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MULTIDISCIPLINARY IMAGING OF ROCK PROPERTIES IN CARBONATE RESERVOIRS FOR FLOW-UNIT TARGETING

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Abstract

Despite initial delays, significant progress has been achieved on the project in the first 6 months since the D.O.E. award. Progress has been especially noteworthy in seven subtask areas. Facies and cyclicity have been characterized in both outcrops and subsurface cores. These findings have been used to construct a preliminary model of stratigraphic architecture that is being used to guide studies of rock fabrics, wireline log character, and 3-D seismic data. Core descriptions, integrated with outcrop studies, have also been used to develop a preliminary correlation framework for the reservoir. Rock fabric studies are also well under way. On the basis of the description of thin sections from four cored wells, major rock fabrics in the field have been preliminarily characterized. Although initially delayed because of log quality problems, log calibration studies, based on core-log comparisons, are nearly complete. Finally, our preliminary analysis and interpretation of 3-D seismic data have revealed several important characteristics of the field that would not otherwise be apparent. These and other early findings will be tested, modified, refined, and improved in the next phase of the study.

Introduction

Although this project was awarded by D.O.E. in November of 2001, delays in receiving approval and funding from the reservoir operator, ExxonMobil, caused the actual start of the project to be delayed until January 1. In effect, this report describes the work accomplished on the project during the first 4 months of activity. Nevertheless, despite the delay in start-up, the project is essentially on schedule.

Executive Summary

Despite delays in project start-up and in data collection, good progress has been achieved in the first 6 months of the project. Major accomplishments during the period were in (1) characterization of facies and cyclicity in subsurface cores and in outcrop, (2) construction of a preliminary stratigraphic framework, (3) definition of rock fabrics, and (4) correlation of 3-D seismic data. Progress was also made in calibration of wireline logs. We have also begun to define samples for analysis of petrophysical properties and description of rock fabrics.

Studies of facies and cyclicity have defined the major reservoir facies and their distribution and have provided the basis for construction of a cycle-based stratigraphic framework across the field. Rock fabric studies, based on integration of thin section studies and porosity and permeability data, have resulted in recognition of the range of petrophysical rock fabric relationships that control fluid flow. 3-D seismic studies document the subreservoir structure and show its control on facies, porosity distribution, and reservoir architecture. These relationships, along with evidence that shows a strong correlation

between seismic attributes and porosity and production, demonstrate the critical value of 3-D data in the characterization and modeling of the reservoir.

With the exception of 3-D seismic studies, activities are being concentrated in a small part of the field so that early conclusions can be reached about the major controlling factors of reservoir heterogeneity and original and current oil distribution. This first phase of study will be completed early in the second 6 months of the project and used as a basis for study of the remainder of the reservoir.

Experimental

No experimental work was conducted during the first 6 months of the project.

Results and Discussion

This report describes the accomplishments of the project during the first 6 months of study. We have made substantial progress in most parts of the project, including Task 1, Construct Cycle Stratigraphic Framework, Task 2, Characterize and Model Rock Fabrics, and Task 4, Correlate and Model Rock Properties and 3-D Seismic Attributes.

Study of the Fullerton Clear Fork reservoir has been subdivided into three phases. The first two phases, Phase 1 and Phase 2,will focus in turn on two small areas of the reservoir; Phase 3 will involve study of the remaining parts of the reservoir and an integration of all three areas. Studies during the first 6 months of the project were concentrated in the Phase 1 area and involved Tasks 1 and 2. Task 4 activities were undertaken in Phase 2 and Phase 3 areas because 3-D seismic coverage does not extend to the Phase 1 area.

Subtask 1.1 Describe Facies and Cyclicity in Cores.

Facies and cyclicity were described in five cores in the Phase 1 area, an area approximately 2 miles wide by 1 mile. These cores, which total about 2,500 ft in length, provide coverage for the entire reservoir interval section (about 700 ft). Cores were described on a foot-by-foot basis. Core descriptions were supplemented by examination of thin sections. The reservoir comprises parts of the Lower Clear Fork Group and the underlying Wichita facies. The Wichita facies (about 350 ft in thickness) is characterized by very shallow subtidal to tidal flat facies. Cyclicity is variably developed through the Wichita succession. These deposits are locally overprinted by evidence of karst-related processes, including cave-filling collapse breccias and cave-roof crackle breccias. Although the Wichita succession is dominantly dolostone, an interval of alternating dolostone and limestone is well developed in the upper part of the unit. The Lower Clear Fork (about 350 ft in thickness) comprises three definable depositional sequences. The lower two consist of relatively complete transgressive-regressive high frequency sequences, each of which is characterized by a tidal-flat-dominated transgressive leg; a subtidal-dominated, maximum-flooding to early highstand leg; and a tidal-flat-dominated, late highstand leg. The uppermost of the three Lower Clear Fork sequences is characterized by a succession of tidal-flat-capped subtidal cycles. Cyclicity is best developed in this uppermost of the three sequences. Limestone is locally common in subtidal rocks in the Lower Clear Fork, especially in the maximum flooding legs of the two lower Lower Clear Fork sequences.

