Oil shale and reservoir rocks of the Hudson Bay Lowland, northeastern Manitoba

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1.

The Hudson Bay and Foxe basins project is in its fourth and final year. It is part of the Geological Survey of Canada (GSC) Geomapping for Energy and Minerals (GEM) program. In Manitoba, the Hudson Bay Basin is represented by the Paleozoic carbonate succession of the Hudson Bay Lowland (HBL) in the northeastern corner of the province. (**Figure 1**)

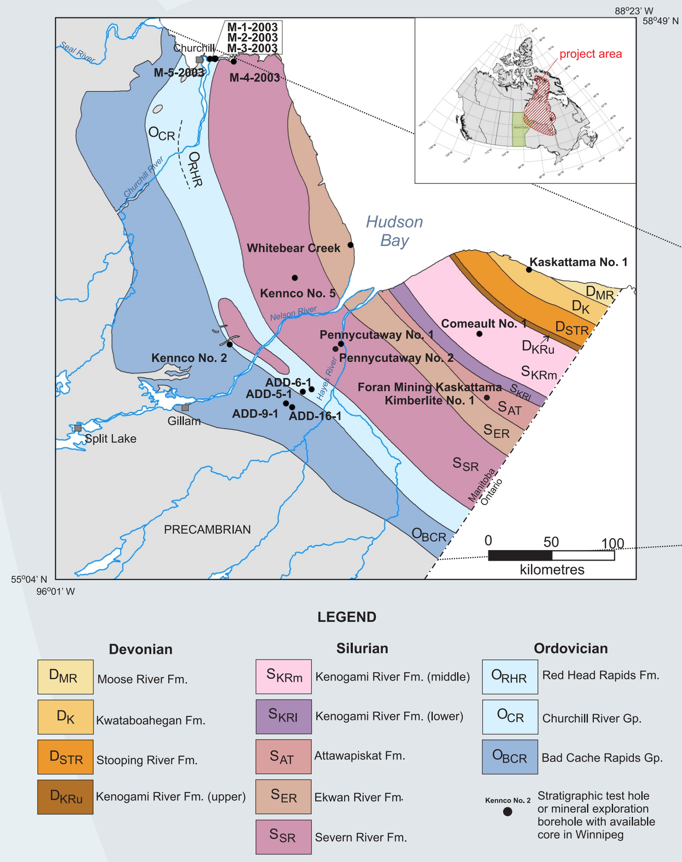

Figure 1: Hudson Bay Lowland in northeastern Manitoba, showing the location of cores available; insert is the project areas for the GEM Hudson Bay and Foxe Basins Project.

While work is still needed to better understand the stratigraphy at a basin scale, this project has demonstrated that the Hudson Bay Basin has all the right elements and conditions for hydrocarbon systems to exist, including mature and diverse source rocks, attractive reservoirs and efficient traps and seals. Identification of mature source rocks is key to having a hydrocarbon system, and these have been identified in parts of the basin. (**Figure 2**)

