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Upper Ordovician reefs in the Hudson Bay Basin: Porosity evolution and hydrocarbon charge

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Summary

Research on hydrocarbon systems for the Hudson Bay (GEM 2 program 2014-2020) has initially focussed on detailed source rocks kinetic and potential hydrocarbon reservoir appraisal. Upper Ordovician reefs are sizeable mound structures in outcrop and on vintage seismic profiles. In outcrop, the reefs are porous (15-25%) with bitumen coating some pore space. The reefs are on top of high TOC and HI source rocks. Conventional and cathodoluminescence petrography has identified different cement phases (early marine to late cements) which were characterized with oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) stable isotopes and fluid inclusion microthermometry; clumped isotopes signature (Δ_{47}) on late cements will be acquired for more temperature constraints on late cements. The Upper Ordovician reefs had significant open porosity at the time the slightly older source rocks entered the oil window.

Introduction

The Hudson Bay Basin is the largest intracratonic basin in North America; from 1970 to 1990, over 86 000 linear-kilometres of deep (industry) and shallow (GSC) seismic data were acquired but only 11 wells (5 offshore and 6 onshore) exploration wells have been drilled (Fig. 1). All these wells had oil and gas shows but none of them were tested (Lavoie et al., 2015).

The succession preserved in the Hudson Bay Basin is 2500 m thick and consists of Upper Ordovician to Upper Devonian shallow marine carbonates with local reefs (Upper Ordovician, Lower Silurian and Middle Devonian) and secondary shales and sandstones. The Upper Ordovician to Lower Devonian interval is cut by extensional faults that were active during sedimentation but no faulting is discernable in the Middle to Upper Devonian strata (Pinet et al., 2013; Fig. 2). Pinet (2016) linked the Silurian active tectonism in the Hudson Bay to far field events generated by the Salinic Orogeny along the distant (1000 km) continental margin of Laurentia.

Upper Ordovician source rocks have been identified in offshore and onshore wells and in outcrops surrounding the basin (Lavoie et al., 2015; Fig. 1). At the margin of the preserved succession, the source rocks are immature to marginally mature. Modified hydrous pyrolysis of samples from 4 localities has shown that the organic-rich shale starts to generate hydrocarbons at low burial temperature (Reyes et al., 2016). Inverse modeling of Apatite Fission Tracks data from various localities suggest that the Upper Ordovician succession entered the oil window with a maximum burial temperature of around 90°C at the eastern end of the Hudson Strait (Pinet et al., 2016).

Most of the initial research (2008-2013) for the Hudson Bay Basin focussed on tectonostratigraphy, source rock evaluation and assessment of various burial indicators. Other than a limited description of one occurrence of hydrothermal dolomite, no work on potential reservoir was carried out.

