Regional and global correlations of the Devonian stratigraphic succession in the Hudson Bay and Moose River basins from onshore Manitoba and Ontario to offshore Hudson Bay

S. Larmagnat[1*] and D. Lavoie[1, 2]

Larmagnat, S. and Lavoie, D., 2022. Regional and global correlations of the Devonian stratigraphic succession in the Hudson Bay and Moose River basins from onshore Manitoba and Ontario to offshore Hudson Bay; in *Sedimentary basins of northern Canada: contributions to a 1000 Ma geological journey and insight on resource potential, (ed.) D. Lavoie and K. Dewing; Geological Survey of Canada, Bulletin 609, p. 185–213. https://doi.org/10.4095/326091*

Abstract: The Devonian successions in northeastern Manitoba and northern Ontario are integrated in a single stratigraphic framework. To the north, in the offshore Hudson Bay Basin, stratigraphic nomenclatures are unified and correlated with the successions to the south.

The carbon stable-isotope ($\delta^{13}C_{VPDB}$) trends for Devonian carbonate rocks are used for regional correlations and are compared with global Devonian isotope trends. Local and global $\delta^{13}C_{VPDB}$ trends are used to evaluate the position of the Silurian–Devonian boundary in the Hudson Bay Platform.
The Devonian succession of the Hudson Bay Platform belongs to the Kaskaskia Sequence and compares with similar carbonate–evaporite successions of the adjacent Williston and Michigan basins. In these basins, two episodes of roughly coeval reef development are present (Emsian–Eifelian and Givetian), with corals and stromatoporoids as main framework constituents.

The Hudson Bay Platform reefs and dolomitized facies exhibit significant porosity and have the potential to form hydrocarbon reservoirs, with intervals bearing direct and petrophysical evidence of hydrocarbon charge.

Résumé : Les successions dévoniennes du nord-est du Manitoba et du nord de l’Ontario sont intégrées dans un cadre stratigraphique unique. Plus au nord, dans le domaine marin du bassin de la baie d’Hudson, les nomenclatures stratigraphiques sont uniformisées et corrélées avec celles des successions plus au sud.

Les tendances de la signature des isotopes stables du carbone ($\delta^{13}C_{VPDB}$) dans les roches carbonatées du Dévonien sont utilisées aux fins de corrélations régionales et sont comparées avec les tendances isotopiques globales au Dévonien. Les tendances locales et globales de $\delta^{13}C_{VPDB}$ sont utilisées pour évaluer la position de la limite Silurien-Dévonien dans la plate-forme de la baie d’Hudson.

La succession dévonienne de la plate-forme de la baie d’Hudson appartient à la Séquence de Kaskaskia et est semblable aux successions de roches carbonatées-évaporitiques des bassins adjacents de Williston et de Michigan. Dans ces bassins, deux épisodes de développement récifal à peu près coïncidents sont connus (Emsien-Eifélien et Givétien), où les coraux et les stromatopores constituent les principaux organismes constructeurs.

Les récifs et les faciès dolomitisés de la plate-forme de la baie d’Hudson montrent une porosité importante et ont le potentiel de former des réservoirs d’hydrocarbures avec des intervalles présentant des preuves directes et pétrophysiques de charge en hydrocarbures.

---

[1] Geological Survey of Canada, 490, rue de la Couronne, Québec, Quebec G1K 9A9
[2] Retired
*Corresponding author: S. Larmagnat (email: stephanie.larmagnat@nrcan-rncan.gc.ca)

PREVIOUS WORKS

Geological context and stratigraphy

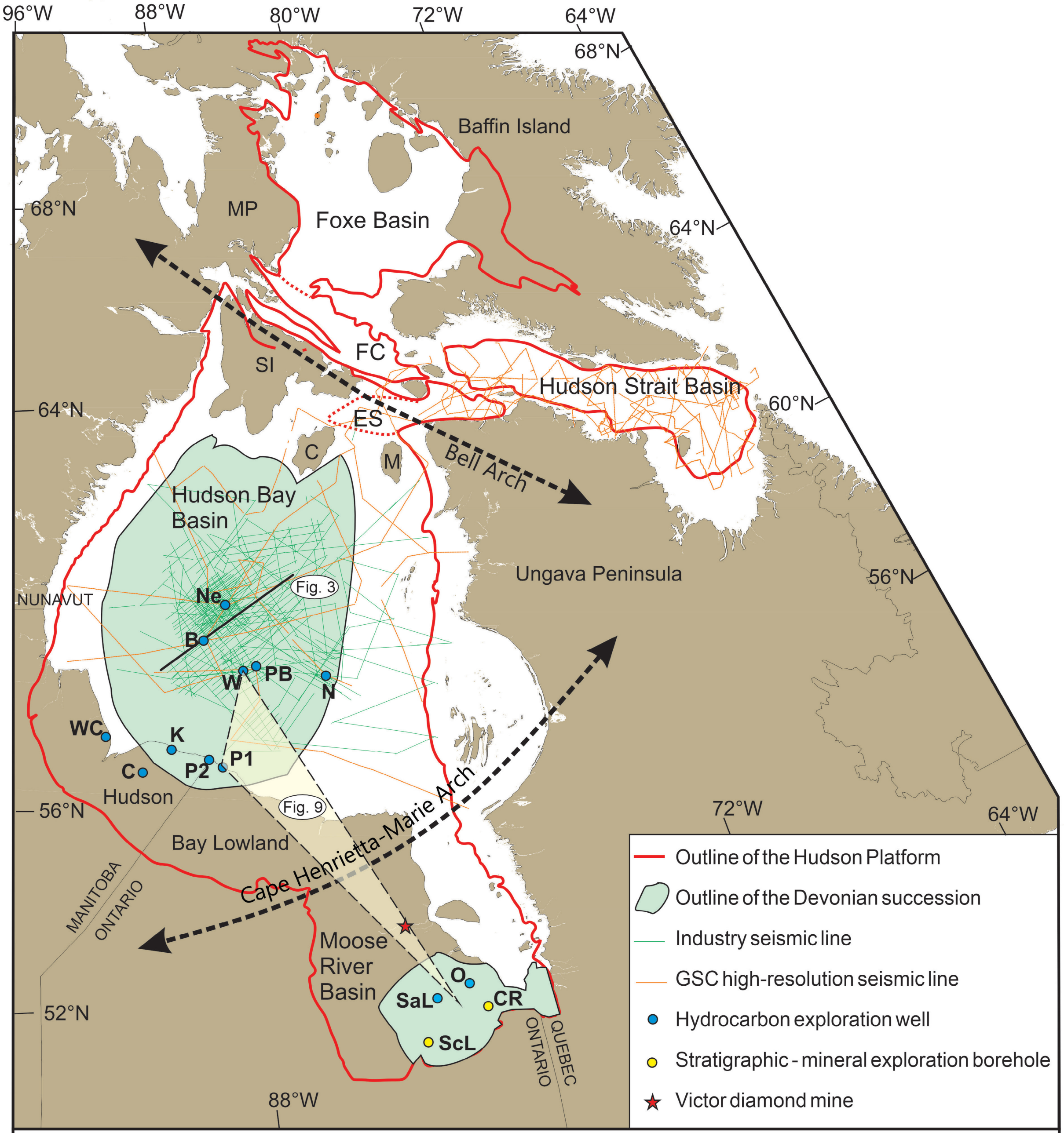
The Hudson Platform (*sensu* Sanford and Norris, 1973) represents one of the largest Phanerozoic sedimentary basins in Canada. It covers close to 1 000 000 km^2 (about 10% of the area of Canada), of which two thirds is under water. The Hudson Platform encompasses parts of northeastern Manitoba, northern Ontario, and Nunavut (Fig. 1); it contains the large Hudson Bay Basin and the smaller, adjacent Moose River, Foxe, and Hudson Strait basins. The Hudson Bay Basin is separated from the Moose River Basin by the Cape Henrietta-Maria Arch, whereas the Bell Arch separates the Hudson Bay Basin from the Foxe Basin and Hudson Strait Basin (Fig. 1). The two arches (Henrietta-Maria Arch and Bell Arch) are broad, positive, basement-involved structural elements, for which the formation mechanism(s) is poorly understood. The Hudson Platform unconformably overlies, and is encircled by, Precambrian rocks. The basement includes metamorphic and igneous rocks of the Paleoproterozoic Trans-Hudson Orogen, a tectonic suture zone marking the contact between the Superior and Churchill cratons that underlie the southern and northern parts of the Hudson Platform, respectively (Eaton and Darbyshire, 2010).