Patterns of facies stacking and cyclicity defined from the cores described to date will be used to guide correlation throughout the reservoir. The stratigraphic architecture developed using these correlations will provide the fundamental framework for the construction of the reservoir model.

Subtask 1.2 Describe Facies and Cyclicity in Outcrops.

Facies and cyclicity have been described for the Lower Clear Fork succession in the Sierra Diablo Mountains of West Texas. Judging by four complete measured sections (approximately 800 ft of total section), it is apparent that the Lower Clear Fork contains parts of two high frequency sequences. These sequences have been correlated to the subsurface in some areas of the Permian Basin. We are currently comparing the outcrop stratigraphy with that observed in the Phase 1 area. The Abo Formation has also been studied in Sierra Diablo outcrops. These studies reveal the same styles of karst development seen in the Fullerton Wichita facies. We plan to use outcrop observations to define and model the distribution of karst facies for purposes of modeling their distribution in Fullerton field.

Subtask 1.3 Develop Wireline Correlation Framework.

Although well log data were provided by the operator at the beginning of the project, quality control checks of these data showed that they were of very poor quality. Accordingly, it was necessary to have all wireline logs redigitized, thus delaying analysis of wireline logs and development of the wireline correlation framework. Nevertheless, progress on this subtask has been made. Calibration of wireline log response using the six cored wells is well under way. Preliminary results of this work indicate that gamma-ray response is substantially affected by the variable distribution of uranium in the section. As a result, a somewhat inconsistent gamma response occurs both laterally and vertically throughout the reservoir.

Accordingly, correlations using the gamma-ray curve alone are likely to be erroneous. It appears that correlations based on a combination of gamma-ray and porosity logs will be necessary for accuracy.

Subtask 2.1 Measure Petrophysical Properties in Core.

To begin this phase of the project we have selected a core for closely spaced sampling for petrophysical analysis. We have drilled 390 standard core plugs from this core, representing 1 plug for each foot of core. Samples have been cut from each plug for thin section preparation. Thin sections will be used to tie rock fabric descriptions to porosity and permeability measurements made from the plugs. This core covers about 60 percent of the reservoir. Other cores will be selected for additional sampling of petrophysical properties as the study moves to other parts of the reservoir.

Subtask 2.2 Define and Characterize Rock Fabrics.

Rock fabrics are defined by relating petrophysical measurements, porosity, permeability, and saturation to rock fabric groups. To define reservoir rock fabrics, we described more than 280 thin sections, most of which came from cored wells in the Phase 1 study area (well #s 6122, 1184, 1284). However, 55 thin sections were also described from sidewall core plugs taken in a newly drilled well in the Phase 2 area (well # 2564). This latter data set, although outside the current Phase 1 study area, is the best data set available for characterizing rock fabrics because it contains thin sections from core plugs that were measured for porosity and permeability. Preliminary analysis of rock fabric studies suggests the presence of several distinctive rock fabric groups, each with different porosity/permeability relationships. These groups include (1) tidal flat dolostones; (2) subtidal dolostones; (3) subtidal, grain-rich limestones; and (4) muddy, tidal flat limestones. Tidal flat dolostones, which are abundant in the Wichita but also common in the Lower Clear Fork, include a wide range of textures and facies, but most have highly variable porosity and generally very low permeability and oil saturation. Subtidal dolostones, which are most abundant in the Lower Clear Fork, appear to be the best and most widely developed rock fabric in the reservoir. Porosity typically varies directly with grain content, but permeability and saturation can be quite high. Subtidal, grain-rich limestones are restricted to the Lower Clear Fork. They commonly exhibit very high porosities (up to 30 percent) and although usually moldic, constitute an important reservoir rock fabric. Muddy, tidal flat limestones are restricted to the Wichita and typically contain very low porosity and associated permeability. These rocks are not reservoir rocks but may form reservoir baffles.

Because of the variable porosity to permeability and saturation relationships exhibited by these rock fabrics, distinguishing among them is critical for accurate reservoir model construction. Particularly challenging will be distinguishing between limestone and dolostone, as well as tidal flat and subtidal rock fabrics. We will be able to refine this preliminary grouping of rock fabrics with the analysis of the 390 new plug and thin section pairs that we have sampled from the # 5927 well in the Phase 1 area.

Subtask 2.4 Calibrate Wireline Logs for Rock Fabric Identification.

