GS2024-20

Pore space resource potential of the Paleozoic sequence in the Hudson Bay Basin, northeastern Manitoba (parts of NTS 53N, O, 54A–F, K, L)

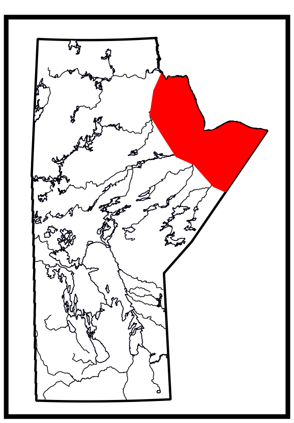
by M.P.B. Nicolas

In Brief:

- Hudson Bay Lowland has potential for oil, helium, natural hydrogen and lithium brines, low enthalpy geothermal heat, but limited stratigraphic potential for geologic storage of CO_2
- Resource assessments are not available for these pore spaces resources, but should still be considered as a future opportunity in land-use planning

Citation:

Nicolas, M.P.B. 2024: Pore space resource potential of the Paleozoic sequence in the Hudson Bay Basin, northeastern Manitoba (parts of NTS 53N, O, 54A–F, K, L); *in* Report of Activities 2024, Manitoba Economic Development, Investment, Trade and Natural Resources, Manitoba Geological Survey, p. 172–180.



Summary

Exploration and studies conducted in the Hudson Bay Basin have been focused on hydrocarbons with no attention to other subsurface pore space resources and commodities. Commodities such as helium, geologic hydrogen and metal (lithium) brines, as well as resources such as carbon capture and storage and geothermal energy all have potential within this basin. Yet, the geological understanding of this large basin is insufficient to inform of their true potential for formal resource assessments. Despite this, datasets collected through multijurisdictional studies support an active hydrocarbon system in the Hudson Bay Basin, both offshore and onshore, and the potential for onshore oil accumulations in northeastern Manitoba is very good. Using the geological framework and models of the basin, predictions for other pore space resources can be deduced and there is considered to be good potential for accumulations of helium, geologic hydrogen and metal (lithium) brines. Furthermore, low enthalpy, localized geothermal heat is possible whereas deep geologic carbon storage is considered to be limited at this time.

Introduction

Pore space resource refers to a resource or commodity that is stored in and extracted from fluids within pore spaces of subsurface rocks, often within sedimentary basins. These resources can include hydrocarbons, dissolved metals, dissolved or exsolved gases, storage space and stored thermal energy. Historically, sedimentary basins are best known for their hydrocarbon resources, which has informed subsurface geological models. A societal shift in focus to reducing emissions, combined with the emergence of new commodity requirements, has prompted renewed geological evaluation and exploration of these sedimentary basins. Hydrocarbon-focused exploration, while still important, is now occurring in parallel with exploration for new commodities within the same sedimentary basins, but often in different strata and with different exploration models. Commodities such as helium, geologic hydrogen (also known as natural, white, gold or free hydrogen) and metal (lithium) brines are the focus of current exploration. These exploration activities are being informed by geological models and the fundamental knowledge used for oil exploration to inform new models and identify new exploration targets both within and outside of the usual oil fields. Commodifying pore space itself is at the forefront, with the rise in carbon capture and storage (CCS) projects seeking subsurface geological reservoirs as disposal sites. Additionally, extracting energy for heat or electrical generation from deep, subsurface warm and hot saline fluids is also a 'commodity' gaining momentum in the pore space resource sector.

The Western Canada Sedimentary Basin (WCSB) is undergoing this pore space transformation, but more remote basins lag behind. It is under this broad context of pore space resources that the Hudson Bay Basin (HBB) has not yet been evaluated, historically having only been assessed for its hydrocarbon potential. This report will discuss its general potential for pore space resources, including hydrocarbons, helium, geologic hydrogen, metal brines, geothermal energy and CCS.

