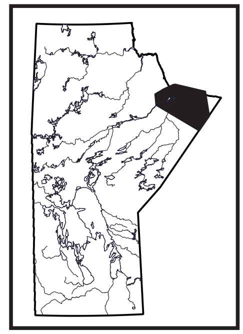
GS-13 Carbon and oxygen stable-isotope profiles of Paleozoic core from the Hudson Bay Basin, northeastern Manitoba (parts of NTS 54B7, 8, 54F8, 54G1)

by M.P.B. Nicolas



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Summary

This report summarizes the continued work by the Manitoba Geological Survey as part of the Hudson–Ungava Project of the Geo-mapping for Energy and Minerals program, Phase 2 (GEM-2). The objective of the Manitoba portion of this project is to further enhance understanding of the stratigraphic and sedimentological framework and structural complexities in this part of the Hudson Bay Basin, in order to help promote hydrocarbon exploration in this underexplored frontier region.

Isotope sampling and analysis of the Paleozoic sequence in the Hudson Bay Lowland portion of the Hudson Bay Basin are partially completed. Carbon and oxygen stable-isotope ($\delta^{13}C$ and $\delta^{18}O$) results from core of the Sogepet Aquitaine Kaskattama Prov. No. 1, Houston Oils et al. Comeault Prov. No. 1 and Merland et al. Whitebear Creek Prov. were plotted in the form of a vertical profile. Preliminary comparison of the profiles indicates that the cores have very similar isotope curves and that these provide a powerful tool for stratigraphic correlation with other parts of the basin, as well as with cores and outcrop samples with uncertain stratigraphic assignment.

Introduction

Phase 2 of the Geological Survey of Canada's (GSC) Geo-mapping for Energy and Minerals (GEM-2) program runs from 2013 to 2020. Manitoba's contribution to this program is in the Hudson Bay Lowland (HBL) of northeastern Manitoba, and is part of the Hudson-Ungava Project (Nicolas et al., 2014). This project's hydrocarbon objectives include the study of the Paleozoic strata in the Hudson Bay Basin (HBB). To help promote hydrocarbon exploration in this underexplored frontier region, it is necessary to enhance understanding of the stratigraphic and sedimentological framework and structural complexities in this part of the HBB.

Carbon and oxygen stable-isotope ($\delta^{13}C$ and $\delta^{18}O$) profiling has been used in HBB outcrop exposures and cores to define the Ordovician–Silurian boundary by identifying the Hirnantian isotopic-carbon excursion (HICE; Wheadon, 2011; Duncan, 2012; Lapenskie, 2012; Demski et al., 2015; Hanasyk, 2015), and as a chemostratigraphic tool (Armstrong, 2011; Armstrong et al., 2013). The purpose of this detailed profiling is to expand the $\delta^{13}C$ and $\delta^{18}O$ curves beyond the HICE interval and provide a chemical profile of the entire preserved Paleozoic sequence in the HBB of Manitoba. This will be used as a chemostratigraphic tool to correlate Manitoba's Paleozoic sequence with other parts of the basin.

A detailed core-logging and -sampling program, undertaken by Nicolas et al. (2014), included sampling at regular intervals for ^{13}C and ^{18}O isotope analysis. The samples were sent for analysis in batches during the course of three years, with the last of the samples submitted during the summer of 2016. To date, the results received and reported here are from the Sogepet Aquitaine Kaskattama Prov. No. 1, Houston Oils et al. Comeault Prov. No. 1 and Merland et al. Whitebear Creek Prov. cores, herein referred to as Kaskattama, Comeault and Whitebear, respectively (Figure GS-13-1). Results for the Foran Mining Kaskattama Kimberlite No. 1 (KK1) and Pennycutaway No. 1 cores, and the middle Kenogami Formation interval of the Kaskattama (depth interval 221.8–284.9 m) core are pending. Table GS-13-1 lists the depth intervals and formations sampled in the Kaskattama, Comeault and Whitebear cores.