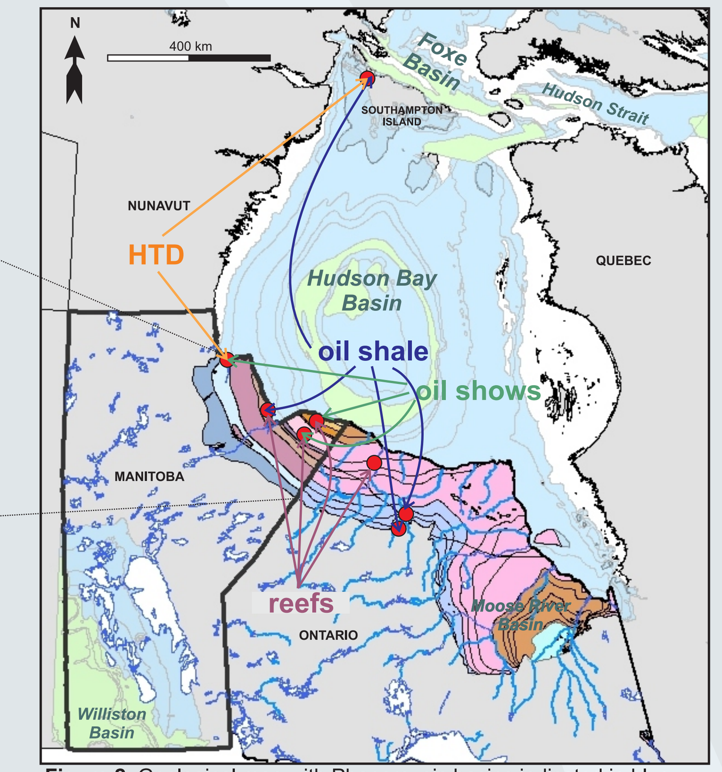

Figure 2: Geological map with Phanerozoic basins indicated in blue (Paleozoic-aged units) and green (Mesozoic-aged units). Manitoba and Ontario Paleozoic strata in the Hudson Bay Lowland is shown in different colours. Stratigraphic border "faults" between Manitoba and Ontario's strata show how much more work is still needed to better understand the complex stratigraphic relationships in the Hudson Bay Basin. (Ontario and Nunavut unit boundaries are from Douglas, 1969).

During an intensive core sampling program, samples for biostratigraphy were collected, and conodont and chitinozoan analyses were used to assist in formational assignments and to better understand the straigraphy. As well, RockEval 6™ analyses were conducted on 37 samples from Silurian and Ordovician formations to look for potential source rocks in the succession preserved in the HBL of Manitoba. (**Figure 3**)

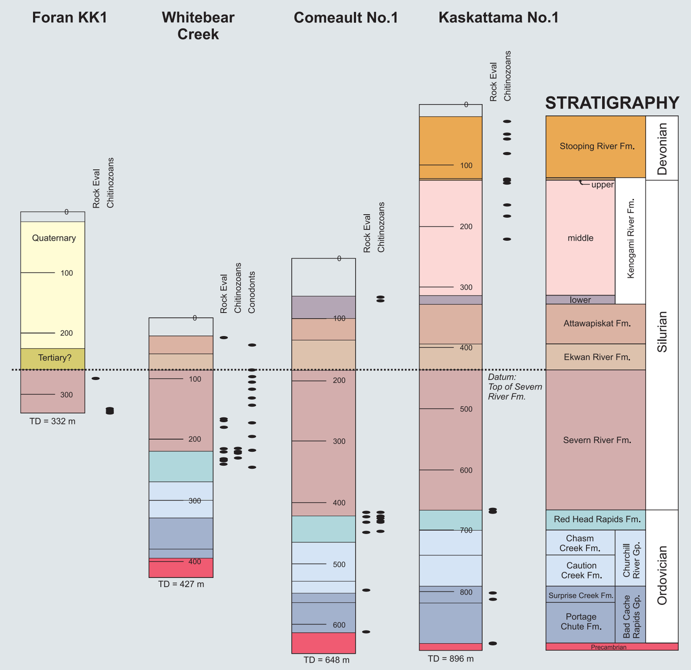

Figure 3: Stratigraphic columns for four of the wells on which sampling was conducted for Rock Eval geochemistry, and conodont and chitinozoan biostratigraphy; sampled intervals are shown by the black dots; depths are in metres. Formations are indicated by similar colours as **Figure 1**.

2.

Overall, the RockEval 6™ analyses resulted in the recognition of a fair number of samples having moderate to good source rock potential, but most of them are considered thermally immature (**Figure 4, 5 and 6**). One sample (106-11-HBL-WB-7) from the Red Head Rapids Formation has yielded 8.44 wt.% total organic carbon (TOC; sample shown in **Figure 5c** and outlined in **Figure 6a**), thus is considered a true oil shale, and confirms the extension of previously found oil shale units in Nunavut (**Figure 7;** Zhang, 2008) and northern Ontario (**Figure 8;** Armstrong and Lavoie, 2010). Evidence of oil generation and migration are seen in the core in the form of (1) live oil shows from shale samples submersed in acetone (**Figure 9**), (2) bituminous residue along open vertical fractures (**Figure 10**), and (3) oil staining in porous carbonate units (**Figure 11**). **Figure 2** shows the locations of the source rocks and evidence for oil migration.

