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Stratigraphic Patterns of Organic Carbon Enrichment in the Upper Devonian Duvernay Formation, Alberta

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Summary

Organic carbon enrichment in Duvernay Formation mudstones is related to sequence stratigraphic systems tracts and to paleogeographic position with respect to the Rimbey-Meadowbrook Trend, a a major reef trend that separates the carbonate-rich East Shale Basin (ESB) from the siliceous West Shale Basin (WSB). In the WSB, above a second order maximum flooding surface, TOC peaks just above third order maximum flooding surfaces and decreases gradually through the highstand systems tracts. TOCs are generally lower below the second order maximum flooding surface and are highest in the third order transgressive systems tract.In the ESB, organic enrichment is less regular and apparently related to dilution by carbonate shed from adjacent platforms.

Introduction

The accumulation of organic matter in mudstones has been related to sequence stratigraphy and transgressive – regressive cycles in numerous studies over the past 25 years. Such studies commonly predicate their interpretations on the assumption that organic matter is particularly enriched in transgressive systems tracts or at maximum flooding surfaces. This assumption is generally supported by careful sequence stratigraphic analyses of black shale systems (e.g. Arthur and Sageman, 2004). These interpretations implicitly (or explicitly) assume that increasing water depth leads to reduced oxygen levels, which enhances organic preservation, and to reduced sedimentation rates, which concentrates organic matter. Models for organic enrichment based on bioproductivity are less obviously related to transgressive systems tracts or maximum flooding surfaces. Some researchers note that the importance of feedback loops between these factors that also do not necessarily lend themselves to a simple transgressive model.

We test the relationship between organic carbon accumulation and position within a stratigraphic sequence in the Duvernay Formation of the Western Canada Sedimentary Basin, developing a core-based sequence stratigraphic interpretation and comparing it to a high resolution geochemical and organic petrologic database. This data set enables us to associate total organic matter content and specific organic assemblages with particular systems tracts and to examine how the organic assemblages change across the basin. These are tested against proxies for redox conditions and bioproductivity to relate relative sea level to specific mechanisms for organic accumulation.

Dataset and Methods

The sequence stratigraphic analysis of the Duvernay Formation is based on detailed core descriptions and interpretations of 8 cores from exploration wells located from the Peace River Arch in the north nearly to the Killiam Reef in the south and from the eastern margin of the basin to the deep basin near the deformation front. Studied wells represent both the East Shale Basin (ESB), southeast of the Rimbey-Meadowbrook Trend, and the West Shale Basin (WSB) to the northwest of the Trend. An additional 16 cores were examined more briefly to fill gaps in our core coverage. Facies and stratigraphic results are presented in Knapp (2016) and Knapp et al. (2017). Five wells, 3 from the WSB and 2 from

the ESB, were selected for geochemical analysis, including major, minor and trace element analysis by ICP and ICP-MS, total organic carbon (TOC) by LECO analysis and Rock-eval parameters by the Weatherford Source Rock Analyzer. Core were sampled at a spacing of 1 meter or finer, and organic and inorganic geochemical analyses represent identical splits of each sample. Geochemical analytic procedures and results are reported in McMillan (2016). Three wells with a total of 38 samples were selected for organic petrologic analysis. Samples were prepared as polished blocks following the standard organic petrography techniques. Vitrinite and solid bitumen reflectance was measured with a Zeiss Photoscope. Maceral analysis was conducted by point-counting 500 spots on each sample, and recalculated to volume %.

Results

The Duvernay Formation comprises three third order sequences, termed DS1, DS2 and DS3 in ascending order (Knapp, 2016). These are superimposed on a second order late transgressive systems tract and early highstand systems tract, where the second order maximum flooding surface coincides with the maximum flooding surface of DS2. DS1 corresponds to the lower Duvernay, with the middle Duvernay carbonate unit marking the maximum regressive surface at the top of the DS1. DS2 and DS3 together correspond to the upper Duvernay. The sequences are composed almost entirely of transgressive systems tracts (TSTs) and highstand systems tracts (HSTs). A lowstand systems tract (LST) is only present at the base of DS3, which effectively marks the second order sea level turnaround. Depositional facies generally vary from bioturbated carbonate-rich siltstones to siliceous mudstones from the platform margins to basin center (Knapp et al., 2017); sections from the ESB are generally carbonate-rich whereas sections from the WSB are siliceous.

