Thermal history of the Hudson Bay Basin – An evaluation based on a multiple-tool approach

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Summary

Research on hydrocarbon systems for the Hudson Bay (GEM 2 program 2014-2020) focusses on detailed stratigraphic framework, source rocks kinetics, thermal history and potential hydrocarbon reservoir appraisal. Historical thermal data (Rock-Eval) and multiple-sources of new thermal data have been reevalauted and acquired, respectively. The data from multiple locations over that large sedimentary basin are somewhat contradictory. Some of the data suggest that the basin is immature whereas other type of data, sometimes in the immediate vicinity of the immature samples indicate oil window conditions. Part of the discrepancy could be related to the different type of material evaluated for the thermal history as well as imprecisions of each of the tool used. We present here the results from Rock-Eval T_{max} in shale, organic matter (OM) reflectance, apatite fission tracks (AFT) data in basement and sandstone, carbonate cements fluid inclusions (FI) and (yet to come) clumped isotopes data from the same carbonate cements.

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 the offshore 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 relatively thin shale and sandstone intervals. The Upper Ordovician to Lower Devonian interval is cut by normal faults that were active during sedimentation; no faulting is discernable in post Lower Devonian strata (Pinet et al., 2013).

Recent research on porous Upper Ordovician reefs concluded that fracture-controlled high temperature brine circulation occurred after the inception of burial and recrystallization of original marine cements and resulted in significant secondary porosity that was later filled by lower temperature burial cements and hydrocarbons (Lavoie et al, submitted). The study of RADARSAT images (Decker et al. 2013) and recent SLAR (Side-Looking Airborne Radar) coverage indicate that potential sea surface natural oil slicks are present at various places in the marine domain with one of them coinciding with a seafloor pockmark occurrence.

Results from thermal maturation indicators are ambiguous; Upper Ordovician source rocks have been identified in offshore and onshore wells and in outcrops surrounding the basin (Lavoie et al., 2015; Fig. 1); the maturation of these source rocks have been evaluated through Rock-Eval and programmed hydrous pyrolysis whereas the thermal history for central Hudson Bay was also appraised through a detailed organic matter reflectance study. To complement these organic matter-based approaches, apatite fission track (AFT) from basement and basal sandstone have been analyzed. Moreover, temperatures of entrapment of fluid inclusions in carbonate cements of Upper Ordovician reef have been measured and independent temperatures of precipitation and/or recrystallization of carbonate cements based on clumped isotopes are being gathered.

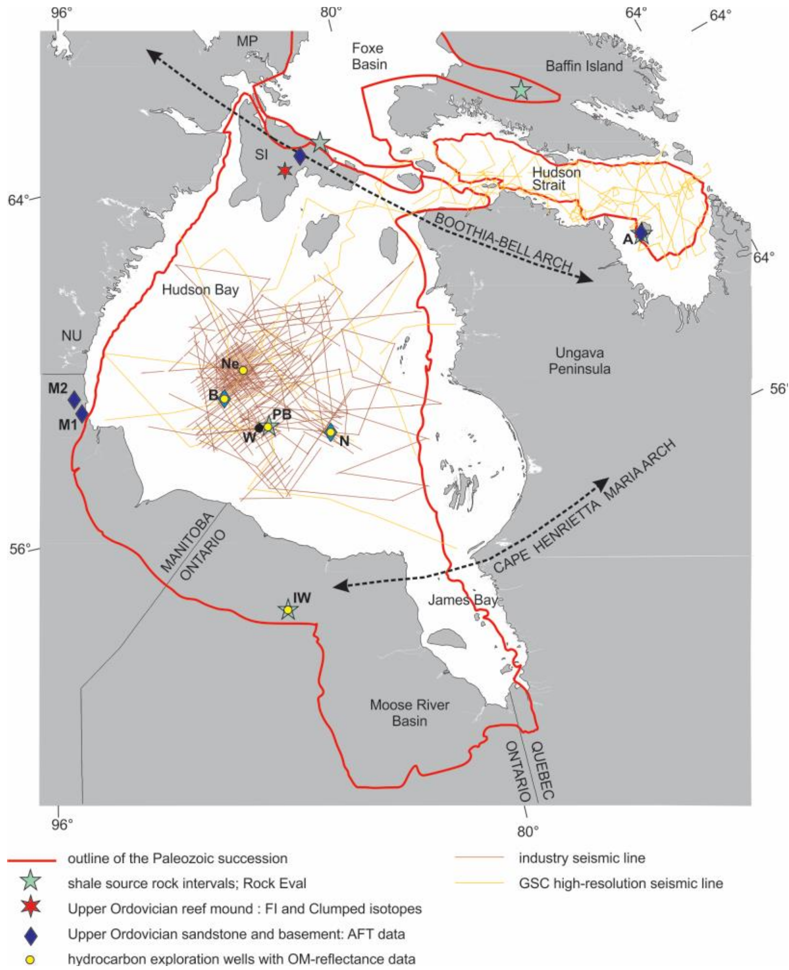

Figure 1. Location of various thermal data set. Wells: A: Akpatok, IW: Inco-Winnisk, Ne: Netsiq, B: Beluga, W: Walrus, PB: Polar Bear; N: Narwhal. Localities: SI, Southampton Island; NU, Nunavut; M1 and M2 refer to two samples from Manitoba.