Initial examination of wireline logs revealed many errors of digitization and organization in the wireline data supplied by the operator. Consequently, much of the first 6 months has been devoted to quality checking and redigitizing the logs. ExxonMobil, the operator of the field, has agreed to redigitize all field logs to correct these problems. Most calibration work during the first 6 months has thus been focused on the one cored well where good quality logs are available. Preliminary comparison of wireline log response with core facies and rock fabrics identified from thin sections has begun. We have also started to test methods for recognizing limestone and dolostone from wireline logs and defining important rock fabric types.

Subtask 4.1 Construct 3-D Seismic Attribute Model of Reservoir Porosity.

3-D seismic data are available for about 60 percent of the reservoir. Analysis of 3-D seismic data in the first 6 months of the project has been focused on tying seismic response to reservoir stratigraphy. 3-D coverage does not extend to the area of the Phase 1 study; however, preliminary attribute analysis of major porosity zones has also been completed for the area of the field covered by the seismic.

We have completed preliminary time-depth modeling of the seismic data and have correlated major stratigraphic surfaces through the entire area of the 3-D survey (approximately 30 square miles). Five major stratigraphic surfaces were defined: the base of the Tubb (top of the gross reservoir section), sequence boundary B (top of the middle Lower Clear Fork sequence), sequence boundary A (top of the lowermost Lower Clear Fork sequence), the top of the Wichita facies, and the top of the Abo (lowermost Leonard unit). The Abo is defined seismically by inclined to top-lapping reflectors under the Wichita facies that generally dip eastward. This architecture is consistent with recent observations of the Abo in outcrops in the Sierra Diablo Mountains and in the subsurface, which show the succession to consist of prograding clinoformal outer platform carbonates. This interpretation is confirmed by core through the Abo section in this part of the field, which shows the Abo to contain fusulinid and crinoidal packstones, typically outer platform facies. 3-D data show the overlying Wichita and Lower Clear Fork part of the reservoir section to be generally flat lying.

To evaluate the potential of using 3-D seismic data to predict the interwell distribution of porosity, we generated amplitude maps for Lower Clear Fork sequences A and B, the two major reservoir intervals in the Lower Clear Fork. We compared these maps with phih maps for the same intervals generated from porosity log data provided by ExxonMobil. The two sets of maps show good agreement, indicating that the 3-D is a good predictor of reservoir porosity distribution.

Our studies of the 3-D data defined the presence of three large horst blocks under the Leonardian section. These blocks, which were presumably upfaulted during the Pennsylvanian, contain Siluro-Devonian rocks that constitute the Fullerton 8500 Silurian reservoir. Comparison of the distribution of these structural features with seismic architectural patterns and porosity distribution in the Leonardian reservoir section suggests that the underlying structures exerted control on reservoir development. We will investigate these relationships more closely when the project moves to Phase 2; the Phase 2 area is partly covered by 3-D data, thus permitting us to more fully integrate detailed studies of stratigraphic architecture, rock fabrics, and facies development with 3-D data.

Additional Activity.

We have also begun testing of 3-D reservoir modeling software to prepare for the construction of a 3-D reservoir model. A preliminary 3-D model of porosity was constructed for the entire Fullerton Clear Fork Unit (including approximately 1,100 wells) to provide insights into the general distribution of porosity across the field and to provide a preliminary model for comparison with 3-D seismic attributes. We have also nearly completed compilation of historical production and completion data for the reservoir.

Seven new wells were drilled in the field in late 2001. Although not specifically part of the proposed project, this drilling activity was spurred by Bureau of Economic Geology involvement and negotiation with the operator, ExxonMobil, and OXY, the other major working interest partner on the field. These wells were drilled in the Phase 2 study area to obtain new data for purposes of characterizing that part of the field. At the Bureau's request, acoustic logs were obtained in the wells to aid in analysis of the 3-D seismic data. Sidewall cores were collected in one of the wells, along with a borehole image log for locating sidewall cores and visualizing possible fractures in the borehole. Modern log suites, which were obtained in all wells, will greatly aid in the characterization of the reservoir in this part of the field. Five of these wells are currently on production with a total production of approximately 7,000 barrels per month. The other two wells were completed as water injectors to test the flood response in this part of the field. Although implemented before the project was fully under way, this drilling activity is the first installment in a program to recover the remaining oil in this reservoir, in which this study is key.

Conclusions

We have made considerable progress during the first 6 months of the program. Some delays were experienced in calibrating and interpreting the wireline logs because of problems in the quality of the originally supplied data. However, those problems have now been corrected, and we are now making good progress and are almost back on our original schedule.

It is clear, even at this early stage of the project, that identification and mapping of carbonate rock fabrics will be crucial to successfully defining the distribution of the remaining oil fraction in this reservoir. We have already made good progress in defining the rock fabrics present in the reservoir. Our planned analysis of additional core plugs will refine this knowledge base. We have also observed that the 3-D seismic may play a critical role in our mapping the potential distribution of these fabrics. We are discussing acquisition of a new 3-D survey over the field as a key to effective reservoir characterization.