OIL SOURCE

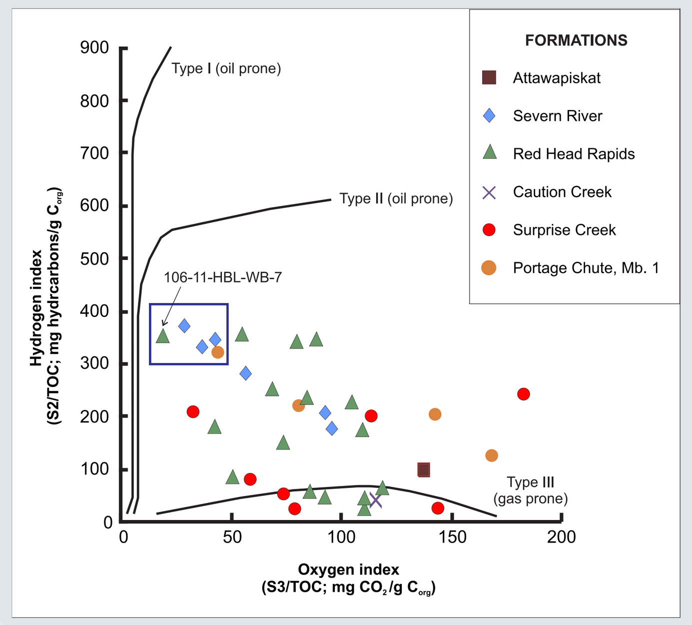

Figure 4: Modified van Krevelen diagram of new Rock Eval data grouped by formation; blue box indicates samples that have a HI > 300 and OI < 50.

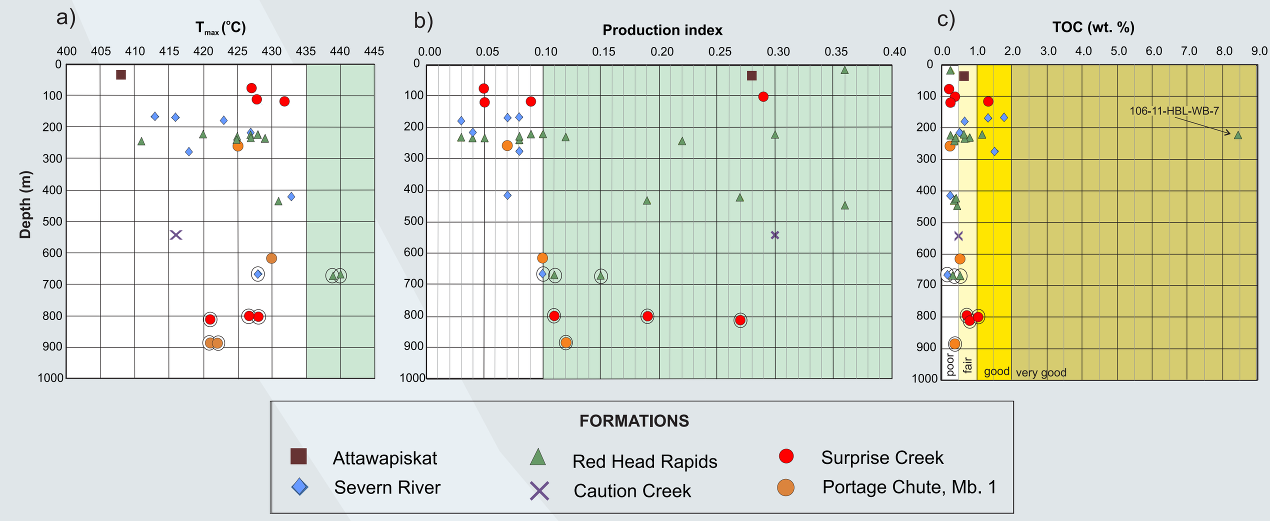

Figure 5: Rock Eval data grouped by formation and plotted against depth for (a) T_{max}, (b) Production Index, and (c) TOC. Kaskattama No.1 samples are highlighted with open circles. In (a) and (b) green shaded areas indicate the area of thermal maturation, that is they are within the oil window; for PI it may also indicate contamination by migrated hydrocarbons. In (c) the yellow shaded areas indicate the quality of the hydrocarbon generative potential of the source rock (poor to very good).