Duvernay shales represent a range of organic enrichment and organic matter type. Organic petrologic analysis records predominantly amorphous organic matter and solid bitumen, with much less abundant vitrinite and inertinite. Organic matter type indicated by Rock-eval analysis shows that in most cases, lower TOC content is associated with poorer quality organic matter (low hydrogen index), indicating either more reducing conditions or higher bioproductivity were responsibility for organic enrichment. However, in a carbonate-rich part of the East Shale Basin, hydrogen index is uncorrelated with TOC, indicating that here, dilution by carbonate minerals was the primary control on organic enrichment.

Stratigraphic patterns of organic carbon enrichment in the WSB are consistent. Highest TOCs are recorded just above the maximum flooding surface in DS2 (also the second order MFS). Secondary peaks in TOC are recorded above the MFS in DS3 and in the transgressive systems tract of DS1. Low TOC values are recorded in the lowstand systems tract of DS3 and in the transgressive systems tracts of DS2 and DS3 almost up to the MFSs. Organic carbon concentrations are related to proxies for redox conditions and bioproductivity. Organic enrichment in the central ESB is erratic, varying sharply over narrow stratigraphic intervals, probably reflecting variable sedimentation rates.

Conclusions

Organic enrichment in the Duvernay Formation is predictable in a sequence stratigraphic framework throughout much of the Alberta portion of the Western Canada Sedimentary Basin. Above a second order maximum flooding surface, TOC is highest just above third order maximum flooding surfaces. TOCs are lower below the second order maximum flooding surface and are most enriched in the transgressive systems tract.

Acknowledgements

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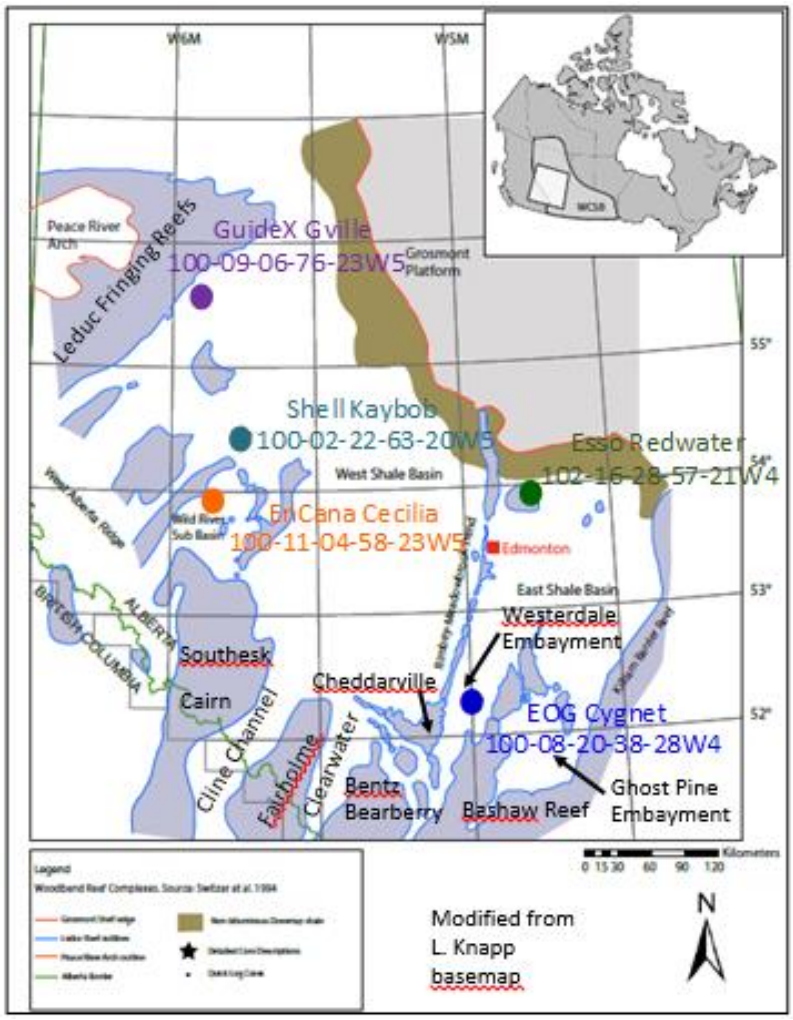

Figure 1. Map of the Alberta portion of the Western Canada Basin, showing basin paleogeography in the early Frasnian. Locations of wells with geochemical data are shown.

