TECHNICAL PROGRESS REPORT

DOE/BC/14936--7

Title:

APPLICATION OF ADVANCED
RESERVOIR CHARACTERIZATION,
SIMULATION, AND PRODUCTION
OPTIMIZATION STRATEGIES TO
MAXIMIZE RECOVERY IN SLOPE AND
BASIN CLASTIC RESERVOIRS, WEST
TEXAS (DELAWARE BASIN)

Cooperative Agreement No.:

DE-FC22-95BC14936

Institution:

Bureau of Economic Geology
The University of Texas at Austin
University Station, Box X
Austin, Texas 78713-7508

Date of Report:

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\$1,010,208

Program Manager:

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Reporting Period:

July 1, 1996 - September 30, 1996

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OBJECTIVES

The objective of this project is to demonstrate that detailed reservoir characterization of slope and basin clastic reservoirs in sandstones of the Delaware Mountain Group in the Delaware Basin of West Texas and New Mexico is a cost effective way to recover a higher percentage of the original oil in place through strategic placement of infill wells and geologically based field development. Project objectives are divided into two major phases. The objectives of the reservoir characterization phase of the project are to provide a detailed understanding of the architecture and heterogeneity of two fields, the Ford Geraldine unit and Ford West field, which produce from the Bell Canyon and Cherry Canyon Formations, respectively, of the Delaware Mountain Group and to compare Bell Canyon and Cherry Canyon reservoirs. Reservoir characterization will utilize 3-D seismic data, high-resolution sequence stratigraphy, subsurface field studies, outcrop characterization, and other techniques. Once the reservoir-characterization study of both fields is completed, a pilot area of approximately 1 mi² in one of the fields will be chosen for reservoir simulation.

The objectives of the implementation phase of the project are to (1) apply the knowledge gained from reservoir characterization and simulation studies to increase recovery from the pilot area, (2) demonstrate that economically significant unrecovered oil remains in geologically resolvable untapped compartments, and (3) test the accuracy of reservoir characterization and flow simulation as predictive tools in resource preservation of mature fields. A geologically designed, enhanced-recovery program (CO₂ flood, waterflood, or polymer flood) and well-completion program will be developed, and one to three infill wells will be drilled and cored. Through technology transfer workshops and other presentations, the knowledge gained in the comparative study of these two fields can then be applied to increase production from the more than 100 other Delaware Mountain Group reservoirs.

SUMMARY OF TECHNICAL PROGRESS

Geophysical Characterization

Seismic interpretation continued on the Ford Geraldine Unit 3-D survey. The top of the Lamar Lime and the top of the Manzanita Lime have been picked and interpreted, and the horizons are being refined across the survey. Work on the seismic attributes of Instantaneous Phase, Instantaneous Frequency, and Reflection Strength are continuing. The imaging of the top of the Lamar with seismic data is a noteworthy technological success. The top of the Lamar has not previously been satisfactorily imaged with seismic data due to shallow statics problems in the area. The top of the Lamar was imaged in areas where the seismic data has a value of 48 fold to stack or greater.

Reservoir Characterization

Subsurface Field Studies.—In addition to using 3-D seismic data, the project is also characterizing heterogeneity of Geraldine Ford and West Ford fields using subsurface logs and cores. All logs have been digitized and entered into the Landmark software OpenWorks™, along with core-analysis and perforation data. Tops have been picked in the main reservoir intervals of both fields, and a grid of cross sections in West Ford field and Ford Geraldine unit has been produced. A complete suite of structure maps and isopach maps of key reservoir surfaces and intervals has been made.

All whole cores received from Conoco for this study have been slabbled. A total of 3,370 ft of core from 63 wells from the Ford Geraldine unit and Ford West field have been described. Approximately 400 ft of core from 8 wells located in the Ford Geraldine unit remain to be described. Core descriptions, sampling, and photography will be completed by the end of October.

A major focus of the project this quarter was petrophysical characterization of the Ford Geraldine unit. Because most of the wells in the unit were drilled and logged in the 1950s and early 1960s, special techniques had to be used to maximize the information that could be derived from old logs. A new technique was developed to determine the value of saturation exponent (n), which is used to calculate hydrocarbon saturation of a reservoir from geophysical logs. This approach uses water saturations measured by core analysis; these data are generally available in mature fields that have few or no relative permeability curves.

Prior to this quarter, the gamma ray logs were normalized. This quarter, all the Ford Geraldine unit and West Ford field wells that have "old" non-porosity neutron logs were normalized. Next, core porosity versus core permeability cross plots were constructed to determine porosity cut-offs based on permeability and a porosity-permeability transform. Using core porosity and log data, sonic travel times and normalized neutron porosities were cross plotted in order to determine log-core porosity transforms.

