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THE DEPARTMENT OF ENERGY'S WESTERN GAS SANDS PROJECT MULTI-WELL EXPERIMENT

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ABSTRACT

The Department of Energy has initiated a Multi-well Experiment with the objectives: (1) characterization of low permeability, lenticular gas sands and (2) evaluation of state-of-the-art and developing technology for their production. The location is in the Rulison Field in the Piceance Basin, Garfield County, Colorado where the lenticular Mesaverde sequence and the underlying blanket Corcoran-Cozzette are the formations of interest and lie at depths between 4,000 and 8,600 ft.

Features of this research-oriented field experiment include: (1) three close-spaced wells (100 to 500 ft) for reservoir characterization, conventional well tests, interference testing, well-to-well geophysical profiling, and placement of diagnostic instrumentation adjacent to fracture treatments; (2) complete core taken through the formations of interest; (3) a comprehensive core analysis program; (4) an extensive logging program featuring conventional and experimental logs; (5) determination of in situ stress in sand lenses and bounding shales; (6) application of geophysical techniques to determine sand lens orientation; (7) use of seismic, electrical potential and tilt diagnostic methods for hydraulic fracture characterization; and (8) a series of stimulation experiments.

Analysis of data from these activities will yield the following kinds of information: (1) geologic characterization emphasizing the morphology, properties and variability of lenticular sands; (2) a reservoir model for lenticular sand production; (3) a fracture model including correlations between stress, geometry and lens orientation; (4) core-log-well test correlations for improved formation evaluation, and (5) economic assessments.

INTRODUCTION

The United States government's efforts to fracture and stimulate natural gas production from low-permeability reservoirs in the western United States began in the mid-1960's. This work involved three cooperative experiments with industry to evaluate the use of nuclear explosives for fracturing. Partial success was achieved, however, the nuclear explosive technique was abandoned following the 1973 Rio Blanco project. The Federal Power Commission's National Gas Survey was published at about the same time. It included studies of the potential of nuclear and massive hydraulic fracturing (MHF) for production stimulation. An outgrowth of this study was a government-industry cooperative project to test MHF at a location one mile from the Rio Blanco nuclear test and compare the two. This and eight more cost-shared projects, the last of which was only recently completed, were generally designed to be demonstrations of the technology that industry had developed. In the lenticular sands of the Piceance and Uinta Basins, the results of MHF were mixed and often disappointing. In these demonstrations, there was not enough data taken to diagnose what happened and why the results were below expectations. The history of these projects is available in government publications of reports prepared by the industry cooperator.

The large resource of gas in the lenticular sands of western basins makes it imperative to continue efforts to develop economic production techniques. In a major effort to do this, the Department of Energy's Western Gas Sands Project Multi-well Experiment (MWX) was conceived about two years ago. Government funds in the amount of Twelve Million Dollars ($12,000,000) have been pooled to drill the first two wells, closely spaced, to obtain data which should allow a good evaluation of the lenticular tight sand potential. Additional funding from future budgets will be required for the planned third well. Assistance from industry is being received in obtaining the experiment site, marketing test gas, reviewing technical plans and recommending test procedures.

The project objectives are the characterization of low-permeability, lenticular gas sands and evaluation of state-of the art and developing technology

Illustrations at end of paper.

for production stimulation. Experience has identified the following problems in producing this type of reservoir:

1. Pay sands cannot be identified consistently by log interpretation, and DSTs and individual sand production tests of the dozens of sands typical in a well are prohibitively expensive.

2. Size and geometry of the sand lenses are unknown; this prohibits efficient design of stimulation treatments.

3. Hydraulic fractures have not been performing as designed; this may be the result of breaking out of the productive zone, the inability to break into other lenses, damage to the formation, or poor fracture conductivity due to proppant crushing and embedment.

4. Even with price incentives, more efficient production techniques must be developed for purposes of conservation.

The Multi-well Experiment activities have been designed to address these and other uncertainties concerning economic production of this unconventional gas resource. Features of the Experiment include: (1) three close-spaced wells (100 to 500 ft) for reservoir characterization, conventional well tests, interference testing, well-to-well geophysical profiling, and placement of diagnostic instrumentation adjacent to fracture treatments; (2) complete core taken through the formations of interest; (3) a comprehensive core analysis program; (4) an extensive logging program featuring conventional and experimental logs; (5) determination of in situ stress in sand lenses and bounding shales; (6) application of geophysical techniques to determine sand lens orientation; (7) use of seismic, electrical potential and tilt diagnostic methods for hydraulic fracture characterization; and (8) a series of stimulation experiments.