Geological setting

The HBB of northeastern Manitoba consists of a thick sequence (up to ~900 m) of Paleozoic carbonate and clastic sedimentary rocks (Figure GS2024-20-1). Roughly centred in the modern Hudson Bay, the HBB is the largest Phanerozoic basin in Canada, with an area of ~820 000 km^2, and the least explored and understood basin in North America (Lavoie et al., 2013). The sedimentary rocks preserved and exposed onshore were deposited during the Paleozoic era (roughly 250 to 550 million years ago) in a shallow tropical marine environment. This marine environment resulted in the deposition of organic-bearing argillaceous carbonate and shale beds interbedded with thick carbonate strata

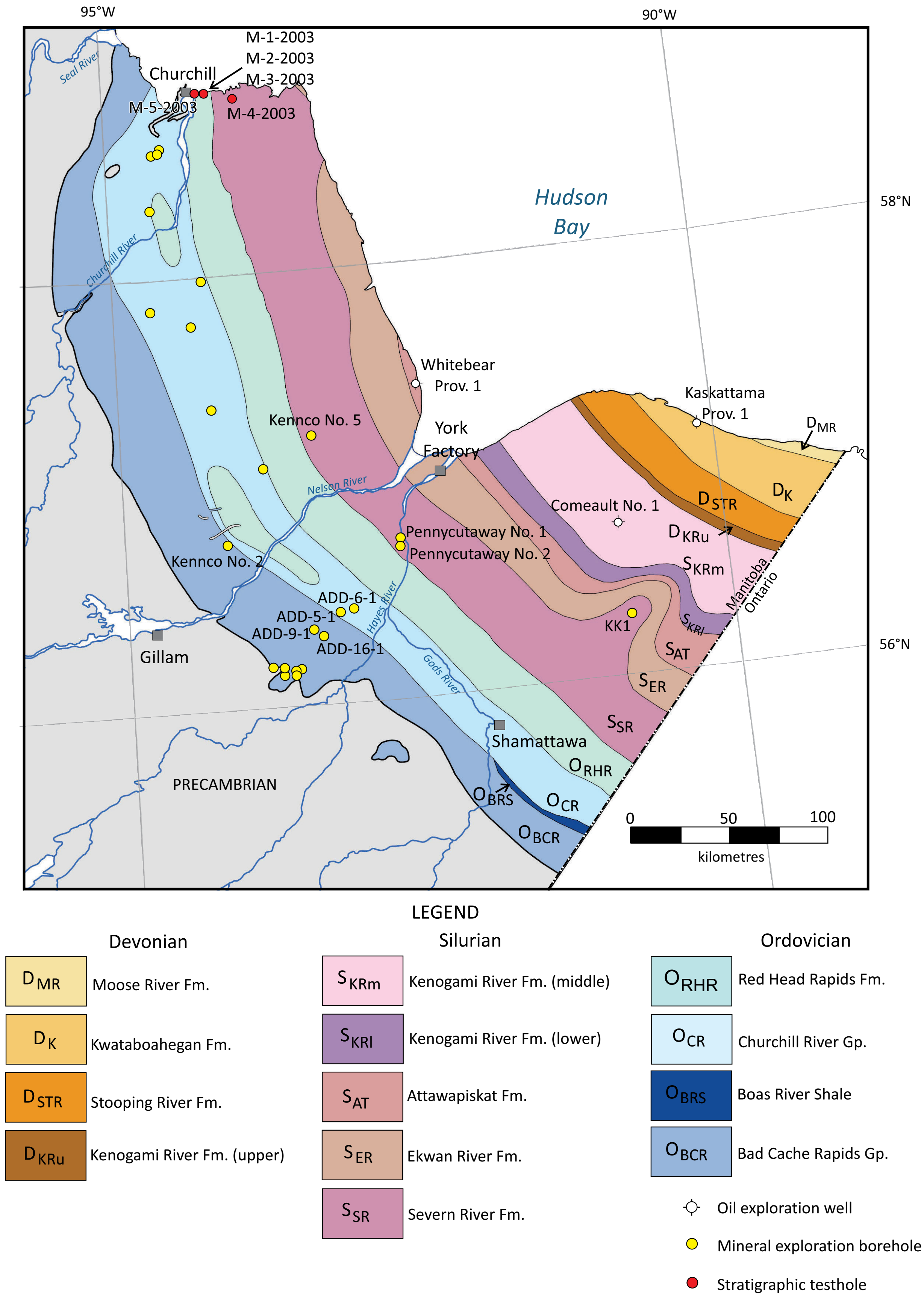


***Figure GS2024-20-1:** Bedrock geology of the Hudson Bay Basin in northeastern Manitoba, showing locations of exploration and stratigraphic test drillholes. Only wells/boreholes/testholes with core available are labelled, with shortened names; see Nicolas and Lavoie (2010) for list of full names and cored intervals.*

during periods of reefal growth and the deposition of evaporitic sequences during periods of restricted and arid conditions (Nelson, 1964; Sanford et al., 1968; Cumming, 1971; Norford, 1971; Norris, 1993; Lavoie et al., 2013). This depositional environment is prospective for hydrocarbons and the development of reservoirs and conditions conducive to other pore space commodities, such as helium, geologic hydrogen, metal brines, geothermal energy and CCS reservoirs.

