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

Quarterly Technical Progress Report
October 1, 1998-December 31, 1998

By
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Application of Advanced Reservoir Characterization, Simulation, and Production
Optimization Strategies to Maximize Recovery in Slope and Basin Clastic Reservoirs,
West Texas (Delaware Basin)

By
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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)

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OBJECTIVES

The objective of this Class 3 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 main phases. The original objectives of the reservoir-characterization phase of the project were (1) to provide a detailed understanding of the architecture and heterogeneity of two representative fields of the Delaware Mountain Group, Geraldine Ford and Ford West, which produce from the Bell Canyon and Cherry Canyon Formations, respectively, (2) to choose a demonstration area in one of the fields, and (3) to simulate a CO₂ flood in the demonstration area.

After the reservoir characterization and simulation of an area at the northern end of the Ford Geraldine unit were completed, the industry partner decided not to proceed to Phase 2, installation of a CO₂ flood in the demonstration area. A new industry partner, Orla Petco, Inc., will participate in the remainder of the project, which includes a field demonstration to be conducted in the East Ford unit. The East Ford unit is immediately adjacent to the Ford Geraldine unit and produces from the same Ramsey sandstone channel. The reservoir characterization phase of the project has been expanded to include East Ford unit. This additional reservoir-characterization task provides an excellent opportunity to test the transferability of the geologic model and log-interpretation methods developed during reservoir characterization of the Ford Geraldine unit to another Delaware sandstone field.

The objectives of the implementation phase of the project remain the same, to (1) apply the knowledge gained from reservoir characterization and simulation studies to increase recovery from a demonstration area, (2) demonstrate that economically significant unrecovered oil can be recovered by a CO₂ flood of the demonstration area, and (3) test the accuracy of reservoir characterization and flow simulation as predictive tools in resource preservation of mature fields. The goal is to develop a geologically designed CO₂ flood and well-completion program in a representative Delaware Sandstone field that can serve as a model for other fields in the play. Through technology transfer, the knowledge gained in this study can be applied to increase production from more than 100 other Delaware Mountain Group reservoirs.

SUMMARY OF TECHNICAL PROGRESS

Reservoir Characterization

Petrophysical characterization of the East Ford unit is being accomplished by integrating core and log data and quantifying petrophysical properties from wireline logs; the goal is a set of maps of porosity, permeability, net pay, water saturation, porous hydrocarbon volume, and other reservoir properties across the unit. Because interval-transit-time (ITT) logs were the most common, log analysis for porosity was done using the 23 interval-transit-time logs.

Porosity Transforms

One goal of the petrophysical analysis was to calculate porosity and permeability from ITT logs of wells lacking core data. Data from the Ramsey interval in all cored wells were combined in a plot of core porosity versus core permeability in order to determine porosity cutoffs for pay

zones and to determine a porosity-versus-permeability transform. The least-squares linear regression line relating core porosity and permeability is:

$$\text{Permeability (md)} = 0.014 \times 10^{[0.144 \times \text{porosity (percent)}]}$$

On the basis of this equation, a porosity cutoff of 17.5 percent (permeability of 5 md) was selected.

Core-to-log correction factors were determined for each cored well, and core depths were shifted to log depths. A cross plot of ITT versus core porosity was constructed to determine an ITT-log-to-core-porosity transform. Several of the ITT logs had zones where the readings went off scale ($>100 \mu\text{sec/ft}$) because of hole washout, and these intervals were omitted from the plot of ITT versus porosity. From this plot, a reduced-major-axis (RMA) equation was calculated that can be used to determine porosity in wells with ITT logs. The RMA equation relating porosity and ITT is:

$$\text{Porosity (percent)} = 0.533 (\text{ITT}) - 26.5$$

Because so few ITT logs were available in the East Ford unit, logs from wells with hole washout were used in the petrophysical analysis. ITT values were extrapolated into the washed-out zones from depths where the Ramsey sandstone had good log response, and these extrapolated values were used to calculate porosity from the RMA equation.

Volume of Clay

Volume of clay is one of the parameters used to determine pay intervals in the Ramsey sandstone. To determine volume of clay (V_{cl}), the values for gamma-ray response in a clean sandstone (GR_{cl}) and in a shale (GR_{sh}) must be obtained. In the Delaware sandstones, determining an accurate value for GR_{sh} is difficult because of the lack of true shales. The gamma-ray response of organic-rich siltstones was substituted for GR_{sh} .

A cross plot of interval transit time (ITT) versus normalized gamma-ray response (GR) in the East Ford unit was constructed. From this plot, a GR_{cl} value of 50 API and GR_{sh} of 89 API were selected. The V_{cl} for the Ramsey sandstone was then calculated by the following formulas:

$$IGR = (GR - 50) / (89 - 50) \text{ and}$$

$$V_{cl} = 0.33[2^{(2 \times IGR)} - 1.0] \text{ (Atlas Wireline, 1985),}$$

where IGR is gamma-ray index and V_{cl} is volume of clay.

Calculation of Water Saturation

Resistivity logs are electric logs that are used to determine hydrocarbon- versus water-bearing zones. Data from resistivity logs can be used to calculate a formation's water saturation if several parameters, including true formation resistivity (R_t), formation water resistivity (R_w), cementation exponent (m), and saturation exponent (n) are known (Archie, 1942).