Next, an examination of the wells with resistivity logs revealed that in many wells only a deep laterolog was run. Therefore, in order to determine true formation resistivity (R_t), a deep laterolog- R_t transform was developed based on data from wells with shallow laterologs or microresistivity logs (MLL or MSFL) in addition to deep laterologs. Without this transform, oil saturation would be underestimated in all the wells with only deep laterologs.

A combination of both core and log data was then used to determine values for cementation exponent ($m=1.83$) and saturation exponent ($n=1.90$) for use in the Archie water-saturation equation. Cross plots of core porosities and core water saturations, when compared to log-derived porosities and log-derived water saturations, indicated very similar values, thus verifying the log-derived data. The next step in the analysis will be to calculate bulk volume water (BVW) values in all the wells with resistivity logs and map BVW across the field. BVW values can then be assigned to the many wells (80%) with no resistivity logs, based on their location on the BVW map. Water saturation can then be calculated in the wells without resistivity logs by the equation $S_w = BVW / \text{Porosity}$. With water saturations calculated in all the wells that have a porosity log, a hydrocarbon pore-foot map can then be constructed.

In order to determine a value for saturation exponent (n) for the Ramsey sandstone in the Ford-Geraldine unit, two different, independent approaches were used, including a new approach that was developed as part of this study. In the traditional approach, core and log data from well FGU 156 were used.

Data for Calculating Saturation Exponent

a=1.0

m=1.83

Rw=0.092 @ Tf

<u>Depth (ft)</u>	<u>Core Porosity</u>	<u>Rt</u>	<u>Sw*</u>	<u>n</u>
2575	15.65	9.25	47%	1.60
2583	26.2%	7.90	38%	2.07
2583	25.8%	7.54	37%	1.94
2593	23.8%	7.96	40%	2.00
2599	26.0%	6.44	39%	1.89
				average n = 1.90

* Sw from relative permeability curves

However, a weakness in the above procedure is the use of only five saturation exponents (n) to represent the average saturation exponent for the entire field. To help verify the average n value of 1.90, a new procedure was developed. The new procedure also involved the use of both core and log data, but water saturations (Sw) were determined from core-analysis data, not from the relative permeability curves. The advantage of using the core-analysis water saturations is that much more data can be analyzed to obtain saturation exponent. Using core porosities and core water saturations from 5 wells (192 depths) plus true formation resistivity values (Rt) from the same depths, the ratio of Rt/Ro was calculated ($R_o = [1/\text{Core Porosity}^{1.83}]$), and a cross plot of Sw versus Rt/Ro was constructed. The slope of the best fit line (i.e., n) on the cross plot (assuming: Rt/Ro=1.0 @ Sw=100%) was 1.97. A saturation exponent (n) of 1.97 compares very well with the 1.90 value determined from the relative permeability curves but is based on much more data. The larger data set used to determine that n=1.97 should result in more reliable log-derived water saturations.

Outcrop Characterization

Detailed characterization of outcrops located on the Cowden Ranch, Culberson County, Texas, is currently underway. The purpose of this task is to develop an architectural model of reservoir heterogeneity based on outcrop observations of the Bell Canyon Formation and to refine current models that account for the deposition of these sandstones. The detailed study site was selected because it represents a well exposed basinal deep-water system, it displays many similarities to deep-water reservoirs in the Delaware Basin, and the outcrops provide an excellent opportunity for defining the three-dimensional facies architecture.

Our approach is to collect quantitative geologic data from laterally continuous exposures over the distance of several kilometers and use this information to construct realistic models of reservoir heterogeneity. The site is being characterized by describing facies successions and correlating the bounding discontinuities that terminate the successions along closely spaced transects. As a result the correlations are largely descriptive rather than interpretative.

The exposures have been photographed using a large format camera, and the images assembled into mosaics that provide complete coverage of the outcrop. Within the study area, more than twenty lithologic logs spaced at intervals of approximately 1,000 ft have been measured. Key surfaces and facies successions have been correlated between each log in the field and recorded on the photomosaics. The data are currently being assembled into a cross section from which both qualitative and quantitative information on the geometry, dimensions, and continuity of sandstone and mudstone beds can be extracted. In the next quarter, scintillometer data will be collected from each lithologic log to help demonstrate the relationship between the outcrop sections and reservoir equivalents.

While it has long been recognized that laterally extensive, organic-rich siltstones, interpreted as marine condensed sections, subdivide the mid-Permian Bell Canyon Formation into a number of genetic stratigraphic units, the processes responsible for deposition of the sandstones have remained the source of controversy (Ruggiero, 1985 and 1993; Fischer and Sarnthein, 1988; Gardner, 1992 and in press). Relationships seen within a single genetic unit indicate the sandstones were largely deposited by turbidity currents during the progradation, aggradation, and retrogradation of a submarine fan and channel-levee system.

