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Sequence stratigraphic analysis of the Duvernay Formation shale, Kaybob area, Alberta

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Summary

The Upper Devonian (Frasnian) Duvernay Formation mudstone has become a significant unconventional reservoir within the last decade. In the West Shale Basin, development has been focused on thick, organic-rich, biosiliceous mudstones (Wong et al., 2001; Harris et al., 2018). Our study utilizes 7 long cores through the Duvernay in the Kaybob area and logs from roughly 600 wells to develop a high resolution depositional and sequence stratigraphic model for the formation, in order to model the architecture of favorable units for development. Five lithofacies are identified in the Duvernay cores, associated with depositional processes that include hemipelagic suspension settling, turbidity currents, and bottom currents in conditions ranging from anoxic to fully oxygenated. Lithofacies are used in conjunction with wireline logs to develop a sequence stratigraphic framework that includes three 3rd order depositional sequences superimposed on a 2nd order late transgression to early highstand. We also identify 4th order parasequences within 3rd order highstands.

Methods

Seven long drill cores from the Kaybob area were examined and described in detail for this project, chosen based on their recovery, quality, and length of the Duvernay Formation represented. Core descriptions recorded lithology, sedimentary structures, fabrics, trace and body fossils, mineralogy, cement type and abundance, pyrite abundance and form, and the abundance and fill of natural fractures. Complementary extra-thin, thin sections of important features, fabrics, contacts, and representative examples of lithofacies were taken for the purpose of petrographic evaluation. Lithofacies were determined from the sedimentological analysis of the cores and thin sections. Core descriptions were correlated to petrophysical well logs and roughly 600 wells in the Kaybob area are correlated to produce regional cross sections, plot sequence stratigraphic surfaces, and produce a regional map of the formation.

Lithofacies

Five lithofacies are identified in the Duvernay Formation: planar-laminated siliceous mudstone, wavy-laminated siltstone and silty mudstone, fossiliferous wackestone, bioturbated siliceous pyritic mudstone, and nodular wackestone.

Planar-laminated siliceous mudstone is interpreted as being deposited by hemipelagic suspension settling based on the mud-supported fabric and planar laminae (Lazar et al., 2015; Knapp et al., 2017). This facies locally contains discontinuous laminae made up of pyritized silt

and fossil fragments or continuous silt laminae that display normal and or inverse grading, both likely the product of bottom water currents (Lazar et al., 2015; Knapp et al., 2017).

Wavy-laminated silt and silty mudstone is interpreted to be deposited by bottom water currents and or turbidity currents, based on the planar to wavy laminae, normal (sharp bases) and inverse grading (sharp tops), ripples, pinching and swelling laminae, and silt lenses (Shanmugam, 2000; Konitzer et al., 2014; Rebesco et al., 2014; Knapp et al., 2017).

Fossiliferous wackestone is interpreted to be deposited by turbidity currents. Units are typically sharp-based, normally graded, and moderately bioturbated, with much of the lamination and grading likely destroyed by bioturbation. Units of this lithofacies are likely fossiliferous due to grain size sorting (Konitzer et al., 2014; Lazar et al., 2015; Knapp et al., 2017).

Bioturbated siliceous, pyritic mudstone was likely deposited during times of elevated bottom water oxygen conditions based on the presence of moderate to intense bioturbation as well as the greatest abundance of body fossils (Lazar et al., 2015; Knapp et al., 2017). Burrows are often pyrite-infilled or lined and may be mud or silt infilled.

Nodular wackestone is interpreted as the product of carbonate detritus shed from reefs during highstands (Knapp et al., 2017) and possibly deposited by turbidites (Shanmugam, 2000; Konitzer et al., 2014; Lazar et al., 2015; Knapp et al., 2017). Moderate to intense bioturbation within the facies suggest it was also deposited during elevated bottom water oxygen conditions.

Systems Tracts

Three 3rd order depositional sequences (DS1-3) are recognized within the Duvernay Formation, bounded by 4 sequence boundaries (SB0-3). Sequences are defined by vertical facies patterns in cores and by stratal stacking patterns on wireline logs. DS1 spans the Lower and Middle Duvernay Members and DS2 and DS3 divide the Upper Duvernay Member. DS1 and DS2 comprise transgressive systems tracts (TSTs) overlain by highstand systems tracts (HSTs). DS3 contains a lowstand systems tract (LST) overlain by a TST and then HST. The LST displays decreasing grain size and increasing clay content and bioturbation moving stratigraphically upward. TSTs display increasing planar laminated and siliceous sediment and decreasing grain size upward. HSTs display increasing grain size, carbonate content, and bioturbation upward.