Analysis of data from these activities will yield the following kinds of information: (1) geologic characterization emphasizing the morphology, properties and variability of lenticular sands; (2) a reservoir model for lenticular sand production; (3) a fracture model including correlations between stress, geometry and lens orientation; (4) core-log-well test correlations for improved formation evaluation, and (5) economic assessments.

EXPERIMENT SITE

Criteria for site selection were: (1) a sequence of lenticular sands representative of those which contain the bulk of the tight sand resource; (2) a blanket sand section so that a comparison can be made of stimulation results; (3) sufficient geological control for assurance of productivity; (4) both water-productive and gas-productive sands to compare log responses in each; (5) a site close to a road, pipeline and electric power and at an elevation to allow year-around operations; and (6) a site to be made available to the government for the estimated five-year term of the experiment.

Such a site was found in the Rulison Field in the Piceance Basin of Colorado. Figure 1 shows the test location in Section 34, Township 6S, Range 94W, Garfield County, Colorado. A field well exists approximately one-half mile from the test site; the Mesaverde sequence and the underlying Corcoran-Cozzette are the formations of interest and lie at depths between 4,000 and 8,600 ft. The Superior Oil Company assigned the tract to CER Corporation, who, under contract to Sandia National Laboratories, will be the operator during the life of the project, after which, Superior will resume operations.

ENVIRONMENTAL REVIEW

A Special Conditional Use Permit will be obtained from the Garfield County Commission to comply with the Garfield County zoning resolutions. A public hearing will be held by the Board of County Commissioners, at which time adjacent land owners and interested parties will be given an opportunity to express their opinions. An explanation of the operations to be conducted on site and discussion of the overall impact on Garfield County during the five-year duration of the Multi-well Experiment will be presented.

An environmental review, prepared by Lawrence Livermore National Laboratory of Livermore, California, will incorporate parts of the Garfield County Special Conditional Use Permit but will be a more comprehensive and detailed study of the MWX site. Expanded areas of study included in the review will include air quality, water quality, terrain, wildlife, habitation, vegetation, and the impact on Garfield County relating to social and economic environments associated with conducting the experiment.

DRILLING, CORING AND LOGGING PLANS

The three closely spaced wells of the Multi-well Experiment will be drilled and completed in a similar manner. The first well, MWX-1, will be cored from the top of the Mesaverde at approximately 3,950 ft to the base of the Corcoran at approximately 8,504 ft. The upper portion of the well will be drilled using a conventional low solids non-dispersed mud system. A 13-3/4 in. hole will be drilled to the top of the Mesaverde. After running a minimum logging suite, 10-3/4 in. casing will be set and cemented. After drilling out the shoe, the mud system will be converted to an oil base system for coring. An 8-3/4 in. x 4 in. conventional coring assembly will be used and selected core intervals will be oriented. Oil base mud has been selected because it should insure better core recovery and stable hole conditions for any DSTs that will be run on potential reservoir sands encountered during the coring operation, and because of the long duration the hole will be open.

At 6,500 ft interim logging will be conducted. The complete logging program is shown in Appendix I.

At total depth after logging in the oil base system, this mud will be displaced with a modified polymer mud system and the hole reamed from 8-3/4 inches to 9-1/2 inches through the open hole section from 3,950 to 8,600 ft to obtain maximum well bore exposure. The well will again be logged with the modified polymer mud in the hole and then a 7 in. production string will be run and cemented.

Present plans are to drill MWX-2 and -3 in a similar manner except that only selected intervals will be cored and tested based on results of MWX-1. A limited amount of coring will be attempted in selected intervals using a pressure core barrel. After the three wells are drilled and cased, the individual zone testing and stimulation will be initiated.

TESTING AND STIMULATION

All potential pay intervals that are identified from core analysis and mud logging will be drill stem tested using the closed chamber technique. It is planned to use a very short initial open flow (approximately 30 seconds) and then 30 minutes to one hour shut-in to establish initial bottom hole pressure in these low permeability sections. The second flow and shut-in period will be determined from testing experience in other zones. Initially it is planned for the second flow period to be one hour with a 12-hour shut-in period. These times will be adjusted as hole condition and testing experience dictate. Intervals will be selected on the basis of log, core, and test information for a series of individualized stimulation programs.

Two wells, MWX-1 and MWX-3, will be completed as potential production wells. The use of both wells would allow side-by-side comparison of different stimulations in as nearly the same geologic setting as possible. Also, both lenticular and blanket sands will be present and results of stimulation in both will be compared. Factors that will be studied during this series of experiments include: (1) fracture height and extension and treatment design factors controlling fracture containment; (2) fracturing fluids, formation and fracture face damage, fracturing fluid cleanup, fracture conductivity and proppant transport; and (3) proppant performance including crushing, imbedment, placement and concentrations.

