DOE/BC/14936--8

BC/14936-8

TECHNICAL PROGRESS REPORT

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:	January 30, 1997
Award Date:	March 31, 1995
Anticipated Completion Date for this Budget:	March 30, 1997
Government Award for this Budget Period:	$1,010,208
Program Manager:	Edith C. Allison
Principal Investigator:	Shirley P. Dutton
Permanent Contracting Officer's Representative:	Edith C. Allison
Temporary Contracting Officer's Representative	Jerry Casteel
Reporting Period:	October 1, 1996 - December 31, 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 mi^2 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 (CO_2 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. Work on the seismic attributes of instantaneous phase, instantaneous frequency, and reflection strength is continuing. The next step in the seismic interpretation is correlation of seismic attributes with reservoir attributes such as sandstone thickness, net pay, porosity-feet, and permeability-feet. This correlation is scheduled to be completed in February, 1997 and will complete the seismic interpretation task.

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 whole cores received from Conoco for this study have been slabbed. Core descriptions from the Conoco archives have been completed and includes a total of 3,787 feet from 74 wells. This includes 4 cores from the Ford West field for a total of 172 feet and 70 cores from the Ford Geraldine field for 3,615 feet. Sampling and photography will be an ongoing effort, but all representative sampling and photography has been completed. The excellent coverage of cores in the Ford Geraldine and Ford West fields provides a unique opportunity to collect from these cores diagenetic and stratigraphic data, and identification of facies as they relate to the depositional environment.

Reservoir characterization of Geraldine Ford field has integrated data from cores and core-analysis data, outcrop characterization, petrography, and petrophysical data from wireline logs. Ramsey sandstones occur in the uppermost cycle of the Bell Canyon Formation and are interpreted to represent progradation, then retrogradation, of an elongate submarine channel and lobe complex formed by sediment-gravity flows on the basin floor. On the basis of core description and field mapping of Bell Canyon sandstones exposed in outcrop 24 mi from Ford Geraldine unit, the reservoir sandstones are interpreted to consist of sheetlike lobe deposits overlain and incised by lenticular 1,000-ft-wide channels. Adjacent levee and overbank deposits vertically and laterally separate channel sandstone bodies. At the northern end of the field, the Ramsey reservoir interval is divided into two layers separated by a low-permeability siltstone. The Ramsey interval is bounded by laterally continuous, organic-rich distal-fan siltstones.

Petrophysical characterization of the Ford Geraldine unit continued this quarter. Most of the wells in the unit were drilled and logged in the 1950s and early 1960s, so special techniques had to be used to maximize the information that could be derived from old logs. Because 80% of the available wells with porosity logs do not have resistivity logs, an indirect method for obtaining water saturation was applied. This indirect method is as follows:

1. Using core corrected porosity plus water saturations calculated by the modified Archie equation (i.e. a=1.00, m =1.83 and n=1.90), calculate bulk volume water (BVW=Sw*Porosity) at each depth with a porosity of 15% or greater in each well that has a resistivity log.

2. Calculate an average BVW (BVW_{ave}) value for each of these wells and construct a BVW_{ave} contour map.

3. Assign BVW_{ave} values to each of the wells that do not have resistivity logs, based on the position the individual wells plot on the BVWave map.

4. Calculate water saturation (Sw=BVWave/Porosity) at each depth with a porosity ≥ 15% in each of the wells that do not contain a resistivity log.

With water saturations calculated in all the wells that have a porosity log, net-pay and hydrocarbon pore-foot maps will be constructed.

Outcrop Characterization

During the reporting period, the collection of field scintillometer data and mapping of stratal architecture continued on exposures of the Permian Bell Canyon Formation in Culberson County, west Texas. Objectives of this work are the following: (1) develop a more detailed interpretation of the stratigraphy and processes responsible for deposition of the Bell Canyon Formation, (2) characterize the dimensions and internal arrangement of flow units, baffles, and barriers as seen in outcrop, and (3) establish methods for applying outcrop data to characterization studies in analog reservoirs.

