and measurement data between the DRT and the surface. The design, breadboard assembly, and testing of electronic circuits was performed. Communication and power transmission testing was performed on a 2,000-foot section of armored cable suitable for the DRT wireline. Pressure transducers suitable for the space confinements were evaluated.

A cooperative agreement is anticipated for design and development of the mechanical systems of the DRT. Integrated design of electrical and mechanical systems will be performed this year. Operation, calibration, and testing

procedures will be formulated. Complete prototype assembly and testing of the DRT are projected for late 1986.

ACKNOWLEDGEMENT

This research is being performed in conjunction with Technology Development, Inc. (TDI), Dr. L. Z. Shuck, President.

UNCONVENTIONAL GAS RECOVERY
CONTRACTORS MEETING

PROJECT SYNOPSIS

CONTRACT TITLE:	Analysis of Fracturing Mechanisms in Naturally Fractured Rocks
CONTRACT NUMBER:	DE-AC21-83MC20289
CONTRACTOR:	Science Applications International Corporation
ADDRESS:	30096 Spruce Road
CITY, STATE, ZIP:	Evergreen, CO 80439
TELEPHONE:	(303) 674-5661
PROGRAM MANAGER (CONTRACTOR):	Thomas L. Blanton
PRINCIPAL INVESTIGATOR:	Thomas L. Blanton
METC PROJECT MANAGER:	Albert B. Yost, II
PERIOD OF PERFORMANCE:	September 30, 1983 - December 31, 1985

ABSTRACT

The objective of this project is to provide a basis for selecting fracturing treatments that will cross and connect as much of the natural fracture system to the wellbore as possible. Tapping the natural fracture system has been recognized as essential to obtaining significant well stimulation.

The work is divided into three groups of tasks. The objective of the first group is to determine the type of interaction that can be expected between induced and natural fractures under various in-situ conditions. Interaction criteria to predict the type of interaction are to be developed for both hydraulically and dynamically induced fractures. The second group of tasks involves developing data on in-situ conditions that are required for application of the criteria in the field. Specific tasks are concerned with identifying fractures that are conductive to gas, quantifying the current state of stress in the Appalachian Basin, and using regional tectonics to predict fracture patterns across the basin. The objective of the final task group is to synthesize the results of the first two groups into a field-applicable determination of the type of interaction that can be expected from different fracturing treatments in different parts of the basin.

Scaled laboratory experiments have been run in such a way as to form a basis for predicting the type of interaction that can be expected in the field between hydraulically induced and pre-

existing fractures. Dimensional analysis forms the basis for all scale model studies and was used in this project to select the appropriate experimental conditions. The two parameters varied in the experiments were differential stress and angle of approach. Hydraulic fractures crossed pre-existing fractures when angles of approach were 60 degrees or greater, except when differential stress was relatively low. When the angle of approach was 30 degrees or higher, however, pre-existing fractures tended to open, diverting fracturing fluid and preventing the hydraulic fracture from crossing. A simple theoretical relation has been developed which fits the experimental data and may be useful in predicting the type of interaction that can be expected in the field. For conditions where hydraulic fractures opened pre-existing fractures, tests are currently being run to determine if more constructive crossing interaction can be obtained from dynamically induced fractures.

A compilation of existing data on the state of stress in the Appalachian Basin has been completed as well as a comparative study of stress measuring techniques that can be used on a local basis to determine stress. Data is currently being collected on fracture patterns and basin tectonics. When this is complete, the interaction criteria, stress data, and fracture pattern data will be synthesized in order to predict the type of interaction that can be expected in different parts of the basin.

ACCOMPLISHMENTS

The primary accomplishment to date has been the development of a hydraulic/natural fracture interaction criterion that has been experimentally verified in the laboratory and is stated in dimensionless terms so that it can be applied to field situations. An important characteristic of of this criterion is that angle of approach is the most important parameter for applications. The sensitivity to differential stress is confined primarily to angles of approach between 45 and 60 degrees. Below 45 degrees opening interaction is preferred; above 60 degrees crossing is preferred, at least for differential stresses greater than a few hundred psi.

ARTICLES AND PRESENTATIONS

Blanton, T.L., "In Situ Stress Determination from Wellbore Elongation Measurements", Proc. SPE/DOE Sym. on Low Permeability Reservoirs, pp. 279-291 (1985).

Blanton, T.L., "Induced/Natural Fracture Interaction in Devonian Shale Gas Reservoirs", SPE Forum Series: Naturally Fractured Reservoirs, abstract and presentation (1985).

Blanton, T.L., "Interaction Between Hydraulic and Natural Fractures", abstract submitted for SPE Unconventional Gas Technology Symposium (1986).

UNCONVENTIONAL GAS RECOVERY

CONTRACTORS MEETING

Project Synopsis

Contract Title: Unconventional Gas Program/Eastern Devonian Shales

Contract Number: W-7405-ENG-48

Contractor: Lawrence Livermore National Laboratory (LLNL)
Address: P O Box 808
City, State, Zip: Livermore, CA 94550
Telephone: (415)423-0363 or FTS 543-0363

Program Manager (Contractor): Francois E. Heuze, Code L-200

Principal Investigator(s): J. R. Hearst, N-H. Mao, and R. P. Swift

METC Project Manager: C. Komar and A. Yost

Period of Performance: FY 1985 continuing in FY 1986

Objective

The objective of this research is to contribute to improvements in gas recovery from Eastern Devonian Shales (EDS).

Program Tasks

In FY 1985 there were 4 tasks under the EDS Subprogram.

1. development of a probe to estimate stresses in situ; the tool is based on the principle of measuring the stress-induced anisotropy of shear wave velocities around boreholes.

2. investigation of the use of sonic reflection from dry holes to map fractures which do not intersect the holes.

3. geostatistical analysis (kriging) of geologic and gas production data from West Virginia.

4. modeling of dynamic stimulation of wells by propellants (Tailored Pulse Loading/TPL).

The last 3 tasks are more specifically addressed to Eastern Shales; the first one has applications throughout gas bearing rock formations.

ACCOMPLISHMENTS

1. Sonic Stress Tool:

A laboratory version of the LLNL sonic stress probe designed for a 6-in. diameter hole was fabricated and tested. Twelve wedge transducers in 4 groups were embedded in a polyurethane expandable bladder/loading cell. Each group has one transmitter and two receivers, which now permit absolute velocity measurement. The polyurethane loading cell has a maximum capacity of 10,000 psi and can be used to measure the stress-velocity relationship in situ. The orientation of stresses can be estimated from a plot of velocity vs transducer orientation. Good signals were observed using the probe in a large block of Nugget sandstone. A new data acquisition system was developed. The digitized data are being analyzed using cross correlation techniques.

2. Sonic reflection fracture mapping:

The previous application of P-wave transducers was not successful. The latest effort concentrated on the use of shear waves. New transducers were designed and built in cooperation with Southwest Research Institute. They were designed to operate at 20 kHz, so that the wavelength, in hard rock, would be approximately the same as the transducer length. The transducers did indeed produce shear waves with a visible frequency of about 20 kHz. The transducers were also designed to minimize the length of the direct wave. We tested the transducers on granite slabs, attempting to observe reflections from a free surface. The direct wave was considerably shorter than that seen with the transducers used in the past. We used common-depth-point stacking to enhance reflected signals. We observed events at the times at which reflections would be expected. These results were obtained with very sharp reflectors. The concept remains to be proven by testing again at a field rock site, such as the quarry used in the P-wave study.

3. Kriging:

The statistical (kriging) analyses of geological and gas production data in southwestern West Virginia were completed and are being documented. The parameters studied include the elevations of the Greenbrier formation and Devonian shale as well as rock pressure and 10-year cumulative production data in the same area. Strong correlation between the surface and subsurface structures were observed. However the gas production data are much less cohesive. No strong correspondence between the kriged geological data and the kriged production data was observed. However the general trend between the two sets of maps do show some similarity.

4. Tailored-Pulse loading:

We have evolved a strategy to model arbitrary propagation of gas driven fractures in jointed rock. It involves coupling a gas dynamic algorithm (FAST) from S-Cubed with our own jointed rock fracture propagation simulator (FEFFLAP), developed under Western Gas Sands. This work is in progress.

ARTICLES AND PRESENTATIONS

Hearst, J.R. et al. "Remote Sensing of Rock Fractures by Shear Wave Reflections: A Progress Report", Lawrence Livermore National Laboratory, UCID-Draft, October 1985.

Mao, N. et al. "On the feasibility of Using Sonic Techniques to Estimate In Situ Stresses", Lawrence Livermore National Laboratory, UCRL-53424, June 1983.

Mao, N. et al. "Using a Sonic Technique to Estimate In-situ Stresses", Unconventional Gas Recovery Symposium, May. Also Lawrence Livermore National Laboratory, UCRL-90590, 1984.

Mao, N. "The LLNL Sonic In-situ Stress Probe: A Progress Report", Lawrence Livermore National Laboratory UCID-Draft, November 1985.

Mao, N. "Geostatistical (Kriging) Study of Geological and Gas Production Data from West Virginia", Lawrence Livermore National Laboratory, UCID-Draft, November 1985.

Swift, R.P. "A Perspective on Modeling Tailored-Pulse Loading (TPL) for Borehole Stimulation", Lawrence Livermore National Laboratory, UCID-20147, August 1984.

UNCONVENTIONAL GAS RECOVERY
CONTRACTORS MEETING

PROJECT SYNOPSIS

CONTRACT TITLE:	Installation of a Devonian Shale Reservoir Testing Facility and Acquisition of Reservoir Property Measurements
CONTRACT NUMBER:	DE-AC21-84MC21216
CONTRACTOR:	The BDM Corporation
ADDRESS:	7915 Jones Branch Drive
CITY, STATE, ZIP:	McLean, VA 22102
TELEPHONE:	(703) 821-5000
PROGRAM MANAGER:	Jeffrey B. Smith
PRINCIPAL INVESTIGATORS:	Dr. James N. Kirr C. David Locke
METC PROJECT MANAGER:	Albert B. Yost II
PERIOD OF PERFORMANCE:	September 30, 1984 - September 30, 1986

ABSTRACT

The contract research objective is to gather and analyze geologic and production data on the Rhinestreet-Marcellus interval within 10 DOE-specified target areas in the Appalachian, Michigan and Illinois basins. Data gathered from 9 individual "wells of opportunity" and 1 multiple well site (Offset Well Test Facility) will lead to a more comprehensive understanding of the overall producing mechanism for a greater portion of the Devonian shale resource base. Reservoir models will provide a more accurate methodology for predicting shale well production performance for each target area.

The Fossil Energy program goal is to develop potential domestic fossil fuel resources in order to ensure a secure energy supply and bridge the technology gap between present day conventional, non-renewable resources and renewable future resources. The Devonian shales represent a large gas resource that can be utilized in the heavily industrialized Eastern U.S. Full development of this resource will not occur until technology is available to explore for and produce conventional shale wells in those areas where the shale has not been traditionally exploited. Determination of the reservoir producing mechanism and development of a reservoir model(s) is a critical research objective that will provide industry with data necessary to expand shale development.

Project results to date are somewhat limited due to the overall industry downturn and limited drilling activity in many of the target areas. Four wells have been drilled, cored and logged. Two wells have been production tested. Two wells are currently undergoing production testing.

A reservoir model and draft final report on the first well of opportunity (Crawford County, PA) has been prepared.

Six additional wells of opportunity will be cored, logged, and tested over the next ten months. An offset well test facility will be established and well-to-well interference testing will be conducted to evaluate matrix versus fracture contribution to well productivity.

ACCOMPLISHMENTS

- Individual Site Work Plans prepared for 6 Cooperative wells.
- Four wells (Target Areas A, E, F, and J) have been cored, logged and tested (2) or undergoing testing (2).
- SUGAR-MD Simulations/History Matching performed on previous cooperative wells tested by Gruy Federal.
- Draft Final Report on WAINOCO Cooperative Well submitted (Target Area F).

ARTICLES AND PRESENTATIONS

- None published to date.
- Two papers in preparation for SPE Unconventional Gas Technology Symposium in Louisville, Kentucky, May 18-21, 1986.

(1) G.E. Eddy, J.N. Kirr, J.B. Smith; Geological Site Selection and Data Analysis on Three Devonian Shale Research Wells.

(2) C.D. Locke, M.A. Grabowski; Devonian Shale Well Tests, Techniques and Results of Field Tests.

SESSION 2.0

COALBED METHANE

UNCONVENTIONAL GAS RECOVERY

CONTRACTORS MEETING

PROJECT SYNOPSIS

Contract Title: "Technical and Commercial Feasibility of Utilizing Gas from Coalbeds and Devonian Shale for Purposes of Community and Rural Development".
Contract Number: DC-FG01-79RA 33101

Contractor: American Public Gas Association (APGA)
Address: 301 Maple Ave., West, Section 4, Suite G
City, State, Zip: Vienna, VA 22180
Telephone: (703) 281-2910

Program Manager (Contractor): Arie Verrips, APGA
John Gustavson, Gustavson Asso.
Principal Investigator(s): Richard Winar, Mike Hickey, Kim Lucks, Bruce Osmun, Todd Schulman, Daniel Murphy, Jackie Bath, Gene Topic
METC Project Manager: Charlie W. Byrer

Period of Performance: October 1979 -

ABSTRACT

Discussion will include information learned from the wells drilled to date under this project including 1) expected production characteristics, 2) geologic considerations, 3) completion techniques, and 4) minimum completion criteria.

