Lithofacies and the Paleo Environment of the Southern West Shale Basin of the Duvernay Formation

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Summary

A sedimentological assessment of seven wells was performed and the resultant data used to define a set of lithofacies. The lithofacies relate to natural lithological subdivisions seen in the core. Colour was successfully utilized as one of the primary lithofacies characteristics and has resulted in a substantial degree of correlatability with conventional well logs and source rock data. It is proposed that these lithofacies display a predictable and logical progression of environmental change within the Duvernay Formation that can be related to cyclical deposition and sequences in a restricted basin with a stratified water column that is affected by variations in energy, oxygenation, and sea level. The association with depth allows for sequence stratigraphic interpretation and the relationship with well logs allows for extrapolation to parts of the basin that do not have readily available core. Based on results from this study it appears that an application of colour as a primary lithofacies characteristic may be effective when interpreting or correlating other source rock shales deposited in restricted basins that once contained stratified water columns.

Theory / Method / Workflow

To characterize and extrapolate lithological core data from a formation found within a particular basin or field, a set of lithofacies is often created. The set should recognize variability within the formation while grouping together rocks with similar characteristics in distinct packages. These lithofacies commonly allow for the interpretation of changes in the paleoenvironment responsible for different lithologies within a formation and within different parts of a basin.

In this study natural subdivisions in the Duvernay Formation provide the basis for defined lithofacies. The most common and consistent repeating characteristics have been deemed primary and are included in the definition of the primary lithofacies. Inspired by a method for determining TOC through grey scale analysis pioneered by Jean-Yves Chattelier (Chattelier et al., 2016; and, Chatellier et al., 2017), along with a careful examination of logged intervals and conventional well logs, core colour became one of the primary characteristics utilized in this study for lithofacies determination. Determined primary lithofacies characteristics commonly also include lithology and sedimentary structures. The primary lithofacies determined in this study can be seen in Figure 1.

Core was available in all wells studied while thin sections were only available in 4 of the 7 wells studied. Most of these cores contain the upper 4/5 of the Duvernay Formation which commonly includes the Duvernay Formation top and some of the overlying Ireton Formation. The portion of the available core allows for a relatively accurate description of the stratigraphic intervals that represent the Upper, Middle and Lower Duvernay Formation in the Southern West Shale Basin. The core was carefully examined to ensure that the logging would account for almost all visible lithological variations. Each determined interval of core (ranging from 5cm to 300cm and averaging 40cm) was logged for 13 distinct characteristics including colour, texture and textural relationships, structure, grain size and distribution, bedding and laminae, mineralogical composition, probable organic matter distribution, sedimentological structures, bioturbation and trace fossils, fossils, matrix type, probable oxygenation, and additional accessories. Lithofacies were then created based on the consistency of these key characteristics in intervals with similar well log responses. Once determined, lithofacies were assigned to the logged thin sections and thin section data was tabulated in Excel®. This allowed for sorting and in-depth analysis of thin section scale texture, grain distribution, and mineralogy. Observed characteristics in the defined lithofacies were then used to infer variations in depositional conditions and sequential variations in the depositional environment.

Results, Observations, Conclusions

Core length ranged from 39 to 55 meters and each well involved two to three separate cores that were obtained in a contiguous fashion. The thickness of the Duvernay Formation ranges from 45 to 61 meters. Primary lithologies observed in this area of the Duvernay Formation include nodular and banded limestone/wackestone (LF5), brownish grey bioturbated marlstone (LF4), very dark grey planar laminated mudstone (LF3), black planar laminated mudstone (LF2), and very black planar laminated mudstone (LF1). Contacts between these rock types occasionally are marked by thick laminae or very thin beds that have increased pyrite, increased silt and calcareous material, erosive bases and bioturbation (LF8). Relatively rare sporadic occurrences of thin to medium thickness beds of sharp based light to medium grey wackestone that range from burrow mottled to mixed and chaotic also occur (LF7). The interbedded dark grey and medium grey laminated calcareous mudstone (LF6) only occurs in the overlying Ireton Formation and the brownish grey planar laminated mudstone (LF9) only occurs in the underlying formation. Primary lithofacies can be seen below in Figure 1.