Stable carbon- and oxygen-isotope chemostratigraphy

The variation of the stable carbon-isotope $^{13}C/^{12}C$ ratio from carbonate rocks measures the total dissolved inorganic carbon in the world's oceans through time and is commonly used to date and correlate sediments (Saltzman and Thomas, 2012). On a geological time scale, this variation is linked directly to the global carbon cycle; therefore, measurements of coeval carbonate samples from different locations should be similar. This ratio is not generally affected by diagenesis, making it a good chemostratigraphic tool, so it will be used to correlate the carbonate rocks in the HBB and to compare the measurements from this study with the worldwide composite profile as defined by Saltzman and Thomas (2012).

The variation of the stable-isotope $^{18}O/^{16}O$ ratio from marine fossils and microfossils records the changes in seawater temperature and can be used for correlations at a global scale (Grossman, 2012). This ratio can serve as a good chemostratigraphic marker for both regional and global correlations as a paleoclimatic indicator. For example, variation in oxygen ratios marks glacial and interglacial periods and cyclicity (Grossman, 2012). However, oxygen-isotope ratios can be affected by diagenesis, so

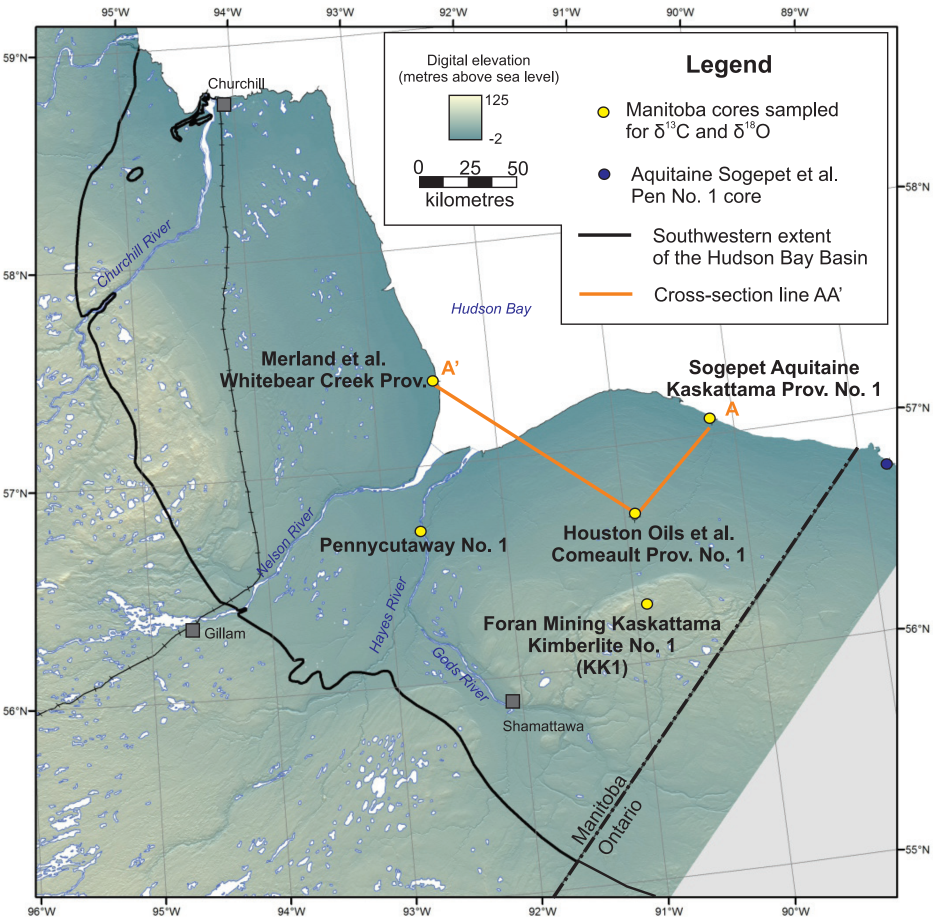

***Figure GS-13-1:** Digital elevation model of the Hudson Bay Lowland in northeastern Manitoba, showing the location of wells sampled for $\delta^{13}C$ and $\delta^{18}O$ isotope analysis; cross-section line AA' for Figure GS-13-5 is indicated. Grey-shaded area is outside the limit of digital elevation model information. Digital elevation model is from United States Geological Survey (2002).*

Table GS-13-1: Depth intervals and formations sampled from the Kaskattama, Comeault and Whitebear cores for $\delta^{13}C$ and $\delta^{18}O$ stable-isotope profiling.