Accomplishments to date

Gustavson Associates has drilled 15 unconventional gas recovery wells in: Alabama, Colorado, Indiana, New Mexico, New York, and Tennessee. Distribution between coal bed and shale test wells and their current status is shown by Table 1.

Status	Shale Wells	Coal Bed Wells	Overall Status
Producing (%)	3 (60%)	5 (50%)	8 (53%)
Plugged and abandoned	2	5	7
		TOTAL	15

These 15 wells have tested 8 potentially productive areas. The three coal degasification wells composing the Pleasant Grove, Alabama tests have been economically successful. The gas extracted from these wells is being utilized by a local public utility.

Drilling of a coal bed methane well in north-west Washington state is currently being investigated.

A final report of the knowledge gained from this demonstration project is currently being prepared to provide a site selection guide and procedure manual or "cookbook" for the drilling and completion of coal bed degasification and Devonian shale wells for use by the public and private sectors. This report is anticipated to consist of three volumes.

Volume 1 - A synopsis of these 15 wells.

Volume 11 - Application Guide for Small Utility; a brief guide to degasification technology and to evaluate the feasibility for your community's energy needs.

Volume 111 - How-To-Manual: Well Feasibility and Installations; a step-by-step guide to locating and installing your own coal bed degasification well.

Articles and Presentations

An update of the project was presented by Mr. John Gustavson to "The Coal bed Methane Forum" in Denver, Colorado March 1984.

UNCONVENTIONAL GAS RECOVERY

CONTRACTORS MEETING

PROJECT SYNOPSIS

Contract Title:	AN EVALUATION OF THE EFFECT OF METHANE ADSORPTION/ DESORPTION IN WELL TESTS ON COAL BEDS
Contract Number:	DE-AH21-85MC03193
Contractor:	University of Pittsburgh
Address:	Dept. of Chemical & Petroleum Engineering, 1249 BEH
City, State, Zip:	Pittsburgh, Pennsylvania 15261
Telephone:	(412) 624-5280
Program Manager (Contractor):	Alan A. Reznik, Ph.D.
Principal Investigator(s):	Alan A. Reznik, Ph.D. Gary A. Bayles
METC Project Manager:	Charles W. Byrer
Period of Performance:	May 1, 1985-October 1, 1985

ABSTRACT

The objective of the present work is to evaluate the effect of methane desorption or adsorption on the analysis of pressure drawdown and build up data, respectively, during well testing on coal beds.

This analysis involves modification of the radial diffusivity equation for flow is porous media. The addition of a desorption/adsorption term to the inverse hydraulic diffusivity term yields a non-linear partial differential equation which will be solved numerically and analytically for the constant terminal-rate case and the transient and semi-steady-state time periods. Mechanical, LIT, and permeability "skin factors" will be analyzed about the wellbone. The inclusion of the three independent skin factors requires at least five muti-rate pressure tests for rational analysis.

The overall objective of the analysis is to provide an analytical or semi-analytical method for determining the net permeability, area of drainage, reservoir shape, and deliverability of coalbed methane reservoirs. Such analysis provides a rapid method for assessment of coalbed methane as an energy resource.

Current analysis follows the gas phase only and omits all skin factors. Further, the analysis is limited to single-rate drawdown tests and omits any desorption transport (time) dependency. Future work will include Krg (Sw) data to account for the water phase; muti-rate testing including skin factors and build up tests. A transport term will be eventually incorporated into the analysis.

ACCOMPLISHMENTS

- The open-form of the radial diffusivity equation, modified to include a desorption term, has been solved numerically for the case of single-phase gas flow.

- The numerical solution is based on the pseudo gas pressure transformation and assumes instantaneous, Langmuir-type gas desorption which represents a worst-case scenario in terms of pressure interference.

- Numerical simulations of single-rate drawdown tests, without skin pressure drops, show that m(p) is still proportional to $\ln(t/r^2)$ for the transient time period.

- The above implies that an analytical solution for the transient time period may be obtained if the sum of the desorption and inverse hydraulic diffusivity terms are approximated by $\exp[c_1 m(p) + C_2]$.

- Numerical analysis of the relative effects of desorption and inverse hydraulic diffusivity show that the former becomes dominant for pressures less than (600-800) psia. At higher pressures, the effect of desorption becomes insignificant.

- Preliminary analysis beyond the infinite-acting period indicates that the semi-or pseudo- steady-state period may not develop. If this result persists, then the area of drainage and reservoir shape cannot be determined from the slope of the pressure- vs. -time plot and consequently a new correlation may have to be devised.

UNCONVENTIONAL GAS RECOVERY
CONTRACTORS MEETING

PROJECT SYNOPSIS

Contract Title:	The Measurement of Dynamic Reservoir Conditions
Contract Number:	DE-AC21-82MC 19404
Contractor:	U. S. Steel Corporation - Technical Center
Address:	One Tech Center Drive
City, State, Zip:	Monroeville, PA 15146
Telephone:	412-825-2122
Program Manager (Contractor):	C. M. Boyer II
Principal Investigator(s):	C. M. Boyer II
METC Project Manager:	C. W. Byrer
Period of Performance:	9-23-82 to 12-31-85

ABSTRACT

U. S. Steel Corporation, the U. S. Department of Energy, and the Gas Research Institute jointly installed and tested a single-zone coalbed methane well in the Warrior Coal Basin of Alabama. The well was installed into the Mary Lee Coal Group at U. S. Steel's Oak Gorve Mine near Birmingham, Alabama. Static reservoir tests were performed to determine the reservoir properties of the target coal seam and the surrounding rock formations. Dynamic reservoir tests prior to hydraulic stimulation were also performed to further delineate the reservoir conditions. These tests results were incorporated in the design and implementation of a large-scale gelled water stimulation of the target coal seam. Additional dynamic reservoir tests were performed following the stimulation to determine the effectiveness of treatment. Following completion of the stimulated production testing, the coal was mined-out in the wellbore area and direct observation and evaluation of the induced hydraulic fracture was made.

ACCOMPLISHMENTS

- Blue Creek coal seam permeability (water) measured.
- Mechanical and reservoir properties of the Blue Creek coal seam and surrounding rock strata measured from core samples.
- In-situ state-of-stress measurements performed on Blue Creek coal seam.
- Hydraulic stimulation designed on the basis of measured reservoir properties and implemented successfully.

ARTICLES AND PRESENTATIONS

Boyer, C. M. and Stubbs, P. B., "Measurement of Dynamic Reservoir Conditions Required to Design Near-Mine Methane Control Activities In The Warrior Coal Basin," DOE/ET/14204-1477 (DE84000226).

UNCONVENTIONAL GAS RECOVERY
CONTRACTORS MEETING

PROJECT SYNOPSIS

IN-HOUSE RESEARCH TITLE: Coalbed Methane Stimulation Analysis

METC PROJECT MANAGER: Gary L. Covatch

PRINCIPAL INVESTIGATOR: Abbie W. Layne

ABSTRACT

The objective of METC's in-house coalbed methane stimulation research is to improve coal seam hydraulic fracturing techniques by improving the understanding of stimulation treatments. The analysis includes examining data from a mine excavation to observe stimulation results, conducting Nolte Analyses (concept to measure how induced crack propagated), and exercising METC's stimulation modeling codes. U.S. Steel Test Wells DHM-6 and DHM-7, two research degasification wells located in the Oak Grove Field, Alabama, were analyzed in this project. METC's hydraulic fracture models predicted DHM-6 coal seam winglengths accurately (3 to 5 percent greater than the excavated winglength). This modeling was based on guidelines derived from Nolte's method which suggested vertical propagation into the bounding strata and the observation of fluid penetration into the shale roof rock. Results to date indicate that Nolte's method may provide adequate interpretation of coalbed fracture behavior when the effects of variable injection rates, natural fracture fluid interaction, and coal seam/bounding formation interface effects are considered in the procedure. A future mine excavation to expose the coal seam roof rock and assess the extent of vertical fracture propagation in DHM-7 will help to validate the model further. These efforts would provide information to improve guidelines for productive coal seam stimulation through hydraulic fracture model evaluation of vertical propagation and further assessment of Nolte's method.

ACCOMPLISHMENTS

- Results to date indicate that Nolte's method provides adequate interpretation of coal seam stimulation results.
- METC hydraulic fracture models predict coalbed fracture winglengths which compare favorably to those observed from mine excavation when vertical propagation is depicted.
- Test Well DHM-6 was analyzed with a hydraulic fracture model which predicts pressurized fluid behavior in jointed rock.

ARTICLES AND PRESENTATION

Layne, A. W., 1985. Test Well USS DHM-7 Pre-Mineback Hydraulic Fracture Geometry Predictions. Currently in Press.

UNCONVENTIONAL GAS RECOVERY
CONTRACTORS MEETING

PROJECT SYNOPSIS

IN-HOUSE RESEARCH TITLE: Coalbed Methane Geostatistical Analysis Project

METC PROJECT MANAGER: James C. Mercer

PRINCIPAL INVESTIGATORS: James C. Mercer

ABSTRACT

The purpose of the coalbed methane geostatistical study was to identify correlations between geologic parameters and gas production for wells completed in the Oak Grove (U.S. Steel) field in Alabama. The approach was to first categorize the wells on the basis of production and then construct a classification criteria for predicting gas well performance. Results indicated that most of the variation (90 percent) in the gas production of the wells was explained by total production and by the "shape" of their production versus time profiles. Four variables contributed to the joint classification of wells. About 90 percent of the wells in the degasification grid were correctly classified utilizing the classification scheme. Results indicated that poor overall producing wells whose last 2 years were more productive than their first 2 years (poor-late producing wells) had thicker coal seams, were near more lineament intersections, were close to shorter lineaments, and were at higher elevations than high-early producing wells. This suggests that the methodology could be used to rank potential well drilling prospects in advance of drilling.

ACCOMPLISHMENTS

Results of a principal components analysis indicated that wells could be grouped into four categories based upon their overall production and by the "shape" of their production profiles. A total of four variables were identified as contributing to the classification of these four groups. The variables were well elevation (a proxy variable for other geologic variables), number of lineament intersections within 250 feet, thickness of the Blue Creek coal seam, and the length of the nearest lineament. About 90 percent of the wells inside the degasification grid were correctly classified into the four groups. Several relationships were also found that may justify further investigation. For example, it may be possible to characterize a well based upon its production profile rather than a simple one-number summary such as 4-year cumulative production.

ARTICLES AND PRESENTATIONS

Caceres, F., S. Pratt, E. Robey, and R. Wojewodka, 1985. Coalbed Methane Geostatistical Analysis Project, Final Report. Internal Report to DOE/METC.

SESSION 3.0

WESTERN GAS SANDS

UNCONVENTIONAL GAS RECOVERY
CONTRACTORS MEETING

PROJECT SYNOPSIS

CONTRACT TITLE:	Western Gas Sands Geologic Characterization (Greater Green River Basin)
CONTRACT NUMBER:	DE-AI21-83MC20422
CONTRACTOR:	U.S. Geological Survey
ADDRESS:	P.O. Box 25046, MS-971
CITY, STATE, ZIP:	Denver, Colorado 80225
TELEPHONE:	(303) 236-5779; FTS 776-5779)
PROGRAM MANAGER (CONTRACTOR):	B. E. Law
PRINCIPAL INVESTIGATORS:	B. E. Law M. R. Lickus C. W. Spencer W. W. Dickinson
METC PROJECT MANAGER:	Karl-Heinz Frohne
PERIOD OF PERFORMANCE:	October 1, 1984 - October 1, 1985

ABSTRACT

The objective of USGS research in the Greater Green River Basin is to geologically characterize tight gas-bearing reservoirs. During the reporting period, the USGS has confirmed earlier observations that gas-bearing reservoirs are abnormally pressured and occur as basin-centered accumulations, independent of structure and stratigraphy. The vertical and lateral distribution of these reservoirs is facilitated by detailed analyses of the burial and thermal history. Consequently, research has focused on the temporal variations of temperature, pressure, and organic maturation. Other ongoing activities include stratigraphy, structure, application of gamma-ray well log responses to stratigraphy and structure, gas resource evaluation and methodology in the Pinedale anticline area, and initiation of regional permeability variations.

Future research activities include continuing efforts to resolve some stratigraphic correlation problems, refinement of thermal maturity mapping, and regional variations of permeability in selected reservoirs.

ACCOMPLISHMENTS

- Four thermal maturity maps that include 1) a surface thermal maturity map, 2) a map showing the drilling depth to 0.6% vitrinite reflectance, 3) a map showing the drilling depth to 1.3% vitrinite reflectance and, 4) a map

showing the subsurface elevation of 0.8% vitrinite reflectance. These maps are used to identify the depths at which oil and gas should occur.

