

Sequence Stratigraphic Model of the Duvernay Shale, Willesden Green Area: Understanding Influence on Well Performance

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Shale reservoirs have often been considered as low risk statistical plays that require minimal to moderate geological characterization. It is commonly believed that black shale possesses homogeneous properties as source and reservoir rock. This misconception can result in the same well engineering design implemented in all parts of a shale play expecting to achieve consistent and repeatable results. Detailed well log and core analyses have revealed that both source rock quality and reservoir quality of the Upper Devonian Duvernay liquid rich shale vary laterally and vertically within the play. Understanding and predicting the complexity associated with stratigraphic units of the Duvernay shale is critical for optimum completion design, development strategies and reservoir engineering analyses.

This study focuses on Willesden Green/Pembina area only. Building sequence stratigraphic framework of a shale play is quite challenging compared with conventional coarse clastic successions. It is not easy to recognize rock parameters such as texture, grain size, mineralogy, sedimentary structures etc. using conventional logs and core analysis. A sequence stratigraphic model of the Duvernay shale was built using conventional logs, mainly gamma-ray (GR), and incorporating core observations and analyses where available. Sequence stratigraphic units and surfaces of the Duvernay shale were interpreted by recognizing lithofacies stacking patterns and interpreting these patterns as representing relative sea level change events. These patterns were:

- 1) upward decreasing GR (regressive event representing sea level falling, whereby generally deeper water organic rich shale lithofacies are replaced upward by relatively higher energy calcite rich lithofacies)
- 2) upward increasing GR (transgressive event representing sea level rising, whereby generally calcite rich lithofacies are replaced upward by lower energy clay/shale rich lithofacies)

Two major surfaces, i.e. transgressive surface of erosion (TSE) and flooding surface (FS), were identified to delineate the stratigraphic sequences. Based on these criteria, seven stratigraphic parasequences (complete and partial cycles of regressive and transgressive events) were identified (Figure 1). The sequence stratigraphic framework of the Duvernay shale was developed by correlating stratigraphic parasequences and surfaces identified in well logs from more than 30 vertical wells. Based on integrated analysis of the sequence stratigraphic model and reservoir properties derived from well logs and core analysis, the Duvernay shale package is sub-divided into three major intervals i.e. Upper Duvernay (U-DVNY), Middle Carbonate Member (M-Carb) and Lower Duvernay (L-DVNY) (Figure 2). Both U-DVNY and L-DVNY intervals show high total organic content (TOC), effective porosity and silica content but low water saturations, Poisson's Ratio and volume of calcite. The M-Carb has high calcite content, water saturation, bulk density and Poisson's Ratio; but low values of GR, porosity and TOC. Significant density-neutron crossover is associated only with U- and L-DVNY (Figure 1) and is interpreted as gas effect. Both of these intervals are being targeted for landing horizontal wells in the study area.

High uranium content in an interval indicate anoxic environment of deposition with slow rate of sedimentation (Abouelresh and Slatt, 2012). Average uranium contents of U-DVNY is significantly high comparing with L-DVNY suggesting the M-Carb marks a significant change in depositional environment. Thickness of the M-Carb varies across the study area from absent to more than 20m. The M-Carb is mainly nodular and does not exhibit sedimentary structures (Figure 3). Other carbonate rich layers that are intermittently present within both U- and L-DVNY exhibit sedimentary structures but typically these layers have limited geographical extent. Identifying the M-Carb is challenging when its thickness is less than ~2m using a lithostratigraphic approach, as the other thin carbonate layers can be confused with the M-Carb in absence of full diameter core (Figure 3). This sequence stratigraphic approach has successfully identified the stratigraphic position of the M-Carb in the study area.

Figure 1 and 2 shows L-DVNY is comprised of five thin parasequences, whereas U-DVNY has only two thick parasequences; largely U-DVNY is a thick continuous stratigraphic interval. Generally value of reservoir properties change significantly within each thin zone of L-DVNY comparing with U-DVNY, and it is assumed the sea level variation is responsible for this change. The L-DVNY is a complex shale reservoir due to extreme value distribution of reservoir's properties (Figure 1).