Core	Depth intervals sampled (m)	Formations
Sogepet Aquitaine Kaskattama Prov. No. 1	29.0–884.6	Stooping River, Kenogami River, Attawapiskat, Ekwan River, Severn River, Red Head Rapids, Chasm Creek, Caution Creek, Surprise Creek, Portage Chute
Houston Oils et al. Comeault Prov. No. 1	61.9–613.8	Kenogami River, Attawapiskat, Ekwan River, Severn River, Red Head Rapids, Chasm Creek, Caution Creek, Surprise Creek, Portage Chute
Merland et al. Whitebear Creek Prov.	31.5–305.7	Attawapiskat, Ekwan River, Severn River, Red Head Rapids, Chasm Creek, Caution Creek

care must be taken in interpreting results if diagenetic alteration is pervasive. Samples for this study were collected mainly from carbonate mudstones instead of from fossils, and these mudstones may have been affected by cumulative diagenetic effects. Some of these limitations can be overcome by selecting the results from samples that have minimal diagenetic affects (e.g., calcite versus dolomite samples) and comparing them to known values for a given time frame (e.g., Paleozoic brachiopods have $\delta^{18}O$ values of –10 to –4‰ for the Cambrian and Ordovician, and –8 to –2‰ for the Silurian and Devonian [Grossman, 2012]).

Sampling and methodology

The cores sampled for ^{13}C and ^{18}O isotope analysis are Comeault, KK1, Kaskattama, Whitebear and Pennycutaway No. 1. According to Nicolas et al. (2014), samples "were collected at minimum 1.5 m (5 ft.) intervals, ensuring that at least one sample was taken from each unit described by Nicolas (unpublished core description for Whitebear, 2011; unpublished core description for Comeault, 2013; unpublished core description for Kaskattama, 2013; unpublished core description for Foran KK1, 2014) or McCabe (unpublished core description for Pennycutaway, 1962). Concurrently, to better identify the location of the HICE, increased sample density was conducted within the individual sedimentary cycles, with samples being taken at the top and base of each unit preserved in the Red Head Rapids Formation and near the base of the Severn River Formation. Every 20th sample was a blind duplicate. Samples were collected from carbonate mud, avoiding allochems and cements as much as possible. In highly fossiliferous beds that did not contain sufficient carbonate mud, brachiopods were sampled. Stable isotope values from diagenetically well-preserved brachiopod shells in Paleozoic rocks are considered as a proxy for seawater isotopic composition (Popp et al., 1986; Bates and Brand, 1991). The proportion of calcite relative to dolomite was estimated for each sample site using HCl."

Nicolas et al. (2014) described the methodology for stable-isotope sampling as follows: "…powdered samples were taken using a drill press with a 4.76 mm (3/16 in.) carbide-tipped masonry drill bit. Between samples, the drill bit was cleaned with acetone. Compressed air was used to remove loose material from the surface of the core and to ensure that the core was dry. The core was first drilled shallowly to remove surface contamination, and compressed air was used to remove the powdered material from the drillhole and drill bit. Next, the core was drilled to a depth of approximately 1.5 cm in the same location. A 0.5 g sample of the carbonate powder was collected from the drillhole and from the surface of the core. The samples were sent to the Delta Lab, GSC–Quebec (Ste-Foy, Quebec) for analysis."

Results and future work

Results of ^{13}C and ^{18}O isotopic analysis are in MGS Data Repository Item DRI2016002[1]. The chemostratigraphic profiles for the Kaskattama, Comeault and Whitebear cores are in Figure GS-13-2, Figure GS-13-3 and Figure GS-13-4, respectively. The isotope profiles are plotted, together with the lithology log, geophysical log (gamma ray or spontaneous potential) and stratigraphic column for reference. Figure GS-13-5 shows the cores in cross-section.

The $\delta^{13}C$ profiles correlate well for all three cores, as well as with the worldwide composite profiles in Saltzman and Thomas (2012). The $\delta^{18}O$ profiles for the cores are more difficult to compare to the worldwide composite profiles because they are based on allochem-specific (brachiopods or conodonts) standards as in Grossman (2012), whereas the results herein are dominantly from carbonate mudstone samples. The adverse effect of diagenesis on the $\delta^{18}O$ values is also a factor.

