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Duvernay Formation sequence stratigraphy: integrating sedimentology, geochemistry, and petrophysics

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Summary

Prediction of reservoir properties using sequence stratigraphic analysis is well demonstrated in conventional reservoirs, but similar applications of sequence stratigraphy to self-sourced reservoirs are much less common. The Duvernay Formation of the Western Canadian Sedimentary Basin is an organic-rich mudstone that has come into intense focus as a self-sourced resource play, and the growing volume of cores and data available make it a prime candidate for studying fine-grained, organic-rich strata. This study demonstrates how a sequence stratigraphic model was created for the Duvernay formation. The model was grounded in detailed lithofacies analysis, supplemented with organic and inorganic geochemistry, and correlated through an extensive database of wireline logs. Sequence stratigraphic analysis of organic rich mudstones is based on traditional sequence stratigraphic methods but requires an awareness of pitfalls that may lead to incorrect interpretations. Facies analysis and integration of multiple datasets is critical in understanding the dynamic environment responsible for the deposition and preservation of organic-rich mudstones. High resolution examination of rock properties is vital in planning well locations, choosing horizons to land horizontal wells, carrying out an appropriate hydraulic fracturing program, and predicting flow rates and draw down curves.

The Duvernay Formation is a siliceous to calcareous, organic-rich mudstone. Fringing and intrabasinal reefs supply carbonate material to the basin (Switzer et al., 1994) and clay and silt sized terrigenous material is sourced from the north and northeast (Stokes, 1980). A significant amount of quartz silt may be eolian-sourced, and organic-rich deposits have a significant biogenic silica component. The focus of exploration and development in the last several years has been in a NW-SE trending corridor where Duvernay sediments are in the liquids-rich gas window, in areas where siliceous, carbonaceous mudstones are thick, and limestone beds are minimal.

The foundation for the sequence stratigraphic model presented here is a robust set of core descriptions. Eight Duvernay Formation drill cores were described in high resolution in order to identify meaningful lithofacies and interpret environmental conditions and sediment transport mechanisms. Cores were examined for mineralogy, sedimentary structure and fabric on a macro- and micro-scale, microfossil content, cement type and abundance, as well the abundance and character of natural fractures. Bed-normal and bed-parallel thin sections were cut from 4 cores to for higher magnification petrographic descriptions. An additional 18 cores were logged in less detail so that the sequence stratigraphic model could be tied to cores across as much of the basin as possible. To correlate depositional units and sequence stratigraphic surfaces away from core control, a large database of wireline logs were analyzed. Resistivity and spectral gamma logs, when available, were the most effective in identifying depositional packages in wireline. A parallel geochemical and petrophysical study was carried out on 5 of the cores that were described, and that data supplements and supports the lithological descriptions.

Identifying Duvernay Formation depositional packages and interpreting sea level changes from wireline logs has some potential pitfalls. One major hazard is the assumption that increasing gamma means increasing sea level. This is not always true in Duvernay strata. Increasing gamma can be the result of uranium enrichment associated with the formation of organo-metallic complexes in organic-rich sediments. In this case, increasing gamma is generally associated with transgression. Alternatively, increasing gamma may be associated with regression. Duvernay sediments are generally lacking in clay minerals, with most of the clay-sized minerals being quartz and calcite (Rokosh et al., 2011). Where there is enrichment in clay minerals in Duvernay sediments, it is a result of progradation of a clastic source during regression. The spectral gamma log is very beneficial in differentiating between transgressive gamma increases and regressive gamma increases. Resistivity logs are one of the best ways of mapping cyclicity in Duvernay sediments because they are very common, even in old wells, and because they do a fairly good job of identifying clay-rich intervals associated with regression. Resistivity logs are not adequate as a stand-alone tool to map Duvernay strata however, as values can be affected by a variety of factors including clay, organic matter, hydrocarbon, pore water, and pyrite abundances.

The Duvernay Formation can be subdivided into several 4rd order T-R cycles that progressively fill the basin from east to west. East to west basin filling results in a higher number of depositional packages towards the west. At least one major interval of lowstand deposits exists within Duvernay strata that can be mapped across the basin. This interval marks a major change in sedimentation and environmental conditions at the sediment-water interface. Mudstones enriched in terrigenous clay minerals are deposited across the basin as a result of progradation of the clastic source. Bioturbation becomes extensive and some areas of the basin contain abundant *in situ* benthic macrofossils, indicating that oxygen levels at the sediment water interface had markedly increased. A second, potentially less significant lowstand is recorded in upper Duvernay sediments. Similarly, there is a record of shallowing and an increase in terrigenous material to the basin, but not to the same degree as during the middle Duvernay lowstand. Lowstand deposits are generally associated with reduced TOC and may be be subject to carbonate cementation if the subsequent transgression is of great enough magnitude.

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