Regionally, the Bell Canyon Formation consists of stratigraphic cycles at several scales. At the larger scale, cycles (referred to as intermediate-order) are 50 to 125 m thick and are composed of a sandstone-dominated succession bounded by regionally correlative carbonate mudstones (i.e. Hegler, Pinery, Radar, Flaggy, McCombs, Middle, and Lamar Limestones). In turn, these intermediate-order cycles are composed of 3 to 6 high-order cycles bounded by thin organic-rich

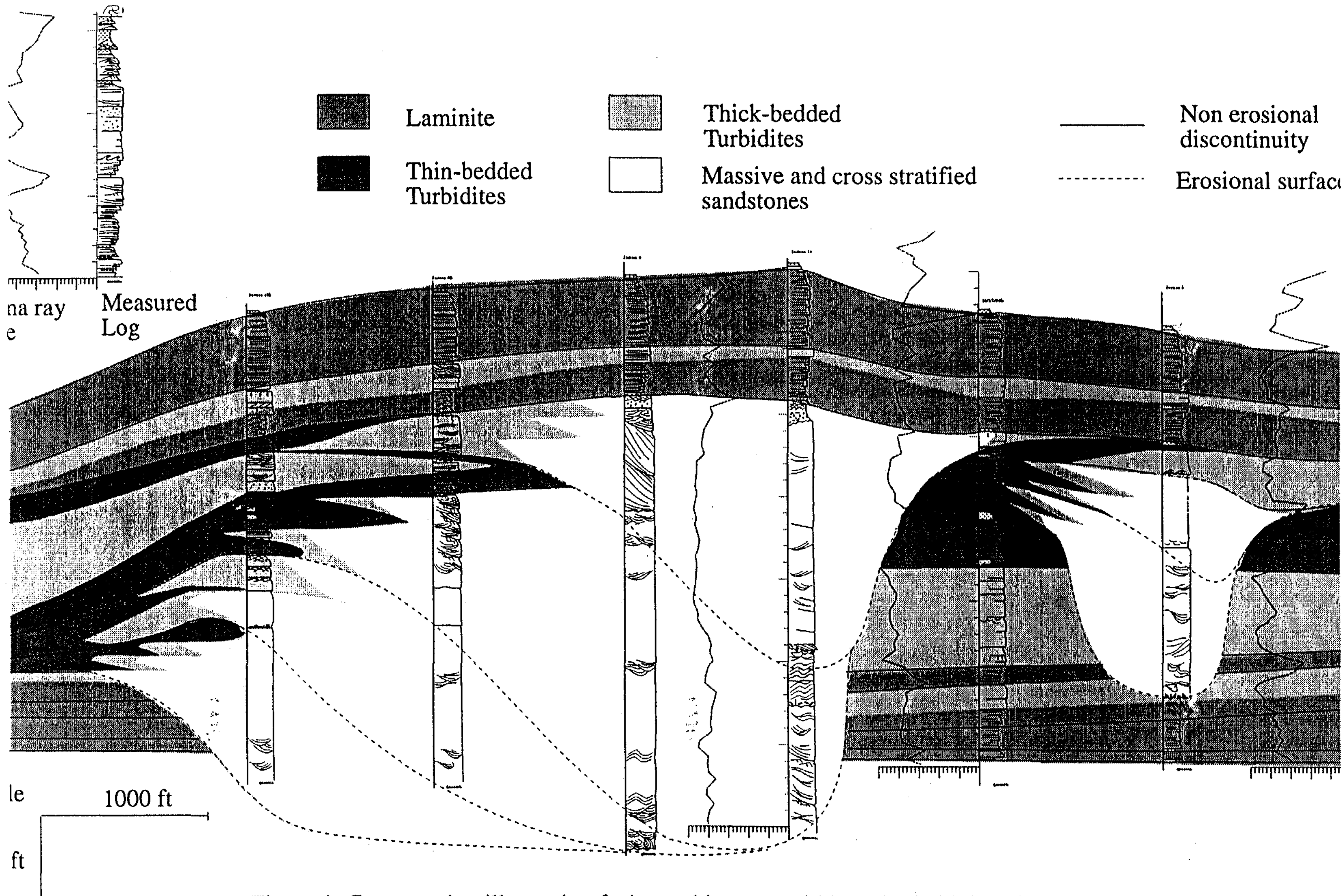

Figure 1. Cross section illustrating facies architecture within a single high-order cycle.
Location of cross section is from Willow Mountian case study, Cowden Ranch, Culberson County, Texas

siltstones. These high-order cycles are 15 to 30 m thick and are composed of an upward-coarsening, followed by an upward-fining, sandstone-dominated succession.