In the study area, the Duvernay shale is still an emerging play. Horizontal wells have targeted both U- and L-DVNY shale intervals, but to date completion and production results are quite variable within a small geographical area. It is generally assumed that an induced hydraulic fracture should be able to effectively stimulate the total Duvernay Formation when thickness of the M-Carb is less than 5m which limited microseismic data has confirmed. Variable production results within a small geographical area demonstrate the geological complexity as described earlier is one of the key factors responsible for this behaviour; therefore it is challenging to optimally stimulate and produce a well. Dykstra-Parson Heterogeneity Coefficient (DPHC) is used to quantify the amount of complexity associated with shale reservoir properties within the U- and L-DVNY. DPHC values range between zero to one; zero meaning perfectly homogenous value distribution of a property and one meaning infinitely heterogeneous. DPHC is calculated for many attributes that are related with storage and fracability (porosity, bulk density, Poisson's Ratio etc.). Figure 4 is linear regression plot showing relationship between the DPHC values of reservoir's attribute and completion/production indicators. Better completion/production is associated with reservoir intervals that possess low DPHC values; assuming all other things equal. This methodology is helpful to identify optimum landing interval for horizontal wells and to identify Duvernay sweet spots that can lead towards better production.

Conclusions

This work demonstrates that a detailed sequence stratigraphic model of the Duvernay shale can help to identify and predict the geological complexity. The Dykstra-Parson Heterogeneity Coefficient (DPHC) is used to quantify the complexity associated with reservoir's attributes within stratigraphic units. Linear regression analyses show good correlation between completion/production indicators and DPHC values. Proposed work flow can high grade the Duvernay liquid rich shale.

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References

Abouelresh, M.O., Slatt, R.M. 2012. Lithofacies and Sequence Stratigraphy of the Barnett Shale in East-Central Fort Worth Basin, Texas. AAPG Bulletin, v. 96, no. 1, p. 1-22.

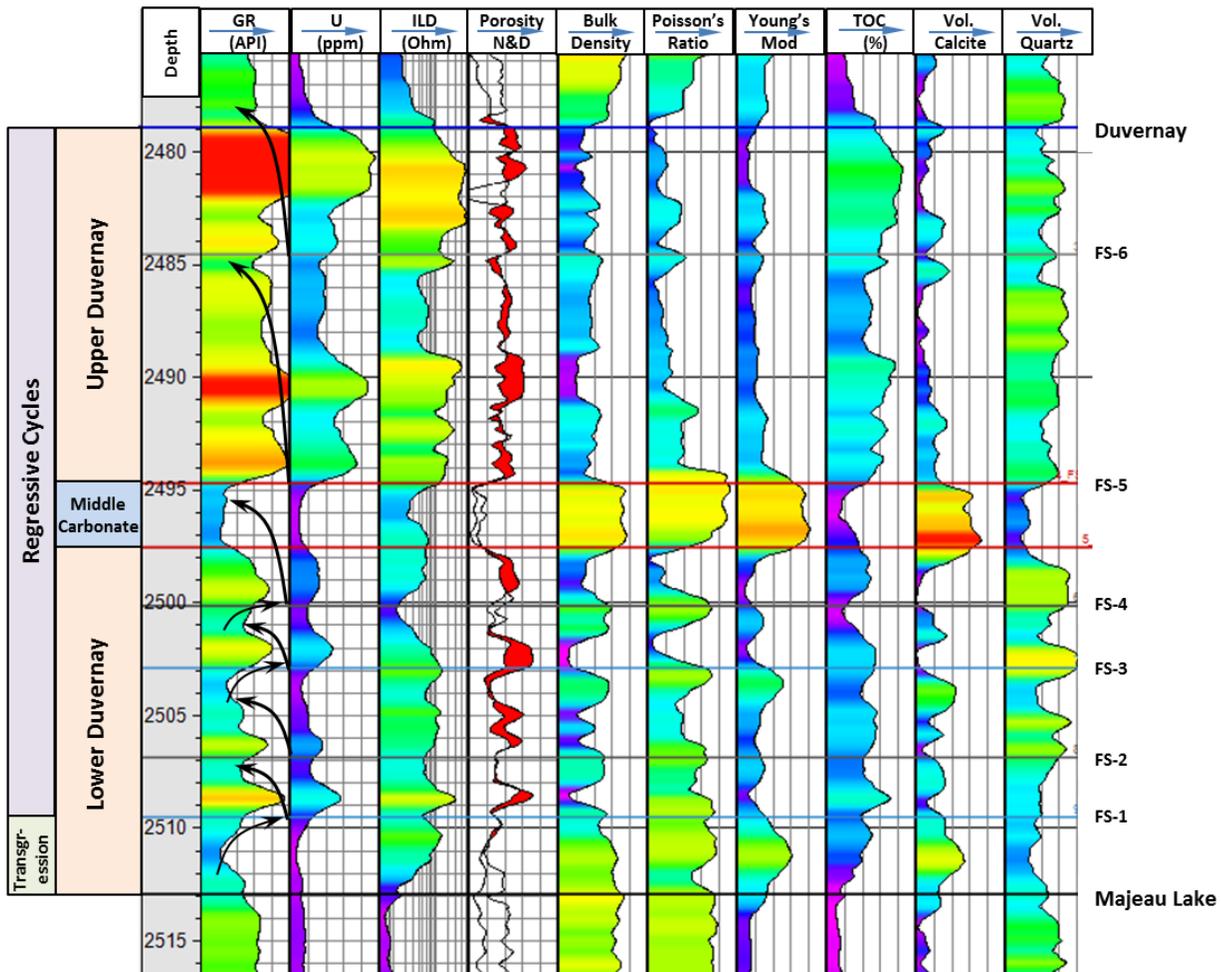


Figure 1: Duvernay shale well log showing sequence stratigraphic interpretation.

