GS-12 Introduction to the GEM-2 Hudson–Ungava Project, Hudson Bay Lowland, northeastern Manitoba

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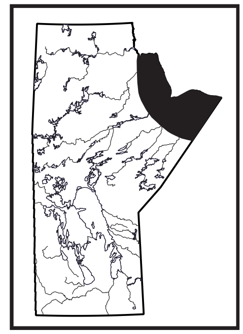

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Summary

The Manitoba Geological Survey is participating in the energy (hydrocarbon) component of the Geo-mapping for Energy and Minerals, Phase 2 (GEM-2) program's Hudson–Ungava Project. The Hudson–Ungava Project's hydrocarbon component involves the study of the Paleozoic strata of the Hudson Bay Basin, in the Hudson Bay Lowland area, northeastern Manitoba.

This project builds on the first GEM program results (GEM Energy: Hudson Bay and Foxe Basins Project, which ran from 2008 to 2013), with the addition of more detailed stratigraphic and structural studies. Activities started this year include detailed logging of core and outcrop descriptions; sampling of organic-rich beds and laminae for organic-geochemistry analysis by Rock-Eval 6™; detailed profiling of $\delta^{13}C$ and $\delta^{18}O$ stable isotopes on select core; determining conodont, chitinozoan and micropalynological biostratigraphy; and reconnaissance mapping of the Paleozoic outcrops along the Churchill River and Churchill area coast.

Detailed core descriptions resulted in the sampling of organic-rich laminae, which were submitted for Rock-Eval 6 analysis. Rock-Eval 6 results have indicated that there are organic-rich beds and laminae throughout a thick interval of the strata. Total organic contents (TOC) as high as 8.23 wt. % were measured in the Ordovician Red Head Rapids Formation in the Merland et al. Whitebear Creek Prov. core, 5.65 wt. % in the Ordovician Surprise Creek Formation, and 3.87 wt. % in the Silurian Severn River Formation in the Houston Oils et al. Comeault Prov. No. 1 core. The T_{max} values indicate that the rocks are thermally immature, but the production index values indicate most of the succession is mature, while the hydrogen index is high. This relationship is well documented in samples with elevated TOC and high hydrogen content in the kerogen resulting in T_{max} suppression and therefore an under-representation of the true maturity of the samples.

Conodont biostratigraphic results from the Foran Mining Kaskattama Kimberlite No. 1 core confirm an early Silurian age for the core assigned to the Severn River Formation. Chitinozoan and micropalynological biostratigraphy and $\delta^{13}C$ and $\delta^{18}O$ stable isotope results are pending.

Introduction

The second phase of the Geological Survey of Canada (GSC)'s Geo-mapping for Energy and Minerals (GEM-2) program was announced in August 2013, with an end date of March 2020. The new GEM-2 program for the Hudson–Ungava region consists of two components: energy (hydrocarbon) and minerals. The former component is being addressed by the Manitoba Geological Survey (MGS), whose formal participation is from 2013 to 2017. There has been significant progress in the geological and economic understanding of the hydrocarbon potential of the Hudson Bay Basin based on the GEM (2008–2013) program. The new GEM-2 program builds on this data, and includes the Hudson–Ungava Project, in which the energy component is designed to address unsolved or new scientific issues. The GEM Energy research for the Hudson Bay and Foxe Basins Project was published in a comprehensive report by Lavoie et al. (2013) with the main conclusion that the Hudson Bay Basin is prospective for oil in places. The study area for the new GEM-2 project encompasses several large geologically significant regions, including Hudson Bay Basin, Foxe Basin, Hudson Strait, Moose River Basin and Ungava Basin (Figure GS-12-1).