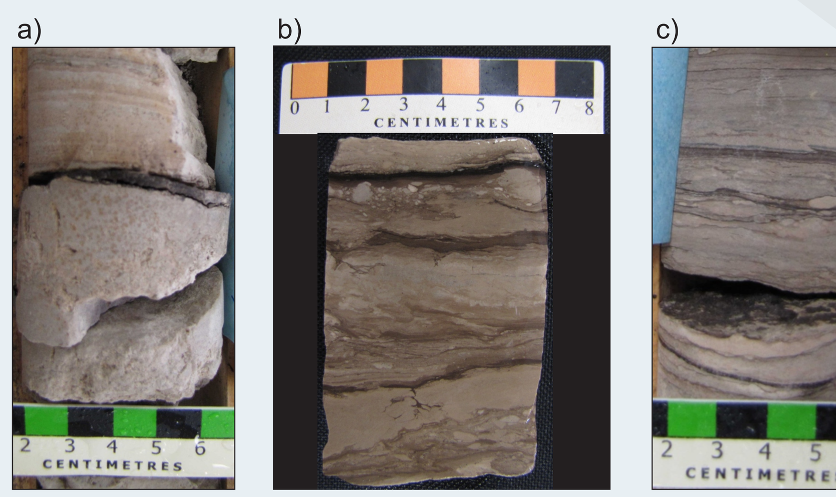

Figure 6: Core photographs of dark brown laminated oil shale from the Merland et al. Whitebear Creek Prov. well in the Red Head Rapids Formations at a depth of (a) 221.28 m, (b) 220.98 m, and (c) 179.98 m in the Severn River Formation. Scale is in centimetres.

Figure 8: Oil shale of the Boas River Formation along Asheweig River, northern Ontario. The Boas River Formation is only officially recognized in Ontario, and occurs as the uppermost unit of the Ordovician Bad Cache Rapids Group.

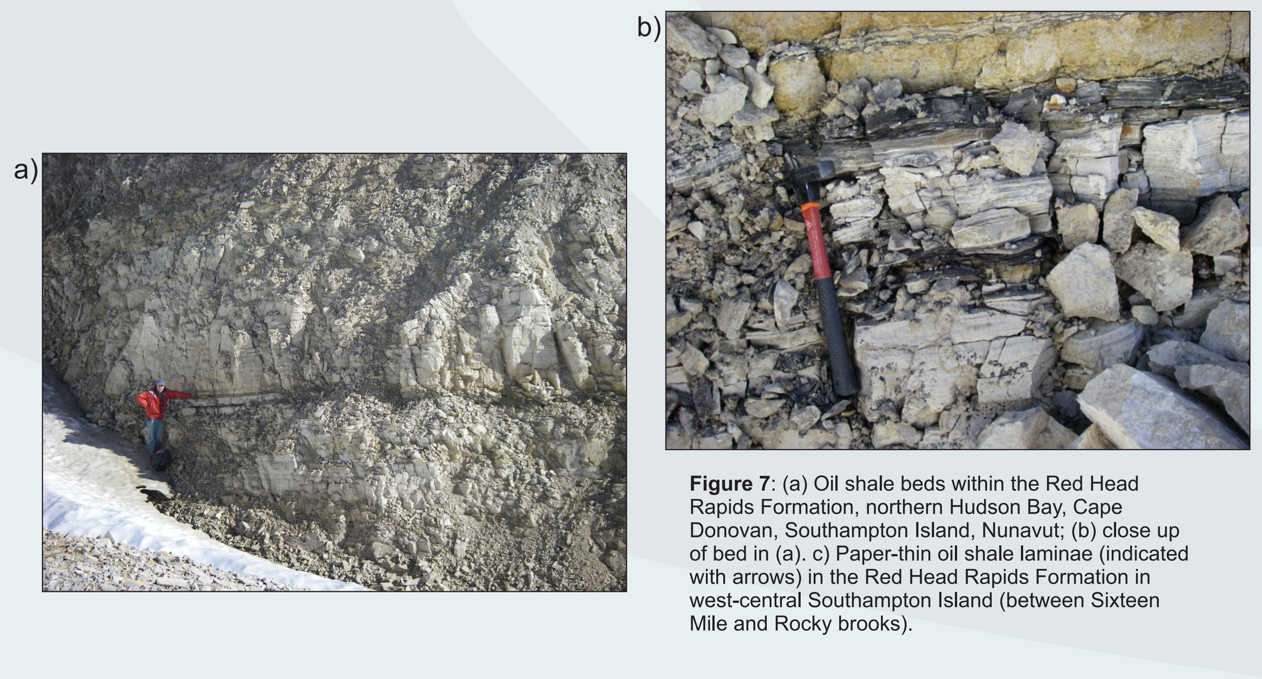

Figure 7: (a) Oil shale beds within the Red Head Rapids Formation, northern Hudson Bay, Cape Donovan, Southampton Island, Nunavut; (b) close up of bed in (a). c) Paper-thin oil shale laminae (indicated with arrows) in the Red Head Rapids Formation in west-central Southampton Island (between Sixteen Mile and Rocky brooks).