Our outcrop work focuses on stratigraphic relationships within basinal deposits of a single high-order cycle. The cycle under investigation is situated near the top of an intermediate order cycle bounded at the base by the McCombs Limestone and at the top by the Middle Limestone. The scale and position of this stratigraphic unit within the larger intermediate-order cycle is directly analogous to the Ramsey interval in the Geraldine Ford Field, which occurs in an equivalent position in the intermediate cycle below the Lamar Limestone.

Field work has been concentrated at two study areas referred to as Willow Mountain and Wild Horse Draw. At Willow Mountain, exposures are several kilometers in length and are aligned perpendicular and parallel to the depositional strike of the system. Photographs of the outcrops have been assembled into photomosaics. Twenty-four sections have been measured, described, correlated, and assembled into cross sections. The cross sections (see figure 1) establish the dimensions, geometry, and stacking pattern of interpreted submarine lobe and channel-levee complexes. The internal architecture within a single channel-levee system is documented in detail from exceptional exposures located in Wild Horse Draw.

Preliminary interpretations of the stratigraphy and lithofacies indicate the presence of several large channel-form sandstone bodies (figure 1). These sandstone bodies are elongate in a north–south direction and display a broad, funnel-shaped geometry that is up to 20 meters thick and several hundred meters wide. The channel-form bodies are incised into upward-coarsening successions of lutite, siltstone, and sandstone that are 1-5 m thick and have a sheet-like geometry. The channel-form bodies show evidence of lateral migration and are bounded by lenticular fine-grained deposits interpreted as channel levees. In a basinward direction the channels bifurcate and are flanked by laterally extensive, sheet-like sandstones interpreted as submarine lobes. Within the high-order cycle, submarine lobe and channel-levee complexes initially step basinward, then aggrade, and finally retrograde.

Gamma-ray measurements were also made along many of the measured lithologic logs. Gamma logs are used by geologists to evaluate lithology and correlate strata between subsurface wells. The use of outcrop-derived gamma logs provides a link between what is observed on outcrop and what is interpreted with well logs. Comparisons of outcrop gamma logs with maps of stratal architecture generate a better understanding of correlation techniques and their pitfalls. A total of 20 gamma-ray logs have been collected from the Willow Mountain and Wild Horse Draw case studies areas. Each traverse spans the entire high-order cycle and consists of 120 to 160 measurements. The traverses were selected to encompass the majority of lithofacies present within the submarine lobe and channel-levee system.

Producibility Problem Characterization

A summary of well completion histories has been entered into a spreadsheet. Initial potentials for oil (bopd), gas (mcfpd), and water (bwpd) are entered for more than 300 wells in the Ford Geraldine unit. These data will be transferred into Landmark StratWorks to map initial potential and compare it to sandstone thickness, porosity, and permeability.

Recovery Technology Identification and Analysis

Work began this quarter to develop a detailed permeability model for the demonstration area of the Ford Geraldine unit generated by conditional simulation. In this technique, the generated field honors the measured data, follows a desired correlation structure, and maintains reasonable heterogeneity (Journel and Huijbregts, 1978; Hewett, 1986; Lake and Malik, 1993; Malik, 1996). This geostatistical model will be used as an input for reservoir simulations of the demonstration area to evaluate the fluid flow performance of the reservoir.

In the demonstration area, core permeability data are available for 21 wells with a total of 722 measured permeability values. These data were analyzed for their distribution type, correlation structure, and statistics. The cumulative distribution function (CDF) of the permeability data in Fig. 2 on log-probability coordinates shows that the data plot almost as a straight line. This is an indication that the permeability data in this field are approximately log-normally distributed. The mean and the standard deviation of natural-log-permeability are 2.38 and 1.85 respectively. The resulting coefficient of variation of 0.77 indicates that heterogeneity is of moderate degree (Jensen and Lake, 1988).