The thickness of Ordovician section in all three cores is consistent, and the isotope profiles are similar, as expected. This same trend continues into the Silurian Severn River Formation in the Kaskattama and Comeault cores, with consistent section thicknesses and similar isotopic profiles. However, the Severn River Formation in the Whitebear core is thinner and therefore has isotopic profiles that are compressed compared to the same section in the other two cores. The $\delta^{13}C$ profile in the Whitebear currently assigned to the Ekwan River and Attawapiskat formations is more similar to the upper portion of the Severn River Formation profile for the Kaskattama and Comeault cores. This suggests that, in the Whitebear area, deposition of the Severn River was cut short and the Ekwan River and Attawapiskat formations were deposited first, indicating that formation deposition moved eastward (relative to current HBB configuration) with time. Alternatively, there could be an error in stratigraphic assignment of the units. Both these theories will be further investigated in the next phase of work.

The Comeault core has unusually low and highly erratic carbon- and oxygen-isotope readings throughout the Attawapiskat Formation interval; this is likely due to the high allochem content of this formation, with samples containing a mixture of both carbonate mud and allochems. The consistent behaviour of the $\delta^{13}C$ and $\delta^{18}O$ profiles suggests that diagenesis (which would preferentially affect the oxygen isotopes) is likely not affecting these curves, leaving sample contamination as the more likely limiting factor.

These carbon- and oxygen-isotope profiles compare very well with a set measured by Armstrong et al. (2013) for the Aquitaine Sogepet et al. Pen No. 1 core, located in Ontario just east of the Kaskattama core; however, there are some discrepancies in stratigraphic assignment of formation boundaries. Resolving these discrepancies and basin-wide correlations is part of the next phase of this project.

Future work for this project includes resolving and confirming uncertainties in the stratigraphy of the Pennycutaway No. 1 and KK1 cores, once the isotope results for samples from these cores are received. This will be accomplished by comparing the results from cores where the stratigraphy is known to the samples taken from the Pennycutaway No. 1 and KK1 cores. The stable-isotope results from outcrop samples collected in 2014 (Nicolas

[1] MGS Data Repository Item DRI2016002, containing the data or other information sources used to compile this report, is available online to download free of charge at http://www2.gov.mb.ca/itm-cat/web/freedownloads.html or on request from minesinfo@gov.mb.ca or Mineral Resources Library, Manitoba Growth, Enterprise and Trade, 360 – 1395 Ellice Avenue, Winnipeg, Manitoba R3G 3P2, Canada.