MIGRATED OIL

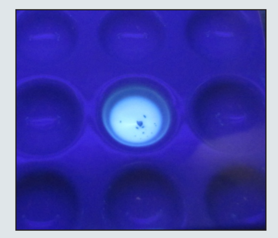

Figure 9: Milky white cut from oil in a sample of an oil shale from the Severn River Formation in the Comeault Prov. 1 core, as seen under ultraviolet (UV) light.

Figure 10: Bituminous residue along an open vertical fracture in MH unit 3 of Manitoba Hydro Conawapa Axis B - C292 core (Nicolas and Lavoie, 2012).

Figure 11: Core photograph showing oil staining in the Severn River Formation of the Houston Oils et al. Comeault Prov. No. 1 well at a depth of 415.4 m; scale in centimetres.

3.

Previously, the presence of hydrothermal dolomite (HTD) in Manitoba core in the HBL was confirmed petrographically and with stable isotopes geochemistry (**Figure 12 and 13**). HTD was also found and confirmed in outcrop on Southampton Island (**Figure 14;** Lavoie et al., 2011).Two more occurrences of potential HTD in Manitoba core indicate that this type of feature may be common in the HBL; **Figure 15** shows one of these occurrences. A magnetotelluric survey conducted by the GSC (Roberts and Craven, 2012) in the vicinity of the confirmed HTD occurrence near Churchill indicated potential porous zones in the subsurface, which is common in HTD.

For northeastern Manitoba, the best reservoirs are likely in the Upper Ordovician to Lower–Middle Devonian succession. In that interval, two main types of reservoirs can be envisaged:

1) HTD documented in the Ordovician succession near Churchill (**Figure 12**; Nicolas and Lavoie, 2009; Lavoie et al., 2011) and postulated in the Lower Silurian carbonate rocks (**Figure 15**; Nicolas and Lavoie, 2012) and; locations shown in **Figure 2**.

2) lower Silurian reefs of the Attawapiskat Formation which have only recently been shown to be locally highly porous (**Figure 16**; Ramdoyal, 2012). **Figure 17** shows Attawapiskat Formation patch reefs outcropping in northern Ontario along the Severn River (Armstrong, 2011); locations shown in **Figure 2**.

OIL RESERVOIRS

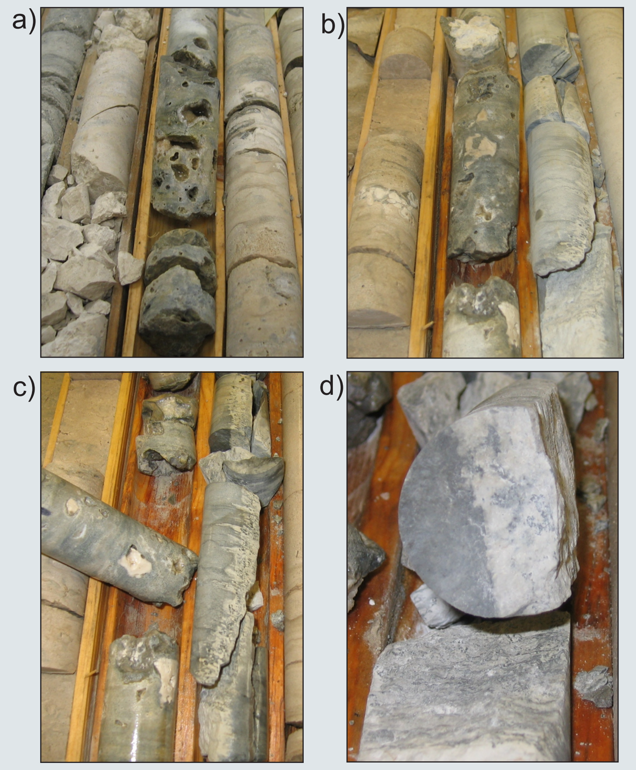

Figure 12: Core photos of M-4-03 showing: (a) dissolution vugs in limestone with dolomite coating walls and late calcite cement; (b) dissolution vugs in limestone with fine sucrosic dolomite filling pore spaces; (c) forced replacement of limestone by dolomite, dark specks are bitumen droplets in dolomite, and 30 cm long open vertical fracture which controlled dolomitization; (d) cross-section of controlled dolomitization along fracture wall. Core diameter is 2 inches. (from Nicolas and Lavoie, 2009)