To determine the autocorrelation structure, semivariograms of permeability as well as the log-permeability were plotted for the cored wells. Rescaled range (R/S) plots (Hewett, 1986; Malik, 1996) were also made to investigate the possibility of a power-law or fractal autocorrelation structure. The results did not indicate a well defined autocorrelation structure. Data in many wells indicated a spherical semivariogram, whereas a few wells appeared to support the possibility of a fractal semivariogram. Both types of semivariograms were tested in two vertical cross sections, and the resulting permeability distributions were evaluated in conjunction with the geologic model of the reservoir. Results indicated that a spherical semivariogram with a dimensionless correlation length of 0.3 is a preferable model for geostatistical permeability distribution in this field. A permeability image for a 56x40 block cross section generated by using a spherical semivariogram is shown in Fig. 3. In this figure the heterogeneity is realistic, extreme values are not predominant, and the low-permeability laminated siltstone within the Ramsey reservoir interval is reasonably represented by continuous low permeabilities in the middle horizontal portion. The CDFs of the generated and conditioning data were also found to match closely.

The demonstration area of the field requires about 66,000 blocks for 3D permeability distribution. This is based on a 150 ft block size in each of the two horizontal directions x and y and 1 ft in the vertical z direction. A program based on matrix decomposition method (MDM) (Yang, 1990; Fogg and Lucia, 1989) is being used to generate the 3D permeabilities. This method involves the inversion of a full matrix that is computationally intensive and time consuming. Therefore, the permeability distributions are being generated in separate parts, each consisting of about 10,000 blocks. This work is expected to be completed in two weeks. The generated permeabilities will be scaled-up (Malik, 1996) to bring the total number of blocks close to 10,000 for use in fluid flow simulations.

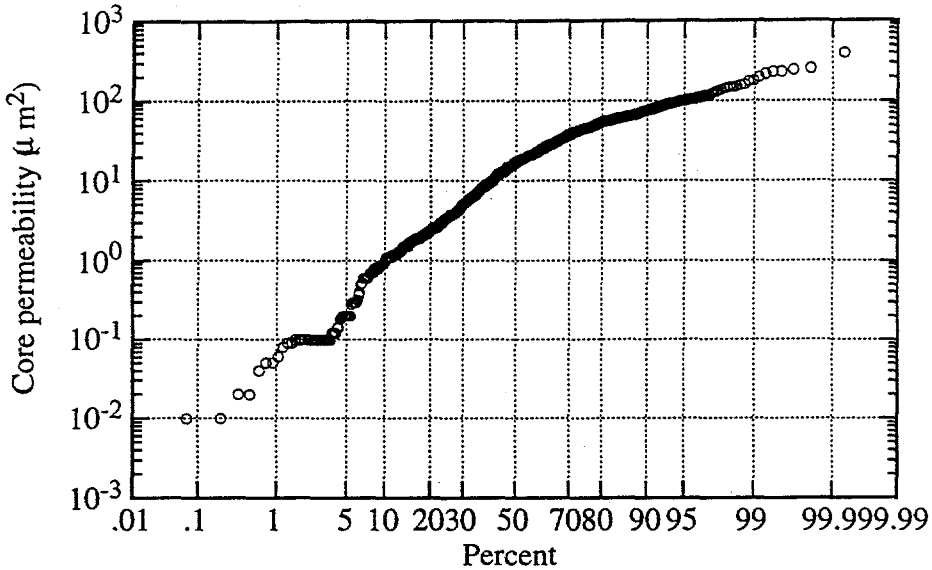

Figure 2. Cumulative distribution function (CDF) for core permeability from 21 wells in the northern part of Ford Geraldine unit.