Hydrocarbon exploration history

Hydrocarbon (petroleum) exploration was first attempted in the HBB (onshore and offshore) from approximately 1964 to 1972, then renewed interest followed in the mid 1980s. Between these bouts of exploration a total of nine exploration oil and gas wells were drilled, five of them were drilled offshore in the centre of the basin and four of them were drilled onshore (three in Manitoba and one in Ontario; Nicolas and Lavoie, 2010; Nicolas and Armstrong, 2017), and seismic surveys were conducted in the centre of the basin (Lavoie et al., 2013). By 1990, the industry and the Geological Survey of Canada (GSC) had gathered a total of 96 000 linear-km of deep and shallow seismic data. Difficulties in acquiring seismic data in Hudson Bay resulted in much of the data to be of poor quality. Even though no commercial discoveries of oil or gas resulted from the drilling (according to the methods of the time), traces of oil and gas and bitumen-impregnated rocks were reported from all of the offshore wells, as well as minor traces in some onshore wells (Nicolas and Lavoie, 2012a; Lavoie et al., 2013). A quantitative resource evaluation concluded that the HBB has an estimated oil potential of 818 Mb (130×10^6 m^3) and gas potential of 3.2 Tcf (90×10^9 m^3; Procter et al., 1984). Unfortunately, the lack of economic success resulted in industry discontinuing their exploration of the HBB, and although there has been occasional industry interest since the 1980s, no advanced exploration has occurred.

Recent research

From 2008–2018, the Geological Survey of Canada led the Geo-mapping for Energy and Minerals (GEM) and GEM-2 programs, which included the successful Hudson Bay and Foxe Basins Project (2008–2013) and Hudson–Ungava Project (2014–2018), to study the geology and hydrocarbon potential of these northern sedimentary basins. Over the course of 10 years, the GEM Energy research team included geoscientists from the federal government, provincial and territorial governments (Manitoba, Ontario, Quebec and Nunavut) and Canadian universities. This team reviewed archival data, reinterpreting data using new geoscientific theories and techniques, and acquired new data from which to verify the hydrocarbon prospectivity of these basins. This work concluded that these basins have excellent hydrocarbon prospectivity (Lavoie et al., 2013, 2019, 2022). Although no new resource estimate was completed during this research, a new resource estimate would most certainly be higher than that calculated by Procter et al. (1984) since hydrocarbon resource evaluations have significantly changed. A qualitative assessment published by Hanna et al. (2018) supports the high hydrocarbon potential of the basin.

The potential for a sedimentary basin to host economic conventional hydrocarbon accumulations is based on the presence of multiple independent elements: a mature source rock rich in organic matter, a porous reservoir capped by a seal and trapping mechanism(s), and timing for fluids to charge the pore space within the reservoir. These studies demonstrated that the HBB has all the geological conditions for hydrocarbon systems to exist, including mature and diverse source rocks, attractive reservoirs and efficient traps and seals (Lavoie et al., 2013, 2019, 2022).

Hudson Bay Basin hydrocarbon potential

To date, study results support an active hydrocarbon system in the HBB, both offshore and onshore, favouring the accumulation of oil but not as much natural gas (Nicolas and Lavoie, 2012a, b). Evidence of migration pathways includes fractures in core that are lined with migrated oil residue (Nicolas and Lavoie, 2010) and the presence of hydrothermal dolomite (identified in the Churchill area; Nicolas and Lavoie, 2012a). Potential reservoir targets were identified in porous strata in all the oil exploration core and in some mineral exploration borehole core (Suchy and Stearn, 1993; Eggie et al., 2014), including clastic beds of the Bad Cache Rapids Group and Silurian reefs of the Severn River and Attawapiskat formations. Lastly, faults identified in the field and in geophysical datasets along with stratigraphic relationships indicate the potential presence of the traps needed for a conventional hydrocarbon system. The areas with the best potential for subsurface accumulations of oil in Manitoba are outlined in Figure GS2024-20-2a and shown vertically in Figure GS2024-20-3.

Within this oil potential area, the prospectivity of oil accumulations is primarily in Devonian and Silurian strata and increases across the region from the southwestern edge of the oil potential area outlined in Figure GS2024-20-2a, toward the northeast, along the Hudson Bay shoreline.