The GEM-2 program has three key elements: collaborating to ensure research quality and accessibility, ensuring the delivery of high-quality integrated geoscience, and maximizing benefits for northerners. The GEM-2 program is structured so that each project's research activities are designed to answer key scientific questions. While the GEM-2 program covers a seven year time span, individual activities within each project are to have a two to four year lifespan. To provide focus during the program, activities within the project must strive to address at least one of the six key scientific questions developed for the Hudson–Ungava Project. The key scientific question relevant to hydrocarbon exploration in the Manitoba portion of the GEM-2 Hudson–Ungava Project is: how have tectonic factors such as faulting, burial and exhumation influenced the architecture and geological evolution in relation to petroleum prospectivity of the Hudson Bay Basin?

In Manitoba, this project falls within the Hudson Bay Lowland (HBL), in the northeastern corner of the

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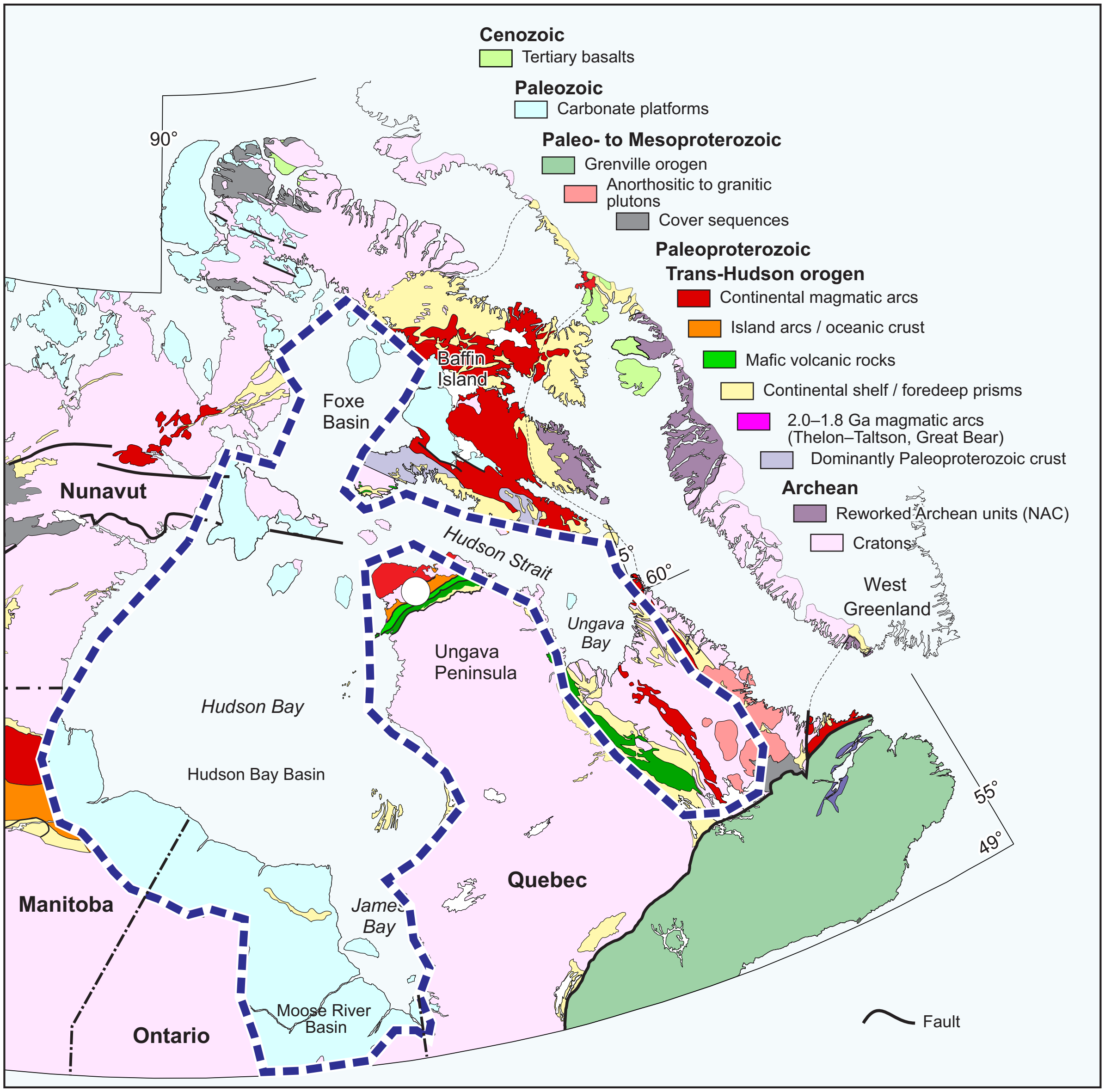