The Hudson Platform surface area significantly exceeds that of other North American intracratonic basins (e.g. Michigan, Illinois, Williston basins), but the Hudson Platform is characterized by the thinnest and the shortest time-preserved sedimentary succession among these basins (Quinlan, 1987; Burgess, 2019). This has been attributed to the stiff lithospheric root and high elastic thickness beneath the basin, which may have existed during its formation (Kaminski and Jaupart, 2000). The age of the base of the preserved Paleozoic succession is variable throughout the platform. Paleozoic rocks can be as old as Cambrian in the northern part of the Foxe Basin but are usually Late Ordovician elsewhere. The youngest well dated Paleozoic strata are Upper Devonian rocks in the Hudson Bay and Moose River basins. Reports of upper Paleozoic (Carboniferous) strata by Tillement et al. (1976) have not been supported by subsequent work. Mesozoic to recently documented mid-Cenozoic strata (Galloway et al., 2012) locally occur at the top of the Paleozoic strata. The maximum preserved thickness of the Phanerozoic basin fill is about 2500 m in Hudson Bay (Pinet et al., 2013). The Hudson Platform is the erosional remnant of a more extensive marine cratonic cover that probably had episodic connection with platform areas to the north (Arctic Platform) and south (St. Lawrence Platform, Michigan and Williston basins) during the Paleozoic (Sanford, 1987) and possibly Mesozoic (White et al., 2000).

Hudson Bay was explored by English navigator Henry Hudson in 1610 and, given its relatively remote location and lack of known resources, remained poorly known geographically and geologically well into the twentieth century. This basin is still one of the least studied sedimentary basins in Canada. To the south, the Phanerozoic succession extends onshore and consists of a relatively thin (approximately 1000 m) succession of nearly flat-lying sedimentary rocks exposed in the Hudson Bay Lowland of northeastern Manitoba and northern Ontario. Northward, onshore exposures are known on the southern part of Southampton Island as well as on Coats and Mansel islands in Nunavut (Fig. 1). Similarly, the Foxe Basin is a largely marine sedimentary basin with preserved onshore erosional margins expressed as nearly flat-lying strata known on Melville Peninsula, in the northern part of Southampton Island, as well as on southwestern and southern Baffin Island (Fig. 1). All onshore exposures of the Hudson Bay Platform Paleozoic succession in Nunavut are restricted to the Ordovician–Silurian stratigraphic interval; no Devonian-aged rocks are known (Fig. 1).

Sketchy geological observations started in the Hudson Bay area in the 1880s (Bell, 1885a, b; Low, 1887; Dowling, 1901; Wilson, 1903; Parks, 1904). The first fairly comprehensive summary of the stratigraphy was by Savage and Van Tuyl (1919). Little work was done on the Paleozoic strata of the Hudson Platform during the 1920s to 1940s. Studies of the Paleozoic strata restarted in the 1950s (e.g. Nelson, 1952; Hogg et al., 1953; Fritz et al., 1957), but it was only in the mid-1960s to 1970s that regional-scale mapping was conducted by Geological Survey of Canada (GSC) officers along major rivers in Manitoba and Ontario, also known as the Hudson Bay Lowland (Fig. 1; Nelson, 1963, 1964; Nelson and Johnson, 1966; Sanford et al., 1968; Sanford and Norris, 1973; Cumming, 1975). Ordovician and Silurian units were mapped although the geology is obscured by the very low relief and swampy muskeg terrain that covers the Hudson Bay Lowland. No outcrops of Devonian rock are known from the lowland; however, Devonian rocks form successions 120 to 200 m thick in cores from three wells drilled in Manitoba (Kaskattama Prov. No. 1) and Ontario (Pen No. 1 and No. 2) (Fig. 1; Nicolas and Armstrong, 2017).