- A multidisciplinary geological analysis of tight gas reservoirs in the Pinedale anticline, northern Green River Basin was published. The report includes discussions of stratigraphy, structure, source-rock, reservoir petrography, clay mineralogy, thermal maturity, reservoir pressures, apatite fission-track dating, fluid inclusions, application of gamma-ray responses to stratigraphy, and isotopic composition of fractured-filled cements.

- C. W. Spencer has extended the concepts of abnormally overpressured tight gas reservoirs, previously identified in the Greater Green River Basin, into the Piceance and other Rocky Mountain basins.

- A published report by B. E. Law and W. W. Dickinson on the origin of abnormally pressured gas reservoirs concludes that overpressured and underpressured low-permeability reservoirs have a common origin and are highly dependent on the burial and thermal history.

- E. A. Merewether completed and published a paper concerning the stratigraphic correlations and facies of lower Upper Cretaceous tight gas reservoirs.

- The finite element analysis of the gas resources contained in the Pinedale anticline is near completion.

SELECTED ARTICLES AND PRESENTATIONS

Since the inception of the program in the Greater Green River Basin, 78 papers, maps, and abstracts have been published. A complete listing of USGS publications in the Greater Green River Basin is provided in USGS Open-File Report 85-548 by C. W. Spencer and M. P. Krupa.

Law, B. E., Relationships of source rock, thermal maturity, and overpressuring to gas generation and occurrence in low-permeability Upper Cretaceous and lower Tertiary rocks, Greater Green River Basin, Wyoming, Colorado, and Utah, in Woodward, Jane, Meissner, F. F., and Clayton, J. L., eds., Hydrocarbon source rocks of the greater Rocky Mountain region: Rocky Mountain Association of Geologists, p. 469-490, 1984.

Law, B. E., Geological characteristics of low-permeability Upper Cretaceous and lower Tertiary rocks in the Pinedale anticline area, Sublette County, Wyoming: U.S. Geological Survey Open-File Report 84-753, 107 p., 1984.

Law, B. E., Spencer, C. W., and Bostick, N. H., Evaluation of organic matter, subsurface temperature, and pressure with regard to gas generation in low-permeability Upper Cretaceous and lower Tertiary sandstones in Pacific Creek area, Sublette and Sweetwater Counties, Wyoming: The Mountain Geologist, v. 17, no. 2, p. 23-35, 1980.

UNCONVENTIONAL GAS RECOVERY
CONTRACTORS MEETING

CONTRACT TITLE:	Western Gas Sands Geologic Characterization (Piceance-Uinta Basins)
CONTRACT NUMBER:	DE-AI21-83MC20422
ADDRESS:	U.S. Geological Survey P.O. Box 25046, MS 971
CITY, STATE, ZIP:	Denver, CO 80225
TELEPHONE:	(303) 236-5779; FTS 776-5779
PROGRAM MANAGER (CONTRACTOR):	B. E. Law
PRINCIPAL INVESTIGATORS:	C. W. Spencer, V. F. Nuccio, R. C. Johnson, J. K. Pitman
METC PROJECT MANAGER:	Karl-Heinz Frohne
PERIOD OF PERFORMANCE:	October 1, 1984 - October 1, 1985

ABSTRACT

The objectives of the USGS research in the Piceance and Uinta Basins are to geologically characterize the reservoirs, define the distribution of gas generation and gas accumulations, and provide geologic support for the MWX engineering research. Surface fracture studies of the Piceance Basin and vertical seismic profile work were completed. This work was done in direct cooperation with Sandia NL and has now been terminated.

During the period of performance the work concentrated on (1) a series of papers that summerized the MWX geologic research, (2) compiling data on gas generation (thermal maturity) in the Uinta Basin and (3) preparation of a report summarizing the geology of tight reservoirs in the Piceance Basin. At DOE request, the work in the Uinta Basin was temporarily suspended.

ACCOMPLISHMENTS

- A summary of MWX petrography was published by J. K. Pitman and C. W. Spencer. The reservoirs are impure sandstones containing a high content of rock fragments, feldspar, and clay and very susceptible to formation damage.

- R. M. Pollastro studied whole-rock mineralogy, and clay mineral separates from 22 MWX sandstone and shale cores. On the basis of X-ray analysis the clay (and mica) content of the sandstone samples ranged from 18 to 34 percent.

- A burial history and gas generation (thermal maturation) analysis of the Mesaverde Group was published by V. F. Nuccio and R. C. Johnson. This work demonstrates the basin was hotter in the south than in the north and, therefore, gas can occur higher in the geologic section in the southern part of the basin.

- An analysis of overpressuring was made at the MWX site by C. W. Spencer. The pressure is believed to be caused by gas generation and present data indicate the top of abnormal pressure starts at about 5600 ft continues to

total depth. In the Paludal Zone and deeper the pore pressure is nearly as high as the sandstone fracture gradients. The pore pressure is believed to be limited by the natural fracture gradient of the rocks and the gas pressure probably causes some natural fracturing.

SELECTED ARTICLES AND PRESENTATIONS

Since the inception of the USGS/DOE cooperation, 22 papers have been published on Uinta Basin and 40 papers have been published on the Piceance-MWX research. A few selected papers are listed below. For a more complete list see USGS Open-File Report 85-548.

Granica, M. P., and Johnson, R. C., Structure contour and isochore map of the nonmarine part of the Mesaverde Formation/Group Piceance Creek Basin, Colorado: U.S. Geological Survey Miscellaneous Field Investigations Map MF-1189, 1 sheet, scale 1:250,000, 10 page pamphlet (1980).

Johnson, R. C., Structure contour map of the top of the Rollins and Trout Creek sandstones, Piceance Creek Basin, Colorado: U.S. Geological Survey Miscellaneous Field Investigations Map MF-1667, scale 1:253,400 (1983).

Johnson, R. C., and Keighin, C. W., Cretaceous and Tertiary history and resources of the Piceance Creek Basin, western Colorado: New Mexico Geological Society Guidebook, 32nd Field Conference, Western Slope Colorado, p. 199-210 (1981).

Keighin, C. W., and Sampath, Krishnaswamy, Evaluation of pore geometry of some low-permeability sandstones, Uinta Basin, Utah: Journal of Petroleum Technology, v. 34, no. 1, p. 65-70 (1982).

Nuccio, V. F., and Johnson, R. C., Map showing drill-stem test and perforation recoveries of the Upper Cretaceous Mesaverde Group, Piceance Creek Basin, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-1359, 1 sheet, scale 1:250,000 (1981).

Nuccio, V. F., and Johnson, R. C., Preliminary thermal maturity map of the Cameo-Fairfield or equivalent coal zone through the Piceance Creek Basin, Colorado: U.S. Geological Survey Miscellaneous Field Study Map MF-1575, 2 sheets (1983).

Lee, M. W., Vertical seismic profiles at the Multiwell Experiment site, Garfield County, Colorado: U.S. Geological Survey Open-File Report 84-168, 57 p. (1984).

Spencer, C. W., and Keighin, C. W., eds., Geologic studies in support of the U.S. Department of Energy Multiwell Experiment, Garfield County, Colorado: U.S. Geological Survey Open-File Report 84-757, 134 p., 1 plate (1984).

Verbeek, E. R., and Grout, M. A., Fracture studies in Cretaceous and Paleocene strata in and around the Piceance Basin, Colorado--Preliminary results and their bearing on a fracture-controlled natural gas reservoir at the MWX site: U.S. Geological Survey Open-File report 84-156, 30 p. (1984).

UNCONVENTIONAL GAS RECOVERY
CONTRACTORS MEETING

PROJECT SYNOPSIS

CONTRACT TITLE:	Multiwell Experiment Site Geology
CONTRACT NUMBER:	DE-AC04-76DP00789
CONTRACTOR:	Sandia National Laboratories
ADDRESS:	Division 6253, P. O. Box 5800
CITY, STATE, ZIP:	Albuquerque, New Mexico 87185
TELEPHONE:	(505) 844-2302
PROGRAM MANAGER:	David A. Northrop
PRINCIPAL INVESTIGATOR:	John C. Lorenz
METC PROJECT MANAGER:	K-H. Frohne
PERIOD OF PERFORMANCE:	October 1, 1984 - September 30, 1985

ABSTRACT

The objective of the MWX Site Geology study is the characterization of the lenticular, low-permeability, natural gas reservoirs of the Mesaverde formation. This characterization includes the size (thickness, width, length), shape, and orientation of the gross sandstone body, as well as the internal features that may control permeability (lithologic discontinuities and fractures).

There are two major activities.

- A comprehensive study of the Mesaverde in outcrops (located only 10-12 miles from the well site) was undertaken. During this study, the local Mesaverde was first subdivided into three categories of different depositional environments, each with its own typical reservoir size and shape (shoreline/shallow marine blanket sandstones, delta plain lenticular sandstones, and fluvial meander-belt sandstones). Detailed mapping of outcrops of representative sandstones in each category provided data on reservoir shapes and sizes, as well as their internal characteristics (fractures and permeability discontinuities).

- Concurrent with outcrop studies, the core from the three MWX wells was slabbed and studied in detail, in order to make outcrop to subsurface extrapolations of reservoir sizes, shapes, orientations, and internal permeabilities. Details of the core study included sedimentary structures and fracture characteristics. These studies currently provide the only estimates of reservoir sizes and orientations in specific intervals of MWX tests and stimulation experiments.

ACCOMPLISHMENTS

Results from these studies have suggested a high degree of heterogeneity both within and among the reservoirs. Widths and orientations of specific reservoirs penetrated at MWX, as well as for each depositional environment in general, have been estimated. A new model of fracture networks within such reservoirs is being proposed, one that is highly anisotropic and poorly interconnected, both vertically and horizontally. Permeability within the reservoirs is dominantly along fractures, the extents of which are controlled by frequent lithologic discontinuities within the reservoir.

ARTICLES AND PRESENTATIONS

1. J. C. Lorenz, "Sedimentology of the Mesaverde Formation at Rifle Gap, Colorado, and Its Implications for Gas-bearing Intervals in the Subsurface," Sandia National Laboratories Report, SAND82-0604, March 1982.

2. J. C. Lorenz, "Lateral Variability in the Corcoran and Cozzette Blanket Sandstones and Associated Mesaverde Rocks, Piceance Creek Basin, Northwestern Colorado," SPE/DOE 11608, Proceedings of the 1983 SPE/DOE Symposium on Low Permeability Gas Reservoirs, Denver, Colorado, May, 1983.

3. J. C. Lorenz, "Reservoir Sedimentology in the Mesaverde Rocks at the Multi-Well Experiment Site," Sandia National Laboratories Report, SAND83-1078, June, 1983.

4. L. W. Teufel, N. R. Warpinski, and J. C. Lorenz, "A model for fracture genesis--application to Mesaverde Group, Piceance Creek basin, Colorado" [abstract], American Ass'n Petroleum Geol., Bull., 68, p. 534, April, 1984.

5. J. C. Lorenz and A. K. Rutledge, "Facies Relationships and Reservoir Potential of the Ohio Creek Interval across the Piceance Creek Basin, Northwestern Colorado," Sandia National Laboratories Report, SAND84-2610, February, 1985 (condensed version published in Oil and Gas Journal, 83, January 21, 1985, p. 91-96.)

6. J. C. Lorenz, "Tectonic and Stress Histories of the Piceance Creek Basin and the MWX site, from 75 Million Years Ago to the Present," Sandia National Laboratories Report, SAND84-2603, March, 1985.

7. J. C. Lorenz, "Predictions of Size and Orientations of Lenticular Reservoir in the Mesaverde Group, Northwestern Colorado," SPE/DOE 13851, Proceedings of the 1985 SPE/DOE Symposium on Low-Permeability Gas Reservoirs, Denver, Colorado, May, 1985.

8. J. C. Lorenz, D. M. Heinze, J. A. Clark, and C. A. Searls, "Determination of widths of meander-belt sandstone reservoirs from vertical downhole data, Mesaverde Group, Piceance Creek basin, Colorado," American Ass'n Petrol. Geol., Bull., v. 69, p. 710-721, May 1985. (Also in AAPG Bull. [abstract], 67, p. 505-506, March, 1983.)

UNCONVENTIONAL GAS RECOVERY
CONTRACTORS MEETING

PROJECT SYNOPSIS

CONTRACT TITLE:	Rock Matrix and Fracture Analysis of Flow in Western Tight Gas Sands
CONTRACT NUMBER:	DE-AC21-84MC21179
CONTRACTOR:	New Mexico Institute of Mining and Technology
ADDRESS:	New Mexico Petroleum Recovery Research Center
CITY,STATE,ZIP:	Socorro, NM 87801
TELEPHONE:	(505) 835-5403
PROGRAM MANAGER (CONTRACTOR):	Joseph J. Taber
PRINCIPAL INVESTIGATOR:	Norman R. Morrow
METC PROJECT MANAGER:	Karl-Heinz Frohne
PERIOD OF PERFORMANCE:	June 1984 - June 1985

ABSTRACT

The objective of this project is to develop reliable core analysis techniques for tight gas sands properties that are essential to proper formation evaluation. The study is mainly concerned with the dependence of flow in tight gas sands on water saturation and confining pressure. This dependency is to be related to the detailed pore structure of tight sands as typified by cores recovered in the Multi-Well Experiment.