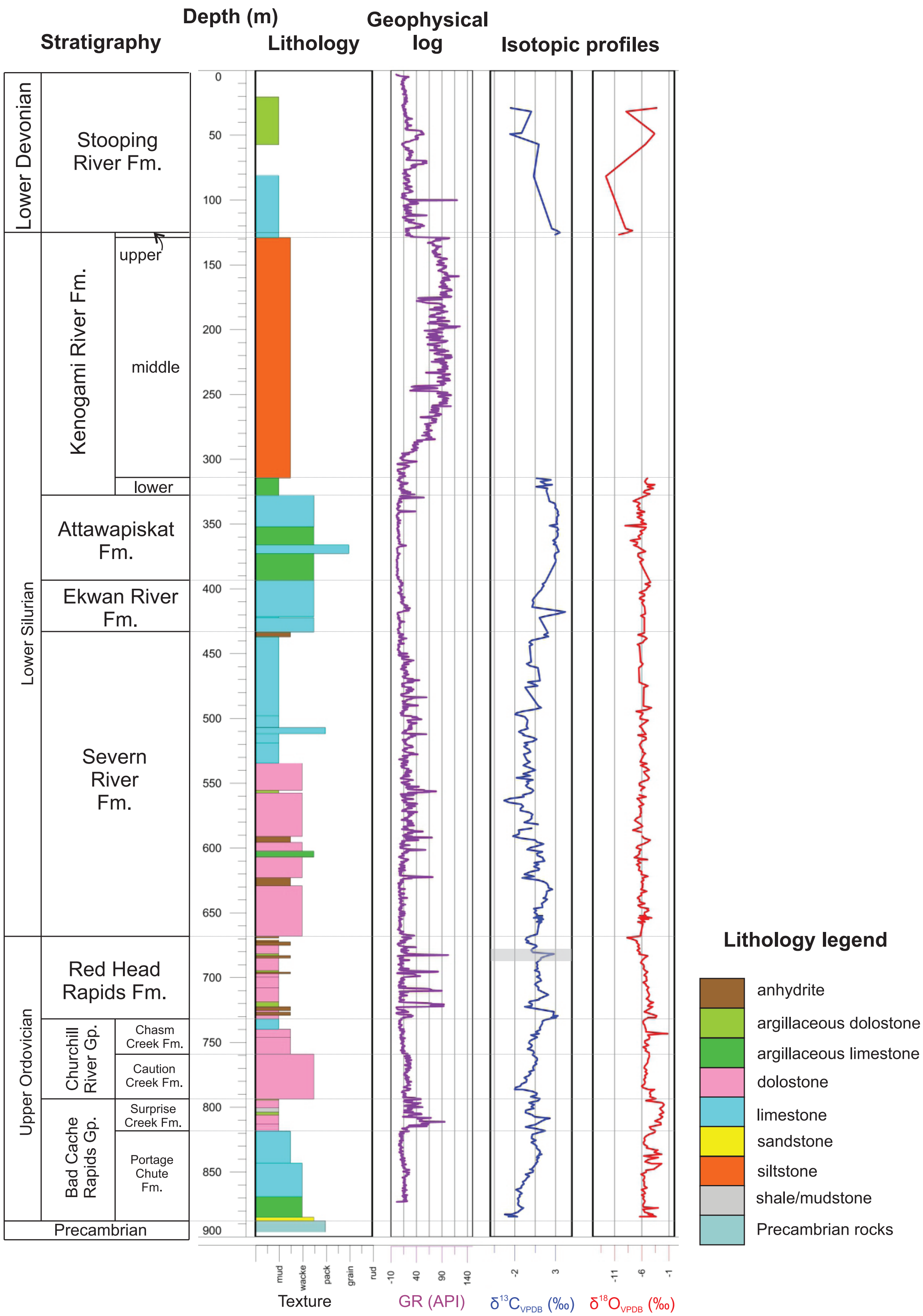

Figure GS-13-2: *Profile of the Sogepet Aquitaine Kaskattama Prov. No. 1 core, showing tracks for lithology, gamma ray, and $\delta^{13}C$ and $\delta^{18}O$ stable-isotope profiles. Shaded grey box indicates approximate location of HICE. There is poor core recovery above 130 m, resulting in larger sample spacing. No results were available for the middle Kenogami section as of this printing. Abbreviations: Fm., Formation; grain, grainstone; Gp., Group.; GR, gamma ray; mud, mudstone; pack, packstone; rud, rudstone; VPDB, Vienna Peedee Belemnite; wacke, wackestone.*