The early geological exploration history of the Moose River Basin (Fig. 1) has been summarized by Bell (1904), Savage and Van Tuyl (1919), and Kindle (1924). These surveys were primarily conducted because of the presence of lignite deposits in the area (Verma, 1982). Operation Winisk, conducted by the GSC in 1967, covered parts of the Moose River Basin and resulted in several local and regional contributions (Norris and Sanford 1968a, b; Sanford et al., 1968; Sanford and Norris, 1975; Price, 1978; Verma, 1982). The onshore mapping program led to the recognition of an approximately 500 m thick succession of Ordovician–Silurian carbonate- and evaporite-dominated strata, in which the Ordovician strata presented notable correlation issues with those of the Hudson Bay Basin (Armstrong et al., 2018), as well as a Lower to Upper Devonian succession about 750 m thick (Sanford et al., 1968). Unconsolidated Middle Jurassic and Lower Cretaceous rocks unconformably overlie the Paleozoic succession in the Moose River Basin (Sanford and Grant, 1998); the presence of mid-Cenozoic



C - Coats Island
ES - Evans Strait
FC - Foxe Channel
M - Mansel Island
MP - Melville Peninsula
SI - Southampton Island

B - Trillium et al. Beluga O-23
C - Houston et al. Comeault No. 1
CR - Kerr Addison Coral Rapids CR-78-08
K - Sogepet Aquitaine Kaskattama Prov. No. 1
N - Aquitaine et al. Narwhal South O-58
Ne - ICG et al. Netsiq N-01
O - Consumers 85509 Onakwahegan No. 2

P1 - Aquitaine Sogepet et al. Pen No. 1
P2 - Aquitaine Sogepet et al. Pen No. 2
PB - Aquitaine et al. Polar Bear C-11
SaL - Aquitaine Sogepet et al. Sandbank Lake No. 1
ScL - Schlievert Lake OGS-83-8D
W - Aquitaine et al. Walrus A-71
WC - Merland Exploration Whitebear Creek No. 1

Figure 1. Map of the Hudson Bay Platform showing the extent of the Hudson Bay Basin and adjacent basins, areal distribution of the Devonian succession, seismic lines, and exploration wells. Distribution of Devonian and younger units (green area) is based on Sanford and Grant (1998) and Nicolas and Armstrong (2017) for the offshore and onshore areas, respectively. The detailed distribution of formations is found in the two former references. Locations of cross-section (Fig. 3) and fence diagram (Fig. 9) are shown.

unconsolidated clastic rocks associated with diamond-bearing kimberlite emplacement in northern Ontario (Victor diamond mine; Fig. 1) has more recently been documented (Galloway et al., 2012; Gao et al., 2012). The Moose River Basin is the type area, where the Devonian stratigraphic nomenclature was proposed (Sanford et al., 1968).

Prior to the Hudson Bay Geo-mapping for Energy and Minerals (GEM) projects (2008–2020), the most recent and comprehensive attempts at stratigraphic correlation and synthesis of the Devonian successions of the Hudson Bay and Moose River basins (Fig. 2) were those of Sanford and Grant (1990, 1998) and Hamblin (2008).

Hydrocarbon exploration

Industry onshore drilling in the Hudson Bay Basin started in 1966 with the Sogepet Aquitaine Kaskattama Prov. No. 1 well in northeastern Manitoba (Fig. 1; Norford, 1970). Five onshore wells were drilled by industry between 1966 and 1970, three in Manitoba and two in Ontario (Fig. 1). From late 1960 to 1990, the energy industry and the GSC acquired in the Hudson Bay and Hudson Strait over 46 000 and 40 000 line-kilometres of deep and shallow seismic-reflection data, respectively (Fig. 1). Seismic acquisition by industry was largely concentrated in the central part of Hudson Bay and resulted in generally low-quality seismic lines due to acquisition problems. The marine seismic acquisition program demonstrated that the sedimentary succession of the central part of the Hudson Bay is much thicker than its onshore counterpart. Based on the seismic information, the industry drilled five offshore wells from 1969 to 1985 (Fig. 1). For all these offshore wells, local stratigraphic nomenclatures were largely defined based on the study of well cuttings. Industry data (paper copies of seismic lines, digital well logs, cuttings, and a few cores) were filed with the Canada Energy Regulator (at the time National Energy Board) for future use. The reinterpretation of the vintage offshore seismic data led to a new regional tectonostratigraphic framework (Fig. 3). Faults were shown to be active during Ordovician–Silurian sedimentation; no synsedimentary-basin tectonic activity can be detected in the Devonian assemblage (Fig. 3; Pinet et al., 2013). A summary of the hydrocarbon systems of the Hudson Bay Basin was initially proposed by Hamblin (2008). Modern hydrocarbon-system syntheses for the Hudson Bay Basin were published under the GSC GEM programs (Lavoie et al., 2013, 2015). A qualitative petroleum resource assessment of the Hudson Bay Basin (Hanna et al., 2018), also produced by the GSC but external to GEM, suggested local oil-prospectivity of the basin.

Oil and gas exploration in the Moose River Basin began in the early 1920s (Kindle, 1924; Dyer, 1928). The James Bay Basin Oil Company Limited drilled three wells along the Moose River in 1929 (Satterly, 1953). Stratigraphic drilling was undertaken by the Government of Ontario in the 1930s (the Onakawana A hole; Martison, 1953), again in the late 1940s and early 1950s (Hogg et al., 1953), and subsequently in the 1980s (Bezys, 1989). As recorded in the Ontario Oil, Gas and Salt Resources Library's database, at least 32 oil and gas shallow exploration wells and 6 government stratigraphic test wells were drilled in the Moose River Basin; those relevant to this synthesis are shown in Figure 1. A summary of the hydrocarbon systems of the Moose River Basin was initially published by Hamblin (2008). A qualitative petroleum resource assessment of the Moose River Basin (Hanna et al., 2019) produced similar conclusions as Hamblin (2008), suggesting a very low potential for the area.

RECENT WORK AND DATA USED FOR CORRELATIONS

The synthesis of the Devonian succession presented in this report is based on recent re-evaluation of vintage stratigraphic and well-log data, as well as the acquisition of new stratigraphic (litho-, bio-, and chemostratigraphic) information at strategic locations (wells and outcrops).

Hudson Bay Lowland in northeastern Manitoba and northern Ontario

In 2016, the Manitoba Geological Survey relogged the Devonian interval of the Sogepet Aquitaine Kaskattama Prov. No. 1 well, which contains the only Devonian section available in northeastern Manitoba (Nicolas, 2016a). Twenty samples for chemostratigraphic analysis of carbon-isotope ratios relative to the Vienna Pee Dee Belemnite international reference standard ($\delta^{13}C_{VPDB}$) were collected; the results helped refine stratigraphic correlations in the upper Silurian–Lower Devonian interval (Nicolas, 2016a, b).

The Ontario Geological Survey relogged the Devonian interval of the Aquitaine Sogepet et al. Pen No. 1 well, which contains one of the only two available sections of Devonian strata in the Hudson Bay Lowland of northern Ontario (Armstrong et al., 2013). Forty-eight samples for carbon-isotope ($\delta^{13}C_{VPDB}$) chemostratigraphic analysis were collected in the problematic upper Silurian–Lower Devonian interval (Armstrong et al., 2013). Samples collected for chitinozoan biostratigraphy have all proven barren.