WORK PERFORMED

- Advanced Core Analysis

Screening tests of pressure sensitivity for all Multi-Well cores on hand are complete. The tests involved measurement of Klinkenberg permeabilities at overburden pressures of 500 psi and 5000 psi for first unloading. Reduction in permeability with overburden pressure expressed as $K_{\infty,500}/K_{\infty,5000}$ ranged from as low as 1.5 to as high as 45. Cores representing a wide range of sensitivity are now being studied in detail.

- Flow Properties of Natural Fractures

We continue to measure relationships between permeability and confining pressure for core samples containing calcite-filled fractures and for neighboring matrix material from a given whole core sample. Results to date show that calcite-filled fractures act neither as severe permeability barriers for flow across the cement nor as highly conductive paths along the fractures.

In order to determine whether the matrix or the fracture carried the bulk of the gas flow a technique for detecting relative differences in gas flow over a core cross-section was developed. This involved injecting a small

amount of hydrogen sulfide in the inlet gas stream and detecting its distribution at the outflow face by means of moist filter paper which had been soaked in AgCl solution.

- Heterogeneity of Flow in Tight Sand Matrix

More detailed understanding of gas flow in tight sands is being gained through study of heterogeneity in flow within the rock matrix. Thermal conductivity, bubble evolution, soap films and the chemical detection methods have been used to detect flow heterogeneities. A core holder has been designed for investigating the distribution of flow heterogeneities and the effects of overburden on flow rates at sites of high gas flow. In general sites of high gas flow are less pressure sensitive than the matrix as a whole.

- Porosity

We have observed that porosities from thin sections are generally lower than those determined by other measurements of pore volume. A comparative study of commercially prepared slides showed that incomplete impregnation of resin is the most likely cause of low porosity measurements. Porosity originating from dissolution of unstable grains accounts for most of the pore-space volume in tight sands. Casts of solution pores have been prepared by injection of styrene followed by polymerization and acid leaching. Electron micrographs reveal, in detail, the variety of structure of these solution pores.

- Capillary Pressures by High-Speed Centrifuge

High-speed centrifuge measurements have been used to determine capillary pressure versus saturation relationships for selected core samples from the coastal, paludal, paralic and fluvial zones of MWX1, MWX2, and MWX3. Application of the Hassler-Brunner model to interpretation of the raw centrifuge data for tight sands has been investigated in detail. Desorption iostherms for water provided extension of capillary pressure curves to extremely high pressures.

ACCOMPLISHMENTS

- 35 Multi-Well cores have been characterized by sensitivity of permeability to overburden pressure.
- Measurements on 10 Multi-Well cores containing mineralized fractures are 50% complete.
- Effects of overburden pressure and water saturation on gas permeability have been determined together with estimates of relative permeability to water.
- Capillary pressures by high-speed centrifuge have been extended to very high pressures through measurement of desorption isotherms for water.
- Surface area measurements by N_2 adsorption have been completed for over 50 Multi-Well samples.

- Detailed structure of individual solution pores has been revealed through electron micrographs of pore casts.

- Techniques for investigating flow heterogeneities in the rock matrix have been developed.

FUTURE WORK

- Advanced core analysis. Cores representing a wide range of pressure sensitivity will be used in a detailed study of the effects of water saturation and overburden pressure. Fractured core flow properties will be compared with those for neighboring matrix material.

- Heterogeneity of gas flow in the rock matrix will be investigated by new techniques.

- Pore structure will be investigated by microscopy and through capillary pressure, adsorption isotherm and surface area measurements.

PUBLICATIONS AND PRESENTATIONS

1. Brower, K.R. and Morrow, N.R., "Fluid Flow in Cracks as Related to Low Permeability Gas Sands," Soc. Pet. Eng. J., (April 1985) 191-201.

2. Wei, K., Morrow, N.R., and Brower, K.R., "Effect of Fluid, Confining Pressure, and Temperature on Absolute Permeabilities of Low Permeability Sandstones," SPE 13093 presented at 59th Annual Technical Conference and Exhibition, Houston, TX, Sept. 16-19, 1984; Soc. Pet. Eng. J., In Press.

3. Ward, J.S. and Morrow, N.R., "Multiwell Special Core Analysis," PRRC Report to Sandia Laboratories, Petroleum Recovery Research Center (October 1984).

4. Morrow, N.R., Brower, K.R., and Kilmer, N.H., "Relationship of Pore Structure to Fluid Behavior in Low Permeability Gas Sands," Third Annual Western Gas Sands Program Review DOE/METC/85-7, Department of Energy (November 1984) 85-109.

5. Ward, J.S. and Morrow, N.R., "Capillary Pressures and Gas Relative Permeabilities of Low Permeability Sandstone," SPE 13882 presented at the 1985 SPE/DOE Symposium on Low Permeability Reservoirs, Denver, CO, May 19-22, 1985.

UNCONVENTIONAL GAS RECOVERY
CONTRACTORS' MEETING

Project Synopsis

CONTRACT TITLE:	Laboratory Research of Fracturing Materials for the DOE/MWX
CONTRACT NUMBER:	DE-FC01-83FE60149
CONTRACTOR:	NIPER
ADDRESS:	P. O. Box 2128 Bartlesville, OK 74006
TELEPHONE:	(918) 336-2400
PROGRAM MANAGER:	Ian D. Palmer
PRINCIPAL INVESTIGATORS:	Clarence Raible Bonnie Gall Dan Maloney
METC PROJECT MANAGER:	Karl H. Frohne
PERIOD OF PERFORMANCE:	October 1, 1984 - October 1, 1985

ABSTRACT

Laboratory studies were made by researchers at NIPER to investigate core properties and fracturing materials that could limit production from the DOE Multiwell Experiment (MWX) hydraulic fracture treatments. These studies included the effects of fracturing fluids on fluid leakoff and formation damage with reservoir cores, polymer degradation of gelled fluids, proppant pack conductivity, and proppant embedment into reservoir rocks.

The most serious problem resulting from gelled fluid damage to tight sands was high fluid saturation of the invaded reservoir matrix. Excessive time periods were required to recover fluids from lower permeability formations. Limited tests with cracked cores to simulate small natural fractures indicated reduction of flow capacity caused by gelled polymer residues and crack "healing" after brine saturation.

Polymer degradation studies indicated no commercially available gelled fluid was completely satisfactory for both maintaining viscosity during the pumping schedule and then in degrading the polymer for efficient fluid recovery and low proppant pack damage. Breakers prematurely degraded polymer gels, whereas gel stabilizers reduced breaker effectiveness. In addition, the biopolymer used in the MWX foam fracture had an extremely high average molecular weight and resisted degradation.

Proppant embedment tests indicated no significant embedment with coastal reservoir or interbedding rock. Proflow proppant crush tests exceeded anticipated closure stress requirements for the coastal zone stimulations.

Accomplishments

- Tests were made showing significant capillary end effects that slow fluid cleanup. Long time periods were required to clean up lower permeability coastal zone rocks after exposure to fracturing fluids.

- Limited tests, with small artificial fractures, indicated appreciable reduction in flow capacity caused by gelled fluids. Brines also promoted fracture healing.

- Partially degraded polymers and residues could cause serious damage to proppant packs, reducing fluid flow and restricting proppant pack conductivity. Tests were developed using size exclusion chromatography and specific pore size filters to correlate fluid flow restriction and polymer degradation.

- Polymers used in foam frac fluids are large in size and resist degradation (thermal and breaker resistant). This could cause natural fracture and proppant pack damage.

- Repeated applications of proppant crushing stress revealed little additional increase in proppant crushing after the initial crush test. This would indicate no significant decrease in fracture conductivity during repeated drawdown experiments.

Articles and Presentations

Raible, C. J. and B. L. Gall: "Laboratory Formation Damage Studies of Western Tight Sands," SPE/DOE paper 13903 presented at the 1985 SPE/DOE Symposium on Low Permeability Reservoirs, Denver, May 19-22.

Sattler, A. R., C. J. Raible and B. L. Gall: "Integration of Laboratory and Field Data for Insight on the Multiwell Experiment," SPE/DOE paper 13891 presented at the 1985 SPE/DOE Symposium on Low Permeability Reservoirs, Denver, May 19-22.

Gall, B. L. and C. J. Raible: "Molecular Size Studies of Degraded Fracturing Fluid Polymers," SPE paper 13566 presented at the 1985 SPE International Symposium on Oilfield and Geothermal Chemistry, Phoenix, April 9-11.

Volk, L. J., B. L. Gall, C. J. Raible and H. B. Carroll: "A Method for Evaluation of Formation Damage Due to Fracturing Fluids," SPE/DOE paper 11638 presented at the 1983 SPE/DOE Symposium on Low Permeability Reservoirs, Denver, March 14-16.

UNCONVENTIONAL GAS RECOVERY
CONTRACTORS MEETING
PROJECT SYNOPSIS

Contract Title: Unconventional Gas/Western Gas Sands

Contract Number: W-7405-ENG-48

Contractor: Lawrence Livermore National Laboratory (LLNL)
Address: P. O. Box 808
City, State, Zip: Livermore, CA 94550
Telephone: (415) 423-0363 or FTS 543-0363

Program Manager (Contractor): Francois E. Heuze, Code L-200
Principal Investigators: F. E. Heuze, W. Lin, R. J. Shaffer, R. B. Stout

METC Project Managers: C. Komar and K. Frohne

Period of Performance: FY 1985, continuing in FY 1986.

ABSTRACT

Objective: To contribute to improvements in gas recovery from tight reservoirs by describing the mechanics of stimulation in fractured rocks.

Background and Approach: The Western Gas Sands (WGS) subprogram at LLNL is part of the Unconventional Gas Program (UGP). The UGP also includes activities in Eastern Devonian Shales (EDS) and Coal Beds in FY 1986.

LLNL's approach is to

- develop and validate computer models of the interaction between induced fractures and natural fractures.
- develop fully 3-D models of hydrofracture in layered media
- improve the quality and determine the relevance of selected material properties input to the models (another task, under EDS, is concerned with improving the measurement of stresses which are also required input for the models).

LLNL's work and that of CER, DOE, Sandia, Universities, etc.., complement each other.

Program Tasks: According to the objective and the approach, the WGS tasks are:

- 2-D models of arbitrary propagation of fluid driven fractures in jointed rock.
- 3-D hydrofrac simulator for layered media.
- mechanical and physical properties of WGS reservoir rocks: relations between field and laboratory-measured properties.

ACCOMPLISHMENTS

- Version 1.0 of the FEFFLAP (Finite Eelement Fracture and Flow Analysis Program) computer code was completed and delivered with User's and Theory Manuals to the DOE. FEFFLAP is a 2-D state-of-the-art program which permits the explicit analysis of the interaction between induced fluid-driven fractures, and natural discontinuities such as joints, shears, faults, bedding, planes, contacts, etc. The code is now being applied to a study of fracturing near a sandstone lens, and to a coal bed stimulation example.

- Version 1.0 of the 3-D hydrofrac simulator PDCRAC (Pressure Driven Crack Propagation) computer code was completed and documented. PDCRAC was successfully applied to represent the results obtained by Sandia during a Multiwell No. 1 stimulation (Paludal Zone, Minifrac 2).

- The analysis of three series of mechanical and sonic tests on Mesaverde shales and sandstones were completed and documented: field dynamic, laboratory static, and laboratory dynamic. This study highlighted the large discrepancies for the elastic moduli of the same rocks, obtained by different methods. It documented the need for pursuing the definition of which test results are relevant for input into hydrofracture design calculations.

ARTICLES AND PRESENTATIONS

Because of space limitations only FY 1985 publications are listed:

Heuze, F.E., et al., "The Western Gas Sands Subprogram at Lawrence Livermore National Laboratory," LLNL, UCRL-89890-84, December, 1984.

Heuze, F.E., "Unconventional Gas Program - Director's Review of Energy and Resource Programs", Lawrence Livermore National Laboratory, UCIR-1562, January, 1985.

Heuze, F.E., Shaffer, R.J., and Ingraffea, A.R., "A Coupled Model for Fluid-Driven Fractures", Proc. Int. Symp. on Coupled Processes, Berkeley, CA, Sept. (Lawrence Berkeley Laboratory, Earth Sciences Dept.), 1985.

Ingraffea, A.E., Shaffer, R.J., and Heuze, F.E., "FEFFLAP: A Finite Element Program for Analysis of Fluid-Driven Fracture Propagation in Jointed Rock. Vol. 1: Theory and Programmer's Manual", Lawrence Livermore National Laboratory, UCID-20368, March 1985.

Lin, W., "Ultrasonic Velocities and Dynamic Elastic Moduli of Mesaverde Rocks", Lawrence Livermore National Laboratory, UCID-20273 Rev. 1, March 1985.

Lin, W. "Strength and Static Elastic Moduli of Mesaverde Rocks", Lawrence Livermore National Laboratory, UCID-20370, March 1985.