Oil and gas potential areas

An evaluation of the oil and gas potential in the HBB is based on the geological depositional environment, lithology, stratigraphy and subsurface depths. This is achieved through a general ranking for northeastern Manitoba, which is displayed in Figure GS2024-20-2a and shown in a vertical distribution in Figure GS2024-20-3. The southwestern corner of the HBB is considered an oil-rich basin, and is not expected to generate large volumes of natural gas (Nicolas and Lavoie, 2012a).

Rank 3—good potential

Areas with a rank 3 potential contain porous carbonate rocks of the Silurian Severn River Formation (lower units) at minimum depths (~400 m vertical depth) for there to be enough lithostatic pressure to contain oil within a given oil trap scenario, as well

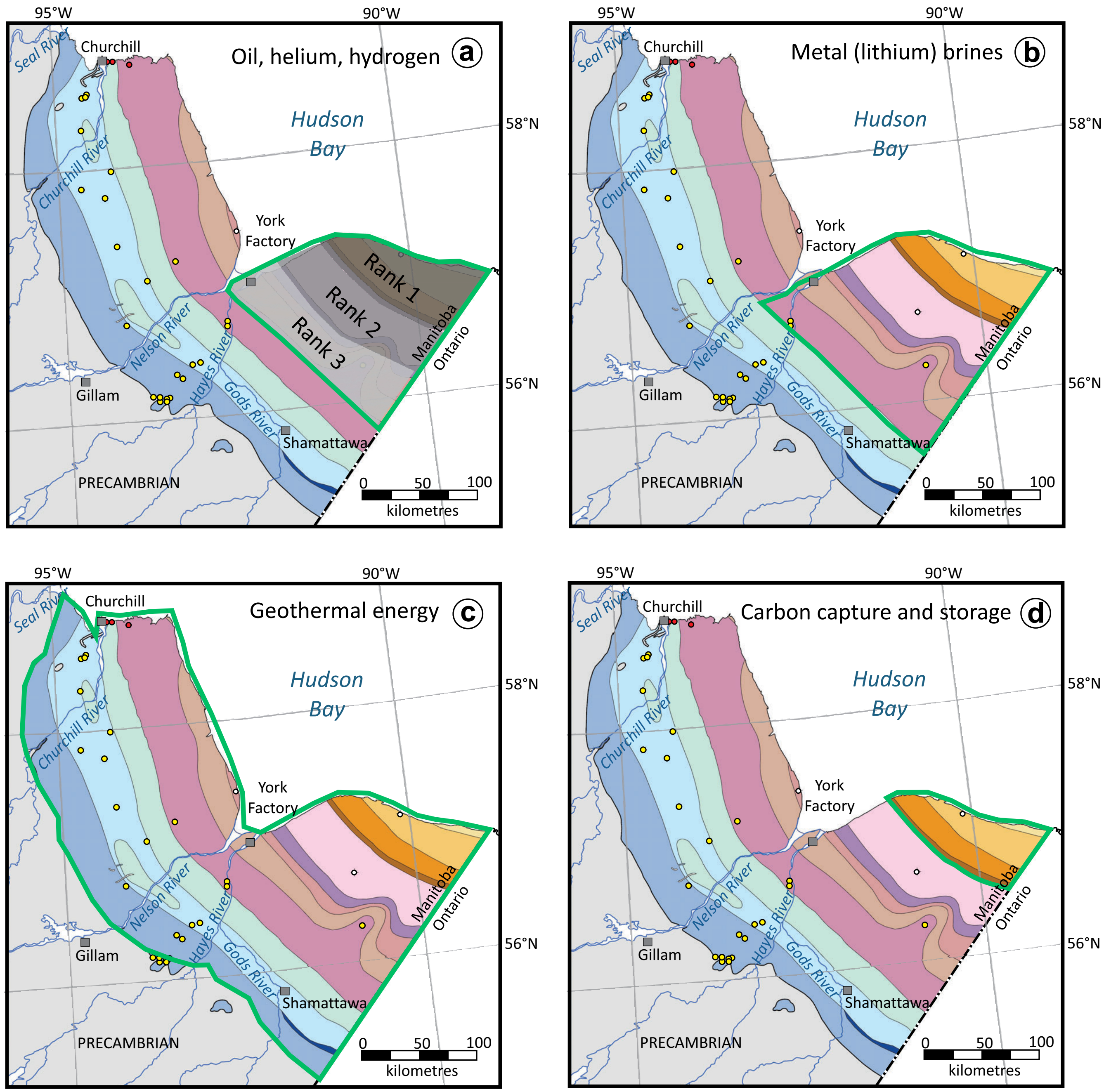


Figure GS2024-20-2: *Prospective areas in the southwestern Hudson Bay Basin are outlined in green for* ***a)*** *oil, helium and hydrogen with ranked areas (rank 1 is excellent, rank 2 is very good and rank 3 is good);* ***b)*** *metal (lithium) brines;* ***c)*** *geothermal energy; and* ***d)*** *carbon capture and storage. See Figure GS2024-20-1 for legend.*

as for unconventional biogenic gas accumulations, which would be accessible with present day technology (Figure GS2024-20-3). The term unconventional here refers to hydrocarbon reservoirs that have much lower porosity and permeability than the traditional (conventional) reservoirs, which require special drilling techniques and stimulation strategies to achieve economic sustainability.

Rank 2—very good potential

Areas with a rank 2 potential meet all the criteria of rank 3 areas, as well as 1) increased strata thicknesses and depth for the porous limestone reservoirs, 2) increased lithostatic pressure to contain larger oil accumulations within any given oil trap scenario, and 3) addition of more porous carbonate beds as a result of the northeastern dip of the strata, allowing more units to occur within the minimum depth zone for economical oil accumulations (middle units of the Silurian Severn River Formation; Figure GS2024-20-3). This area also has evidence of structural disturbances, which increases the probability of complex oil trapping systems. The best unconventional target formations are at greater depths, which translate to better gas generation since at these depths the rock can withstand more rigorous extrac-