Offshore Hudson Bay Basin

The five wells drilled in the central part of Hudson Bay all encountered variable thicknesses of Devonian rock units; the complete log suites were re-evaluated for all wells (Hu et al., 2011; Hu and Dietrich, 2012). To improve the age control of the succession, forty-four cutting samples were processed for chitinozoans in intervals assigned to, or assumed to be part of, the Devonian succession.

Contents

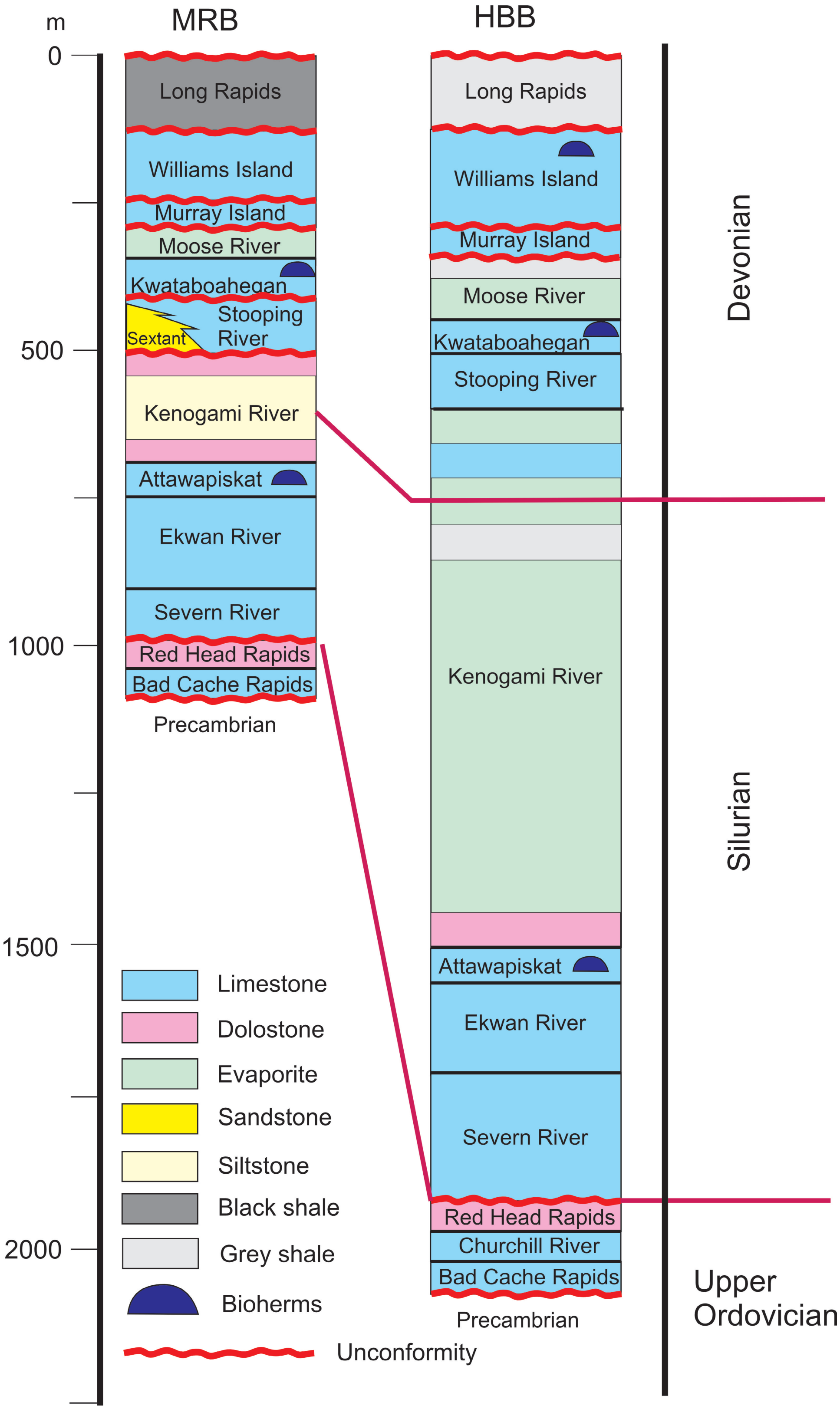


Figure 2. Stratigraphy of the Hudson Bay Basin (HBB; Beluga O-23 well) and Moose River Basin (MRB; field sections composite) as defined before the Geo-mapping for Energy and Minerals program (*modified from* Sanford and Grant, 1990).

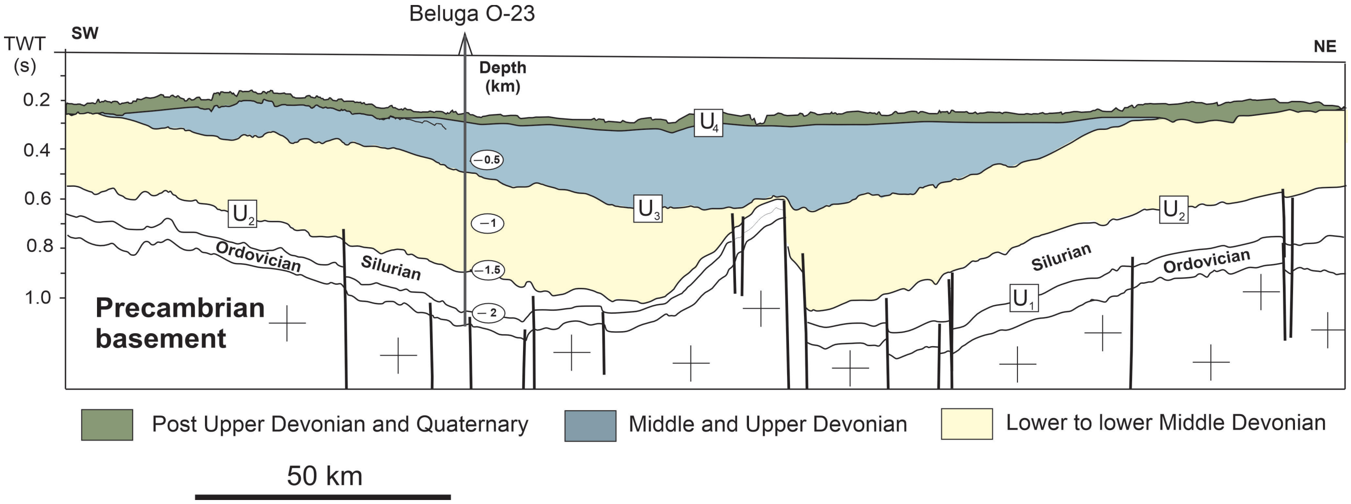


Figure 3. Interpretation of seismic reflection profile S6348. The profile is in central Hudson Bay, across the Beluga O-23 well (Fig. 1), and depicts major lithostratigraphic intervals and unconformities (U_1 to U_4). Vertical axis on the left is two-way travel time (TWT), and a depth scale is shown adjacent to the Beluga O-23 well. Only the post-Silurian rock package (Devonian to Quaternary) is coloured (*modified from* Pinet et al., 2013).