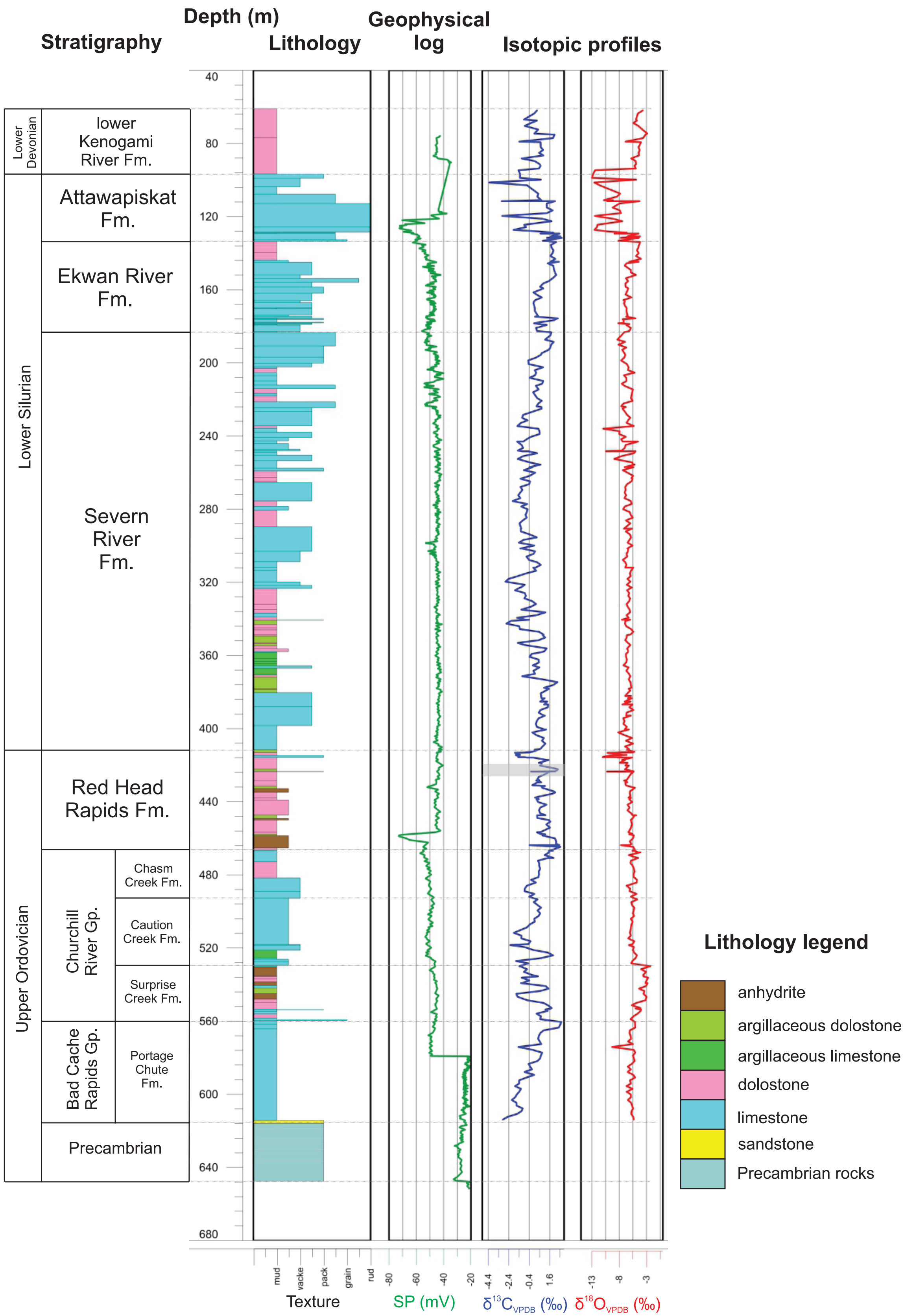

Figure GS-13-3: *Profile of the Houston Oils et al. Comeault Prov. No. 1 core, showing tracks for lithology, spontaneous potential, and $\delta^{13}C$ and $\delta^{18}O$ stable-isotope profiles. Shaded grey box indicates approximate location of HICE. Abbreviations: Fm., Formation; grain, grainstone; Gp., Group.; mud, mudstone; pack, packstone; rud, rudstone; SP, spontaneous potential; VPDB, Vienna Peedee Belemnite; wacke, wackestone.*