Rock-Eval data

Rock-Eval data from over 500 samples were either re-evaluated or acquired during our research. The T_{max} data spread goes from 410°C to 441°C for samples with S2 values over 0.35 mg HC/g rock (Fig. 2). Outcrop samples, surrounding the Hudson Bay and Foxe Basin have lower T_{max} values compared to samples from wells in the central part of the Hudson Bay.

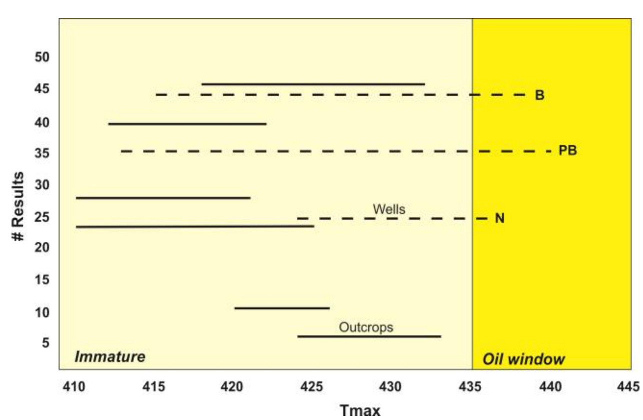

Figure 2. T_{max} data from outcrops and wells. All values have S2>0.35 mg HC/g rock. See Fig. 1 for wells acronyms.

Organic matter reflectance

58 samples from 4 wells in the central Hudson Bay (Fig. 1) were prepared and analysed for reflectance values of diverse organoclasts; reflectance values were transformed in vitrinite equivalent (%$Rovit_{eq}$) (Bertrand and Malo, 2012). The majority of samples from all wells are in the oil window, a strong contrast with the T_{max} results from the same wells (Fig. 3).

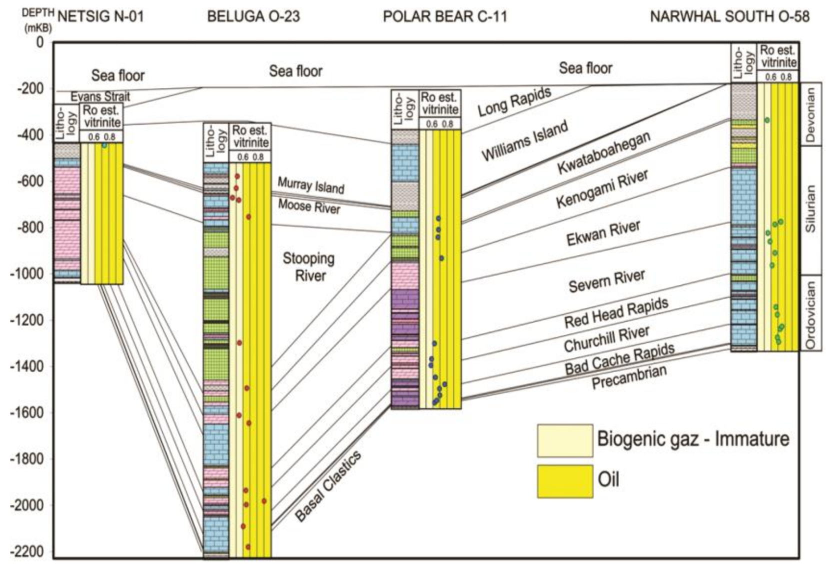

Figure 3: %Ro_{equi} from diverse organoclasts in central Hudson Bay. Form Bertrand and Malo (2012).

Apatite Fission tracks

Six samples (5 basements and one Ordovician sandstone) yielded sufficient apatite for inverse modeling of tracks length and density (Pinet et al., 2016). All samples have yielded best fit temperatures over 70°C (Fig. 4).