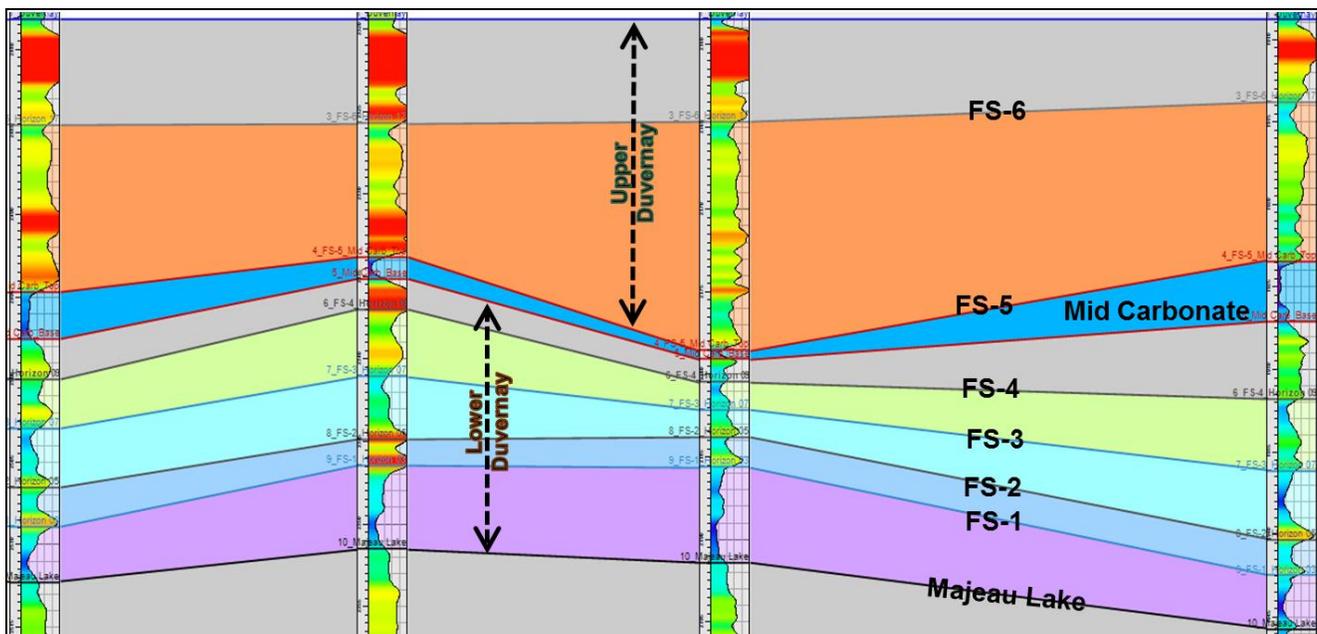


Figure 2: An east-west stratigraphic cross-section built using gamma ray curves showing a sequence stratigraphic model of the Duvernay Formation in Willesden Green area.