Moose River Basin

Outcrops of Devonian units are only found in the Moose River Basin. This area in northern Ontario is mostly covered by muskeg; however, outcrops can be abundant and well exposed along the banks of the numerous rivers draining into James Bay. Tens of outcrops were described and sampled along the main rivers in the Moose River Basin (Ratcliffe and Armstrong, 2013; Nicolas and Armstrong, 2017); 12 carbonate samples from Devonian units were processed for conodonts (Braun et al., 2016; S. Gouwy, unpub. GSC Paleontological Report 4-SAG-2016, 2016). Four wells were logged in detail (Fig. 1), and 284 samples submitted for fine-scale carbon-isotope ($\delta^{13}C_{VPDB}$) chemostratigraphy (Chow and Armstrong, 2015; Braun et al., 2016).

STRATIGRAPHIC FRAMEWORK

Devonian stratigraphy of the Moose River Basin

The extensive Winisk field operation of the GSC concluded in 1967 (Sanford et al., 1968) brought a detailed appraisal of the Devonian stratigraphy in the Moose River Basin and the definition of three new stratigraphic formations to amend and refine the old stratigraphic framework of five formations. The new formations are the Stooping River, Kwataboahegan, and Murray Island formations (Fig. 4; Table 1; Sanford et al., 1968). Sanford and Norris (1975) described in detail 29 sections of Devonian rocks along rivers in the Moose River Basin and 19 exploration and geotechnical wells drilled in this area. Field and laboratory research by the Ontario Geological Survey and academia research teams, as part of the GEM-2 Hudson–Ungava project, significantly refined the age and correlation of these units with biostratigraphy and $\delta^{13}C$ chemostratigraphy.

Out of the eight formations (Fig. 4), seven have been recognized in the central part of Hudson Bay; the Sextant Formation is restricted to the Moose River Basin. The variations in the internal stratigraphy between studied areas is presented below (*see* 'Discussion' section).

Devonian stratigraphy in the offshore Hudson Bay

Sanford and Grant (1998) applied the Devonian stratigraphy, as defined in the Moose River Basin, to the offshore domain of Hudson Bay. Figure 5 presents the correlation of the actual Devonian stratigraphic framework (Hu et al., 2011; Hu and Dietrich, 2012), with the original stratigraphic nomenclature used by the oil industry while drilling the offshore wells. The only geological report available for Walrus A-71 uses the Moose River Basin stratigraphy of Sanford et al. (1968); the detailed well description can be found in Sanford and Norris (1975). The original stratigraphy was defined on a well-to-well basis by the operators, and correlation between wells was highly problematic. The summary of the lithological interpretations, based on log analyses, is presented with available litho- and biostratigraphic data in Tables 2 and 3 and summarized in Figure 6.

In their original framework for Hudson Bay, Sanford and Grant (1990, 1998) assigned the thick evaporite succession found in the Beluga O-23 well to the upper Silurian Kenogami River Formation (Fig. 2). As part of the GEM study, chitinozoan assemblages from the intervening limestone beds indicated Early to Middle Devonian age (Hu et al., 2011). This

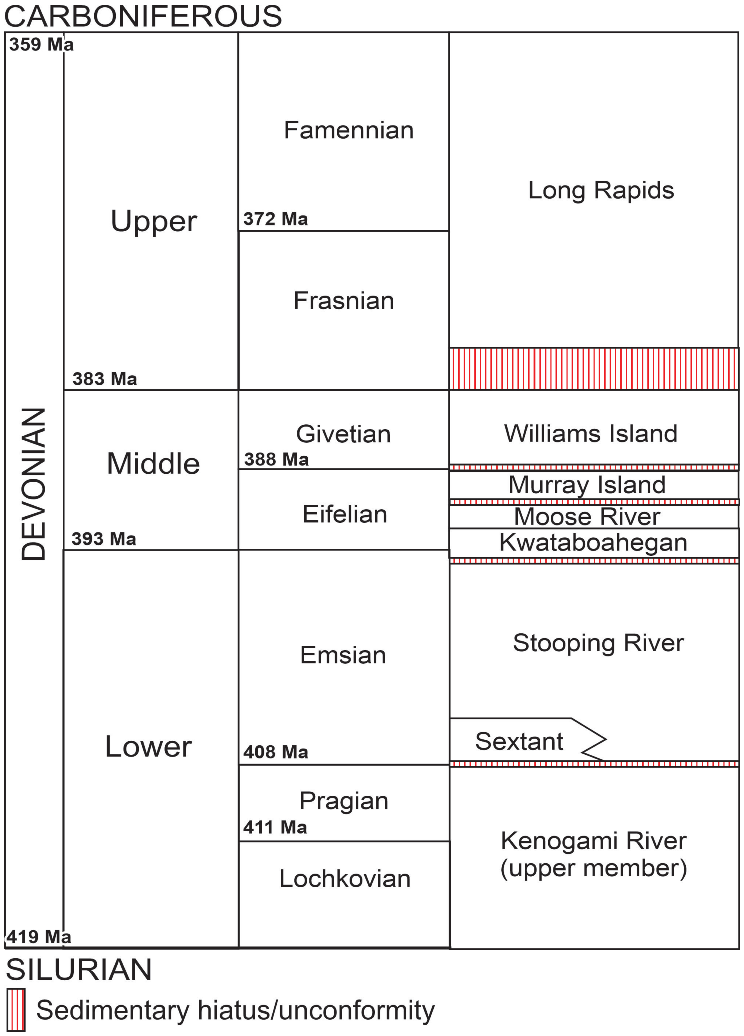


Figure 4. Devonian stratigraphic framework as defined in the Moose River Basin by Sanford et al. (1968). Time scale from Gradstein et al. (2012).

is consistent with the Emsian age from spores and acritarchs reported by Robertson Research Canada Limited (1986), which results support inclusion of the thick evaporite interval of Beluga O-23 into the Lower Devonian Stooping River Formation (Fig. 6).