True Formation Resistivity (R_t)

In the East Ford unit, commonly only a Deep Laterolog (LLD) was run, with no accompanying log to measure either resistivity of the flushed zone ($[R_{xo}]$, which is measured by a Microlaterolog [MLL] or a Microspherically Focused Log [MSFL]) or resistivity of the invaded zone (R_i), which

is measured by a Shallow Laterolog [LLS]). When both an LDD and an R_{XO} or an LLS log are available, the LDD can be corrected for invasion.

In the adjacent Ford Geraldine unit, several wells had both an LLD log and an R_{XO} or an LLS log (Asquith and others, 1997; Dutton and others, 1997). Using these logs, R_t values were calculated from the above equations and plotted versus the LLD values. The calculated linear regression equation is: $R_t = 1.3002 \times LLD + 0.3397$. Because of the similarity of the Ramsey reservoir in the East Ford and Ford Geraldine units, the linear regression equation calculated for the Ford Geraldine unit was used to correct LLD to R_t in East Ford wells lacking an R_{XO} or an LLS log.

Formation Water Resistivity

In preparation for calculating water saturations (S_w), formation-water resistivities (R_w) were estimated across the Ford East unit from a contour map of formation-water salinities. Data from four wells the East Ford unit (EFU 1, 9, 24, and 37) were combined with those from the Ford Geraldine unit (Dutton and others, 1997) to obtain a more regional view of water salinity. The contour map of salinity was used to assign salinity values for each of the East Ford wells. The formation-water resistivity at 75°F was then read from a chart relating NaCl concentration, temperature, and resistivity (Schlumberger, 1995, chart Gen-9, p. 1-5). Values of R_w at 75°F ranged from 0.10 to 0.12 ohm-m in the East Ford unit.

Archie Parameters m and n

No special core analyses of cementation exponent (m) or saturation exponent (n) were available from the East Ford unit. Therefore, the values of m (1.83) and n (1.90) determined for Ramsey sandstone in the Ford Geraldine unit were used in the East Ford unit (Asquith and others, 1997). For the Bell Canyon sandstones in the East Ford unit, water saturations were calculated by the following modified Archie equation:

$$S_w = [(1/\phi^{1.83}) \times (R_w/R_t)]^{1/1.90} \quad \text{where } \phi \text{ is porosity.}$$

Net-Pay Cutoffs

For the Ramsey sandstone in the East Ford unit, three net-pay cutoffs were selected. These cutoffs are volume of clay (V_{cl}), porosity (ϕ), and water saturation (S_w). Accurate values for V_{cl} are difficult to determine for the Delaware sandstones due to the lack of adjacent shales. Therefore, the selection of a V_{cl} cutoff was based on the work of Dewan (1984), which suggests a V_{cl} cutoff of 15 percent for reservoirs with dispersed authigenic clay. This cutoff was used because of the common occurrence of authigenic clay in the Delaware sandstones.

Examination of the core-porosity-versus-core-permeability cross plot for the Ramsey sandstone in the Ford Geraldine unit resulted in the selection of the following porosity cutoff:

$$\phi \leq 17.5 \text{ percent for a permeability of } 5.0 \text{ md.}$$

Five K_{RO} - K_{RW} relative permeability curves from the Ford Geraldine Unit (FGU) No. 156 well were used to determine the water saturation (S_w) cutoff because no relative permeability data were available from the East Ford unit. At S_w of 60 percent, the relative permeability to oil (K_{RO}) should be approximately eight times the relative permeability to water (K_{RW}).

Therefore, for the Ramsey sandstone in the East Ford unit, a water saturation cutoff of 60 percent was selected, the same cutoff that was used for the Ford Geraldine unit.

Residual and Mobile Oil Saturation

Residual oil saturation (ROS) values determined from relative permeability curves from the FGU No. 156 core were plotted against porosity values, and the regression line fitted to the data gives the relationship $ROS = -0.74 \times \phi + 41.41$ (Dutton and others, 1997). By combining the modified Archie water saturations (S_w) with residual oil saturations, original mobile oil saturations (MOS) can be calculated as:

$$MOS = (1.0 - S_w) - ROS$$

These equations and cutoffs developed from the petrophysical analysis were used to map porosity, permeability, net pay, water saturation, mobile oil saturation, and other reservoir properties in the East Ford unit.

Technology Transfer

A poster presentation titled "Controls on Reservoir Quality Distribution in the Ramsey Sandstone Deep-Marine Clastic Reservoirs, Bell Canyon Formation, Delaware Basin, Texas" will be given on April 13, 1999, in San Antonio, Texas at the American Association of Petroleum Geologists 1999 Annual Meeting.

PLANNED ACTIVITIES

A subcontract between The University of Texas at Austin and Orla Petco, Inc. is in progress and should be completed during the next quarter.

Reservoir characterization of East Ford field will continue next quarter. Isopach maps and cross sections of the reservoir sandstone bodies and bounding siltstones will be finalized. The final maps will incorporate information provided by Orla Petco from additional wells outside the East Ford unit. Primary production in the East Ford unit will be mapped. Because primary production data are available by lease only, production will be assigned to individual wells using net pay, permeability-thickness, or initial-potential test data. Petrophysical characterization will be completed, and the petrophysical maps for the East Ford unit will be finalized.

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