Lin, W. "In-Situ Dynamic Elastic Moduli of Mesaverde Rocks, and a Comparison with Static and Dynamic Laboratory Moduli", LLNL, UCID-Draft, October 1985.

Shaffer, R.J., Ingraffea, A.R., and Heuze, F.E., "FEFFLAP: A Finite Element Program for Analysis of Fluid-Driven Fracture Propagation in Jointed Rock, Vol. 2: User's and Verification Manual", Lawrence Livermore National Laboratory, UCID-20369, March 1985.

Shaffer, R.J., Ingraffea, A.R., and Heuze, F.E., "An Improved Model for Fluid-Driven Cracks in Jointed Rocks", Proc. 26th U.S. Symp. on Rock Mechanics, Rapid City, SD (AIME/SME, Littleton, CO).

Stout, R.B., "PDCRAC: A Three-Dimensional Hydrofracture Program - User's Manual", Lawrence Livermore National Laboratory, UCID-20485, July 1985.

SESSION 4.0

WESTERN GAS SANDS

UNCONVENTIONAL GAS RECOVERY
CONTRACTORS MEETING

PROJECT SYNOPSIS

Contract Title: Stimulation Model for Lenticular Sands

Contract Number: DE-AC21-84MC21119

Contractor: Edmund F. Rybicki
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City, State, Zip: Tulsa, OK 74104
Telephone: (918) 592-6000, Ext. 2521

Program Manager: Edmund F. Rybicki

Principal Investigator(s): Edmund F. Rybicki (TU) John R. Sutrick (TU)
Ian Palmer (NIPER) C. T. Luiskutty (ORU)

METC Project Manager: Karl-Heinz Frohne

Period of Performance: June 1, 1984 - June 1, 1985

ABSTRACT

The objective of this project is two-fold. One objective is to develop a computational model to represent hydraulic fracturing and proppant transport for lenticular sands in tight western gas sands formations. The other objective is to apply this model to the multi-well experimental fracture stimulations. The approach to meeting the first objective, the development of the computational model for hydraulic fracturing and proppant transport, is to develop the capabilities of two existing models and combine these models into a single representative model. One computational model is the fracture geometry model developed at Oral Roberts University (ORU) and National Institute for Petroleum Energy Research (NIPER). The other model is a proppant transport model developed at The University of Tulsa (TU). The plan for combining these models is to utilize the NIPER/ORU model for fracture length, width and height calculations and the TU model for proppant pumping, transport and final distribution. The program is a three year project, each year corresponding to one phase of the effort. The following describes the development of the fracture model and the proppant transport model and the progress toward combining these two models.

Research Results

The existing model for highly elongated symmetric fractures has been revised to include a sudden change in the viscosity of the fracturing fluid. The position of the front separating the two fluids has been determined by iteration. Efforts are also underway for incorporating a change in the flow rate.

Another task completed under this project was the interpretation of the Multi-well Experiment (MWX) Minifrac #2 stimulation in the Paludal Zone, using the asymmetric model. The large discrepancy between the measured and predicted well-bore pressures can be resolved with the hypothese that the fracture toughness parameter, K_c, increases by over an order of magnitude as the fracture grows [1]. Using this hypothesis, the model represent the experimental observations better than the results obtained using laboratory measurements of K_c.

A semianalytical model for 3-D hydraulic fracture growth in cases of fractures with length/height ratios $\leq$ 4.0 has been developed. Two dimensional fluid flow is taken into account in this model. The results obtained are in reasonable agreement with those of a fully 3-D model [2]. This model can be applied to one lenticular gas sand formation.

The existing TU proppant transport model was modified to improve the representation for Non-Newtonian fluid flow behavior. The model was expanded to be capable of handling variable flow rates due to varying the pumping schedules and changes in the type and amount of proppant being pumped into the fracture. Extensive effort was directed toward developing a tracking procedure which tracks the proppant particles for the case where the pumping rate and injected proppant particle concentration varies with time. Several checks on the capabilities of the proppant transport model were conducted. These checks range from evaluations of the basic laws of conservation of fluid and conservation of proppant mass to more complex comparisons of proppant distributions and fracture geometries with published results from other computational models.

Five settling models were considered for use in the TU Proppant Transport model. Each settling model was evaluated in terms of five criteria for a representative settling model. One of these settling models, the Sutrick and Rybicki model, was developed in this study. This settling model, which was empirically based on Hydroyethyl Cellulose settling velocity data, was selected for use in the proppant transport model because it met all the criteria and agreed well with other experimental settling velocity data.

Hydraulic fracturing and proppant treatment data from two published proppant transport models were used as input data for the TU Proppant Transport Model. The proppant distributions predicted by the TU model were in good agreement with the results obtained from the other models. [3] [4] A procedure to use fracture geometry data from the NIPER model has been outlined and is being developed. This procedure will include variable fracture height.

Future Activities

Plans for preparing the fracture geometry model to represent lenticular sands include (i) incorporation of flow rate variations into the base model, (ii) development of parametric relationships connecting height, width, and pressure in a vertical fracture plane, so that simpler fracture solutions can be obtained, (iii) extending the semianalytical 3-D

model to multiple lenticular gas sands, (iv) incorporating injected viscosity and flow rate variations into the asymmetric fracture, (v) investigating the behavior of the fracture after pumping has stopped, and (vi) obtaining a solution for fractures of arbitrary perimeter.

Future plans also include automating the data transfer between the NIPER fracture model and the TU Proppant Transport model and developing the capability to represent proppant distribution after pumping has stopped in the combined fracture/proppant transport model. The combined treatment model will be used to study the fracturing and propping of a single sand. Ultimately, the model will include simulation of fracturing and proppant placement in multiple lenses. Throughout these developments, the use of variable flow rates and the use of variable proppant types will be included.

References

1. Shlyapobersky, J., 26th U.S. Symposium on Rock Mechanics, Rapid City, June 1985.

2. Abou-Sayed, A.S. et al, SPE/DOE/GRI 12787, Unconventional Gas Recovery Symposium, Pittsburg (1984), p. 441.

3. Daneshy, A. A., "Numerical Solution of Sand Transport Hydraulic Fracturing", SPE #5636, 1975.

4. Novotny, E. J., "Proppant Transport", SPE 6813, 1977.

ACCOMPLISHMENTS

To data accomplishments for the variable fracture height model and the Non-Newtonian transport model are listed in the following.

- The highly elongated fracture model has been compared to other models (AMOCO, TERRA-TEK, and MIT) and similarities and differences have been pointed out. The model agrees with AMOCO and TERRA-TEK result.

- A semi-analytical model for fractures with a length/height ratio of 4 has been developed. This model includes 2D fluid flow.

- Results of the MWX have been interpreted using the asymmetric fracture model based on the hypothesis of Kc increasing as the fracture expands.

- Develop empirical Settling model that includes wall effects.

- Include variable pumping rates for injecting the pad and proppant.

- Represent variable proppant parameters.

- Include the capability to represent particle tracking for low viscosity fluids with large, high density proppants.

- Results obtained with the proppant transport model showed good agreement when compared with results from two other models published in the literature.

- The proppant transport model was modified so that the program efficiency was increased by a factor of 10.

- Plan were made to couple NIPER and TU models including variable fracture height was developed and is being evaluated.

ARTICLES AND PRESENTATIONS

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2. Palmer, I. D. and Luiskutty, Journal of Energy Resources Technology, accepted for publication (1985).

3. Luiskutty, C. T., Tomutsa, L. and Palmer, I. D., "Abstract submitted SPE California Regional Meeting (1986).

4. Palmer, I.D., Luiskutty, C. T. and Craig, H. R., Journal of Geophysical Research (Red), Paper being prepared for submission (1985).

CONTRACT TITLE:	Crosswell Acoustic Imaging Project
CONTRACT NUMBER:	AB-05-10-10-0
CONTRACTOR:	Los Alamos National Laboratory
PROGRAM MANAGER:	Samuel R. Skaggs
PRINCIPAL INVESTIGATORS:	James N. Albright Paul A. Johnson W. Scott Phillips
METC PROJECT MANAGER:	Karl Heinz Frohne
CONTRACT PERIOD OF PERFORMANCE:	FY:85

OBJECTIVE: To provide information relevant to the structure and properties of coastal zone rock between MWX wells through the development, validation, and application of crosswell acoustic methodology.

PROJECT BACKGROUND: During August 1984 an extensive crosswell acoustic survey was undertaken at the MultiWell Experiment (MWX) site using borehole tools developed in support of DOE geothermal programs at Los Alamos National Laboratory. Roughly a quarter-million signals were transmitted between the three wells that penetrate the coastal zone, beginning beneath the Red sands and extending up past the fractured Purple sands. These measurements represent by far the most extensive crosswell acoustic data set in existence and the first such taken in gas-bearing sands.

Crosswell surveys have advantages which are particularly attractive as a diagnostic aid to facilitate reservoir development. The high-frequency acoustic signals of which a survey is comprised are relatively uncontaminated by passage through rock that is not the subject of study. At the MWX site this enables a dissection of the fine structure of lenticular sands in the coastal zone that is impossible with any other seismic technique. Rock properties, in contrast to geophysical logs, are measured away from wellbore damage due to drilling and in the direction of production flow. Thus, for example, steeply dipping permeability boundaries disrupted or not penetrated by drilling may be detected. Finally, since interpretation in exploration seismology and crosswell acoustics have a common basis, application of the plethora of seismic processing technology to crosswell data can be expected to yield immediate useful results. Although the potential for crosswell acoustics is widely recognized, the comparatively little work underway nationally concentrates on theoretical studies of simulated data, and thus a large gap exists between theory and practice. In this context the MWX surveys provide a minimum of badly needed data.

From the experience at the MWX site, rapid commercialization of the crosswell survey method would seem to be greatly influenced by two factors. Technological hurdles that have been identified and quantified must be overcome before surveying is routinely possible at interwell distances in potentially productive fields. The high attenuation of acoustic signals through the bulk of the coastal zone rock, for example, could not be anticipated based on previously reported values at either seismic or ultrasonic frequencies, and so more energetic signal sources will be needed. Juxtaposed with technological development are discoveries made at the MWX site, which show that special-use surveys using existing technology can provide invaluable data for reservoir development. Gas-bearing sands and thin coals, again for example, exhibit characteristic signatures if continuity between wells is not interrupted. In

showing the application of crosswell surveys to the development of lenticular reservoirs, the WGS-funded research stands out as an important contribution to the future of crosswell acoustic technology.

ACHIEVEMENTS: Fiscal year 1985 work centered on studies of the Red and Yellow sands. Details are found in Symposia papers and Los Alamos reports. Numerous comparisons were made between newly reduced crosswell measurements, borehole sonic logs, and independently reported laboratory data on properties of the coastal zone sands - Young's Modulus, Poisson's Ratio, porosity, and seismic Q. Strengths and weakness of the techniques and the relative certainty in the various measurements were identified. Crosswell data were combined with theory and data acquired on sands in other geologic environments to infer properties not otherwise derivable - relative crack density, presence of fractures, and relative gas saturation among the sands. Four sands were found to be distinctive in amplitude and spectral characteristics; none were stratigraphically continuous between the three MWX wells. Major anisotropy in velocity and attenuation were discovered, the knowledge of which could improve analysis of long-offset and azimuthal VSP. Additional confirmation of the channel-wave hypothesis reported last year was obtained. Reversed-polarity, compressional-wave, first arrivals were observed which facilitate detection of low velocity strata often acoustically opaque to external signal sources and receivers. USGS signal-ray-tracing software was adapted (W. Lee) for use in interpreting crosswell survey data. A method for quantifying the performance of borehole survey tools in field operations was developed so that the performance of the same tool in other geologic environment can be predicted, and the engineering requirements for future tools specified. Mutually beneficial and sustained interactions occurred with researchers at SOHIO and Chevron, Bill Iverson (University of Wyoming), and W. Lee (USGS Menlo Park). Spin-off research was initiated under USAF funding.

REFERENCES

Albright, J.N. and Johnson, P. (1985), "Crosswell Acoustic Surveying of Gas Sands: Travel-time Pattern Recognition, Seismic Q and Channel Waves," SPWLA 26th Annual Logging Symposium, Paper MMM.

Albright, J.N., Terry, D.A., and Bradley, C.R. (1985), "Pattern Recognition and Tomography Using Crosswell Data," SPE/DOE Joint Symposium on Low Permeability Reservoirs, SPE/DOE Paper 13854.

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Albright, J.N. and Terry, D.A. (1984), "Crosswell Acoustic Imaging Project, June 1984 Review," Los Alamos National Laboratory Report, LA-UR-84-192B.

Albright, J.N. and Johnson P.A. (1985), "Crosswell Acoustic Imaging Project, 1984-1985," Los Alamos National Laboratory, Report in preparation.

Terry, D.A. and Albright, J.N. (1984), "Numerical Simulations in Limited-Aperture Tomography with Applications to Crosswell Tomography," Optical Society of America Topical Meeting, August 13-14, Hecla Island, Manitoba Canada.