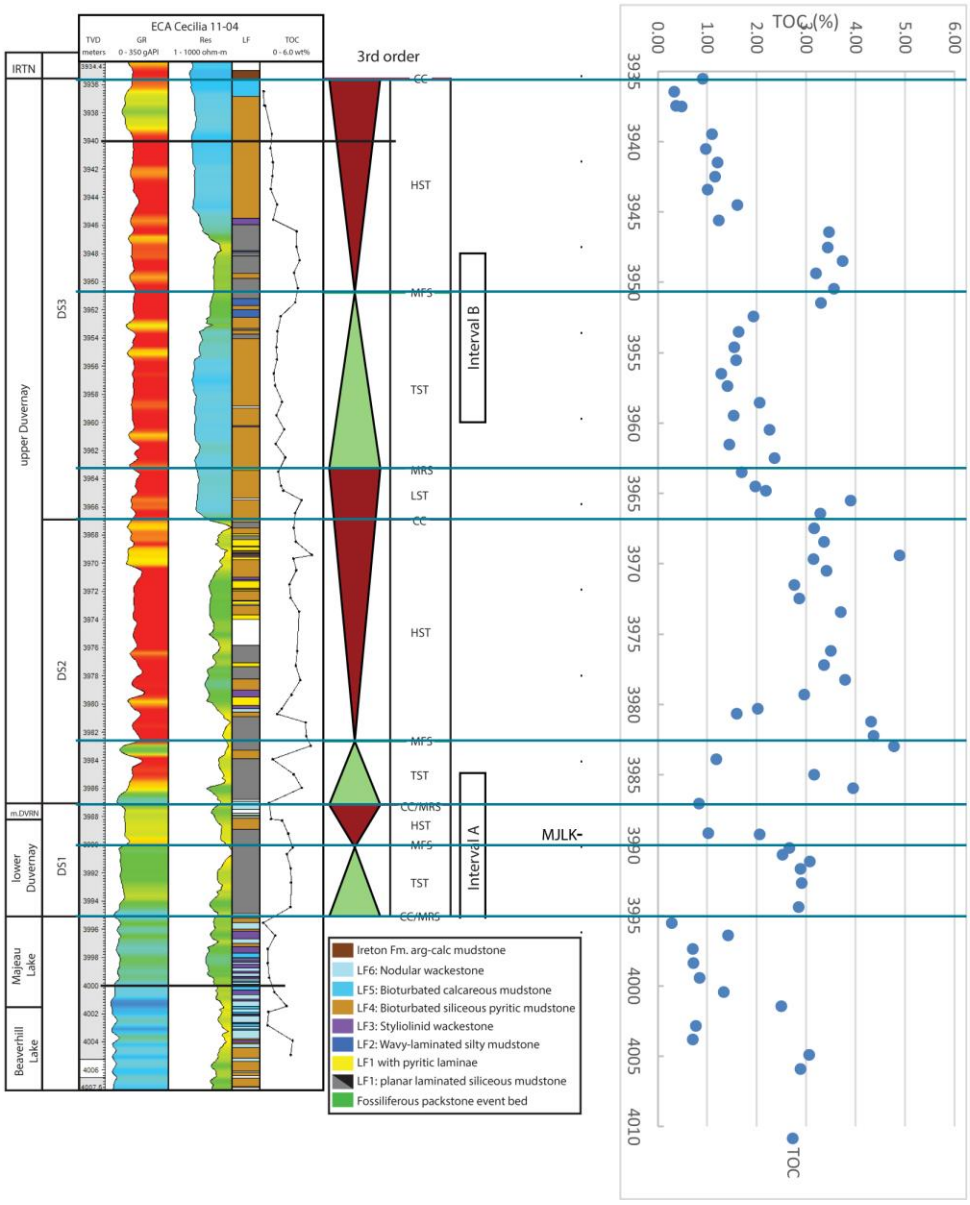

Figure 2. Facies and sequence stratigraphic interpretation of the Encana Cecilia 100-02-22-63-20W5 well. TOC data are shown in relationship to stratigraphic sequences.