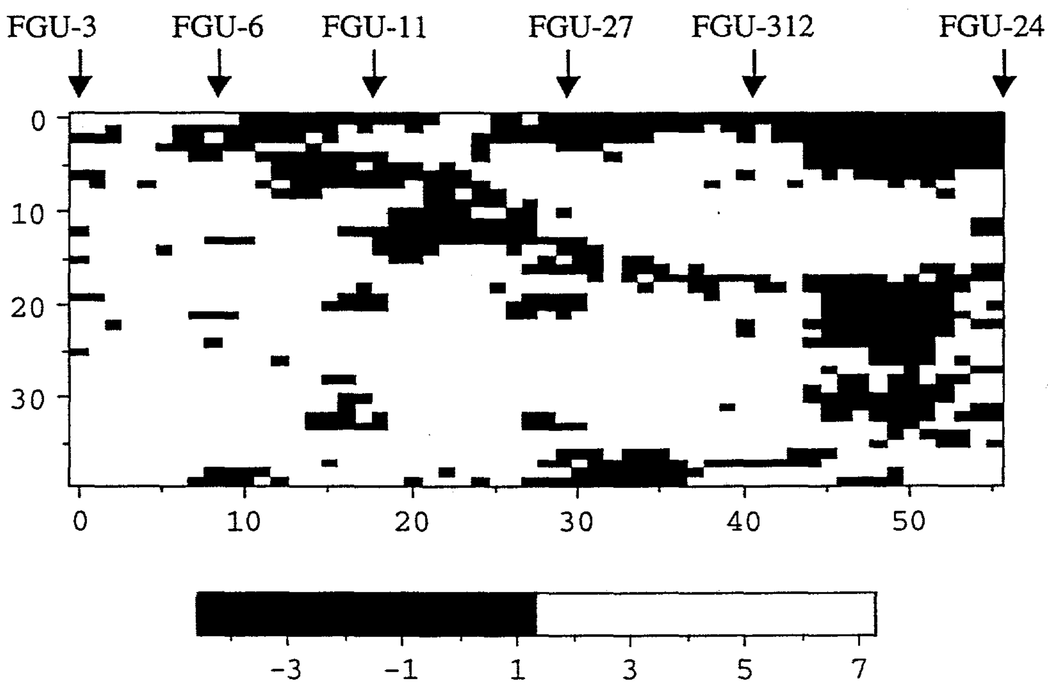

Figure 3. Permeability cross section (56x40 blocks) by conditional simulation using Spherical semivariogram with dimensionless correlation length $l_D = 0.3$. The scale is natural-log-(mm²)

Technology Transfer

A technology transfer workshop titled "Reservoir Characterization of Permian Deep-Water Sandstones, Bell Canyon Formation, Geraldine Ford Area, West Texas (Delaware Basin)" will be held on March 25, 1997, in Midland, Texas, co-hosted by the West Texas Geological Society (WTGS). In addition to the workshop, several talks based on the project are scheduled to be presented this spring:

"Petrophysics of the Ramsey Sandstone, Ford Geraldine Unit, Reeves and Culberson Counties, Texas" talk to be presented by G. B. Asquith on February 20 at the Permian Basin Well Log Society, Midland, Texas.

"Petrophysics of submarine-fan sandstones of the Ramsey Sandstone reservoir, Ford Geraldine Unit, Delaware Basin, Texas" talk to be presented by G. B. Asquith on March 21 at the Society of Independent Professional Earth Scientists, Austin, Texas.

"Basin floor fan and channel-levee complexes, Permian Bell Canyon Formation" poster presentation to be given by M. D. Barton on April 7 at the American Association of Petroleum Geologists 1997 Annual Meeting, Dallas.

"Geophysical characterization of Permian deep-water sandstones, Bell Canyon Formation and Cherry Canyon Formation, Geraldine Ford Area, West Texas (Delaware Basin)" poster presentation to be given by A. G. Cole at the American Association of Petroleum Geologists 1997 Annual Meeting, Dallas.

"Reservoir characterization of Permian deep-water Ramsey sandstones, Bell Canyon Formation, Ford Geraldine Unit, West Texas (Delaware Basin)" poster presentation to be given by S. P. Dutton on April 9 at the American Association of Petroleum Geologists 1997 Annual Meeting, Dallas.

PLANNED ACTIVITIES

Activities in the upcoming quarter will focus on five major areas: (1) completion of maps of reservoir attributes such as net pay, porosity-feet, hydrocarbon pore-feet, permeability-ft, initial potential, and cumulative production, (2) correlation of seismic attributes with reservoir attributes , (3) determination of the distribution of porosity and permeability by facies, (4) preparation and presentation of a technology transfer workshop, and (5) completion of a detailed geostatistical model for the distribution of reservoir properties in the Ford Geraldine demonstration area. This model will be used as an input for reservoir simulations of the demonstration to evaluate the fluid flow performance of the reservoir.