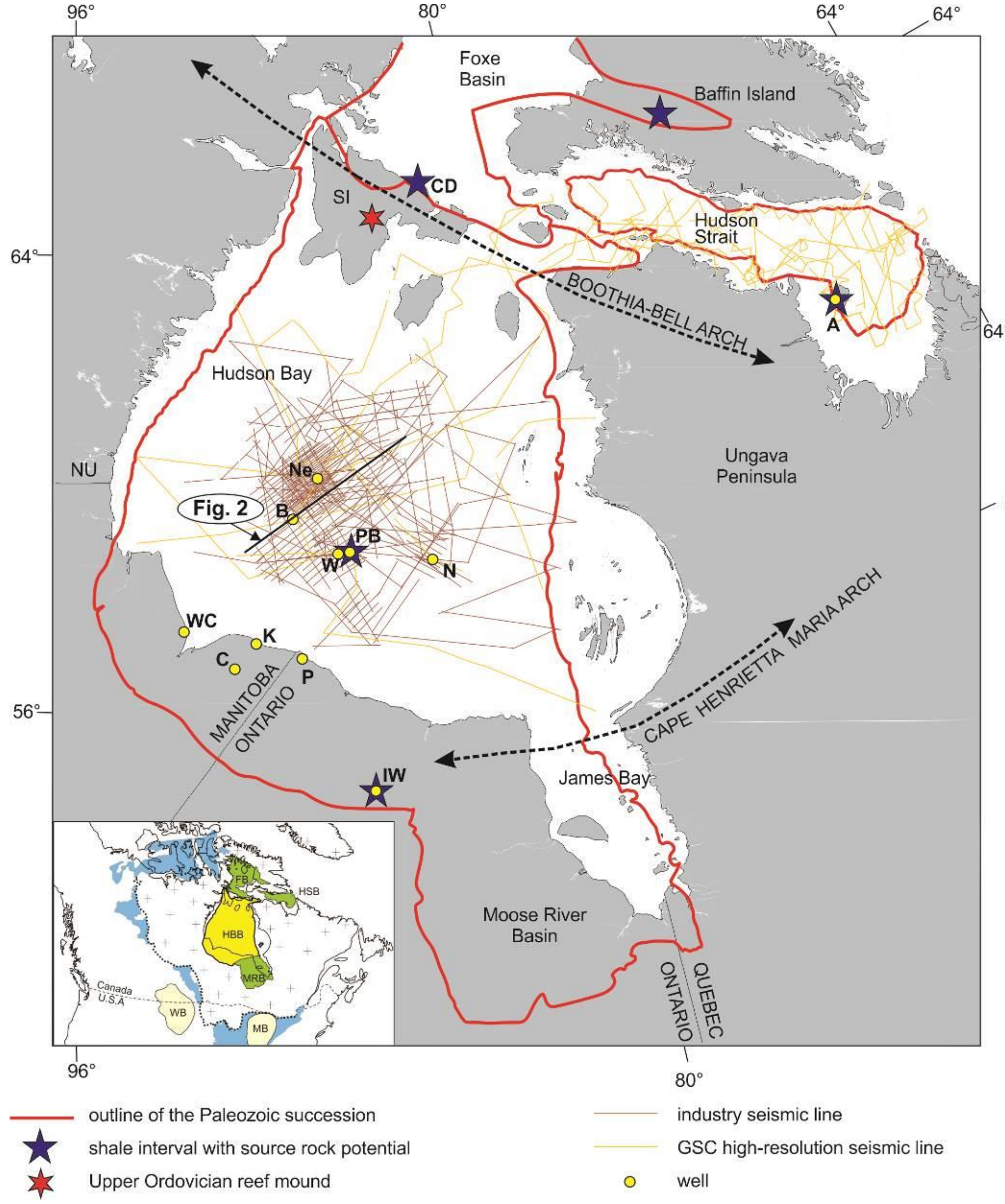

Figure 1: Location map of Hudson Bay with wells, seismic lines, source rock outcrops and location of the studied Upper Ordovician reef. Modified from Lavoie et al. (2015)

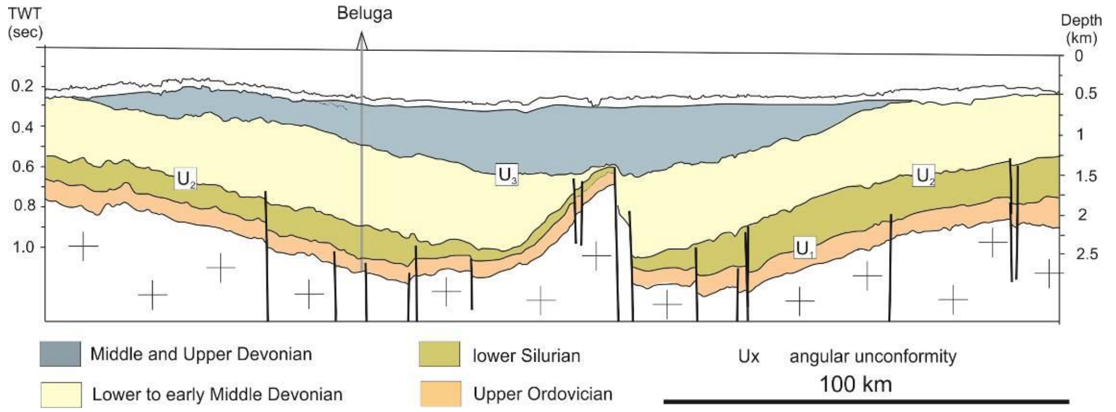

Figure 2: Cross-section (location on Figure 1) illustrating the four major stratigraphic units, the seismic interpreted faults and biostratigraphy-controlled unconformities. Modified from Pinet et al. (2013).