Figure GS-12-1: *Schematic geological map showing the study area for the Geo-mapping for Energy and Minerals, Phase 2 (GEM-2) Hudson–Ungava Project, outlined in the dark blue dashed line.*

province (Figure GS-12-2). The objective of the Manitoba component is to further enhance our 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. The 2013–2014 phase of this project focused on highly detailed stratigraphic outcrop and drillcore investigations, including collecting and submitting samples for geochemical and paleontological analysis, and reconnaissance field mapping of the Paleozoic outcrops along the Churchill River and Churchill area coast. This report will discuss the results of the core work; detail on the outcrop reconnaissance mapping is discussed in Nicolas and Young (GS-13, this volume).

Core studies

During 2013–2014, the primary focus of the project was to log select cores in great detail and to collect samples for analyses. These cores were selected because they had never been logged in extensive detail. The two cores logged were the Houston Oils et al. Comeault Prov. No.1 and the Foran Mining Kaskattama Kimberlite No. 1 (Figure GS-12-2), herein referred to as the Comeault and KK1 cores, respectively. The Comeault core covers depths of 61.0–647.7 m and includes strata from the Silurian Kenogami River Formation through the Ordovician formations and ends in the Precambrian basement rocks. The KK1 section logged here covers core depths from 223.42 to 332.20 m and includes strata of uncertain age overlying