REFERENCES

Fogg, G. E. and Lucia, F. J., " Stochastic Simulation of Interwell-Scale Heterogeneity for Improved Prediction of Sweep Efficiency in a Carbonate Reservoir," NIPER/DOE Second International Reservoir Characterization Technical Conference, Dallas, TX, June 25-28, 1989.

Hewett, T. A., " Fractal Distributions of Reservoir Heterogeneity and Their Influence on Fluid Transport," paper SPE 15386, presented at the SPE Annual Fall Meeting, New Orleans, LA, October 5-8, 1986.

Jensen, J. L. and Lake, L. W., "The Influence of Sample Size and Permeability Distribution upon Heterogeneity Measures," SPE Reservoir Engineering, 3 (1988) 629-637.

Journel, A. G. and Huijbregts, C. J.: Mining Geostatistics, Academic Press, San Diego, CA, 1978.

Lake, L. W. and Malik, M. A., " Modeling Fluid Flow Through Geologically Realistic Media," Geological Society Special Publication: Characterization of Fluvial and Aeolian Reservoirs, C. P. North and D. J. Prosser, eds., The University of Aberdeen, 1993.

Malik, M. A., " Geostatistical Reservoir Characterization and Scale-Up of Permeability and Relative Permeabilities," Ph.D. dissertation, The University of Texas at Austin, 1996.

Yang, An-Ping, " Stochastic Heterogeneity and Dispersion," Ph.D. dissertation, The University of Texas at Austin, 1990.

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		80% 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	11/30/96	100% 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		50% Complete
Task 4.	Analysis of Reservoir Heterogeneity	3/30/97		50% Complete
ACTIVITY 5.	Recovery Technology Identification and Analysis			
Task 1.	Reservoir Simulation	3/30/97		50% Complete
Task 2.	Develop Guidelines for Site Selection-Infill Wells	3/30/97		50% Complete
Task 3.	Develop Guidelines for Site Selection- Injector Wells	3/30/97		50% Complete
ACTIVITY 6.	Technology Transfer			
Task 1.	Publish Results	3/30/97		80% Complete
Task 2.	Workshop	3/30/97		
ACTIVITY 7.	Management and Administration			
Task 1.	Reports and Deliverables	3/30/97		88% Complete
Task 2.	DOE Contractor Review Meetings	3/30/97		88% Complete
ACTIVITY 8.	Project Continuation			
Task 1.	Prepare Project Plan	3/30/97		
Task 2.	Prepare Budget	1/31/97		67% Complete

MILESTONE SCHEDULE ☐ PLAN ☐ STATUS REPORT

FORM APPROVED
OMB NO. 1901-1400

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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: October 1-December 31, 1996	3. IDENTIFICATION NUMBER: DE-FC22-95BC14936
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

ELEMENT CODE	8. REPORTING ELEMENT	9. DURATION (1995: A M J J A S O N D; 1996: J F M A M J J A S O N D; 1997: J F M)	10. PERCENT COMPLETE Plan	Actual
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%	100%
ACTIVITY 4.	Producibility 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		50%	50%
Task 4.	Analysis of Reservoir Heterogeneity		50%	50%
ACTIVITY 5.	Recovery Technology Identification and Analysis			
Task 1.	Reservoir Simulation		50%	50%
Task 2.	Develop Guidelines for Site Selection - Infill Wells		50%	50%
Task 3.	Develop Guidelines for Site Selection - Injector Wells		50%	50%
ACTIVITY 6.	Technology Transfer			
Task 1.	Publish Results		80%	80%
Task 2.	Workshop		0%	0%
ACTIVITY 7.	Management and Administration			
Task 1.	Reports and Deliverables		88%	88%
Task 2.	DOE Contractor Review Meetings		88%	88%
ACTIVITY 8.	Project Continuation			
Task 1.	Prepare Project Plan		0	0
Task 2.	Prepare Budget		67%	67%

. SIGNATURE OF PARTICIPANT'S PROJECT MANAGER AND DATE

Mark Tyler for S. P. Dutton 1/28/97