Geologic Modeling of External and Internal Reservoir Architecture of Fluvial Depositional Systems

[1]Patterson, P.E., [2]Donovan, A.D., [1]Jones, T.A., and [3]Ottmann, J.D. [1]Exxon Production Research Company, Houston, Texas, [2]Exxon (CIS) Ventures, Houston Texas, and [3]Exxon Exploration Company, Houston, Texas.

Summary

Reservoir models were constructed that closely represent three interpreted styles of fluvial depositional systems that are inferred to vary along an up-dip to down-dip transect. The three styles of fluvial deposition include the following, in stratigraphic succession: 1) amalgamated channel complexes; 2) amalgamated to semi-amalgamated bar complexes; and 3) isolated bar complexes. A recently developed computer program was used to more accurately characterize the amalgamated and isolated fluvial-bar deposits.

Introduction

A detailed, integrated study spanning three field areas located in central Africa was undertaken to characterize the facies architecture, sequence-stratigraphic framework and structural framework for construction of reservoir models. The study incorporated information from 3-D seismic interpretations, well-log correlations, facies and petrophysical analyses of cored intervals, and interpretations derived from outcrop exposures of the reservoir interval. This integrated study provided the fundamental data that was applied in development of six reservoir models that were used for improved estimates of reserves, flow-simulation studies, and field-development planning.

Fluvial-Facies Architecture

On the basis of stratal relations, the reservoir intervals were defined in terms of depositional sequences, which are composed of multistory fluvial sandstones overlain by mudstone-prone intervals. The sandstone-prone portions of the depositional sequences possess erosional bases (interpreted as sequence boundaries) and horizontal, conformable tops (interpreted as non-marine flooding surfaces). The mudstone-prone intervals conformably overlie the sandstones and are bounded at their tops by erosional surfaces. Within this context, the sandstone-prone intervals are interpreted as a lowstand systems tract and the mudstone-prone intervals are interpreted as transgressive and highstand systems tracts.

In the three field areas, 24 depositional sequences were interpreted. Of these depositional sequences, eleven sequence boundaries and five flooding surfaces could be resolved and mapped using 3D seismic data. The depositional sequences, which constitute the large-scale, external architecture of the fluvial systems, range from 40 to 200 feet in thickness and are inferred to vary in lateral extents from 1 to 5 miles.

The fluvial depositional systems are interpreted to vary systematically in an up-dip to down-dip transect both in their large-scale (external) and small-scale (internal) reservoir architecture. Three fluvial-facies belts were interpreted to characterize the subsurface reservoirs. Proximal (up-dip) fluvial-facies belts are interpreted to represent lowstand fluvial sandstones that are characterized by amalgamated channel complexes that form thick, widespread sheets. Medial fluvial-facies belts are interpreted as lowstand deposits of amalgamated to semi-amalgamated bar complexes that form thinner and less laterally persistent reservoirs. Distal (down-dip) fluvial-facies belts are interpreted to represent lowstand sandstones characterized by thin, yet laterally persistent, bar complexes.

Object-Based Modeling of Fluvial Reservoirs

As a result of the complex sequence-stratigraphic architecture, each depositional sequence was modeled separately. The external architecture for each of the 24 sequences was derived from the interpreted surfaces from the 3-D seismic data and well-log correlation. In general, the flooding surfaces above and below the lowstand systems tract were used to define the top and base of each modeled reservoir (e.g. lowstand fluvial sandstone). Hence, the sequence boundaries, which bound the base of the lowstand sandstones, were stochastically generated and were largely influenced by well-log data and paleoflow interpretations. In a few reservoir intervals, the incised valleys containing the lowstand sandstones were interpreted from 3-D seismic data to occur in relatively confined regions. Probability maps of sandstone occurrence were used to populate the model with the inferred fluvial facies.

The internal architecture of the reservoir intervals was modeled by means of two techniques. Proximal fluvial facies were modeled using typical object-based modeling software to populate the zones with channel elements that are clustered to form channel complexes. Medial and distal fluvial facies, however, were modeled using a recently developed software module that populates the zones with discrete bar elements that are distributed along thalwegs; these elements then are clustered to form amalgamated bar complexes. This bar-modeling capability provides a better description of the inclined shale baffles that bound the fluvial bars, which previously had not been adequately captured in reservoir models. The facies models honored the thickness and inferred width distributions of both the external as well as the internal fluvial architectural elements.

Subsequent to completion of the facies models, petrophysical properties were assigned to the geologic model. A combined facies analysis and rock-property study revealed that there was a strong correlation between permeability and grain size and clay content. Moreover, permeability typically displayed distinct vertical trends within individual channel and bar deposits. In contrast, porosity did not show a consistent correlation within depositional elements. Hence, permeability was assigned initially to individual fluvial elements (i.e. channels and bars) within the facies models and subsequently porosity values were assigned. Cumulative distributions of permeability and porosity from the geologic models closely matched those from core and well-log analyses.

Conclusions

The resulting geologic models provided an improved reservoir description of the external and internal reservoir architecture for the three field areas. Specifically, these models provide a more accurate description of the complex architecture of the lowstand fluvial sandstone as well as the internal architecture of the mudstones. Finally, these detailed reservoir models more closely match pressure-transient well tests and short-term production tests than did previous modeling methods.