Two key questions will be addressed in these programs. First, can lenses remote from the wellbore be intersected and produced by hydraulic fractures? Second, can a sequence of lenses in contact with the wellbore be effectively stimulated with a single treatment?

Fracturing research necessary to improve stimulation technology is being conducted at various industrial and national laboratories. Output from this R&D effort will be included in these experiments.

One of the wells will be used primarily to obtain stress measurements in order to design and evaluate the fracturing experiments. Downhole and surface monitoring equipment will be used to determine fracturing response and fracture geometry. The closely-spaced wells will not only be used as observation wells during the fracture treatment, but also as pressure monitoring wells during the pre-stimulation testing of the principal well. The pulse or interference type tests should also allow measurement of directional variation in the reservoir properties. Results of the testing program will be used to further the understanding of the log and core correlations.

The following fracture diagnostic techniques will be used during stimulation: surface electrical measurements and tiltmeters (for massive hydraulic fractures), borehole seismic (for smaller fractures) and borehole hydrophones (fracture containment and height). Other methods; X-ray tracer, temperature logs, etc., will be used as appropriate. Instrument packages for fracture detection will be placed in the well to be fractured and also in offset wells. MWX-2 will ultimately be used as an observation well for the fracturing in MWX-1 and/or MWX-3 once the stress testing has been completed.

CORE HANDLING AND ANALYSIS

A comprehensive core analysis program will be conducted. MWX-1 will be cored through the Mesaverde sequence and will provide approximately 4,500 ft of core, portions of which will be oriented. Selected intervals in MWX-2 and MWX-3 will also be cored.

Special field handling procedures include: (1) a core gamma log in the field to correlate log and core depths, (2) taking of plugs for screening analyses, (3) measurement of dip and strike of core features, (4) core field processing in an all weather facility at the site.

An MWX core library is being established in the DOE/Bendix facility at Grand Junction, Colorado, for the handling, examination, distribution and storage of the core. Representative core of all types will be preserved. This location is convenient to the MWX site and all groups that will be examining the core.

Core analysis will be performed on three different "tracks" based on the turnaround required. The fast track analyses will provide data that must be obtained rapidly. These are analyses needed (1) to confirm the adequacy of the site, (2) to determine in situ stress orientations as an aid in locating the offset wells, and (3) to aid in the selection of zones for initial testing. The fast track analysis is to be performed while the drill rig is still on site. By the time casing is set on MWX-1, the location of MWX-2 will have been determined, and the same drilling rig will be used on MWX-2. The tests used to determine the in situ stress orientation from oriented core are: stress/strain relaxation measured at the site, fracture anisotropy, Brazil test, and residual strain. Plug tests will be taken at appropriate intervals to screen the core (porosity, grain density, and some permeabilities). This information, along with the logs, DST, RFT, etc., will then be examined to determine the zones of interest.

The middle track analyses support the stimulation phase of the experiment. The zones which are to be stimulated and their associated boundary strata will be studied in detail. Some of the activities which require these analyses are log interpretation, selection of zones for testing and stimulation, and stimulation design. Analyses will include reservoir parameters at simulated in situ conditions, electrical tests, fracture conductivity studies, and rock mechanics tests plus fracture toughness and sonic velocity at pressure.

Almost all core analysis that does not directly support site verification, placement of wells, well testing, stimulation of log/core correlation can be considered slow track analysis. This work will provide significant understanding of the synergisms among categories of core analyses, (e.g., reservoir parameters, rock mechanical properties, and mineralogy) and will help answer many of the questions concerning production from tight lenticular sands.

IN SITU STRESS PROGRAM

It is known that vertical hydraulic fractures align with the direction of the maximum in situ horizontal stress, and analytical studies support evidence from laboratory and field experiments that vertical changes in the horizontal in situ stress affect vertical containment of an induced fracture. Knowledge of the in situ stress orientation and magnitude as a function of depth at the MWX site will assist in selecting offset well locations and stimulation intervals. The goals of this stress evaluation activity are to measure orientation and magnitude of in situ stress as a function of depth and to develop a stress predictive capability.

Stress measurements will occur at three scales: regional (Piceance Basin); site specific at surface (within 10 miles of the site); and site specific at depth (in the wellbore). A suite of measurements will be used at each scale to allow evaluation of each method and to give a best estimate of the orientation and magnitude of the in situ stress.