UNCONVENTIONAL GAS RECOVERY
CONTRACTORS MEETING

PROJECT SYNOPSIS

IN-HOUSE RESEARCH TITLE: Western Gas Sands Systems Analysis

METC PROJECT MANAGER: John R. Duda

PRINCIPAL INVESTIGATORS: James C. Mercer
James R. Ammer
Abbie W. Layne

ABSTRACT

Research activities at METC in support of the Western Gas Sands Program consisted of two primary study activities: (1) multiwell experiment (MWX) data analysis, and (2) a gas migration study in Western Colorado.

The MWX data analysis, which was obtained by using a reservoir model and history matching procedures, pertains to the post-stimulation (minifracture and full-scale stimulations) well tests of Zones 3 and 4 of the Paludal Sandstone Interval and the prestimulation well tests of the Red and Yellow Zones of the Coastal Sandstone Interval. The following results were obtained:

- The minifracture stimulation of the Paludal Interval did not produce an induced fracture. Also, extreme formation damage occurred since a 65 percent permeability reduction around the wellbore was estimated. The design for this minifracture was a 200 to 300 feet fracture half-length.

- The full-scale stimulation of the Paludal Interval also caused extreme formation damage, since a 75 percent permeability reduction 20 feet on each side of the induced fracture was estimated. A fracture half-length of 100 feet occurred as compared to a designed value of 500 to 600 feet.

- Extreme permeability anisotropy is not a factor for the Coastal Interval.

The gas migration study determined the potential gas migration from Naval Oil Shale Reserve (NOSR) No. 3 to commercially producing wells in the Rulison Field. The study also forecasted production for 14 proposed NOSR offset wells, 6 to be completed in the lenticular Wasatch Formation and 8 in the lenticular portion of the Mesaverde Group. This study used a hydraulic fracture model, a dual porosity reservoir simulator, and engineering calculations for the analysis. The following results were obtained:

- Mesaverde Group lenticular sandstones are probably discrete reservoirs, and gas migration to the Rulison Field is insignificant.

- In the Wasatch Formation, zones of potentially high productivity exist where gas migration from NOSR No. 3 to the Rulison Field is substantial.

- Offset wells should be used only in areas where reservoir properties suggest good production, and where the sandstone lenses are probably in lateral communication with each other.

- Drainage can vary significantly in lenticular reservoirs as a function of the natural fracture network and the distribution and geometry of the sandstone lenses.

- The dominant parameter affecting gas production from lenticular formations is natural fracture permeability.

ACCOMPLISHMENTS

- Determined the effectiveness of both a minifracture stimulation and a full-scale stimulation of the Paludal Interval at the MWX site.

- Showed that extreme permeability anisotropy is not a factor affecting gas production for the Coastal Interval at the MWX site.

- Characterized the NOSR No. 3 Rulison Field area for gas production.

- Forecasted gas production for 14 proposed offset wells located in or near NOSR No. 3.

- Quantified potential gas loss from NOSR No. 3 to commercial wells in the Rulison Field.

- Determined natural fracture permeability to be the dominant parameter affecting gas production from lenticular reservoirs.

- Added the capability to simulate gas production from lenticular reservoirs, where the lenses are disjointed but in hydraulic communication, to an existing dual porosity simulator.

ARTICLES AND PRESENTATIONS

Horton, A. I., February 1985. Status of Multiwell Experiment Reservoir Modeling Analysis, Volume I. DOE/METC-85/4007, NTIS/DE85008559.

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Horton, A. I. and A. W. Layne, April 1985. Status of Models for Analysis of Western Gas Sands. DOE/METC-85/2004, NTIS/DE85003398.

Mercer, J. C., J. R. Ammer, and K-H. Frohne. Study of Gas Migration from Naval Oil Shale Reserve No. 3 to the Rulison Field. DOE/METC Research Report in Press.

Mercer, J. C., J. R. Ammer, and K-H. Frohne, 1985. Case Study of Gas Migration in the Wasatch and Mesaverde Formations of the Piceance Basin, Colorado. Presented at the 60th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers held in Las Vegas, Nevada, September 22-25, 1985. Paper Number SPE 14360.

Layne, A. W., September 1985. Status of Multiwell Stimulation Modeling Analysis and Western Gas Sands Hydraulic Fracture Model Development. DOE/METC-85/4052. In press.

Layne, A. W., September 1985. Hydraulic Fracture Model Analysis of the Multiwell Experiment Paludal Interval Stimulation Treatments. DOE/METC-85/4054. In press.

UNCONVENTIONAL GAS RECOVERY
CONTRACTORS MEETING

PROJECT SYNOPSIS

IN-HOUSE RESEARCH TITLE: Development of the Resource Extraction Data Base to Support the Eastern Gas Shales, Western Gas Sands, and Coalbed Methane Programs

METC PROJECT MANAGER: Albert B. Yost
Karl-Heinz Frohn
Charles W. Byrer

METC DATA BASE MANAGER: Ralph L. Scott

PRINCIPAL INVESTIGATOR: Thomas E. Lukow

ABSTRACT

Common to the Eastern Gas Shales (EGS), Western Gas Sands (WGS), and Coalbed Methane (CBM) Programs is the need to develop efficient menu-driven data base systems that are specific to each program so that METC researchers can use it. Activities are now in progress to develop data bases as repositories for research information from the EGS, WGS, and CBM projects. They will, however, include documented information from other sources. Well specific information such as well descriptions, core data, lithology, core sample descriptions and results, electric log data and stimulation data, and well treatment and test results are being collected for inclusion in the data bases. Also included will be basin information such as regional geology, outcrop survey and other interpretative information, and a bibliography of references used the data base. Current plans are to construct specific data bases using a consistent format and structure because the sources of data and the data base users are generally the same. The Resource Extraction Data Base (REDB) is the data base that meets this objective.

ACCOMPLISHMENTS

Eastern Gas Shales

- Conducted METC on-site inventory of EGS data. Twenty-nine computer tapes and all available hard copy material located at METC were inventoried. During the course of the inventory, about 70 other tapes were identified, most of which are expected to be backup tapes.

- Developed data files for Michigan, Illinois, New York, Ohio, Pennsylvania, and West Virginia for process simulation studies.

- Developed data set for Ohio and West Virginia for process simulation studies.

- Conducted training session for extraction of data from the Well History Control File.

- Developed EGS data structure based on the WGS structure.

Western Gas Sands

- Developed the WGS data structure.
- Developed WGS software users' guide.
- Computerized standards have been established to check all variables that contain ranges.
- A WGS data base was loaded from the Well History Control File and has been entered into the Versatile Interface for Systems Analysis (VISTA).

Coalbed Methane

- Developed VISTA by defining systems needs, evaluating available systems, and modifying the system to meet user needs.
- Loaded a CBM data base that contains about 30,000 blocks of well core coal testing data. Included in the data base are coal composition, proximate and ultimate analyses, petrography data, stimulation, and location data.
- Developed a CBM dictionary which includes an extensive thesaurus of commonly used geological terms.

ARTICLES AND PRESENTATIONS

Eastern Gas Shales

- Daniels, C., 1984. The Geologic Analysis System (GAS): Changes to Well Symbol Numbers in FICS Module CALC. Internal Report to DOE/METC.

Western Gas Sands

- Lopez, R., 1985. WGS REDB Dictionary. Internal Report to DOE/METC.

Coalbed Methane

- Daniels, C., 1985. The WHCS Tape Retrieval System (TRS): A Users Guide for Selecting WHCS Data from Backup Tapes. Internal Report to DOE/METC.
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- Hancock, J., V. Richardson, 1984. Coalbed Methane PASS Dictionary. Internal Report to DOE/METC.

UNCONVENTIONAL GAS RECOVERY
CONTRACTORS MEETING

PROJECT SYNOPSIS

CONTRACT TITLE:	Multiwell Fracturing Experiments
CONTRACT NUMBER:	DE-AC04-76DP00789
CONTRACTOR:	Sandia National Laboratories
ADDRESS:	Division 6253, P. O. Box 5800
CITY, STATE, ZIP:	Albuquerque, New Mexico 87185
TELEPHONE:	(505) 844-2302
PROGRAM MANAGER:	David A. Northrop
PRINCIPAL INVESTIGATOR:	Norm Warpinski
METC PROJECT MANAGER:	K-H. Frohne
PERIOD OF PERFORMANCE:	October 1, 1984 - September 30, 1985

ABSTRACT

The objective of the Multiwell Experiment fracturing experiments is to test and develop the technology for the efficient stimulation of tight, lenticular gas sands. This requires a basic understanding of hydraulic fracture growth, the fracture's interaction with a complex lithologic environment, and gas production into the created fracture. The intricate interplay of the hydraulic fracture with the lens geometry, the internal reservoir characteristics (fractures, reservoir breaks, etc.), the in situ stresses and mechanical defects (fractures, bedding, etc.) needs to be defined in order to develop a successful stimulation program.

Current activities are the stimulation experiments in the red and yellow sands of the coastal zone. We have finished the in situ stress testing associated with the coastal zone. A nitrogen frac (no proppant) and a small, controlled N_2 foam frac have been conducted in the yellow sand. The nitrogen frac was the ultimate nondamaging treatment using a completely nondamaging fluid at the lowest possible pressures with no prop. Treatment pressure history analysis yielded a frac length of about 250-300 ft for this test. The foam frac was a small treatment, designed to stay within the lens dimensions, use a minimum of gel, and yet provide a good conductive path for gas production. A tip screenout at the end of the treatment ensured good conductivity. Fracture lengths from treatment pressure history analysis were near design estimates.

These experiments have shown that it is difficult, if not impossible, to conduct a fracture treatment in these sands without damaging the hairline natural fractures which contribute to pre-frac flow rates. The damage mechanism is not yet known and is currently being studied, but is thought to be due to either the gel, the high treatment pressures, the stresses induced

by the propped fracture, or some combination of these. If this type of damage cannot be avoided in these rocks, we may need to design all fracture treatments for the matrix permeabilities; this will require much larger fractures. Alternately, different types of treatments are being considered.

Future activities include additional damage studies and treatment pressure history analyses and the design of the next treatment in this zone, which will be a refracture of the same yellow zone to evaluate the results of a longer fracture. Completion of this refracture test depends, of course, on satisfactory analysis of the previous two treatments. Additional stimulation experiments will be conducted in the fluvial zone in future years.

ACCOMPLISHMENTS

We have completed the measurements of the distribution of stress through the coastal zone and found good containment features. We have successfully conducted two fracture treatments in the coastal zone and obtained all the required treatment data; we have been able to history-match the treatment pressures and provide estimates of fracture length and propped length. Finally, we have identified possible damage mechanisms and we are now attempting to determine the principal cause and what, if anything, can be done about them.

ARTICLES AND PRESENTATIONS

1. N. R. Warpinski, et al., "In Situ Stress Measurements at U.S. DOE's Multiwell Experiment Site, Mesaverde Group, Rifle, Colorado," J. Pet. Tech., Vol 37, page 527, March 1985.

2. N. R. Warpinski et al., "Fracturing and Testing Case Study of Paludal, Tight, Lenticular Gas Sands," SPE 13876, presented at SPE 1985 Symposium on Low Permeability Gas Reservoirs, Denver, Colorado, p 267, May 1985.

UNCONVENTIONAL GAS RECOVERY
CONTRACTORS MEETING

PROJECT SYNOPSIS

CONTRACT TITLE:	High Energy Gas Fracture Research
CONTRACT NUMBER:	DE-AC04-76DP00789
CONTRACTOR:	Sandia National Laboratories
ADDRESS:	Division 6253, P. O. Box 5800
CITY, STATE, ZIP:	Albuquerque, New Mexico 87185
TELEPHONE:	(505) 844-2302
PROGRAM MANAGER:	David A. Northrop
PRINCIPAL INVESTIGATOR:	Jerry F. Cuderman
METC PROJECT MANAGER:	K-H. Frohne
PERIOD OF PERFORMANCE:	October 1, 1984 - September 30, 1985

ABSTRACT

High Energy Gas Fracturing (HEGF) is a tailored pulse fracturing technique which uses propellants to obtain controlled fracture initiation and extension. Borehole pressurization rate can be tailored, by suitable choice of propellants, to produce four or eight fractures radiating from the wellbore. High Energy Gas Fracture (HEGF) research is conducted at DOE's Nevada Test Site (NTS) in a tunnel complex where experiments can be done under realistic in situ stress conditions. Pressure measurements are made in the test borehole during all fracturing experiments. Experiments are mined back to provide direct observation of fracturing obtained.

The objective of the HEGF research is to develop multiple fracturing technology for application in gas well stimulation. HEGF research at NTS and in Devonian shale demonstration tests has resulted in a completed technology for multiple fracturing in uncased, liquid-free wellbores. Current research is directed toward extending the technique to liquid-filled and to cased and perforated boreholes--both typical borehole conditions for the majority of gas and oil field stimulations.