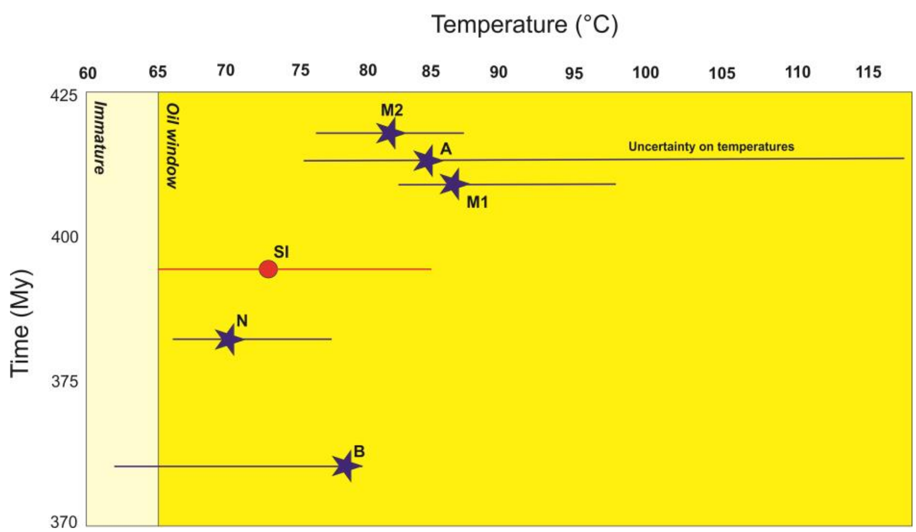

Figure 4: Best-fit data for temperature and burial age from inverse modeling (Pinet et al., 2016). See Figure 1 for abbreviation. Only uncertainty on temperatures are presented. Similar large range of values for time of maximum burial also exists.

Fluid inclusions

Homogenization temperature (T_h) of fluid inclusions were measured in synsedimentary and late cements in pore space of Upper Ordovician reefs on Southampton Island (Lavoie et al., submitted) (Fig.1). The range of T_h for early marine cements is significantly higher (average117.9 ±25°C) compared to late cements (average 92.6 ±9.7°C) (Fig. 5). Early hydrothermal alteration from high temperature brines is proposed.

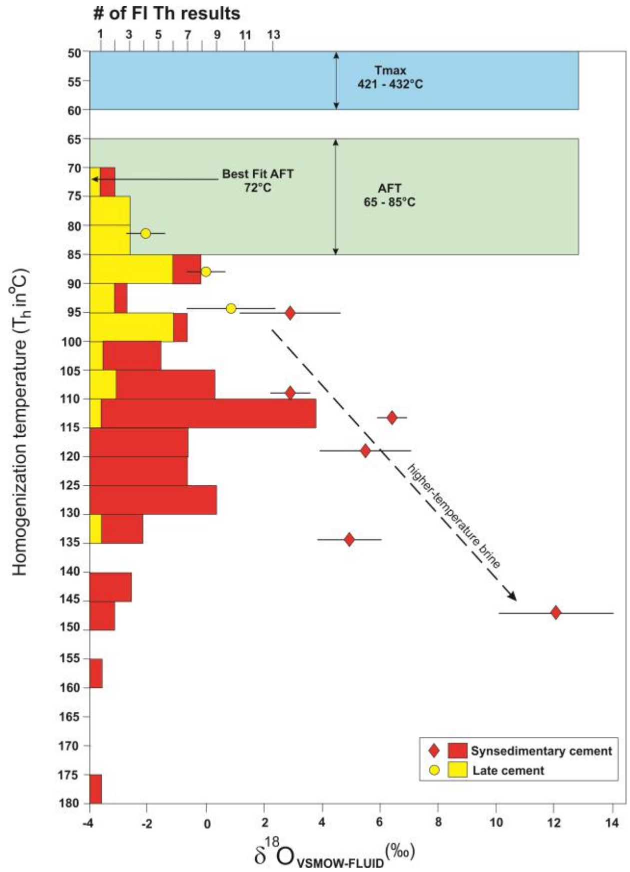

Figure 5. T_h values (vertical axis) of early and late cements in Ordovician reef on Southampton Island. Also shown the range (and best fit) of AFT data and Rock Eval T_{max}. The three independent data set are from nearby sectors on Southampton Island.

Discussion and conclusion

Figure 5 presents a compilation of available thermal indicators on Southampton Island. Upcoming clumped isotope results from pore-filling and recrystallized marine carbonates in Upper Ordovician reefs will later be added. Rock-Eval T_{max} suggests that the organic-rich shales are immature. It was suggested that T_{max} suppression might be a factor for these high TOC and hydrogen index (HI) shales (Lavoie et al., 2015). Programmed pyrolysis of these shales suggests that T_{max} suppression was relatively insignificant (Reyes et al., 2016). The AFT best fit data from inverse modeling agrees with the lower temperature range of fluid inclusion T_h data from late cements. The AFT data is from a sample of Upper Ordovician sandstone (Pinet et al., 2016). The early (?) high temperature hydrothermal event recorded in carbonate cements is not recognized from Rock-Eval or AFT data even if hydrothermal carbonate breccia has been described in the immediate vicinity of organic-rich shale outcrops on northern Southampton Island (Lavoie et al., 2011).

The available data from Southampton Island suggest that approaches for evaluation of thermal history from diverse lithologies and material (OM in shale, apatite in sandstone, and fluid inclusions in carbonates) are likely to generate discordant results. Thus, interpretation of the thermal history has to be done with care.

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