The basal organic-rich siltstone is conformably overlain by thin beds of laminated siltstones and massive to graded, fine sandstones that coarsen and thicken upward. The succession is up to 10 m thick and displays a lobate geometry that is 5-10 km in length. The basal succession is locally cut out by a series of vertically and laterally stacked, lens-shaped sandstone bodies that are up to 20-m thick and 200 to 300 m in width and that can be traced to the south for 5 km between adjacent outcrops. The lens-shaped bodies are flanked by 1-6 m thick, upward-fining successions of thinly-bedded, ripple-laminated siltstones and sandstones that progressively thin and fine away from the lens-shaped bodies over the distance of a few hundred meters. The deposits are conformably overlain an organic-rich siltstone. The relationships described are consistent with turbidity current model. Basal sandstone were deposited by unconfined flows on the lower to middle portion of a submarine fan. The overlying lens shaped sandstone bodies that pass laterally into ripple laminated siltstones were deposited by a system of channels and levees on the mid to upper portion of the fan.

Producibility Problem Characterization

The CO₂ flood history of Ford Geraldine unit was summarized by Pittaway and Rosato (1991). Oil production had dropped to 300 BOPD before the start of the flood in 1981. Production was still near 300 BOPD when higher and constant CO₂ injection began in December, 1985, when a CO₂ supply problem was solved. Production response occurred in 1986, and production increased through 1990. Production was about 1,700 BOPD in October, 1990, with the best well producing 60 BOPD. Gas production was about 200 Mcf/d at the start of CO₂ injection. Gas production in 1991 was up to 10 MMcf/d (84% CO₂), resulting from the response to the CO₂ injection.

Technology Transfer

Three abstracts based on work performed for this project were submitted to the 1997 AAPG Annual Meeting, which will be held in Dallas, Texas, in April, 1997. The paper "Basin Floor Fan and Channel-Levee Complexes, Permian Bell Canyon Formation" by Mark D. Barton was submitted for oral presentation in a session on New Concepts in Deep-Water Reservoir Sand Development. The papers "Reservoir Characterization of Permian Deep-Water Ramsey Sandstones, Bell Canyon Formation, Ford Geraldine Unit, West Texas (Delaware Basin)" by Shirley P. Dutton, Mark D. Barton, Susan D. Hovorka, Andrew G. Cole, and George B. Asquith and "Geophysical Characterization of Permian Deep-Water Sandstones, Bell Canyon Formation and Cherry Canyon Formation, Geraldine Ford Area, West Texas (Delaware Basin)" by Andrew G. Cole, Shirley P. Dutton, Mark D. Barton, Susan D. Hovorka, and George B. Asquith were submitted to a poster session on Results of Joint DOE/ Industry Programs.

PLANNED ACTIVITIES

On the basis of reservoir characterization of Ford Geraldine unit and West Ford field, the decision has been made to focus on the northern end of Ford Geraldine unit as the proposed demonstration area. This area will become the focus of reservoir simulation and detailed evaluation of reservoir heterogeneity during the next two quarters. This area was chosen over West Ford field for the following reasons: (1) the greater amount of available data from Ford Geraldine unit, including cores, logs, and core-analysis data, and (2) the greater applicability of outcrop information to the upper Bell Canyon reservoir interval in Ford Geraldine unit than to the lower Bell Canyon/upper Cherry Canyon reservoir in West Ford field.

Activities in the upcoming quarter will focus on five major areas: (1) using synthetics to tie the 3-D seismic survey to wells in West Ford and Geraldine Ford fields, (2) continuing field studies of Bell Canyon sandstones in outcrop, (3) characterizing depositional heterogeneity in the Geraldine Ford reservoirs by integrating core descriptions with log and core-analysis data, (4) using petrophysical data to map net-pay thickness in Geraldine Ford field, and (5) developing a detailed geostatistical model for the distribution of reservoir properties in the Ford Geraldine demonstration area. The core data are being analyzed to determine statistical parameters and the autocorrelation structure that will be used for developing a detailed geostatistical model for the distribution of reservoir properties. This model will be used as an input for reservoir simulations of the demonstration to evaluate the fluid flow performance of the reservoir.

REFERENCES

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- Gardner, M. H., in press, Reservoir characterization of deep-water siliciclastic reservoirs in the upper Bell Canyon and Cherry Canyon Formations of the northern Delaware Basin, West Texas, in Major, R. P., ed., *Oil and gas on Texas State Lands: an assessment of the resource and characterization of type reservoirs*: The University of Texas, Bureau of Economic Geology Report of Investigations.
- Gardner, M. H., and Sonnenfeld, M. D., 1996, Stratigraphic changes in facies architecture of the Permian Brushy Canyon Formation in Guadalupe Mountains National Park, West Texas, in DeMis, W. D., and Cole, A. G., eds., *The Brushy Canyon play in outcrop and subsurface: concepts and examples*: Guidebook, Permian Basin Section, SEPM, Publication No. 96-38, p. 17-40.
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- Ruggiero, R. W., 1985, Depositional history and performance of a Bell Canyon sandstone reservoir, Ford-Geraldine field, west Texas: unpublished M. A. thesis, Austin, The University of Texas, 242 p.
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**U.S. DEPARTMENT OF ENERGY
MILESTONE LOG**

