Detailed sedimentological and sequence stratigraphic analysis of the Duvernay Formation in the Kaybob area, Alberta

Daniel J. Shaw[1], Nicholas B. Harris[2]
1. Earth and Atmospheric Sciences, University of Alberta

Summary

The Upper Devonian (Frasnian) Duvernay Formation mudstone is a prolific source rock in the Western Canada Sedimentary Basin, believed to have sourced most of the Upper Devonian conventional hydrocarbon reservoirs in Alberta (Allan and Creaney, 1991). More recently, it has become a significant unconventional reservoir, with development focused on thick, organic-rich, biosiliceous mudstones in the West Shale Basin and carbonate-rich mudstones in the East Shale Basin (Wong et al., 2001; Harris et al., 2018). A high resolution depositional and sequence stratigraphic model of the Duvernay within the Kaybob area (a favorable area for prospectivity (Preston et al., 2016)) will be useful in the identification of the most productive intervals.

Method

Six drill cores were examined and described in detail for this project. Cores were chosen based on their recovery, quality, and length in which they penetrate the Duvernay Formation. Descriptions of the cores recorded 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 wells are correlated to produce regional cross sections, plot sequence stratigraphic surfaces, and produce a regional map of the formation.

Lithofacies

We have Identified 6 major lithofacies in the Duvernay Formation: planar laminated siliceous mudstone, wavy-laminated calcareous silt in mudstone, planar-laminated calcareous silt in mudstone, fossiliferous wackestone, bioturbated siliceous pyritic mudstone, and nodular limestone.

Planar-laminated siliceous mudstone is interpreted as the product of hemipelagic suspension settling, based on the mud-supported fabric, planar laminae, and the absence of other sedimentary structures (Lazar et al., 2015; Knapp et al., 2017). This facies locally contains discontinuous pyrite laminae that result from pyrite replacing carbonate silt and fossil fragments during early diagenesis. The pyrite laminae are often found above third order transitions from TST to HST and continue into the HST. Clays being brought into the basin, post transgression, are interpreted as being the source of iron for the pyrite replacement.

Wavy-laminated silt in mudstone is interpreted to have been deposited by bottom water currents. This is based on the presence of wavy (sometimes discontinuous or lenticular) laminae, normal graded laminae with typically sharp or erosive bottom contacts, inverse graded laminae with typically sharp top contacts, ripple marks, and sparse to intense bioturbation (Shanmugam, 2000; Konitzer et al., 2014; Rebesco et al., 2014; Knapp et al., 2017).

Planar-laminated silt in mudstone is interpreted to be the result of turbidity currents and/or bottom water currents. This is based on the presence of parallel laminae, normal graded laminae with typically sharp bottom contacts, inverse graded laminae with typically sharp top contacts, as well as sparse to moderate bioturbation (Shanmugam, 2000; Konitzer et al., 2014; Rebesco et al., 2014; Lazar et al., 2015; Knapp et al., 2017).

Fossiliferous wackestone is interpreted to have been deposited by turbidity currents, based on common sharp bases of units, possible normal grading (which is typically destroyed by bioturbation), and rare visible burrows. 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 is interpreted as being deposited during periods of oxic to dysoxic bottom water, based on the presence of moderate to intense bioturbation as well as low TOC in comparison to other siliceous facies (Lazar et al., 2015; Knapp et al., 2017). Also within this facies are rare ripple cross laminae (likely the product of bottom water currents) and rare thin coarsening-up beds that are sometimes stacked (possibly the product of sediment gravity flows or turbidites). This facies has the most abundant body fossils of any facies.

Nodular limestone is interpreted as carbonate detritus from highstand shedding of reefs (Knapp et al., 2017). This facies also has rare to abundant burrows.