Figure 15: Core photograph showing potential HTD in the Severn River Formation in the Houston Oils et al. Comeault Prov. No. 1 well at a depth of 411.8 m; scale is in centimetres.

HYDROTHERMAL DOLOMITE

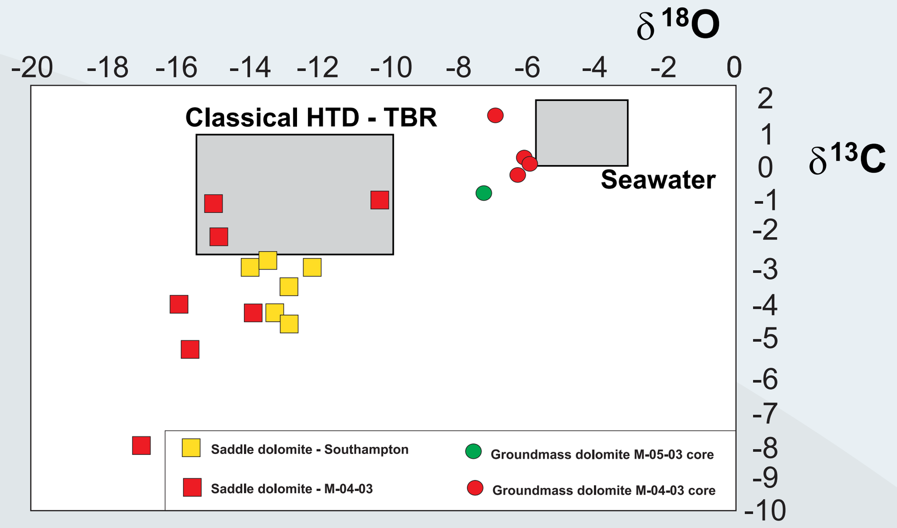

Figure 13: $\delta^{18}O$ vs $\delta^{13}C$ plot for saddle dolomite and groundmass dolomite from various localities in the Hudson platform and Foxe Basin. Classical HTD-TBR refers to hydrothermal dolomite found in the Trenton and Black River (TBR) groups in the Appalachian Basin. (modified from Lavoie et al., 2011)