Lithofacies based on Primary Characteristics

LF1: Very black planar laminated mudstone

LF2: Black planar laminated mudstone

LF3: Dark grey laminated mudstone

LF4: Dark grey to brownish relatively massive to faintly laminated marlstone

LF5: Nodular to banded light to medium grey limestone/wackestone

LF6: Interbedded dark grey and medium grey laminated calcareous mudstone

LF7: Light to medium grey wackestone

LF8: Bioturbated very thin bed of limestone and/or pyrite and mudstone

LF9: Brownish grey planar laminated mudstone

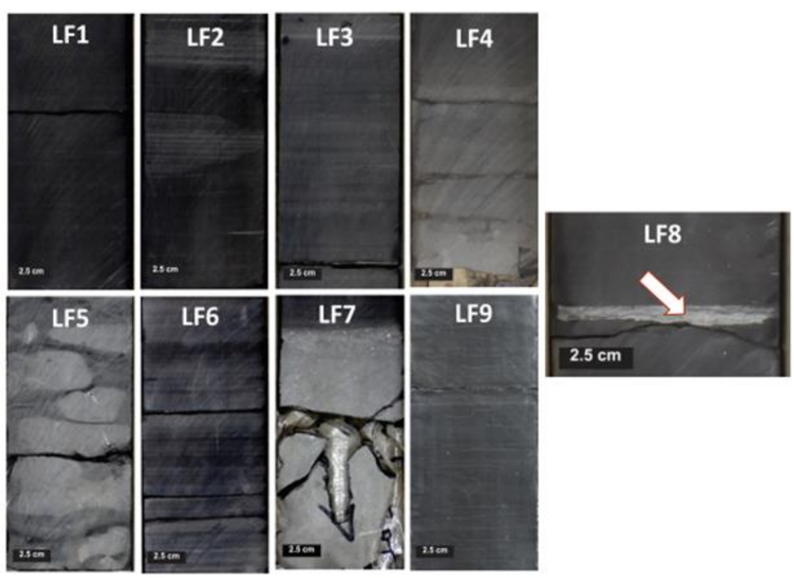

Figure 1: Primary lithofacies names and examples of primary lithofacies seen in core

As stated above, the Duvernay Formation in the Southern West Shale Basin is separated into centimeter to meter scale distinct intervals with consistent characteristics that are represented by the proposed lithofacies. These commonly display relatively sharp but conformable contacts, or slightly erosive contacts, with other intervals. Also, very thin slightly gradational contacts sometimes occur. Sea level change and a stratified water column are proposed to be responsible for the distinct intervals seen throughout the Duvernay Formation that occur at different thicknesses.

Lithofacies in the Duvernay Formation are composed of similar base component parts or characteristics that occur in different quantities within the different facies. The distribution of these characteristics can be related to conditions of deposition. Based on the distribution of silts and matrix, organic matter content, amount of pyrite, sedimentary structures and varying degrees of bioturbation, it is clear that the amount of energy and oxygenation changes throughout the Duvernay Formation and these changes appear to be represented by the defined lithofacies. Based on observations, it seems that the dominant control on energy levels and the degree of oxygenation is sea level. The distribution of facies and characteristics within could be seen to be part of a sequence of deposition with LF1 being the deepest with the least energy and oxygenation, and LF2 being slightly more energetic, oxic and shallower. This is followed by the slightly more energetic, oxic and shallower LF3, which is followed by the more energetic, more oxic and probably shallower LF4. LF5 appears to represent the most shallow, energetic and oxic of the common facies found in the Duvernay Formation. This interpretation is supported by the stratigraphic order of the lithofacies observed in repeating punctuated depositional sequences (parasequences) that commonly overly the nodular to banded limestone (LF5) of the Middle Duvernay. The punctuated nature of the facies within each parasequence can most probably be related to sea level change in a stratified water column and the connectivity of the units of these parasequence is inferred from the conformable sharp to very slightly gradational contacts. Based on the distribution of pelagic fossils, fossil fragments and the very rare benthic fossils, it appears that deposition of all facies occurred in the basin, off of the platforms, and outside of typical carbonate producing environments even though energy, depth and oxygenation vary.