For liquid-free boreholes, multiple fracturing is specified in terms of pressure risetime required for a given borehole diameter. Propellants are mixed to achieve the desired risetime using a semiempirical mixing equation. The addition of liquid in the borehole results in a significantly more complicated fracturing behavior. Hydrodynamic effects are significant. Multiple fractures are initiated, but do not necessarily all propagate. Multiple- and hydraulic-type fracturing and wellbore crushing have been observed in the same experiment. Experiments in cased and perforated boreholes result in fracture surfaces which initiate along axial

lines of perforations and initially propagate in the perf directions and subsequently turn toward the hydraulic fracture direction. Fracture length obtained, with minimal casing damage, is 2 to 3 m. The addition of liquid can prevent fracturing from some of the lines of perforations.

While progress has been made in understanding fracturing in liquid-filled and cased and perforated boreholes, additional experiments are needed to complete and optimize the technology. For example, better control of fracturing obtained in uncased, liquid-filled boreholes needs to be obtained. Critical pressure risetimes and levels to ensure optimum fracturing through all perforations and to minimize casing damage remain to be defined. Research needs to be initiated in which staged propellant burns are used to extend fractures beyond those currently obtained. The newly developed techniques in liquid-filled wells need to be tested in gas and oil well applications.

ACCOMPLISHMENTS

- Technology developed and demonstrated for uncased, liquid-free boreholes.
- Technology developed for cased and perfed, liquid-free boreholes.
- Initial data obtained on behavior of fracturing in liquid-filled and liquid-filled cased and perfed boreholes.

ARTICLES AND PRESENTATIONS

J. F. Cuderman, "High Energy Gas Fracturing Development--Final Report to Gas Research Institute," Sandia National Laboratories Report, SAND84-0247, June 1984.

J. F. Cuderman, and D. A. Northrop, "A Propellant-Based Technology for Multiply Fracturing Wellbores to Enhance Gas Recovery: Application and Results in Devonian Shale," SPE 12838, SPE/DOE/GRI Unconventional Gas Recovery Symposium, Pittsburgh, PA, May 13-15, 1984.

J. F. Cuderman, "Rock Mechanics Effects Observed Subsequent to Multiple Fracturing of Wellbores," 25th U.S. Symposium on Rock Mechanics, June 25-27, 1984, Evanston, IL.

J. F. Cuderman, "Application of Propellants for Controlled Pressurization of Boreholes in Geologic Media," ASCE/ASME Mechanics Conference, June 24-26, 1985, Albuquerque, NM.

J. F. Cuderman, T. Y. Chu, J. Jung, and R. D. Jacobson, "High Energy Gas Fracture Experiments in Liquid Filled Boreholes--Potential Geothermal Application," Sandia National Laboratories Report, in preparation..

UNCONVENTIONAL GAS RECOVERY
CONTRACTORS MEETING

PROJECT SYNOPSIS

CONTRACT TITLE:	Multiwell Experiment
CONTRACT NUMBER:	DE-AC04-76DP00789
CONTRACTOR:	Sandia National Laboratories
ADDRESS:	Division 6253, P. O. Box 5800
CITY, STATE, ZIP:	Albuquerque, New Mexico 87185
TELEPHONE:	(505) 844-2302
PROGRAM MANAGER:	David A. Northrop
PRINCIPAL INVESTIGATORS:	Allan R. Sattler Norman R. Warpinski John C. Lorenz Carolyne M. Hart
METC PROJECT MANAGER:	K-H. Frohne
PERIOD OF PERFORMANCE:	October 1, 1984 - September 30, 1985

ABSTRACT

The Multiwell Experiment is a research-oriented field laboratory located in the east-central Piceance Basin, seven miles southwest of Rifle, Colorado. The overall objectives of the project are to characterize lenticular, low permeability gas reservoirs and to develop technology for their production. Its wide range of activities and its wealth of data are providing a unique, in-depth look at the viability of a significant natural gas resource in the western United States. Field work began in late 1981 and is scheduled through mid-1988.

Three closely spaced wells (115-215 ft apart) have been drilled to establish this laboratory in the Mesaverde formation, which lies at depths between 4000 and 8300 ft at this location. Our geologic studies have divided the Mesaverde by depositional environment into different, distinct reservoir types; these, in turn, serve as the focus of different testing and stimulation programs. We have completed well tests in the Corcoran-Cozzette sandstones (shoreline/shallow marine) and have completed well tests and stimulation experiments in the paludal zone (lower delta plain). We are currently conducting a series of well tests and stimulations in a pair of sands in the coastal zone (upper delta plain). Future work will be conducted in the 1500 ft upper section containing fluvial, lenticular sandstones.

Results to date have shown the dominant effect that geologic factors have upon reservoir performance. Measured in situ permeabilities have been significantly greater than matrix permeabilities measured in careful core analyses. This indicates the importance of natural fractures upon

production in these tight rocks. Interference, transient and other test data further suggest a very heterogeneous reservoir contained within the overall boundary of the sand body. The small stimulations done to date have shown that production from the natural fractures is affected (damaged) by the stimulation; however, the nature of the damage is not yet known.

ACCOMPLISHMENTS

Work in FY85 has focused upon two predominant sands--the red and yellow--in the coastal interval and upon developing a geologic model for these complex lenticular reservoirs. A series of four stimulations in the same interval was defined to address a range of objectives, including damage, fracture containment and performance prediction. The first two, a small, unpropped, nitrogen gas frac and a small, propped, nitrogen foam frac, were conducted and post-frac analyses showed both were completed according to design. Supporting laboratory studies have characterized the properties of the reservoir and bounding rocks and the first studies of N_2 foam--tight sand interactions have been completed. Geologic field studies are aimed at a characterization of the natural fractures and other factors affecting reservoir permeability and performance. In addition, a tectonic and stress history of the Piceance Basin and a viscoelastic geologic model have been developed leading towards an understanding and prediction of natural fracturing at the project site, and for sedimentary basins in general. Additional project information and accomplishments can be found in the accompanying MWX project synopses.

ARTICLES AND PRESENTATIONS

There are currently over 50 articles and presentations resulting from Multiwell Experiment activities.

1. N. R. Warpinski, P. T. Branagan, A. R. Sattler, J. C. Lorenz, D. A. Northrop, R. L. Mann and K-H. Frohne, "Fracturing and Testing Case Study of Paludal, Tight, Lenticular Gas Sands," SPE/DOE 13876, Proceedings of the 1985 SPE/DOE Joint Symposium on Low Permeability Reservoirs, Denver, CO, May 19-22, 1985, pp 267-278.

2. J. C. Lorenz, "Predictions of Size and Orientations of Lenticular Reservoirs in the Mesaverde Group, Northwestern Colorado," SPE/DOE 13851, Proceedings of the 1985 SPE/DOE Joint Symposium on Low Permeability Reservoirs, Denver, CO, May 19-22, 1985, pp 23-32.

3. A. R. Sattler, "Integration of Laboratory and Field Data for Insight on the Multiwell Experiment Paludal Stimulation," SPE/DOE 13891, Proceedings of the 1985 SPE/DOE Joint Symposium on Low Permeability Reservoirs, Denver, CO, May 19-22, 1985, pp 397-410.

4. J. C. Lorenz, D. M. Heinze, J. A. Clark, and C. A. Searls, "Determination of Widths of Meander-Belt Sandstone Reservoirs from Vertical Downhole Data, Mesaverde Group, Piceance Creek Basin, Colorado," The American Association of Petroleum Geologists Bulletin, 69 (5) 710-721, May 1985.

UNCONVENTIONAL GAS RECOVERY
CONTRACTORS MEETING

PROJECT SYNOPSIS

CONTRACT TITLE:	Mineback Stimulation Research Experiments
CONTRACT NUMBER:	DE-AC04-76DP00789
CONTRACTOR:	Sandia National Laboratories
ADDRESS:	Division 6253, P. O. Box 5800
CITY, STATE, ZIP:	Albuquerque, New Mexico 87185
TELEPHONE:	(505) 844-2302
PROGRAM MANAGER:	David A. Northrop
PRINCIPAL INVESTIGATOR:	Norm Warpinski
METC PROJECT MANAGER:	K-H. Frohne
PERIOD OF PERFORMANCE:	October 1, 1984 - September 30, 1985

ABSTRACT

The objective of the Mineback Stimulation Research Experiments is to improve hydraulic fracture stimulation technology by providing an in situ laboratory where basic processes and mechanisms that control and influence fracture propagation can be observed, measured and understood. While previous tests have been instrumental in providing an understanding of the mechanisms controlling fracture height, current experiments are focused on fluid flow through the created fracture and the associated pressure drops and crack widths.

Tests are performed by first creating an "instrumented hydraulic fracture" in which we can measure width and pressure of various locations along the crack length and height. We then inject various fluids, such as water or gels, into this fracture and measure the response. From these data we can calculate friction factors for this flow network and compare them to ideal viscous theory. We can also examine other facets of fracture behavior, such as fracture tip phenomena and height growth processes. Mineback of the fracture yields the final fracture dimensions and specific features of the fracture.

Initial results have showed that pressure drops along hydraulic fractures are much greater than modeled by ideal viscous theory. This results in higher overall levels of pressure in the crack and thus wider cracks. For a given treatment volume, the most significant result is shorter fractures than the design models predict.

We are now evaluating a second, larger, better-instrumented experiment to: (1) reproduce the initial results on a larger scale with better accuracy, and (2) to evaluate the effect of proppant on the flow characteristics. This set of fracture tests was conducted in May 1985, followed by conductivity tests in August and mineback in September. We are currently in the process of analyzing the data. Future activities include: (1) finishing the data reduction and analysis, (2) writing a final report, (3) writing any appropriate technical papers, and (4) completing all hydraulic fracturing mineback activities since funding has ended.

ACCOMPLISHMENTS

We have showed for the first time that pressure drops in fractures are much larger than currently modeled and we are now trying to quantify the discrepancy and develop an empirical relation of pressure drop. We have also shown that this is due to the nature of the fracture, particularly multiple stranding, offsets at joints, surface roughness, and fracture tortuosity. Additionally, we have monitored many of the details of crack closure and we plan to relate these to current pressure analyses, such as that by Nolte (SPE 10911).

ARTICLES AND PRESENTATIONS

1. N. R. Warpinski, et al., "Direct Observation of a Sand-Propped Hydraulic Fracture," Sandia National Laboratories Report, SAND81-0225, May 1981.

2. N. R. Warpinski, et al., "The Formation Interface Experiment: An In Situ Investigation of Hydraulic Fracture Behavior Near a Material Property Interface," Sandia National Laboratories Report, SAND81-0938, June 1981.

3. N. R. Warpinski, et al., "Laboratory Investigation on the Effect of In Situ Stresses on Hydraulic Fracture Containment," SPE/DOE 9834, Proceedings of the 1981 SPE/DOE Symposium on Low Permeability Gas Reservoirs, Denver, CO, May 27-29, 1981.

4. N. R. Warpinski, et al., "In Situ Stresses: the Predominant Influence on Hydraulic Fracture Containment," J. Pet. Tech. 34, 653-664, 1982.

5. N. R. Warpinski, "Measurement of Width and Pressure in a Propagating Hydraulic Fracture," SPE 11648, Proceedings of the 1983 SPE/DOE Symposium on Low Permeability Gas Reservoirs, Denver, CO, March 1983. (Also in Soc. of Petrol. Engin. Jour. 25, 46-54, 1985.)

6. N. R. Warpinski, "In Situ Measurement of Hydraulic Fracture Behavior, PTE-3 Final Report," Sandia National Laboratories Report, SAND 83-1826, July 1985.

UNCONVENTIONAL GAS RECOVERY
CONTRACTORS MEETING

PROJECT SYNOPSIS

CONTRACT TITLE:	Multiwell Experiment: Fracture Diagnostics
CONTRACT NUMBER:	DE-AC04-76DP00789
CONTRACTOR:	Sandia National Laboratories
ADDRESS:	Division 6253, P. O. Box 5800
CITY, STATE, ZIP:	Albuquerque, New Mexico 87185
TELEPHONE:	(505) 844-2302
PROGRAM MANAGER:	David A. Northrop
PRINCIPAL INVESTIGATOR:	Carolyne M. Hart
METC PROJECT MANAGER:	K-H. Frohne
PERIOD OF PERFORMANCE:	October 1, 1984 - September 30, 1985

ABSTRACT

The primary objective of the MWX fracture diagnostics program is to measure fracture geometry for the MWX stimulations. A knowledge of the fracture behavior as a function of treatment parameters as propagation progresses through and out of lenses is key to interpretations of stimulation results. A dual passive borehole seismic system (BSS) designed to monitor hydrofracture growth has been the primary instrumentation system for the MWX stimulation experiments to date.

During the MWX paludal zone stimulations, downhole seismic monitoring proved to be an effective method of estimating fracture orientation, height, and minimum wing length. Nonetheless, several generic deficiencies in the BSS became apparent. Consequently, a project to significantly upgrade Sandia's BSS was initiated in late 1984. The upgrade program was completed prior to the August 1, 1985 MWX coastal zone stimulation, and the upgraded system performed extremely well during the experiment.

We are currently analyzing the data from the coastal stimulation. Upon completion of this activity, work will begin on an improved computational capability including enhanced analog-to-digital, memory buffer and graphic capabilities. These upgrades will not only contribute to improved event location accuracy, but are also an essential step toward the accomplishment of a longer term goal of providing near real-time diagnostics to augment stimulation process control. Additionally, we will be supporting future MWX coastal and fluvial zone stimulations.