ELEMENT CODE	DESCRIPTION	PLANNED COMPLETION DATE	ACTUAL COMPLETION DATE	COMMENTS
ACTIVITY 1.	Geophysical Characterization			
Task 1.	Design 3-D Seismic Program	6/30/95	5/25/95	100% Complete
Task 2.	Acquire 3-D Seismic Grid	12/31/95	7/25/95	100% Complete
Task 3.	Process 3-D Seismic Data	3/30/96	12/31/95	100% Complete
Task 4.	Interpret 3-D Seismic Data	3/30/97		60% Complete
ACTIVITY 2.	Reservoir Characterization			
Task 1.	Data Base Design and Construction	9/30/95	11/10/95	100% Complete
Task 2.	Subsurface Field Studies	9/30/96	9/30/96	100% Complete
ACTIVITY 3.	Outcrop Characterization			
Task 1.	Establish Sequence Stratigraphy	11/31/95	9/30/96	100% Complete
Task 2.	Petrophysical and Statistical Characterization	6/30/96		83% Complete
ACTIVITY 4.	Producibility Problem Characterization			
Task 1.	Review of Waterflood History	3/30/96	9/30/96	100% Complete
Task 2.	Review of CO ₂ Flood History	9/30/96	9/30/96	100% Complete
Task 3.	Review of Ford West Production History	3/30/97		
Task 4.	Analysis of Reservoir Heterogeneity	3/30/97		
ACTIVITY 5.	Recovery Technology Identification and Analysis			
Task 1.	Reservoir Simulation	3/30/97		
Task 2.	Develop Guidelines for Site Selection-Infill Wells	3/30/97		
Task 3.	Develop Guidelines for Site Selection- Injector Wells	3/30/97		
ACTIVITY 6.	Technology Transfer			
Task 1.	Publish Results	3/30/97		60% Complete
Task 2.	Workshop	3/30/97		
ACTIVITY 7.	Management and Administration			
Task 1.	Reports and Deliverables	3/30/97		75% Complete
Task 2.	DOE Contractor Review Meetings	3/30/97		75% Complete
ACTIVITY 8.	Project Continuation			
Task 1.	Prepare Project Plan	3/30/97		
Task 2.	Prepare Budget	1/31/97		

U.S. DEPARTMENT OF ENERGY
MILESTONE SCHEDULE ☐ PLAN ☐ STATUS REPORTFORM APPROVED
OMB NO. 1901-1400

1. TITLE		Application of Advanced Reservoir Characterization, Simulation, and Production Optimization Strategies to Maximize Recovery in Slope and Basin Clastic Reservoirs, West Texas (Delaware Basin)		2. REPORTING PERIOD		April 1-June 30, 1996		3. IDENTIFICATION NUMBER		DE-FC22-95BC14936																	
4. PARTICIPANT NAME AND ADDRESS		Bureau of Economic Geology The University of Texas at Austin Box X, University Station Austin, Texas 78713						5. START DATE		3/31/95																	
6. COMPLETION DATE		3/30/97																									
7. ELEMENT CODE	8. REPORTING ELEMENT	9. DURATION												10. PERCENT COMPLETE													
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ACTIVITY 1. Geophysical Characterization																											
Task 1.	Design 3-D Seismic Program																									100%	100%
Task 2.	Acquire 3-D Seismic Grid																									100%	100%
Task 3.	Process 3-D Seismic Data																									100%	100%
Task 4.	Interpret 3-D Seismic Data																									80%	80%
ACTIVITY 2. Reservoir Characterization																											
Task 1.	Data Base Design and Construction																									100%	100%
Task 2.	Subsurface Field Studies																									100%	100%
ACTIVITY 3. Outcrop Characterization																											
Task 1.	Establish Sequence Stratigraphy																									100%	100%
Task 2.	Petrophysical and Statistical Characterization																									100%	83%
ACTIVITY 4. Productivity Problem Characterization																											
Task 1.	Review of Waterflood History																									100%	100%
Task 2.	Review of CO2 Flood History																									100%	100%
Task 3.	Review of West Ford Production History																										
Task 4.	Analysis of Reservoir Heterogeneity																										
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ACTIVITY 7. Management and Administration																											
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ACTIVITY 8. Project Continuation																											
Task 1.	Prepare Project Plan																										
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11. SIGNATURE OF PARTICIPANT'S PROJECT MANAGER AND DATE																										S. P. Dutton	10/24/96