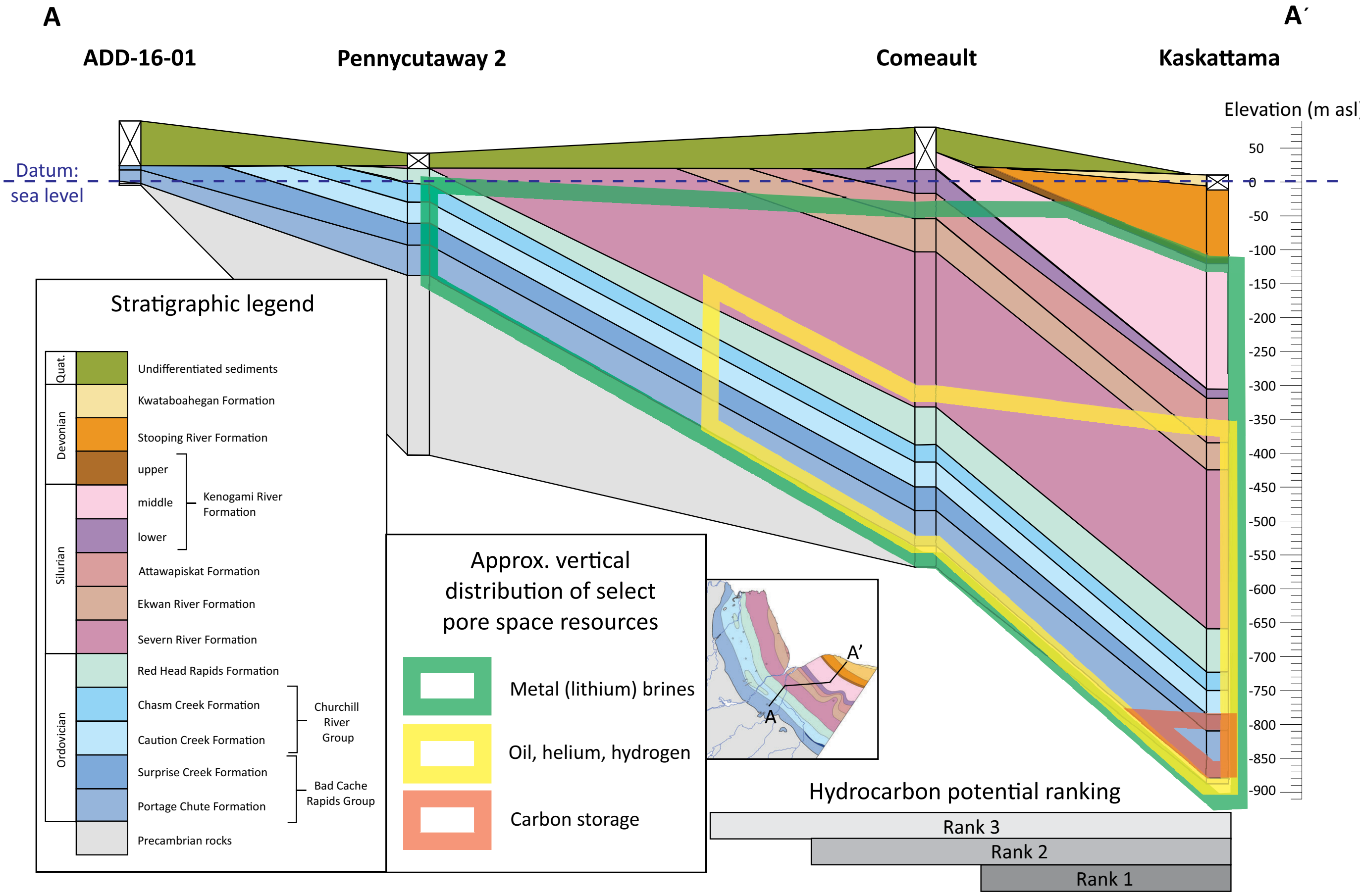


***Figure GS2024-20-3:** Structural cross-section A-A′ showing the approximate vertical depth and stratigraphic distribution of selected pore space resources. The hydrocarbon potential ranking corresponds to the ranking map shown in Figure GS2024-20-2; rank 1 is excellent, rank 2 is very good and rank 3 is good. Inset map shows the location of the cross-section in northeastern Manitoba (see Figure GS2024-20-1 for legend). Full borehole or well names: ADD-16-01, Arctic Star Diamond Corp. ADD-16-01 borehole (Assessment File 74259, Manitoba Economic Development, Investment, Trade and Natural Resources, Winnipeg); Pennycutaway 2, Selco/Hudson Bay Mining and Smelting Pennycutaway 2 borehole (Assessment File 91728); Comeault, Houston Oils et al. Comeault Prov. No. 1 well (oil and gas well licence 2337, Manitoba Economic Development, Investment, Trade and Natural Resources, Winnipeg); Kaskattama, Sogepet Aquitaine Kaskattama Prov. No. 1 well (oil and gas well licence 2168). White boxes with a cross indicate lost core or no core recovered. Abbreviations: Approx., approximately; Quat., Quaternary.*

tion techniques. Geochemical analyses from core within this zone indicate multiple thin (~1–15 cm) zones with high organic contents, and visual evidence of oil migration through fractures (as seen by bitumen staining along naturally fractured horizons; Nicolas and Lavoie, 2010, 2012a).

Rank 1—excellent potential