ACCOMPLISHMENTS

A significant borehole seismic system upgrade program was initiated and completed this period. The upgraded system was fielded during the first MWX coastal zone stimulation. The new system performed well by providing a significant reduction in downtime and a dramatic improvement in both signal strength and signal-to-noise ratio. These results are encouraging in that they potentially provide for a much more definitive determination of fracture geometry. The coastal stimulation data set is currently being analyzed.

ARTICLES AND PRESENTATIONS

1. R. W. Seavey, "Borehole Seismic Units," Sandia National Laboratories Report, SAND82-0373, May 1982.

2. C. M. Hart, et al., "A Comprehensive Fracture Diagnostics Instrumentation Fielding Program," SPE/DOE 11810, 1983 SPE/DOE Symposium on Low Permeability Gas Reservoirs, Denver, CO, March 1983.

3. D. Engi, "Integrated Real-Time Fracture Diagnostics Instrumentation System," Western Gas Sands Subprogram Review Technical Proceedings, January 1984.

4. C. M. Hart, et al., "Fracture Diagnostics Results for the Multiwell Experiment's Paludal Zone Stimulation," SPE/DOE/GRI 12852, 1984 SPE/DOE/GRI Unconventional Gas Recovery Symposium, Pittsburgh, PA, May 1984.

5. L. W. Teufel, et al., "Determination of Hydraulic Fracture Azimuth by Geophysical, Geological, and Oriented Core Methods of the Multiwell Experiment Site, Rifle, Colorado," SPE 13226, 59th Annual SPE Technical Conference and Exhibition, Houston, TX, September, 1984.

UNCONVENTIONAL GAS RECOVERY
CONTRACTORS MEETING

PROJECT SYNOPSIS

CONTRACT TITLE: MWX Reservoir Engineering

CONTRACT NUMBER: Sandia Contract No. 25-3097 Amendment No. 1

CONTRACTOR: CER Corporation
ADDRESS: P. O. Box 15090
CITY, STATE, ZIP: Las Vegas, Nevada 89114
TELEPHONE: (702) 735-7136

PROGRAM MANAGER: Robert L. Mann

PRINCIPAL INVESTIGATORS: Paul Branagan
Craig Cipolla
S. J. Lee
Roy Wilmer

METC PROJECT MANAGER: Karl-Heinz Frohne

PERIOD OF PERFORMANCE: October 1, 1984 - October 1, 1985

ABSTRACT

This portion of the Multiwell Experiment involves the design, implementation and analysis of various well tests with the following principle objectives:

- Develop a thorough description of the unstimulated reservoir.
- Assess the production capacity of the natural fractures.
- Predict the effects of various stimulations on various production mechanisms.
- Assess and describe variations to production following fracturing.
- Integrate all test data to derive an analytic approach to production optimization.

Previous production and stimulation data from a pair of MWX Paludal sandstone reservoirs that were fractured in December 1983 and May 1984 indicated that the use of standard, commercially available gelled fracturing techniques were probably not the best methods to optimize enhanced production from naturally fractured tight sandstones. As a consequence a revised set of testing and stimulation methods were scheduled for utilization in the upcoming stimulation experiments that were focused on a pair of Coastal sandstones, designated Red and Yellow.

Separate prestimulation well tests were performed on the Coastal Red and Yellow sandstones during the fall of 1984. The results of these well tests, that included pressure interference tests using all 3 MWX wells indicated that both the Red and Yellow sands primary production mechanism was markedly enhanced by the existence of natural fractures. Using the results of numerous model runs for various proposed propped fracture lengths induced in a naturally fractured reservoir it was concluded that a series of shorter and less complex fractures should be initially attempted and subsequently analyzed prior to executing a long fracture that would be designed to intercept multiple lenticular sandbodies.

Two separate stimulations of the Yellow sandstone were performed during the

spring and summer of 1985. The first stimulation used only nitrogen gas as the fracturing fluid and did not contain a proppant. Post nitrogen fracture well tests indicated an increase in production by about a factor of 2, however the existence of the unpropped fracture, designed to be less than 250ft. was not evident from analytic pressure methods or simulated history matches. The second stimulation utilized a 75 quality nitrogen foam to carry an intermediate strength proppant and was designed to have a propped frac length of about 250ft. Post foam fracture well testing revealed that although the stimulated Yellow sandstone appeared to be producing primarily through the induced fracture, the production increase was not as predicted and may result from diminished natural fracture flow capacity.

Pressure measurements made in the Red sandstone during the post foam fracture well tests revealed that pressure communications exited between the two sand bodies and therefore the Red may have contributed to the Yellow production during the flow test periods. We are presently pursuing tests that are designed to quantify this potential leak and if possible apply a remedial treatment.

ACCOMPLISHMENTS

A series of well tests and tracer experiments have succeeded in providing MWX project engineers a comprehensive description of these complex sandstone reservoirs, especially pertinent was a measure of the flow capacity of the natural fractures. Post fracture testing revealed that the addition of even a small quantity of high quality foam and proppant to these reservoirs appears to have a detrimental effect on the ability of the natural fractures to maintain there original high flow capacity.

The primary accomplishments that are the direct result of reservoir testing, analysis and simulation include:

- A clear description of the unstimulated Red and Yellow reservoir production capacity and areal extent from which to assess the effects imparted by various stimulations.
- An assessment of the anticipated production enhancement for various stimulations and the impact on natural fractures using a naturally fractured reservoir model.
- A determination of natural fracture flow capacity from combined pressure histories and nitrogen tracer analysis.
- A description of the increased natural fracture flow capacity during gaseous injection.
- A determination of fracture length and modification of production for a propped foam fracture from post frac testing.
- A comparative analysis of the effects of foam and proppant versus gas fracs on the ability of natural fractures to produce.

ARTICLES AND PRESENTATIONS

1. N.R. Warpinski, P.T. Branagan, A.R. Sattler, J.C. Lorenz, D.A. Northrup, R.L. Mann, and K-H. Frohne, "Fracturing and Testing Case Study of the Paludal Tight, Lenticular Gas Sands", SPE/DOE 13876, Proceedings of the 1985 SPE/DOE Joint Symposium on Low Permeability Reservoirs, Denver, Co. May 19-22, 1985.

2. P.T. Branagan, C.L. Cipolla, S.J. Lee and R.H. Wilmer, "Comprehensive Well Testing and Modeling of Pre and Post-Fracture Well Performance of the MWX Lenticular Tight Gas Sands", SPE/DOE 13867, Proceedings of the 1985 SPE/DOE Joint Symposium on Low Permeability Reservoirs, Denver, Co., May 19-22, 1985.

APPENDIX A

AGENDA, UNCONVENTIONAL GAS RECOVERY CONTRACTORS MEETING

TECHNICAL PROGRAM

MONDAY, NOVEMBER 18, 1985

11:00 a.m. - 12:00 p.m. Speakers Briefing Luncheon (Eastern Gas Shales/Coalbed Methane Speakers), VIP Room

11:00 a.m. - 12:30 p.m. Registration, Fireplace Lobby, Buffet Luncheon, Ballrooms C and D

NOTE: All technical sessions will be held in Ballrooms A and B.

SESSION I -- EASTERN GAS SHALES
Chairman: Albert B. Yost, II, Project Manager, Eastern Gas Shales, Morgantown Energy Technology Center

12:45 p.m. 1.1 Opening Remarks -- A. A. Pitrolo, Director, Morgantown Energy Technology Center

1:00 p.m. 1.2 Eastern Gas Shales -- John Roen, U.S. Geological Survey

1:30: p.m. 1.3 Stress-Ratio/Structure Studies and Testing in the Appalachian Basin -- Keith Evans, Lamont Geological Observatory, Columbia University

2:00 p.m. 1.4 Eastern Gas Shales Systems Analysis: Lineament Versus Production -- James C. Mercer, Morgantown Energy Technology Center

2:15 p.m. 1.5 Eastern Gas Shales Reservoir Tester Instrumentation Development -- Larry O. Lawson, Morgantown Energy Technology Center

MONDAY, NOVEMBER 18, 1985 (Continued)

2:30 p.m. BREAK
Fireplace Lobby

2:45 p.m. 1.6 Analysis of Fracturing Mechanisms in Naturally Fractured Rocks -- Thomas L. Blanton, Science Applications International Corporation

3:15 p.m 1.7 Unconventional Gas Program/Eastern Devonian Shales -- Francois E. Heuze, Lawrence Livermore National Laboratory

3:45 p.m. 1.8 Installation of a Devonian Shale Reservoir Testing Facility and Acquisition of Reservoir Property Measurements -- Jeff Smith, The BDM Corporation

4:15 p.m. ADJOURN

5:00 p.m. DINNER
Ballrooms C and D

SESSION II -- COALBED METHANE
Chairman: Charles W. Byrer, Project Manager, Coalbed Methane, Morgantown Energy Technology Center

6:00 p.m. 2.1 Technical and Commercial Feasibility of Utilizing Gas from Coalbeds and Devonian Shale for Purposes of Community and Rural Development -- Arie M. Verrips, American Public Gas Association -- John Gustavson and Richard M. Winar, Gustavson Associates

MONDAY, NOVEMBER 18, 1985 (Continued)

6:30 p.m.	2.2	An Evaluation of the Effect of Methane Adsorption/Desorption in Well Tests on Coal Beds -- Alan A. Reznik, University of Pittsburgh
7:00 p.m.	2.3	The Measurement of Dynamic Reservoir Conditions -- Charles M. Boyer, U.S. Steel Corporation
7:30 p.m.	2.4	Coalbed Methane Stimulation Analysis -- Abbie Layne, Morgantown Energy Technology Center
7:45 p.m.	2.5	Coalbed Methane Geostatistical Analysis Project -- Warrior Basin -- James C. Mercer, Morgantown Energy Technology Center
8:00 p.m.		ADJOURN FOR THE DAY

TUESDAY, NOVEMBER 19, 1985

7:00 a.m. - 8:00 a.m.		Speakers Briefing Breakfast (Western Gas Sands Speakers), VIP Room
7:00 a.m. - 8:00 a.m.		Registration, Fireplace Lobby, Continental Breakfast, Fireplace Lobby

SESSION III -- WESTERN GAS SANDS
Chairman: Karl-Heinz Frohne, Project Manager, Western Gas Sands, Morgantown Energy Technology Center

8:00 a.m.	3.1	Western Gas Sands Geologic Characterization (Greater Green River Basin) -- Ben Law, U.S. Geological Survey
8:30 a.m.	3.2	Western Gas Sands Geologic Characterization (Piceance-Uinta Basins) -- Charles W. Spencer, U.S. Geological Survey
9:00 a.m.	3.3	Multiwell Experiment Site Geology -- John C. Lorenz, Sandia National Laboratories
9:30 a.m.		BREAK Fireplace Lobby
9:45 a.m.	3.4	Rock Matrix and Fracture Analysis of Flow in Western Tight Gas Sands -- Norman R. Morrow, New Mexico Institute of Mining and Technology
10:15 a.m.	3.5	Laboratory Research of Fracturing Materials for the DOE/MWX -- Ian O. Palmer, National Institute for Petroleum and Energy Research

TUESDAY, NOVEMBER 19, 1985

10:45 a.m.	3.6	Unconventional Gas/Western Gas Sands -- Francois E. Heuze, Lawrence Livermore National Laboratory
11:15 a.m.		LUNCHEON Ballrooms C and D

SESSION IV -- WESTERN GAS SANDS
Chairman: Karl-Heinz Frohne, Project Manager, Morgantown Energy Technology Center

12:30 p.m.	4.1	Stimulation Model for Lenticular Sands -- Ed Rybicki, University of Tulsa
1:00 p.m.	4.2	Crosswell Acoustic Imaging Project -- James W. Albright, Los Alamos National Laboratories
1:30 p.m.	4.3	Western Gas Sands Systems Analysis -- James C. Mercer, Morgantown Energy Technology Center
1:45 p.m.	4.4	Development of the Resource Extraction Data Base to Support the Eastern Gas Shale, Western Gas Sands, and Coal Bed Methane Data Bases -- Thomas Lukow, Morgantown Energy Technology Center
2:00 p.m.	4.5	Multiwell Fracturing Experiments -- Norman R. Warpinski, Sandia National Laboratories
2:15 p.m.	4.6	High Energy Gas Fracture Research -- Jerry F. Couderman, Sandia National Laboratories

2:30 p.m.		BREAK Fireplace Lobby
2:45 p.m.	4.7	Multiwell Experiment (MWX) -- David A. Northrop, Sandia National Laboratories
3:15 p.m.	4.8	Mineback Stimulation Research Experiments -- Norman P. Warpinski, Sandia National Laboratories
3:45 p.m.	4.9	Multiwell Experiment: Fraction Diagnostics -- Carolyn Hart, Sandia National Laboratories
4:15 p.m.	4.10	MWX Reservoir Engineering -- Paul T. Branagan, CER Corporation
4:45 p.m.		ADJOURN