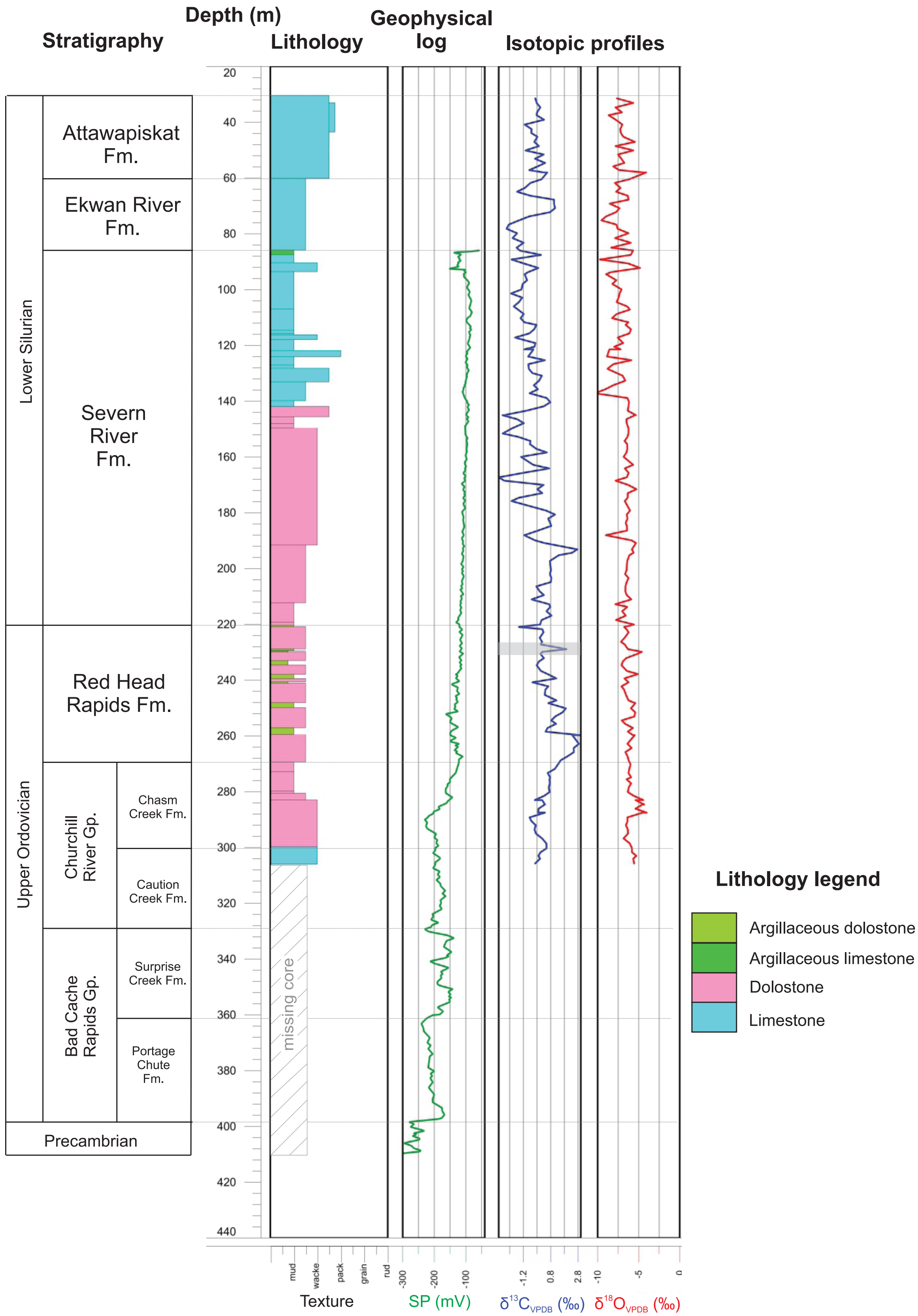

Figure GS-13-4: *Profile of the Merland et al. Whitebear Creek Prov. core, showing tracks for lithology, spontaneous potential, and δ^{13}C and δ^{18}O stable-isotope profiles. Shaded grey box indicates approximate location of HICE. Abbreviations: Fm., Formation; grain, grainstone; Gp., Group; mud, mudstone; pack, packstone; rud, rudstone; SP, spontaneous potential; VPDB, Vienna Peedee Belemnite; wacke, wackestone.*