In Moore (1989) and in Switzer et al. (1994) it is recognized that the Duvernay Formation formed during a transgressive period. When considered temporally the transgression being referenced spans more than just the deposition of the Duvernay Formation and is most probably 2nd order (defined as 10 million to 100 million years). It is recognized in Knapp (2016) that dominant larger sequences that occur within the Duvernay Formation are probably 3rd order (1 million to 10 million years). This agrees with both observations made in this study and the time span proposed for Duvernay Formation deposition. Therefore, the distinct smaller centimeter to meter scale intervals of rock found within the Duvernay Formation could relate to oscillations in sea level during high order sequences or parasequences defined as 4th or 5th order. Oscillations in sea level within a stratified water column should result in deposition occurring in different layers of the water column resulting in deposition within bottom waters that have different levels of anoxia as shown in Figure 2. These changes in anoxia can then commonly be tied to sea level and a cyclical and sequential pattern of deposition. Slatt (2014) notes that within unconventional resource shales cycles of higher geologic time frequency superimposed upon cycles of lower time frequency often results in high frequency sequence stratigraphic patterns, and that changes in eustatic and relative sea level are commonly responsible for these cycles and sequence stratigraphic patterns. Slatt (2014) also states that cyclical and sequential patterns have been observed in the Barnett Shale, Woodford shale, New Albany Shale, Marcellus shale, Haynesville shale, Eagleford shale and the LaLuna shale.

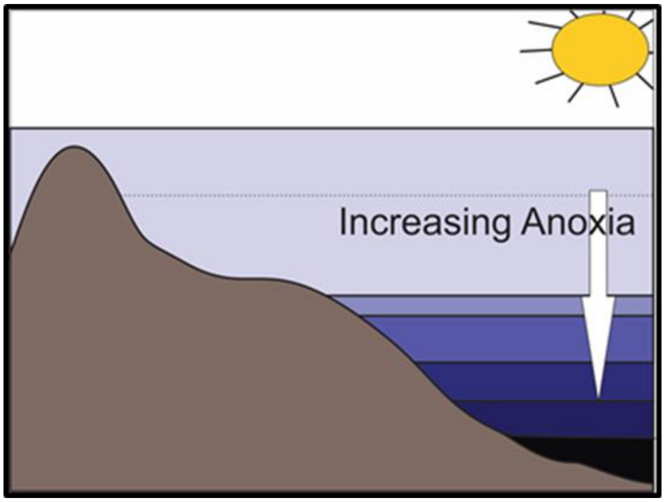

Figure 2: Schematic image of off platform stratification of a water column and the relationship with anoxia

It is possible that within this basin the connectivity of sub-basins increases during transgressions and that this connectivity results in a reduction in restriction, an increase in energy and an increase in oxygenation resulting in deposition of the nodular to banded limestone/wackestones of LF5. However, based on observations made in this study, it appears that as sea level rises the dominant control on oxygenation and organic matter preservation is the reduction in circulation due to increasing depth; and that reef growth that is responsible for the restriction and lack of circulation could keep up with sea level rise, as modern reefs have been known to grow up to 1cm per year. Therefore, end stage transgressions and highstands are believed to be related to black shales, while the higher energy and oxygenation in the nodular to banded limestone of the middle Duvernay (LF5) actually relates to a lowstand in which increased mixing of bottom water was due to a reduction in sea level; and, increased carbonate material relates to increased circulation and reef and platform shedding that would occur during a drop in sea level. Observations made in this study support this interpretation.

In Cann (2018) it is shown that gamma ray cut-offs are well defined for the most common facies in the Duvernay Formation and the relationship with variations in gamma ray values is heavily influenced by changes in TOC content that can be related to the degree of anoxia and core colour. Cut-offs are not well defined for other logs, however trends in density logs, photoelectric factor, neutron porosity, sonic logs or spectral gamma ray logs do help determine the defined facies when uncertainty based on the gamma ray log occurs. So, through the combined application of the gamma ray logs and trends and observations made within other logs, key common lithofacies can be accurately inferred resulting in the ability to infer changes in the depositional environment and associated sequence stratigraphic patterns using only well logs.

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