Upper Ordovician reefs – potential hydrocarbon reservoirs

Upper Ordovician (Katian) buildups have been reported from the Hudson Platform on Southampton Island at the northern end of the Hudson Bay (Heywood and Sanford 1976; Zhang 2010) (Fig. 3A). These mounds belong to the Red Head Rapids Formation and in outcrops, consist of a massive core with thinner stratiform counterparts. The massive cores have been loosely described in the past as micritic, algal, or microbial limestones with metazoans of subsidiary importance. The Red Head Rapids Formation mounds are locally partly dolomitized and are up to 500 m in width with minimum vertical relief of 15 m. They occur a few metres above Upper Ordovician source rocks (Zhang, 2010). The reefs contain large voids and vugs (Fig. 3B) that are locally filled with bitumen and dead oil (Heywood and Sanford, 1976).

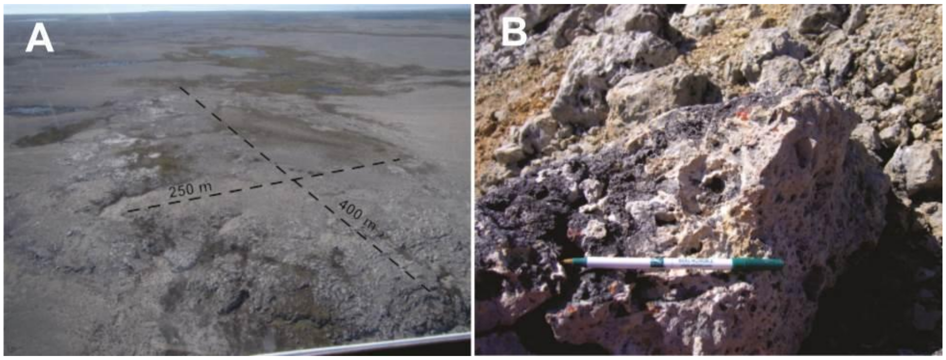

Figure 3: A) Upper Ordovician reef on Southampton Island, location on Figure 1. B) High secondary porosity (25%) in algal reef.

Castagner et al. (2016) presented a detailed description of facies architecture of the mounds. The Red Head Rapids Formation mound is primarily composed of boundstone and cementstone with various proportions of early calcified sponge tissues, microbial encrusters, synsedimentary cement and small metazoans. The accretionary mechanisms of the Red Head Rapids Formation were mainly the result of frame building by early calcified sponges and small colonial corals and binding by calcimicrobial elements for the boundstone facies, and of marine cement precipitation near the seafloor for the cementstone facies.

The petrography has revealed early diagenetic phases (synsedimentary marine cements and neomorphosed sponge network; Fig. 4A) as well as late cements and bitumen (Fig. 4A and B) filling secondary pore space; late stage dolomitization and dedolomitization are observed. Diagenetic phases were sampled for their δ^{18}O and δ^{13}C values (Fig. 5). Early calcite phases, made up of neomorphosed aragonite, have less depleted δ^{18}O values and for samples with paired early and late cements, a trend to more depleted isotope values is clear (Fig. 5).

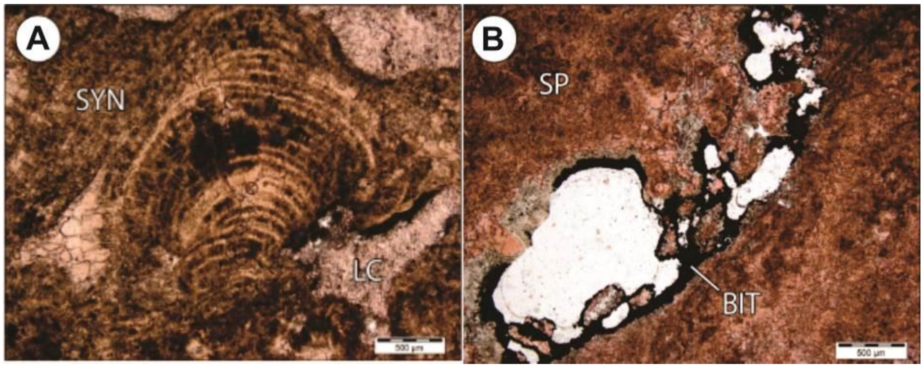

Figure 4: A) Botryoidal synsedimentary calcite cement (SYN) with secondary pore filled by late calcite (LC). B) Bitumen (BI) coating the wall of open secondary pores developed in neomorphosed sponge tissue (SP).