Areas with a rank 1 potential meet all the criteria of rank 2 and 3 areas; in addition, the porous formations mentioned above are situated at greater depths, with additional porous carbonate units added to the stratigraphic section, including the upper units of the Silurian Severn River, Ekwan River and Attawapiskat formations (Figure GS2024-20-3). Within rank 1, the Attawapiskat Formation has the best reservoir potential due to its high porosity and permeability and occurrence of large reefal structures capped with the tight carbonate and mudstone rocks of the Kenogami River Formation. The abundance of organic-rich beds increases in this area (Surprise Creek Formation of the Bad Cache Rapids Group and Red Head Rapids Formation), as does their subsurface depth. This area is also located along the shelf-break location of the paleo-HBB, which is traditionally the most prospective region within a hydrocarbon-bearing sedimentary basin. Geochemical analyses suggest these beds may have been heated and buried deep enough through their geological history to have produced hydrocarbons (Nicolas and Lavoie, 2012a; Lavoie et al., 2013). If not suitable as source rocks for conventional hydrocarbon systems, then these beds have potential for unconventional hydrocarbons. There is a significant increase in sediment thickness (~300 m) and thus burial depths of the strata between the rank 2 (very good) and rank 1 (excellent) areas, which increases their prospectivity.

Potential for other pore space resources

Exploration and studies conducted on the HBB have been focused on hydrocarbons with no attention to other subsurface resources and commodities. Commodities such as helium, geologic hydrogen and metal (lithium) brines and resources such as CCS and geothermal energy all have varying degrees of potential within this basin, but there is a lack of geological knowledge to gauge the prospectivity of these commodities in the HBB.