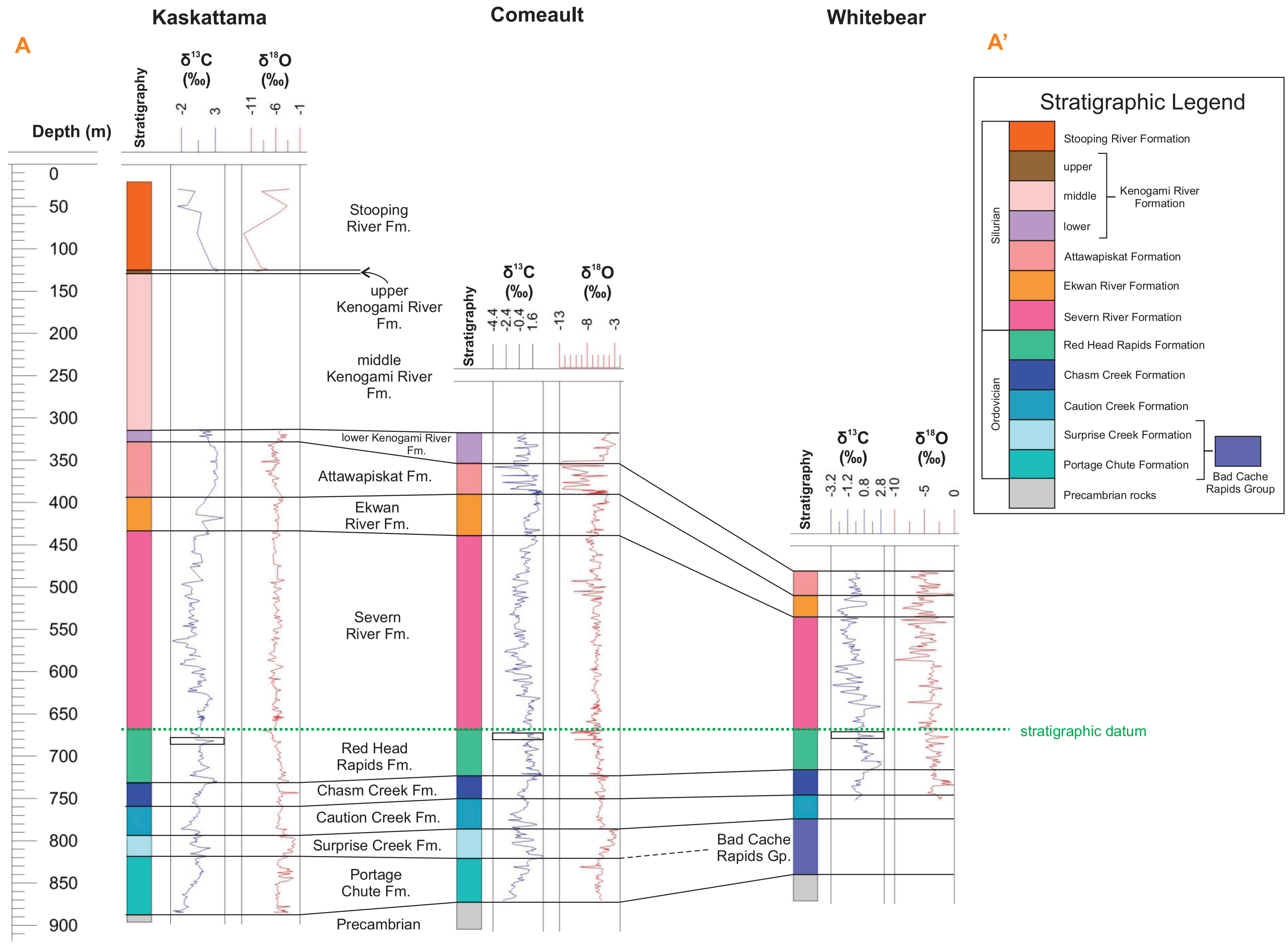

Figure GS-13-5: *Stratigraphic cross-section AA’ through the Kaskattama, Comeault and Whitebear cores; datum is the top of the Red Head Rapids Formation; cross-section line is shown in Figure GS-13-1. Boxed areas on the δ13C curves indicate the approximate location of the HICE. Abbreviations: Fm., Formation; Gp., Group.*

and Young, 2014) will be used in an attempt to bracket the stratigraphic positioning of the outcrops.

Economic considerations

The Hudson Bay Lowland in Manitoba is a large frontier area with good potential for local hydrocarbon accumulations. A basic geological understanding of a sedimentary basin is required to attract exploration because it provides industry with geoscientific information from which to build an exploration program. The stratigraphic information acquired by doing the work described herein indicates the long-distance predictability of rock units, as well as predictability of the depositional environment that formed the rocks. Geographic predictability, particularly in a large basin like the HBB, helps a company identify focus areas for exploration.

Economic benefits from collaborative programs such as GEM-2 can be measured in terms of industry attraction and investments. The program also provides access for the MGS to expertise and services from world-class GSC laboratories, as well as training opportunities for students to develop themselves as new geoscience experts in Manitoba, benefits that can be applied to other projects in the future.

Acknowledgments

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