Devonian stratigraphy of the Hudson Bay Lowland

Devonian units of the Hudson Bay Lowland are recognized by intercepts in exploration wells drilled along the southern coast of Hudson Bay (Fig. 1). Three wells intersected the Devonian succession: Kaskattama Prov. No. 1 (1967) in Manitoba; and Pen No. 1 (1969) and No. 2 (1970) in Ontario. Initial description by Sanford and Norris (1975) identified cored versus cuttings-only intervals. The Devonian stratigraphy of the Kaskattama Prov. No. 1 and Pen No. 1 was re-evaluated during the GEM programs, and correlations between the two were made based on lithological descriptions, gamma-ray and neutron logs, as well as carbon-isotope profiles (Armstrong et al., 2013; Nicolas and Armstrong, 2017). Table 4 summarizes the Devonian stratigraphy of the area; comparisons of unit thickness between the descriptions of cuttings and cores (Sanford and Norris, 1975; Armstrong et al., 2013), and log interpretations (Nicolas and Armstrong, 2017) are presented. The Pen No. 2 well was not re-evaluated during the GEM program. Figure 7 presents the logs and lithology-based correlations between the Kaskattama Prov. No. 1 and Pen No. 1 wells.

Devonian chemostratigraphy of the Hudson Bay Lowland and Moose River Basin

Through chemostratigraphy, which uses various elemental and isotope tracers in sedimentary rocks, stratigraphic correlations for successions with few or no conventional lithostratigraphic markers or limited biostratigraphic data can be established. Chemostratigraphy has become increasingly popular over the last four decades, as geochemical analytical tools evolved dramatically in their precision and affordability (Scholle and Arthur, 1980; Renard, 1986; Narbonne et al., 1994; Pearce and Jarvis, 1995; Racey et al., 1995; Pearce et al., 1999; Mutti et al., 2006; Weissert et al., 2008).

Table 1. Summary of the Devonian stratigraphy, Moose River Basin.

Unit	Age	Author	Thickness, field sections maximum	Main lithology	Secondary lithology	Diagnostic	References
Kenogami River (upper member)	Lochkovian–Pragian	Dyer, 1930	30 m	Oolitic dolomite	Dolomite breccia	Evaporite clasts	Sanford et al., 1968; Sanford and Norris, 1975; Norris, 1993; Braun et al., 2016
Sextant	Emsian	Savage and Van Tuyl, 1919	45 m	Quartz and feldspar conglomerate and sandstone	Siltstone and shale	Reddish clastic. Abundant plant fragments. Local carbonate clasts	Sanford et al., 1968; Sanford and Norris, 1975; Norris, 1993; Braun et al., 2016
Stooping River	Emsian	Sanford et al., 1968	143 m	Cherty fine-grained limestone (wackestone) and dolomite. Fossiliferous (crinoids, corals)	Sandy dolomite and shale. Minor anhydrite	Localized nodular bedding	Sanford et al., 1968; Sanford and Norris, 1975; Norris, 1993; Braun et al., 2016
Kwataboahegan	Eifelian	Sanford et al., 1968	77 m	Thick-bedded bituminous limestone and dolostone. Metazoan floatstone and bindstone	Skeletal packstone to rudstone. Locally dolomitic and rare chert	Bindstone texture and bituminous	Sanford et al., 1968; Sanford and Norris, 1975; Norris, 1993; Chow and Armstrong, 2015; Braun et al., 2016
Moose River	Eifelian	Dyer, 1928	61 m	Limestone and vuggy dolostone. Metazoan floatstone with thick interbeds of gypsum	Thick intervals of carbonate breccia hosted in mudstone	Gypsum and collapse breccia	Sanford et al., 1968; Sanford and Norris, 1975; Norris et al., 1993; Braun et al., 2016
Murray Island	Eifelian	Sanford et al., 1968	20 m	Brecciated limestone (crinoidal wackestone to packstone with mudstone matrix	Lime mudstone	Breccia	Sanford et al., 1968; Sanford and Norris, 1975; Norris, 1993; Braun et al., 2016
Williams Island	Givetian	Kindle, 1924	90 m	Base of unit of grey, green, and red mudstones; bioclastic wackestone to packstone top unit	Stromatoporoid bindstone and dolomudstone	Grey-green mudstone	Sanford et al., 1968; Sanford and Norris, 1975; Norris, 1993; Braun et al., 2016
Long Rapids	Frasnian–Famennian	Savage and Van Tuyl, 1919	87 m	Dark brown and black, organic-rich shale	Dolomite	Black shale and ironstone nodules	Sanford et al., 1968; Sanford and Norris, 1975; Norris, 1993; Bezys and Risk, 1990