Using the same rationale outlined for hydrocarbon potential, a similar exercise can be applied to other pore space resources, with some key differences that are resource specific. Oil generation and source rock geochemistry are not a factor for these other commodities, instead commodity-specific considerations for helium, geologic hydrogen and lithium brine are needed, such as a source of natural radioactive decay for helium and radiolysis for hydrogen (Zgonnik, 2020) and lithium-enriched clays for lithium brine (Bishop and Robbins, 2023). For geothermal resources an increased crustal heat flow is required and for CCS reservoirs need to be situated at a minimum depth of 800 m.

The HBB of northeastern Manitoba does have the geological conditions, including conduits for the migration of gas, porous reservoirs and seals, that are needed to create an economic deposit of helium. Helium occurrences have been identified in the Williston Basin of southeastern Manitoba (Nicolas, 2018; Nicolas et al., 2023) in strata that are correlative to Silurian and Ordovician rocks in the HBB. The Precambrian basement composition underlying the HBB (favouring granitic rocks in places) and the occurrence of clastic sedimentary units with high gamma-ray readings (e.g., shale, sandstone) are excellent sources of helium. The Surprise Creek and Red Head Rapids formations have high gamma-ray responses (Nicolas and Armstrong, 2017), increasing toward the basin centre (Lavoie et al., 2013). Several lineaments related to fracture networks (Nicolas and Clayton, 2015) and basement structures, such as the Winisk River fault and one area currently being studied on the northeastern edge the Kaskattama highland (Craven et al., 2017), provide the conduits for fluid flow. Porous strata of the Severn River and Portage Chute formations occur within the preferred helium reservoir intervals of 500–1500 m depth (Brown, 2010). Particularly efficient seals for helium are evaporitic units, but low permeable carbonate and shale beds can also be good sealing beds. The Red Head Rapids Formation contains salt beds, increasing in thickness towards the centre of the basin, which can serve as a perfect seal for the small helium atom.

There have been no helium or hydrogen measurements conducted on any of the wells in the HBB, however, modern techniques, such as rock volatiles analysis (Nicolas et al., 2023, 2024), have been developed that measure helium concentrations throughout a stratigraphic section. This type of sampling and analysis would be required on the core available to more accurately evaluate the helium potential of the HBB. Since this analysis has not been completed, the entire area outlined for hydrocarbon potential in Figures GS2024-20-2a and -3 could serve as a proxy for a 'good' helium potential.

The understanding of the geological processes that form hydrogen in the subsurface are poorly understood but are receiving rejuvenated interest (Zgonnik, 2020; Jackson et al., 2024). Considering the known association of hydrogen with helium occurrences (Ellis, 2024; Yurkowski et al., 2024), helium targets may also be considered as hydrogen targets; however, the reactivity of hydrogen versus inert helium results in some important differences to consider, specifically in the range of geological environments in which they may occur (Zgonnik, 2020; Ellis, 2024; Jackson et al., 2024;). Despite the scarcity of data available for the HBB, Nicolas (2024) conducted a high level evaluation of hydrogen potential. Overall, it is challenging to confidently indicate where geologic hydrogen may occur in the HBB, therefore, using the prospective area outlined for helium as a maximum area for hydrogen prospectivity is recommended (Figure GS2024-20-2a).

Metal (lithium) brines

Metal brines refer to deep subsurface saline groundwater with elevated concentrations of dissolved metals. The chemistry of saline groundwater in the HBB is poorly documented and there is limited knowledge of the hydrostratigraphy of the HBB. Deep subsurface brines enriched in lithium have been discovered in the WCSB and exploration is currently being undertaken in Saskatchewan (Jensen, 2016; Jensen and Rostron, 2018) and Manitoba (Xtract Lithium, 2024). The source of the lithium in the WCSB is uncertain, but theories include rock-water interactions with lithium-enriched clay layers (Bishop and Robbins, 2023) and episodic erosion of lithium-bearing minerals and/or lithium-rich surface waters flowing from the Canadian Shield into the basin (Nicolas, 2017). Although untested, these same mechanisms and aquifer-specific metal enrichments are just as likely to occur in the HBB, especially within similar porous rocks. The economics of metal brines are less sensitive to depth requirements and more reliant on groundwater chemistry, aquifer characteristics and hydrostatic pressures to ensure reliable production. Based on these factors, the potential area for metal (lithium) brines is larger compared to the designated potential areas for hydrocarbons and helium. The entire Silurian Severn River Formation extent is included in the prospective area since depth is not a limiting factor. This area of potential includes the Red Head Rapids Formation, its argillaceous beds could act as possible aquitards to constrain the brines, and other Ordovician carbonate beds, which could serve as potential metal sources as well as reservoirs. Figure GS2024-20-2b shows the metal (lithium) brine prospectivity map and its distribution at depth is shown in Figure GS2024-20-3.