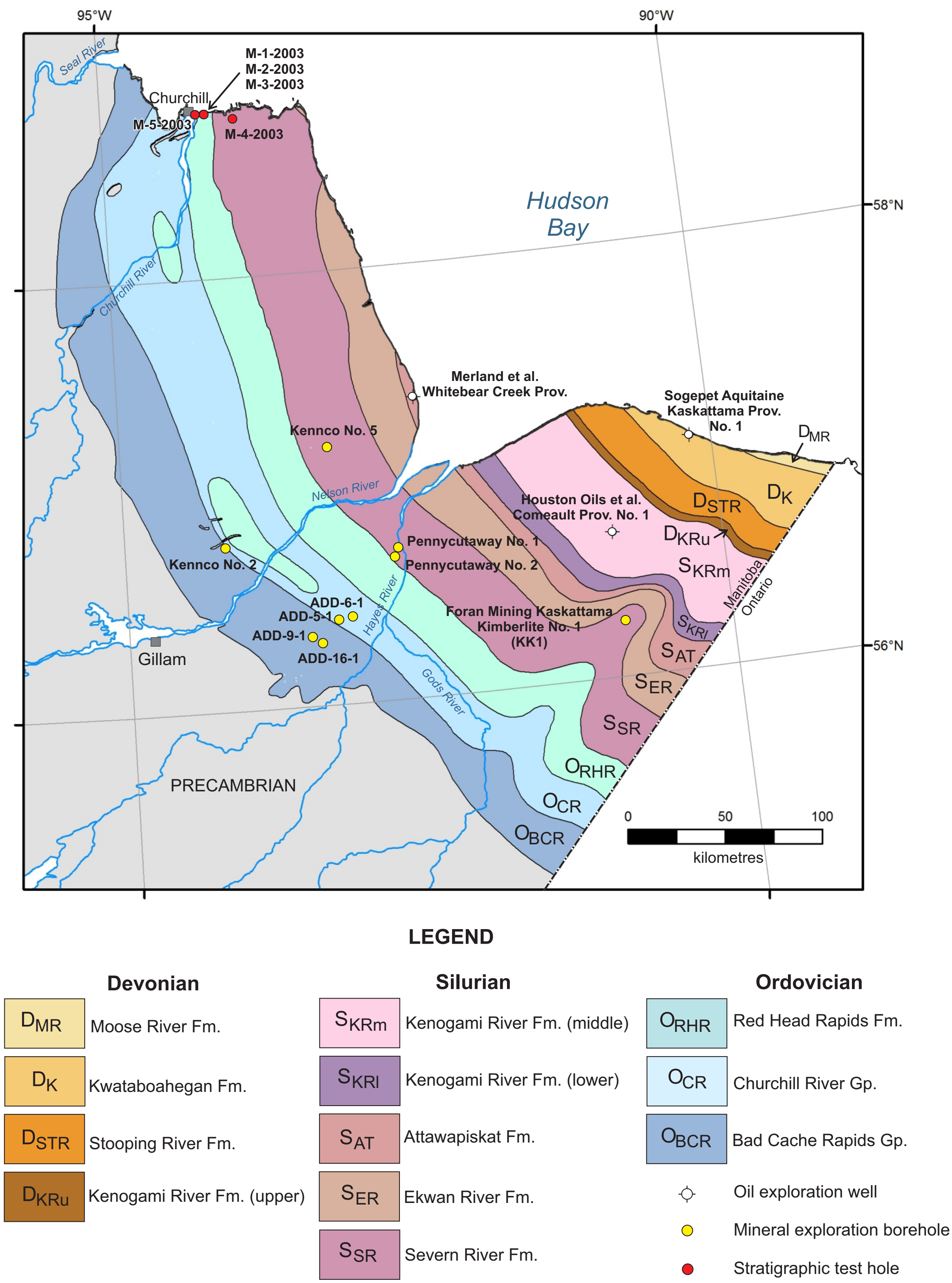

Figure GS-12-2: *Geology of the Hudson Bay Lowland in northeastern Manitoba, showing the location of oil exploration wells, mineral exploration boreholes and stratigraphic test holes for which core is available and stored at the Manitoba Mineral Resources Core and Sample Library (modified from Ramdoyal et al., 2013). Borehole names beginning with ADD were drilled by Arctic Star Diamond Corp. Abbreviations: Fm., Formation; Gp., Group.*

the Silurian Severn River Formation through to the Ordovician Red Head Rapids Formation; the core section from 16.80 to 223.24 m consists of Quaternary sediments and was therefore not logged by the authors. Detailed sampling programs were developed and executed for these two cores, as well as cores from the Sogepet Aquitaine Kaskattama Prov. No. 1, Merland et al. Whitebear Creek Prov. and Selco Pennycutaway No. 1, herein referred to as Kaskattama, Whitebear and Pennycutaway No. 1, respectively. Figure GS-12-2 shows the location of these cores, as well as other important HBL cores stored and available for viewing in Winnipeg.

The detailed sampling and analytical program for Manitoba is scheduled during a three-year period. This program includes

1) sampling thin, shaly and argillaceous mudstone beds and laminae for Rock-Eval 6 analysis, to determine the thermal maturity and organic content of potential oil source beds;
2) sampling carbonate beds for $\delta^{13}C$ and $\delta^{18}O$ stable isotope analysis for geochemical profiling of seawater chemistry variations, and for use as a chemostratigraphic tool;
3) sampling various beds for palynology, conodont and chitinozoan biostratigraphy to help resolve or further constrain biostratigraphic correlations, and the age determinations of beds of uncertain origin;
4) sampling fracture fills for clumped isotope and fluid inclusion analysis, to determine diagenetic fluid chemistry and evolution; and
5) sampling the Precambrian section at various depth intervals, for use in basin exhumation studies (e.g., apatite fission-track analysis).