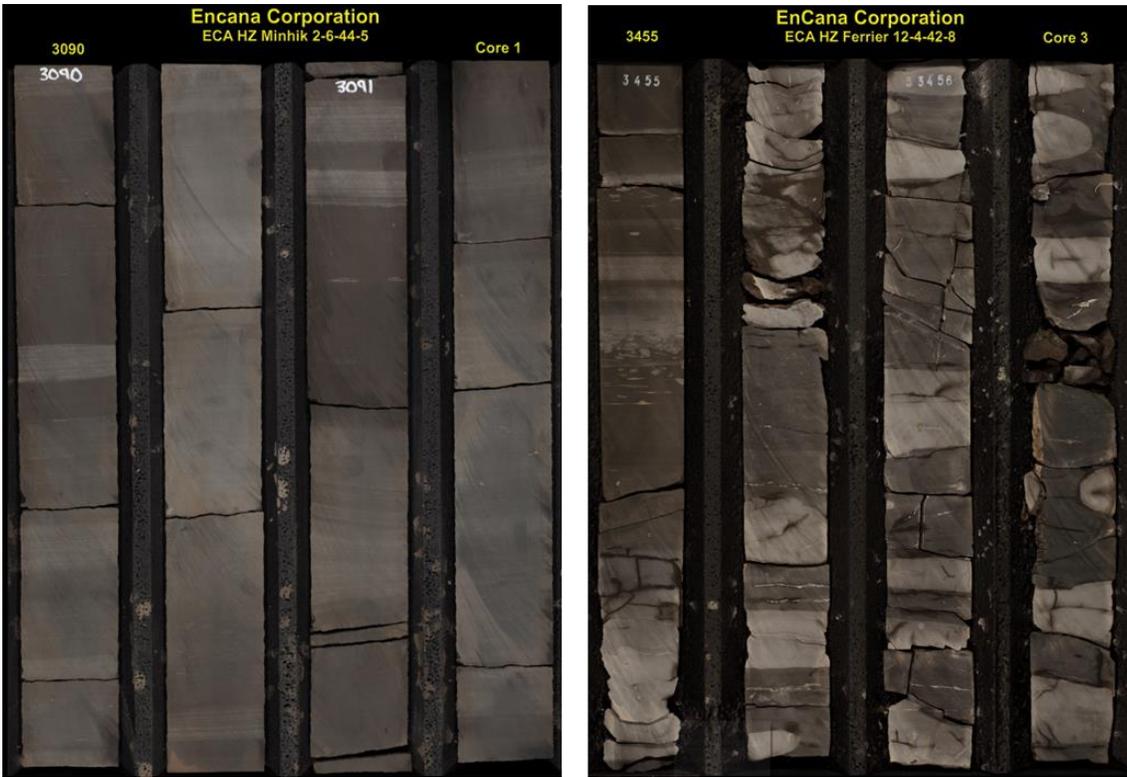


Figure 3: Core photos showing the Middle Carbonate Member (12-4) and other carbonate rich layers (2-6) present within the Duvernay Formation. Both of these carbonate rich layers look similar on well logs.

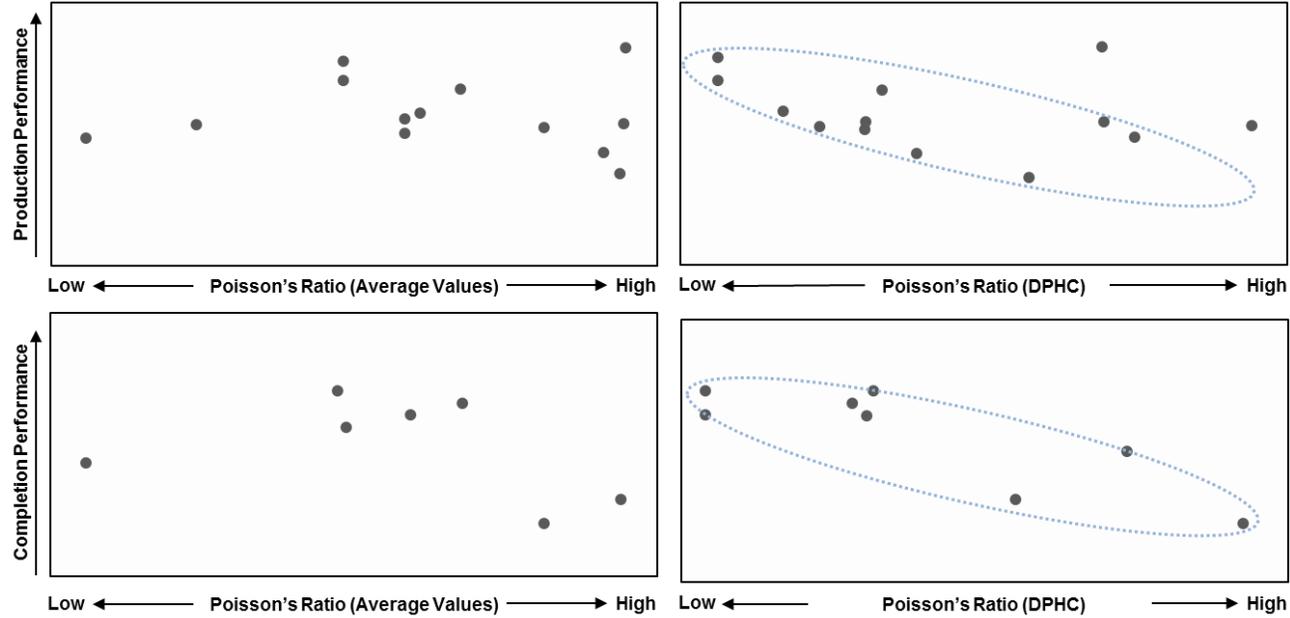


Figure 4: Heterogeneity coefficient of Poisson's Ratio shows good correlation with production/completion performance as compared to average values of Poisson's Ratio. Other reservoir's attributes show similar trend.