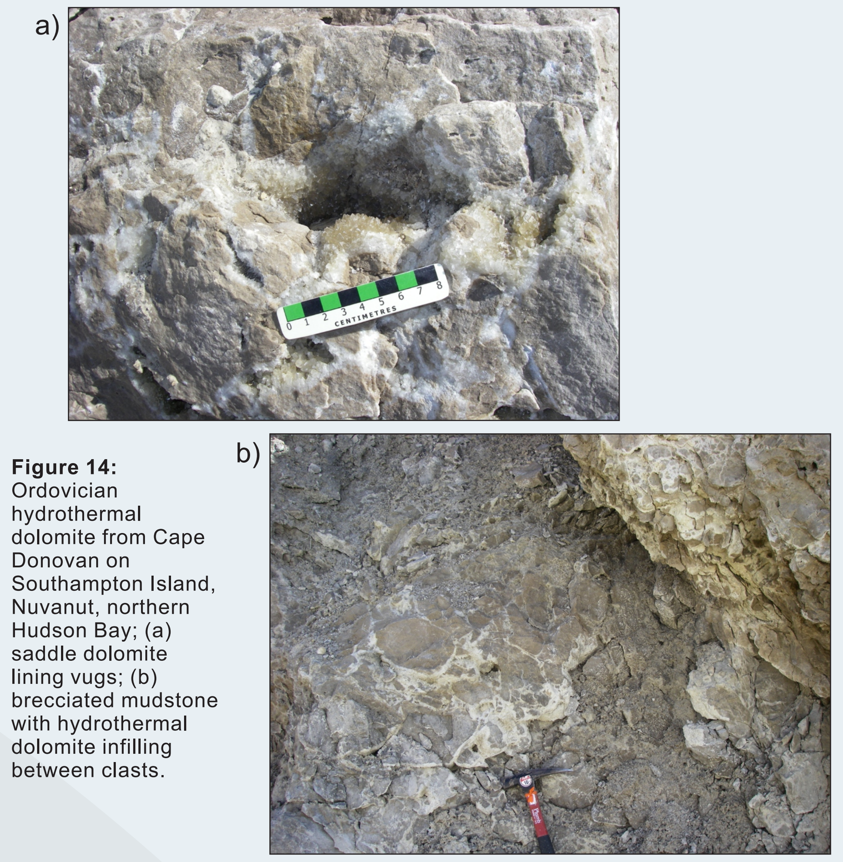

Figure 14: Ordovician hydrothermal dolomite from Cape Donovan on Southampton Island, Nuvanut, northern Hudson Bay; (a) saddle dolomite lining vugs; (b) brecciated mudstone with hydrothermal dolomite infilling between clasts.

REEFS

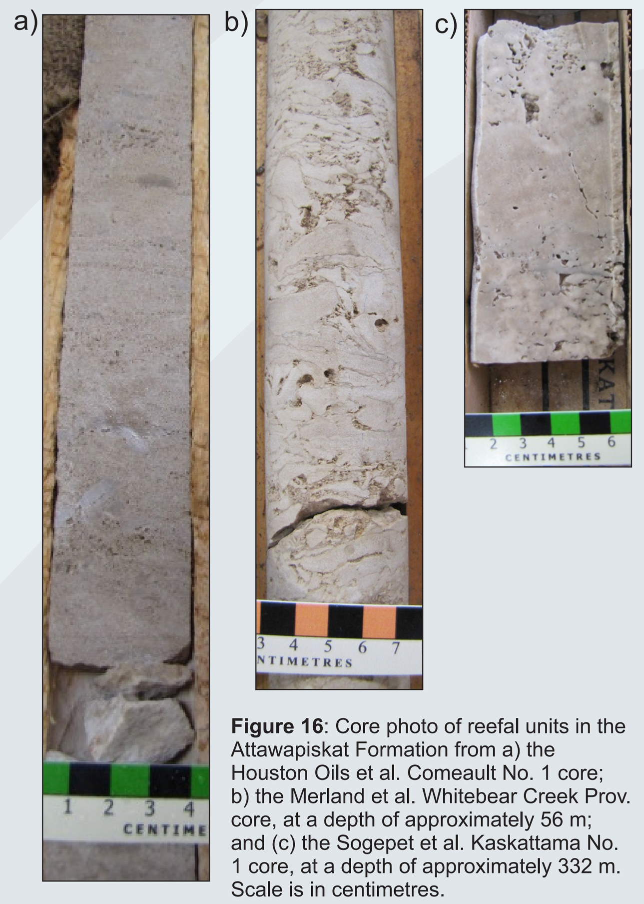

Figure 16: Core photo of reefal units in the Attawapiskat Formation from a) the Houston Oils et al. Comeault No. 1 core; b) the Merland et al. Whitebear Creek Prov. core, at a depth of approximately 56 m; and (c) the Sogepet et al. Kaskattama No. 1 core, at a depth of approximately 332 m. Scale is in centimetres.

Figure 17: (a), (b) and (c) Attawapiskat reefs outcropping along the Severn River, northern Ontario.

4.

Economic considerations

The results that were collected to date support an active hydrocarbon system in the Hudson Bay Basin. As detailed in Nicolas and Lavoie (2012), the Hudson Bay Basin has all the required elements for successful hydrocarbon exploration including confirmed basinal distribution of source rocks, adequate maturation rank of the Silurian and Ordovician succession, HTD and Silurian reefs to provide the reservoirs, and faults and stratigraphic relationships to provide the potential traps.

The re-assessment of the Hudson Bay Basin using modern technology, and viewing old and new data through a modern lens has proven to be a successful venture. What was once thought as a large area without hydrocarbon potential has now been transformed into a highly prospective frontier area worth of industry investment. Exploration in the north brings a significant positive economic impact and development to northern communities, and with Manitoba's coastal location, including a deepwater port at Churchill and rail line to major markets, successful hydrocarbon exploration in the Hudson Bay Basin would benefit all of Manitoba.

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