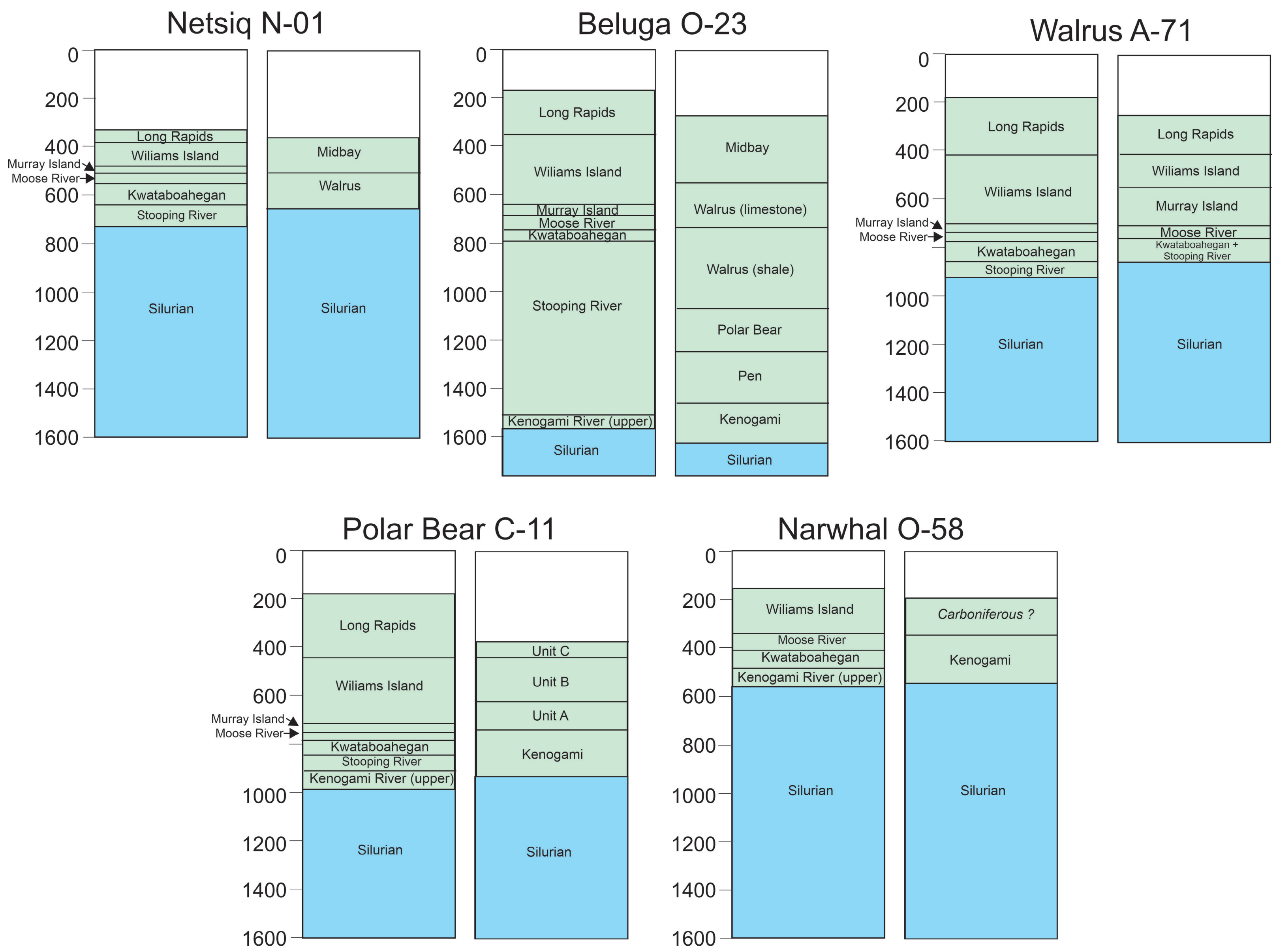


Figure 5. Comparison of original and updated stratigraphic nomenclature of the Devonian interval for the five offshore wells in Hudson Bay. Right column shows the original subdivision by Canterra Energy Limited (1986) for the Netsiq N-01 well, Canterra Energy Limited (1985) for the Beluga O-23 well, Aquitaine Company of Canada (1969) for the Walrus A-71 well; Société Nationale des Pétroles d'Aquitaine and Centre de Recherches de Pau (1975a) for the Polar Bear C-11 well; Société Nationale des Pétroles d'Aquitaine and Centre de Recherches de Pau (1975b) for the Narwhal South O-58 well. The current nomenclature from Sanford and Grant (1990), refined with well logs by Hu et al. (2011), is presented in the left column. Numbers to the left of the stratigraphic columns are measured depth in metres.

Table 2. Summary of the Devonian stratigraphy, offshore Hudson Bay Basin.

Unit	Age	Author	Thickness	Main lithology	Secondary lithology	Diagnostic	Reference
Kenogami River (upper member)	Pragian–Emsian	Dyer, 1930	25–114 m	Halite with interbedded dolostone	Shale		Hu et al., 2011; Hu and Dietrich, 2012
Stooping River	Emsian	Sanford et al., 1968	9–738 m	Thick succession of evaporite in Beluga O-23 well. Limestone and dolostone elsewhere	Shale		Hu et al., 2011; Hu and Dietrich, 2012
Kwataboahegan	Eifelian	Sanford et al., 1968	58–87 m	Bioclastic limestone and stromatoporoid bioherms	Dolostone. Shale and sandstone dominated in Narwhal O-58 well (east Hudson Bay)	Bindstone texture and bituminous	Hu et al., 2011; Hu and Dietrich, 2012
Moose River	Eifelian	Dyer, 1928	26–84 m	Halite and shale	Limestone		Hu et al., 2011; Hu and Dietrich, 2012
Murray Island	Eifelian	Sanford et al., 1968	3–8 m	Limestone and shale			Hu et al., 2011; Hu and Dietrich, 2012
Williams Island	Givetian	Kindle, 1924	128–293 m	Lower shale and limestone at top	Stromatoporoid bindstone		Hu et al., 2011; Hu and Dietrich, 2012
Long Rapids	Frasnian–Famennian	Savage and Van Tuyl, 1919	51–246 m	Dark to grey shale	Limestone		Hu et al., 2011; Hu and Dietrich, 2012

Table 3. Thickness (m) of the Devonian formations in the five wells drilled in the offshore domain of Hudson Bay.

Unit	Netsiq N-01	Beluga O-23	Walrus A-71	Polar Bear C-11	Narwhal O-58
Kenogami River (upper member)	N/A	25	N/A	114	70
Stooping River	9	738	12	9	Combined together 113
Kwataboahegan	87	58	77	70	
Moose River	41	84	43	40	26
Murray Island	3	8	6	5	N/A
Williams Island	128	289	293	267	155
Long Rapids	51	148	225	246	N/A

Data from Hu and Dietrich (2012)
N/A = not recognized

Geochemical tracers are used to correlate stratigraphic sections regionally or globally and can include major, minor, and trace elements and their multiples ratios, as well as stable and radiogenic isotopes (Brand, 1989; Pelechaty et al., 1996; Veizer et al., 1999; McArthur et al., 2001). The fundamental concept behind geochemical correlation is that the vertical distribution of these tracers can record, as sedimentary particles do, events in depositional basins, hence improving correlation of genetically linked sedimentary strata. In order to provide meaningful results, the specific tracer has to keep its original (depositional) signature without alteration from any postsedimentation rock/fluid interactions. The usefulness of chemostratigraphy depends on both the laboratory precision for the tracer analyzed and the scale (resolution) of sampling of the material being analyzed. A low sampling frequency could result in the nonrecognition of vertically short intervals of significant variations/events for correlation.

The Devonian succession of the Hudson Platform is dominated by carbonate rocks. Recently stable- ($\delta^{13}C_{VPDB}$ and $\delta^{18}O_{VPDB}$) and radiogenic- ($^{87}Sr/^{86}Sr$) isotope analyses have become routine for chemostratigraphic correlations of local as well as global depositional and biotic events recorded in carbonate rocks (Buggisch and Mann, 2004; Buggisch and Joachimski, 2006). However, carbonate rocks are prone to alteration during burial. The alteration of the original tracer signatures is dependent on the rock/fluid ratios and the magnitude (time) of the interactions during burial (Marshall, 1992; Criss, 1995). Water (more or less modified) is the most common diagenetic fluid; water is an infinite reservoir with respect to oxygen and a very limited reservoir of carbon and strontium. As such, rock/fluid interactions (dissolution/precipitation) will more significantly affect oxygen isotopes in carbonate units and, to a far lesser degree, carbon and strontium isotopes. Carbonate mud is the least reactive