Sampling for (4) and (5) from the above list were carried out at the request of other project participants, and thus will not be discussed further in this report.

Rock-Eval 6

Rock-Eval 6 analysis is a method that measures hydrocarbons, carbon dioxide and carbon monoxide released during the heating of a sample; in turn, this provides information on the organic content and hydrocarbon-generation potential of a sample. This method was a significant component of the GEM Energy project; results are discussed in Nicolas and Lavoie (2012a, b) and Lavoie et al. (2013). In the GEM (2008–2013) project, the sampling sites were mainly restricted to beds more than 5 mm thick that are dark brown argillaceous mudstone, or common green or lighter coloured mudstone. Review of the GEM (2008–2013) project results and preliminary correlation between analyses from Manitoba (Nicolas and Lavoie, 2012a, b) and Ontario (Armstrong and Lavoie, 2010; Lavoie et al., 2013) suggested new intervals worth sampling within the Severn River, Red Head Rapids, Surprise Creek and Portage Chute formations. These intervals had previously been classified as not being argillaceous enough for consideration or were considered too thin (beds less than 5 mm thick or thin laminae) to be of significance. The new GEM-2 samples collected were mostly from very thin laminae within argillaceous mudstone beds. These samples were sent to the GSC Organic Geochemistry Laboratory in Calgary, Alberta for analysis.

$\delta^{13}C$ and $\delta^{18}O$ stable isotope

During the GEM Energy project, systematic and regular-interval sampling of full-length cores was carried out in Ontario (Armstrong, 2011). In Manitoba, only limited $\delta^{13}C$ and $\delta^{18}O$ stable isotope profiling was carried out through the upper portion of the Upper Ordovician and the lower portion of the Lower Silurian sections (Wheadon, 2011; Duncan, 2012; Lapenskie, 2012). The stable isotope profiling in Manitoba focused on identifying the Ordovician–Silurian boundary and the Hirnantian isotopic carbon excursion (HICE), while the profiling in Ontario identified the HICE and used $\delta^{13}C$ as a potential chemostratigraphic correlation tool.

The purpose of the current sampling program in Manitoba is to expand the $\delta^{13}C$ and $\delta^{18}O$ stable isotope database beyond the Ordovician–Silurian boundary and provide a chemostratigraphic profile of the entire Paleozoic sequence preserved in Manitoba, similar to that previously done in Ontario. This can in turn be tested and used as a stratigraphic correlation tool across long distances.

The cores sampled for carbon and oxygen stable isotope analysis in 2013 were Comeault, KK1, Kaskattama, Whitebear and Pennycutaway No. 1. Data 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 muds, 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.

For stable isotope analysis, 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.

Biostratigraphy

Macrofossils have been used as reliable biostratigraphic correlation tools, to help understand and correlate the Paleozoic strata in the Hudson Bay Basin (e.g., Nelson, 1963, 1964; Sanford and Norris, 1975; Jin et al., 1993, 1997). When it comes to microfossils, however, conodonts have been the most used and most dependable method of biostratigraphy (e.g., LeFèvre et al., 1976; Zhang and Barnes, 2007). During the last decade, new conodont data have supplemented the archival data to clarify and constrain ages and correlations (e.g., Zhang and Barnes, 2007; Armstrong et al., 2013) in the Hudson Bay Basin. During the GEM (2008–2013) project, conodonts were sampled only for the Silurian portion of the Whitebear core because this interval has not been previously sampled and analyzed from this well; these results are discussed in McCracken (2011) and Nicolas and Lavoie (2012a). Chitinozoan biostratigraphy was also used during the GEM (2008–2013) project, although with little success; these results are discussed in Asselin (2012) and Nicolas and Lavoie (2012a).