Geothermal energy

The HBB is considered a cool sedimentary basin, with no anomalous heat flow and low geothermal potential. Geothermal potential is limited to direct heat or heat exchange (Grasby et al., 2012), which can be considered for local/household use. Given the remoteness of the communities in the HBL and their current reliance on diesel fuel for heat, tapping into this low enthalpy but consistent and reliable source of heat stored in the bedrock underlying these communities may be worth considering. Using these types of geothermal systems, the entire distribution of the carbonate strata of the HBB could be considered as a potential area for this geothermal resource, although targeted studies would be required to test this potential. The HBB does not have the potential for geothermal energy for the purposes of electrical generation or large-scale heating infrastructure. Figure GS2024-20-2c shows the area for consideration for low enthalpy geothermal heat.

Carbon capture and storage

The potential to store carbon (as CO_2) in the HBB succession of northeastern Manitoba is very limited. The only formation with sufficient porosity at depths of >800 m is the Ordovician Portage Chute Formation of the Bad Cache Rapids Group. These constraints leave the most prospective area in the HBB to a narrow region that is approximately equivalent to the aerial distribution of the Devonian Stooping River, Kwataboahegan and Moose River formations (Figure GS2024-20-2d). Here, the porous carbonates of the Portage Chute Formation occur at sufficient depths (Figure GS2024-20-3) for deep geologic carbon storage as part of a CCS system. However, this is a remote area with no anthropogenic CO_2 point sources nearby to feed such an operation at this time and the geology remains untested for this type of operation.

Discussion

Only three exploratory wells that penetrate the entire sedimentary section have ever been drilled in this area of Manitoba; therefore, it is not possible to conduct a true resource assessment for any commodity. However, to put the HBB into perspective, the northeastern flank of the Williston Basin in southwestern Manitoba is significantly smaller than the HBB (~182 000 km^2, which is 22% of the size of the entire HBB) and more than 25 dry holes were drilled in southwestern Manitoba before the first oil pool was discovered. The HBB has only nine exploratory oil wells, with three of those in Manitoba.

Geoscientists have a good understanding of hydrocarbon systems, making geoscientific investigations of frontier basins easier to evaluate with limited data. When evaluating for other nonconventional resources, such as the pore space resources discussed herein, the confidence in the prospectivity is reduced significantly. Thus, geologists must rely on foundational understanding of the basin and its stratigraphy as the best tool to developing a prospectivity map for a region, especially one as remote as the HBB, until exploration for a specific pore space resource is conducted.

Economic considerations

The reassessment of the hydrocarbon potential of the HBB using modern technology and reintegrating old and new data through a modern lens has significantly helped to better understand this remote basin. What was once thought as a large area without hydrocarbon potential has now been reinterpreted as a highly prospective frontier area. Successful exploration in northern Manitoba brings significant positive economic impact and development, particularly for northern communities. The coast of Hudson Bay, including the deepwater port at Churchill and connecting rail line, allows access to major markets. Thus, successful hydrocarbon exploration and understanding of other pore space commodities available in the HBB would benefit all of Manitoba.

The assessment of other pore space resources, such as helium, geologic hydrogen and metal (lithium) brines, is difficult given the lack of data currently available, but by applying the knowledge gained from previous reassessments of hydrocarbons, it is possible to extrapolate and conclude that the potential does exist. As technology advances and economic conditions improve, these resources could become a viable exploration target of the future, adding further value to the region. Geothermal energy for use in direct heat and heat exchange systems may be possible to develop at the household scale. However, carbon capture and deep geologic storage potential in the Hudson Bay Basin is extremely limited. From an economic opportunity perspective, and in the broader land-use planning of this northern region, knowing the pore space resource potential, its benefits and limitations, is important in the decision-making process.

Acknowledgments

The author would like to acknowledge D. Lavoie, formerly of the Geological Survey of Canada, the leader of the Hudson Bay and Foxe Basins Project and the Hudson–Ungava Project of the Geo-mapping for Energy and Minerals programs (GEM, 2008-2013; GEM-2, 2013–2020) and the extended GEM Energy team for their extensive support in researching and understanding the geology and hydrocarbon potential of the Hudson Bay Basin. The author thanks P. Fraino and T. Hodder for their critical review of this report.

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