A number of factors may control present in situ stresses at the MWX site. One goal of the stress prediction program is to understand the characteristic stress signature of each factor. This information, in conjunction with early results of the stress measurement program, can be used to determine the most dominant factor. The other goal is a prediction of stress changes with depth with ultimate validation of the prediction by downhole stress measurements.

Numerous mini-fracs will be conducted in the sandstone lenses and bounding shales in the "stress test" well, MWX-2. The most important information to be obtained from these fracture tests is the instantaneous shut-in pressure (ISIP), which theoretically is equivalent to the minimum principal in situ stress (usually horizontal) at that location. Variations in this stress around possible gas producing lenses may provide a containment feature which will allow long penetrating fractures to be created in the lens without breaking into the surrounding shales. Knowledge of the stress distribution can be utilized in the design of the fracture treatment.

This in situ stress data will also be correlated with the in situ stresses (ISIP) obtained from fracture treatments in the other wells. This will provide an estimate of the horizontal variations in the in situ stress and confirm whether in situ stress containment features measured in the stress well are consistent with fracture behavior.

DIAGNOSTIC MEASUREMENTS

Prior to drilling, geophysical seismic surveys will be conducted to map any site specific geologic structures and to determine, if possible, the shape and orientation of the objective channel sand reservoirs.

The techniques employed will include a high resolution, three-dimensional seismic reflection survey, a transient electromagnetic survey, and a controlled-source, audio-magnetotelluric survey. Net areal coverage for all surveys will be approximately 1/4 section.

A velocity check shot survey will be run in MWX-1 to determine accurate interval velocities in the section of interest for log analysis and to provide accurate seismic travel times from the surface to prominent reflecting horizons for calibration of the surface reflection survey.

Spatial variation in velocity and attenuation of seismic waves in the section between two wells will be determined as a means of delineating lens shape and layering within that section.

ANALYSIS AND EVALUATION

The Multi-well Experiment will produce a unique, comprehensive data base. The analysis and evaluation activity will use these data in three general areas.

Sufficient information will be available for the first time to permit identification of specific factors contributing to or detracting from gas production. As such, these results will influence research and development efforts both within DOE's Western Gas Sands Project and industry.

Second, specific project goals and questions can be addressed. These include determination of quantitative core property-log correlations and measurement of accurate in situ reservoir properties from well testing, pressure coring, and core property measurements under restored state conditions. A key question, can lenses remote from the wellbore be intersected and produced by a conductive massive hydraulic fracture, will be answered. As another example the effective fracture area within a given lens can be determined from a correlation of in situ stresses, lens morphology, and hydraulic fracture azimuth and geometry; then, the question, is production consistent with this effective area, can be evaluated.

Finally, significant advances in the different models required to assess lenticular gas production will be possible. These models include: (a) a geologic model based upon site specific information (cores, logs, seismic data, stress, production, etc.) combined with other regional data to yield a sedimentological basin model for the lenticular sands in the Upper Cretaceous in the Piceance Basin; (b) a reservoir model for lenticular sands based on single and well-to-well testing, core data, logs and analyses; (c) modified fracture and stimulation models based upon the improved in situ stress, fracture diagnostic and production test data which will be available; and (d) an overall systems model for lenticular, tight gas sands production.

The latter model consists of three major parts:

geologic-reservoir, stimulation and economic modules. The first yields an estimate of gas in place (the target), the second gives gas produced as a function of time (that recoverable), and the third calculates the dollars obtained (the return on investment). It is feasible in that current data and assumptions can be used and parametric studies run to determine quantitatively the critical parameters affecting production and economics. Thus, it is also a planning tool. As MWX results, analyses, and improved models become available, they can be included and periodic updates obtained. Finally, improved estimates will be made of the recoverable gas from the lenticular gas sands of the Mesaverde.

APPENDIX I

MWX LOGGING PROGRAM

Priorities for logs have been assigned according to the following code:

1 Logs critical to adequately characterize basic reservoir parameters including porosity, fluid saturations and permeability. Logs necessary to compute mechanical rock properties, discern natural fracture systems, measure geologic structure, provide stratigraphic correlation, and characterize sedimentary structures, textures, and lithology. Logs required as a control for cased hole well testing and/or geophysics.

2 Experimental or developmental logs which provide additional information and show promise for tight gas sand resource characterization.

3 Logs which provide additional information and are therefore included for completeness. Logs, which in the final analysis, may prove to be redundant. Logs that provide minimal additional information and are included principally for quality control. Logs that characterize non-productive intervals but may be necessary to establish gradients or profiles.