These three 3rd order cycles are superimposed on a 2nd order late TST and early HST, in which the 2nd order MFS is interpreted to coincide with the 3rd order MFS located within DS2. Likely 4th order depositional sequences (2-8 m scale) are also identified within the Duvernay, based on trends within depositional packages within HSTs that include increasing calcite content, decreasing TOC, increasing abundance and size of burrows, and increasing grain size. Bedsets are recognized within the Duvernay as the smallest visible scale of cyclicity (15-65 cm thick) with similar depositional trends as parasequences.

Stratigraphic Surfaces

Sequence stratigraphic surfaces at contacts between systems tracts display similar characteristics across the study area. Sequence boundaries are correlative conformities (Catuneanu et al., 2011) and are recognized by abrupt facies shifts and locally erosive and soft sediment deformed surfaces overlain by mm to cm scale lag deposits that commonly contain fossil fragments, clay-rip up clasts, and phosphatic and pyrite grains. The surfaces and overlying lag deposits are commonly bioturbated with possible *Glossifungites* occurring locally. Maximum flooding surfaces (MFSs) are identified as discrete surfaces, typically underlain by fine grained, siliceous, planar laminated lithology and overlain by a slightly coarser lithology. Maximum regressive surfaces (MRSs) are typically cryptic, rarely overlain by mm scale lag deposits and are typically underlain by more clay-rich and bioturbated lithologies and overlain by slightly coarser, more carbonate-rich lithologies.

Conclusions

Five lithofacies are identified in Duvernay core with hemipelagic suspension settling, turbidity currents, and bottom currents as major depositional processes occurring in bottom waters ranging from anoxic to fully oxygenated. Three levels of cyclicity are recognized within the Duvernay formation: bedsets (15-65 cm), parasequences (2-8 m), 3rd order depositional sequences (3 constitute the formation). Bedsets and parasequences both display shoaling-up trends. DS1 and DS2 both contain TSTs overlain by HSTs while DS3 also includes a preserved LST at its base. Sequence boundaries are recognized by abrupt facies transitions and local erosion, soft sediment deformation, burrowing and overlying lags. Maximum flooding surfaces and maximum regressive surfaces are typically discrete to cryptic and recognized by facies changes.

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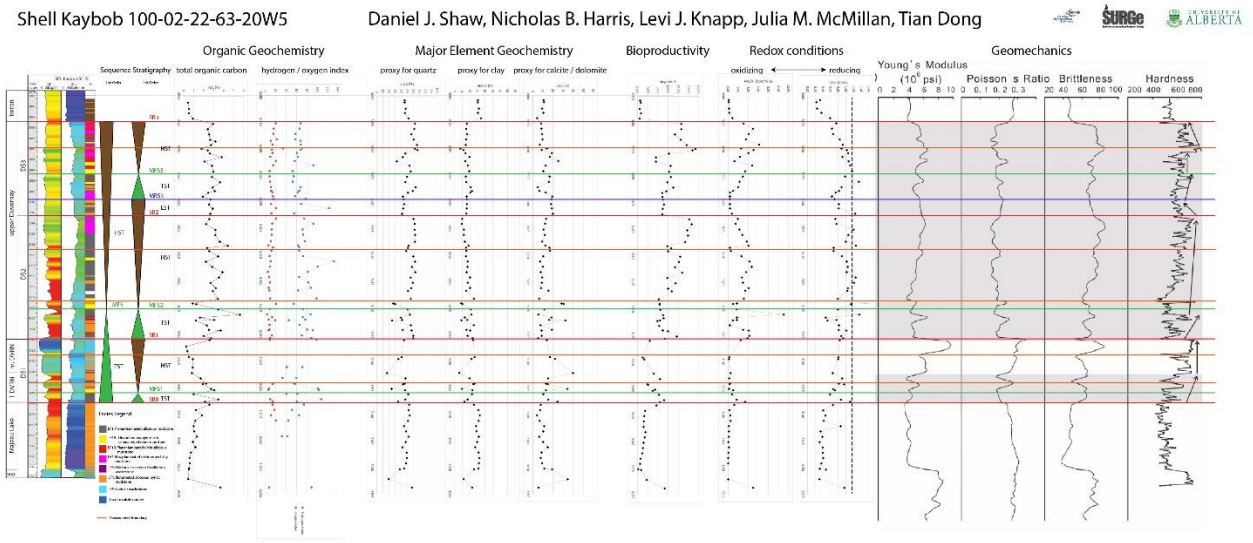

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