Assessing Depositional Architecture and Lithofacies Distribution of a Cretaceous Reservoir within a Clastic-Carbonate System Using Forward Stratigraphic Modeling

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Abstract

The Barinas-Apure Basin (BAB) in western Venezuela, a mature hydrocarbon-producing region, faces challenges related to complex sedimentary architectures. As the basin reaches an advanced stage of development, efforts to discover new hydrocarbon reserves have intensified. These initiatives emphasize the use of innovative techniques and technologies, establishing a strong basis for exploration in new prospective areas within the basin. An innovative and effective technique for reducing exploration uncertainties and quantifying unknown controlling factors in hydrocarbon reservoirs is the application of forward stratigraphic modeling (FSM). This study introduces the first FSM of the Escandalosa Formation and is especially designed to tackle these challenges.

The Escandalosa Formation is subdivided into four informal members with distinct lithological and depositional characteristics. The basal member, 'S,' consists of dark shale representing pelagic deposits, the members 'R' and 'P' comprise sand packages interbedded with shale characterizing delta and estuarine tidal influenced systems. The uppermost member, 'O,' contains carbonate and dolomite deposits intercalated with fine-grained sandstones, representing a carbonate ramp setting deposited during a highstand systems tract (HST).

The FSM integrates multidisciplinary datasets, including 3D seismic data, well logs, core descriptions, and sedimentological analyses to simulate depositional environments and predict grain size distribution through space and time. Additionally, key geological parameters such as sediment supply, subsidence, eustatic sea-level fluctuations, and carbonate production were also incorporated into the model to construct the depositional architecture and spatial grain-size variability.

Clastic deposition within the Escandalosa Formation begins with black shales (member 'S') that extend across the basin as part of a highstand system track. This clastic deposition continues during the falling stage systems track (member 'R'), the lowstand system track, and part of the transgressive system track (member 'P'), with sand deposits concentrated in the south-southeast regions, proximal to the sediment source,

while shale dominates the northernmost areas. Carbonate facies distribution follows a ramp model, with grainstone in the south-middle areas, packstones and wackestones in the middle ramp, and carbonate mudstone in the distal northern zones.

The FSM demonstrated a strong alignment with the well and seismic data, with less than 15% discrepancy in thickness estimations. The areal sediment proportion distribution closely correlates with net sand thickness maps and carbonate ramp interpretations derived from core descriptions. Validation at well level revealed an 86% calibration accuracy for clastic intervals and 70% for carbonate sections.

Additionally, comparisons with modern analogues, including the Indonesian Mahakam Delta, the Amazon River fluvial plain, and the Abu Dhabi carbonate platform, revealed a strong morphological similarity, further validating the FSM. Sensitivity analyses identified production rates of carbonate fines (packstone and wackstone) as the primary control for carbonate thickness and marine water-driven sand transport as a critical control for clastic deposition.

The overall results suggest that differential subsidence played a crucial role in the stratigraphic development of the Escandalosa Formation. The interaction between sediment loading, lithospheric response, and basin evolution controlled the distribution of sediment thickness, stacking patterns, and reservoir potential across the BAB.

These findings refine our understanding of the BAB depositional history, offering valuable insights into the sedimentary architecture and predicting vertical and lateral facies variations within the depositional environment. This provides a robust framework for future hydrocarbon exploration and reservoir characterization.