Run No. Type Mud Depth	Priority	Log	Repeats and Remarks
Run 1 Water base mud 3,900 ft-surface	1	Dual Induction	
	1	BHC Sonic/GR/TTI	
	3	Formation Density	
	3	Compensated Neutron/GR	
Run 2 Oil base mud 6,500-3,900 ft	1	Dual Induction	
	1	BHC Sonic/GR/TTI	
	1	Litho Density	Repeat entire interval
	1	Compensated Neutron/GR	Repeat entire interval
	1	Natural Gamma Spectroscopy	Repeat entire interval
Run 3 Oil base mud 8,600-3,900 ft	1	Multifrequency Induction/GR	
	1	Litho Density	Log to 6,000 ft, repeat to 6,500 ft
	1	Compensated Neutron	Log to 6,000 ft, repeat to 6,500 ft
	1	Natural Gamma Spectroscopy	Log to 6,000 ft, repeat to 6,500 ft
	1	Long Space Sonic/GR/TTI with wave form digitizing	Digitize to 6,000 ft
	1	Carbon/Oxygen Log continuous	Log to 5,600 ft, 20 stations, photo record
	2	Nuclear Magnetic Log	Log 20 stations - digitize free precession decays, repeat to 6,500 ft
	2	Circumferential Microsonic Log (if available)	
	2	Dielectric Constant Log/Gamma	
	3	Sidewall Epithermal Neutron/GR	Repeat to 6,500 ft

	3	Dual Spacing TDT (M tool)	Repeat to 6,500 ft
	3	Borehole Televiewer (or Pulse Echo CBL)	
	3	Compensated Density/Gamma Caliper, 2210 tool	Repeat to 6,500 ft
Run 4 Modified Polymer 8,600-3,900 ft	1	Dual Laterolog/μ SFL/SP	
	1	Litho Density	Repeat 700 ft (selected)
	1	Compensated Neutron/GR	Repeat 700 ft (selected)
	1	Dipmeter Standard 4 x 2 ft cluster Geodip 3 pass 1 ft x 4 in cluster	 800 ft selected intervals
	1	Fracture Identification Log	
	2	Electromagnetic Propogation with Microlog	
	3	Dual Induction/SFL/SP	
Run 5	1	Cement Bond Log-Gamma/csg. collar Log VDL and wave train presentation	
	1	Dual Spacing TDT (M Tool)	Log to 5,000 ft, repeat to 6,500 ft
	1	Long Space Sonic with VDL/GR	Log to 5,000 ft
	1	Surface-Downhole Velocity Survey (check shot survey)	
		Computed Logs - Library Tapes	
		Cyberlog	
		Compositing Runs (runs 2,3,4)	
		Library Tapes (3,900-8,600 ft)	
		Library Tape Copies (2)	
		Advanced Computations (compressional and shear mechanical properties)	
		Other Computations (Rwa, Visual Mergers)	

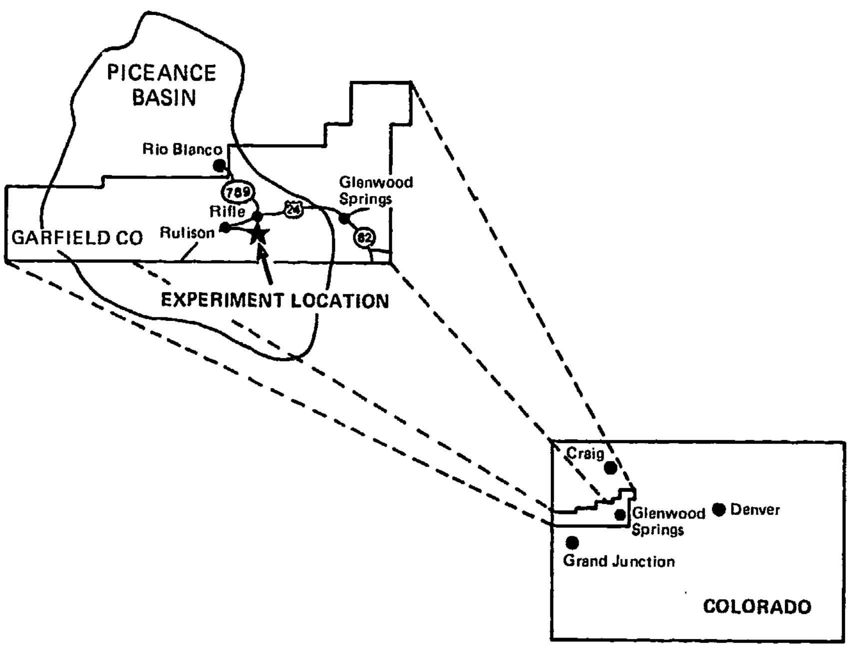

Fig. 1 - Multi-well experiment location