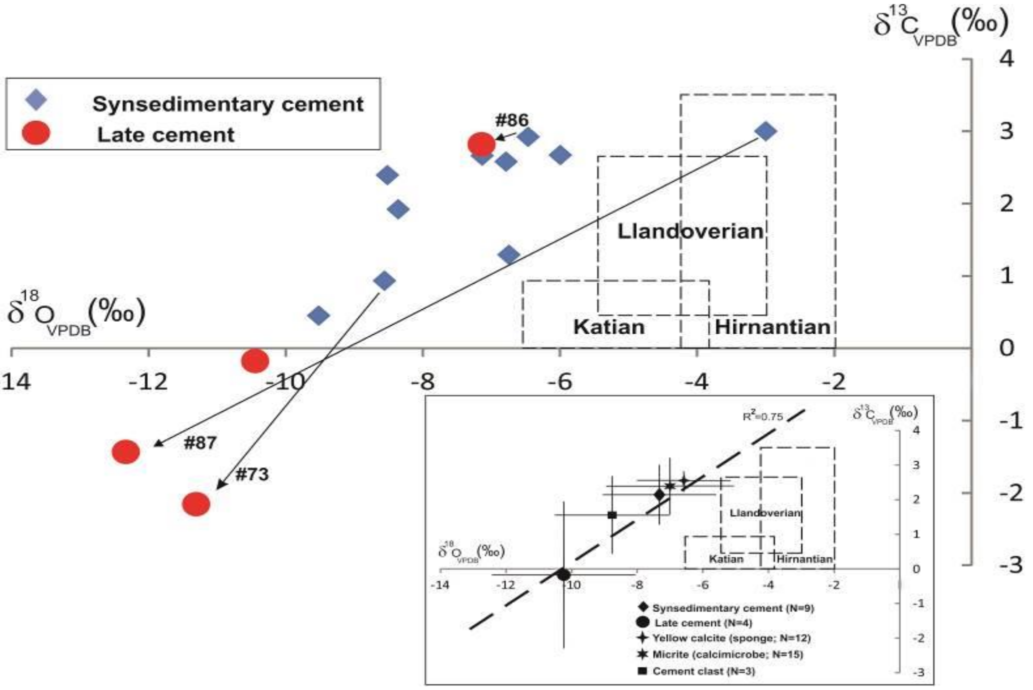

Figure 5: δ^{18}O and δ^{13}C cross-plot showing early and late cements. Arrows link paired early and late cements from one sample (#xx). Average results with 2σ for all diagenetic phases are shown in the inset, regression dashed line (R^2=0.75) is for early and late cements. Dashed boxes are marine signatures.

Fluid inclusions are small (2 to 10 µm in size) and are found in fractures and late pore filling cements. Most of them have both liquid and vapour phases, with the vapour usually making between 10 and 20% of total inclusion volume. Preliminary data (work in progress) on homogenized assemblages generated T_h of 142°C and 156°C. Limited T_m measurements on these provided a temperature of -12.9°C, which translate to salinity of 16.8 wt% $NaCl_{equiv}$. More data are currently being acquired.

The correlation of preliminary FI and $\delta^{18}O_{VPDB}$ data (-7.1 to -12.3‰: Fig. 5) indicate that late pore and fracture filling cements were precipitated from a saline fluid having $\delta^{18}O_{SMOW}$ values between +4 to +8‰ (Fig. 6). This suggests that the reef experienced migration of high temperature burial fluids.

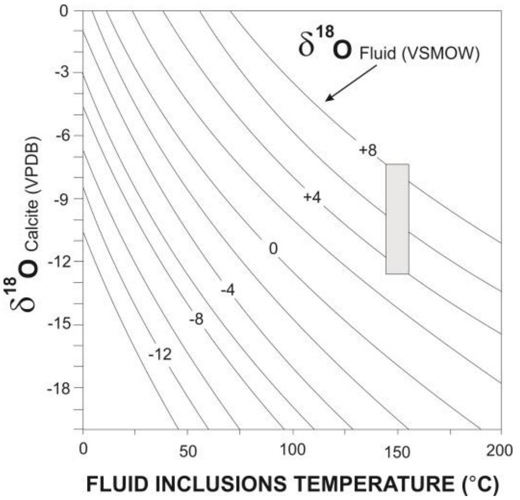

Figure 6: Cross-plot of fluid inclusions temperature and the $\delta^{18}O_{VPDB}$ of the host calcite which define the $\delta^{18}O_{SMOW}$ of the diagenetic fluid.

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