Sequence Stratigraphy

Three 3rd order depositional sequences (DS1-3) were identified within the Duvernay Formation, bounded by 4 sequence boundaries (SB0-3) (based on previous basin scale work done by Knapp (2016)) (Fig. 1). These are defined by cyclical vertical facies patterns in cores and by stratal stacking patterns on wireline logs. Sequence boundaries are typically defined by abrupt facies shifts and are sometimes marked by an erosive surface directly overlain by mm to cm scale lag deposits. These are often comprised of fossil fragments and display local burrowing.

SB0 is located at the Majeau Lake-Duvernay contact, SB1 (top of DS1) is located at or near the top of the middle Duvernay member, SB2 (top of DS2) is located within the upper

Duvernay member, and SB3 (top of DS3) is located at the Duvernay-Ireton contact. The bases of DS1 and DS2 are major flooding surfaces (locally identified by lag deposits) that mark the beginning of transgressive systems tracts (TST's) and deposition of organic-rich, siliceous mudstones. These are overlain by highstand systems tracts (HST), which are represented by an increase in carbonate sediments and bioturbation. The base of DS3 is marked by a rapid transition to more argillaceous (basinward) sediments and is interpreted to be a lowstand systems tract (LST). This is overlain by a transgression (TST), depositing organic-rich, siliceous mudstones, which is then overlain by more bioturbated to calcareous mudstones, indicating a HST.

These three 3rd order cycles are interpreted to be superimposed on a 2nd order late TST and early HST. The 2nd order maximum flooding surface (MFS) and top of the TST is interpreted to coincide with the MFS located within DS2, within the upper Duvernay member.

We have also identified what are likely 4th order depositional sequences (1-5 m scale) in the Duvernay, based on trends within depositional packages that include: increasing calcite content, decreasing TOC, increasing abundance of in-situ benthic macrofossils, and increasing grain size.

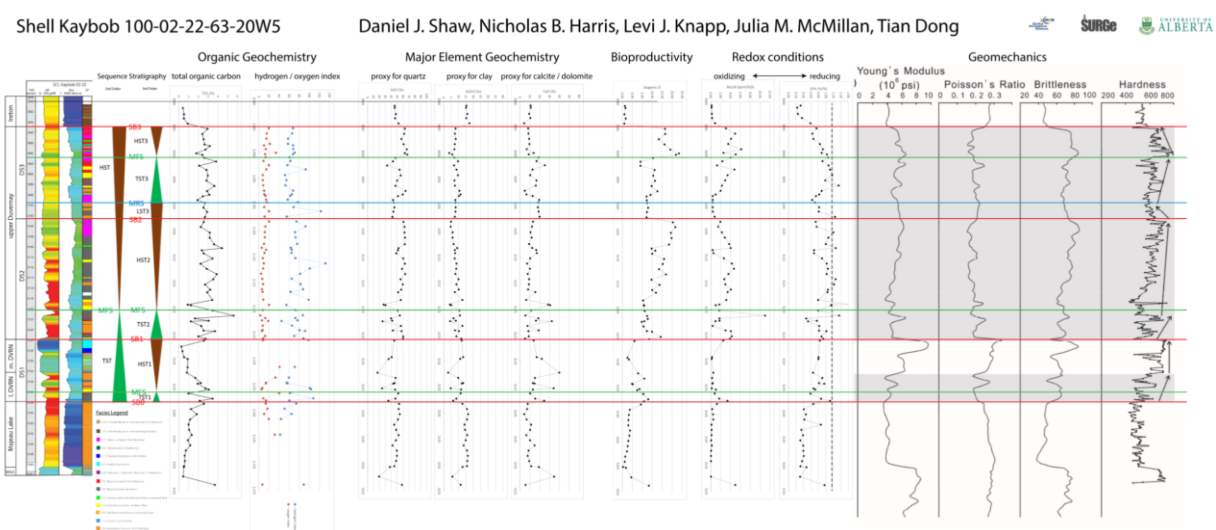

Figure 1: Sequence stratigraphic interpretation of Shell Kaybob 100/02-22-063-20W5/00 core (modified *from* Harris at al. 2018).

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