During the GEM-2 project, samples for chitinozoan biostratigraphy were collected from selected intervals in the Comeault and Whitebear cores straddling the sections through most of the formations represented in each core. The intervals selected for the sampling were based on lithologies thought to yield better results than previous analyses. In addition, samples previously collected by Matile and Bezys (unpublished core description for KK1, 2004) through the Paleozoic section of the KK1 core were submitted for conodont analysis. The chitinozoan samples were submitted to E. Asselin at the GSC in Quebec, and the conodont samples were submitted to A. McCracken at the GSC in Calgary for preparation and analysis.

As with other cores available in the HBL, the KK1 core stands alone for long distances, with the closest correlatable core being the Comeault core more than 45 km to the north-northeast. The KK1 borehole is the only one drilled in the area informally called the 'Kaskattama highland' due to the topographic high dominating this area and standing in stark contrast to the low-lying region characteristic of the HBL (Matile and Keller, 2007). This borehole, drilled as part of a mineral exploration program in search of kimberlites, penetrated an unprecedented 257 m of sedimentary strata prior to reaching the Paleozoic bedrock surface (Nicolas, unpublished core description for KK1, 2014). This upper sedimentary strata consists of 223 m of Quaternary sediments (Matile and Bezys, unpublished core description for KK1, 2004), underlain by a 34 m packages of clay and shale of uncertain age (Sweet, 2004). Sweet (2004) indicated potential ages of Quaternary to Tertiary or as late as Cretaceous for this package. A second suite of samples from this questionable interval has been submitted for more micropaleontological analysis by the first author.

Results and discussion

While the general stratigraphy of the HBL is better understood as a result of the comprehensive work done during the first GEM Energy project and as presented in Lavoie et al. (2013), the fine-tuning of the stratigraphic formation tops is still a work in progress. Detailed core descriptions were completed for the Comeault and KK1 cores and stratigraphic tops for some formations have been modified from the formation tops shown in Nicolas (2011) and Nicolas and Lavoie (2012a).

A detailed core description of the KK1 core provided the most interesting formational assignments, and as a result has repercussions on the stratigraphic mapping of the HBL. The stratigraphic map of the HBL depicted in Ramdoyal et al. (2013) was the most recent interpretation of the subsurface distribution of the formations and their approximated formational edges. This map was originally based on a slightly updated version of the bedrock geology map of Norris et al. (1967). According to the map in Ramdoyal et al. (2013), the KK1 borehole should have intercepted the Attawapiskat Formation at the Paleozoic bedrock surface, when in fact it encountered the Severn River Formation. This discovery represents important subsurface evidence to support the Kaskattama trough and Pen Island high first published by Nelson and Johnson (1966). This trough is a complex syncline and anticline first identified in Sogepet Ltd.'s seismic refraction data (Hobson, 1964) from the area, and is part of a series of synclines and anticlines extending from the Nelson River southeastward to Pen Island, Ontario (Nelson and Johnson, 1966). Older than expected strata were encountered, which suggests that the KK1 borehole may fall on the northwestern flank of the Pen Island high as the strata rises from the Kaskattama trough, where erosion would have stripped the Attawapiskat and Ekwan River formations, exposing the older Severn River Formation. Such inferences raises questions about the previously assumed simplistic drawing of the formation edges (such as in Norris et al., 1967; Sanford and Grant, 1999; and Lavoie et al., 2013) due to the lack of subsurface information. The KK1 borehole is not only the first one to challenge this geometry, but also the first to suggest how structurally complex this area may in fact be. Figure GS-12-2 shows the new interpretation of the formational distribution of the HBL in Manitoba.

Ten samples were selected from the Paleozoic section (between 270.0 and 330.71 m) of the KK1 core, and submitted for conodont biostratigraphy. The results support previous interpretations that the interval assigned to the Severn River Formation is Early Silurian (McCracken, 2014). The one sample that was submitted to represent the interval assigned to the Red Head Rapids Formation was barren of conodonts; therefore, the age of this sample is indeterminate from this method (McCracken, 2014).

Biostratigraphic results for the chitinozoan and micropalynology samples and $\delta^{13}C$ and $\delta^{18}O$ stable isotope analyses are pending.

