OUTCROP GEOLOGY AND PETROPHYSICS

OUTCROP-BASED STRATIGRAPHIC, PETROPHYSICAL, AND GEOSTATISTICAL CHARACTERIZATION AND MODELING OF A CARBONATE PLATFORM RESERVOIR SUCCESSION: MIDDLE PERMIAN, PERMIAN BASIN

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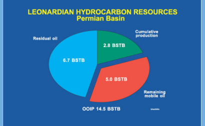
ABSTRACT

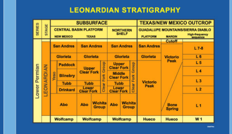
Mature, carbonate platform reservoirs commonly contain sizable volumes of remaining oil. Critical to the development of improved methods for the recovery of this resource is the development of better techniques for reservoir characterization and modeling of interwell reservoir space.

We used high-resolution stratigraphic and petrophysical data from reservoir-equivalent Lower Permian outcrops in the Sierra Diablo of West Texas as a basis for developing improved approaches to modeling reservoir architecture and petrophysical properties in the South Wasson Clear Fork reservoir in the Permian Basin. These outcrops, which provide more than 2 miles of continuous exposure, supplied critical information on reservoir architecture, including styles of cyclicity, vertical and lateral patterns of facies distribution, and continuity. We collected closely spaced porosity and permeability data along both vertical and horizontal traverses to define relationships between facies and petrophysics and to provide data pertinent to the spatial statistics of petrophysical properties in interwell reservoir space. Outcrop data proved crucial for the interpretation and modeling of subsurface wireline and core data. Cycle stratigraphic data provided a basis for defining reservoir architecture and for developing and applying a cycle-based correlation framework.

Integrated geostatistical analysis and modeling of outcrop and subsurface petrophysical data revealed two types of heterogeneity, each having very different effects on fluid flow: a large-scale stratigraphic component and a small-scale, poorly correlated component. Modeling and simulation of these components produced a much more realistic match to historical waterflood performance, suggesting that this approach is a significant improvement over previous reservoir modeling methodologies.

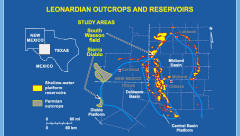
INTRODUCTION

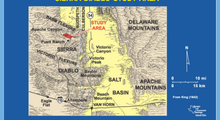


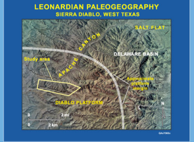


As a play, Leonardian carbonate platform reservoirs in the Permian Basin rank third in total oil production. However, they rank last in recovery efficiency among carbonate reservoirs (18 %). They therefore contain a huge remaining oil resource that is a target for improved reservoir characterization and exploitation technology.

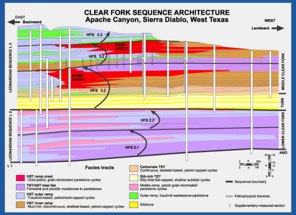
SETTING





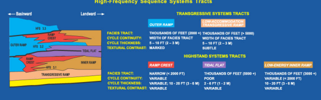


SEQUENCE ARCHITECTURE

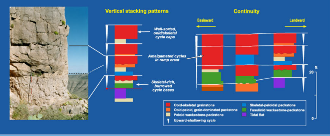


Outcrop studies of the Clear Fork equivalent succession in the Sierra Diablo define the depositional response to sea level change and provide critical data on facies and systems-tract geometry and characteristics that are not obtainable from any other data source. Both are fundamental to interpretation of subsurface data sets. Key insights from the Apache Canyon section that have critical reservoir significance include

1. thickness and architecture of high-frequency sequences,
2. cycle composition (vertical facies-stacking patterns), and
3. cycle continuity.



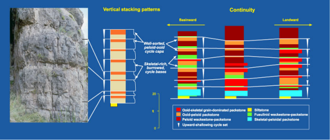
CYCLICITY AND FACIES-STACKING



Styles of cyclicity and facies-stacking patterns defined in outcrop are fundamental for establishing meaningful subsurface correlations. Key observations are:

1. Outer ramp and high-accommodation TST flooding successions are characterized by continuous, 5- to 10- ft-thick cycles with burrowed, fusulinid bases and well-sorted packstone caps. Porosity can be developed in cycle bases and caps. Permeability is highest in cycle caps.

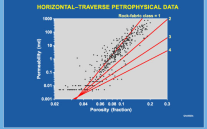
2. Ramp-crest successions are dominated by cycles that have muddy bases and peloid/ooid packstone-grainstone tops. Individual cycles are 5 to 15 ft thick but are locally amalgamated into 20- to 25-ft cycles. Porosity and permeability are usually high in the grain-rich cycle tops.



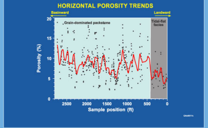
Clear Fork cycle development in the TST legs of basal high-frequency sequences reflects the low-accommodation, aggradational setting. Cycles are 3 to 6 ft thick, mud-dominated, and characterized by burrowed, skeletal-rich bases and well-sorted packstone caps. Although highly continuous, they are generally low porosity.

OUTCROP PETROPHYSICS

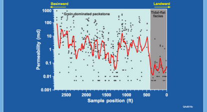
Core-plug samples were collected from vertical and horizontal traverses (see photograph) and analyzed for porosity and permeability. Plugs were collected at 5-ft intervals along a continuous 2,800-ft traverse to examine lateral changes in petrophysical properties within a single bed. Thin sections were cut from each plug to document facies, texture, and rock fabric.



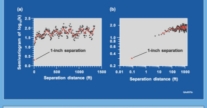
Porosity and permeability interrelationships show that these rocks fall into rock-fabric class 1 of Lucia (1995). Petrographic descriptions, however, show that they are grain-dominated dolopackstone and dolograinstone (classes 1 and 2).



Porosity generally increases basinward reflecting the change from inner-ramp, tidal-flat facies to middle-ramp, peloid-ooid-grain-dominated packstone.The data have a high variability on the short range. A moving average of the data (red line) shows a range of about 5 to 12 percent porosity and a lateral cyclicity with an average length of about 170 ft.



Permeability also increases in basinward. A moving average of the data (red line) shows a range of about 0.1 to 10 md, or about 3 orders of magnitude. Note that the lateral cyclicity expressed in the porosity data is also observed in the permeability data.



Variograms of permeability data are displayed above in Cartesian and log-log formats. The variograms indicate that

1. most of the variance is at a scale of less than 5 ft,
2. short-range spatial correlation is very poor, and
3. a longer range correlation at about 150 ft is present that can also be seen in the porosity and permeability data.