Rock-Eval 6

The results for the Rock-Eval 6 analyses are listed in Nicolas (2014)[3]. The results show total organic contents (TOC) for the Comeault samples that range from 0.49 to 5.65 wt. % (average = 1.91 wt. %, representing 12 samples) for the Surprise Creek Formation, from 0.18 to 3.87 wt. % (average = 1.25 wt. %, representing 12 samples) for the Severn River Formation, and a single value of 0.62 wt. % for the Portage Chute Formation, member 1 (basal clastic unit). The single sample submitted from the Whitebear core yielded a TOC of 8.23 wt. % in the Red Head Rapids Formation. Based on Peters (1986) from which TOC values between 0.5 and 1.0 wt. % are considered to be fair source rocks, 1.0–2.0 wt. % good source rocks and greater than 2.0 wt. % very good source rocks, the average values of these units indicates that they have some good source rock potential, with some intervals having very good potential. While these values are encouraging, care must be taken because the sampled beds and laminae are very thin and spread out over a significant stratigraphic thickness. They do, however, indicate multiple organic influxes into the basin during a significant time period. Hypothetically, the distal paleo-offshore equivalent to these nearshore facies could consist of better preserved, thicker, more continuous packages of organic-rich strata.

Armstrong and Lavoie (2010) and Lavoie et al. (2013) describe the Boas River Formation in northern Ontario and show TOC results from this 9.5 m organic-rich formation to be as high as 12.84 wt. %, with an average of 7.27 wt. %. Stratigraphically located between the overlying Churchill River Group and the underlying Bad Cache Rapids Group (see Figure GS-13-2 in Nicolas and Young, GS-13, this volume), this unit is currently not identified in the HBL in Manitoba's subsurface. This is possibly due to the scarcity of available subsurface information in the latter region. Further deep drilling in this area would be required to resolve this.

The Rock-Eval 6 results are intriguing: most of the T_{max} values are below 435°C and would suggest thermally immature Type II source rocks; samples 106-13-Com-5 and -7 are to be discarded based on the anomalous T_{max} value (<400°C). It is interesting to note, however, that 18 of the 24 valid analyses have production index (PI) values greater than 0.1, which indicate thermal maturation and onset of oil window conditions or hydrocarbon charge (Peters, 1986). This discrepancy between maturity proxies has been reported for the Hudson Bay Basin samples in Lavoie et al. (2013) and has been preliminarily interpreted as the result of T_{max} suppression from high hydrogen content in the kerogen (see hydrogen index [HI] in Nicolas, 2014), a relationship well documented by Snowdon (1995) and Dewing and Sanei (2009). Moreover, based on historical data in Macauley et al. (1990) and new analyses (Zhang, 2011), Lavoie et al. (2013) proposed the presence of sulphur-rich organic matter (Type II-S) in the predominantly restricted and hypersaline Hudson Bay Basin. Type II-S kerogen will start to generate oil at a lower burial temperature (T_{max} of 430°C), which could explain high PI and low T_{max} values. Precise kinetic studies of Ordovician source rocks in the Hudson Bay Basin are in progress and will hopefully shed some light on these anomalous results.

Economic considerations

The Hudson Bay Lowland in Manitoba is a large frontier area with good potential for local hydrocarbon accumulations. Simplistic geological models of the past are slowly being replaced by new, more complex models, as detailed information arises from new studies with better techniques. Through the collaborative work between the GSC and the MGS, the GEM-2 Hudson–Ungava Project (hydrocarbon component) will help resolve the detailed structure, stratigraphy and history of the HBL strata. This information will assist in identifying the best locations for hydrocarbon exploration and aid in land-use planning. Furthermore, this collaboration also provides the MGS access 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.

[3] MGS Data Repository Item DRI2014002, 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 Mineral Resources, 360–1395 Ellice Avenue, Winnipeg, Manitoba, R3G 3P2, Canada.

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