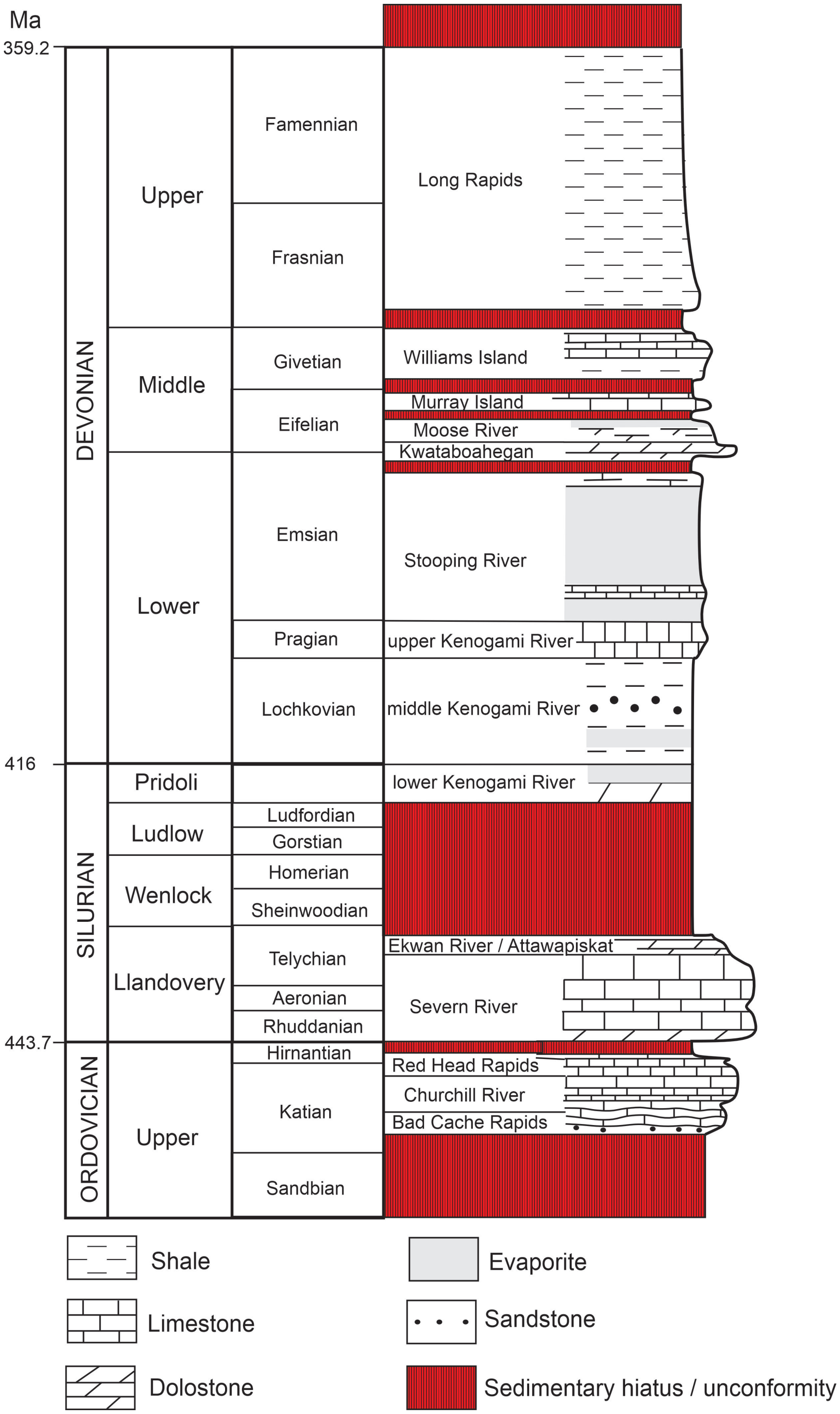


Figure 6. Stratigraphic section (2193 m) of Beluga O-23 well, showing the anomalous thick succession of evaporite rocks in the Stooping River Formation (*modified from* Hu and Dietrich, 2012; Lavoie et al., 2015). Thickness of Devonian units given in Table 3.

Table 4. Summary of the Devonian stratigraphy of the Hudson Bay Lowland in northeastern Manitoba and northern Ontario.

Unit	Age	Thickness (1) Pen No. 1 and Kaskattama	Thickness (2) Pen No. 1 and Kaskattama	Main lithology	Secondary lithology	Diagnostic	Reference
Kenogami River (upper member)	Lochkovian–Pragian	24–25 m	26–9 m	Fine-grained limestone, locally dolomitic	Argillaceous to silty dolostone and minor anhydrite		Nicolas and Armstrong, 2017; Armstrong et al., 2013; Sanford and Norris, 1975
Stooping River	Pragian–Emsian	83–57 m	86–78 m	Argillaceous dolostone at the top of Kaskattama well and dominant fine-grained bioclastic (crinoids, brachiopods, corals, stromatoporoids) limestone at the base. Vuggy porosity	Minor shale and dolomite	Some chert	Nicolas and Armstrong, 2017; Sanford and Norris, 1975
Kwataboahegan	Eifelian	38–39 m	43–41 m	Bioclastic (crinoids, brachiopods) fine-grained limestone, vuggy and locally highly bituminous (Pen No. 1 well)	Minor shale	Highly bituminous	Nicolas and Armstrong, 2017; Sanford and Norris, 1975
Moose River	Eifelian	53 m	41 m	Bioclastic (brachiopods) fine-grained limestone. Locally vuggy and interbedded vuggy dolostone	Rare chert fragments, dolomite and anhydrite		Sanford and Norris, 1975

In the thickness columns, Pen No. 1 well is presented first and Kaskattama Prov. No. 1, second. Thickness column (1) is from Nicolas and Armstrong (2017) and column (2) is from Sanford and Norris (1975).

component in the system, as its low porosity/permeability precludes significant fluid circulation and hence the potential for alteration of the original signal. For carbonate rocks, it is assumed that without megascopic or microscopic evidence for alteration, carbon stable isotopes ($\delta^{13}C_{VPDB}$) can be used for valuable correlations. The precise positions of samples (from either field sections or cores) must be known to achieve accurate and meaningful correlations. Well cuttings are a heterogeneous mix of particles from a relatively wide stratigraphic interval of 5 to 10 m, with potential contamination by cavings from higher up the section. Therefore, cuttings are considered unsuitable for chemostratigraphy.

Carbon stable isotopes have been analyzed from carbonate mudstone of six cores from the Hudson Platform, with a focus on the basal part of the Devonian succession (Kenogami River to Stooping River formations). These isotopic signatures are compared with global trends/profiles from well dated successions to try and delineate the position of the problematic Silurian–Devonian boundary. Crossplots of $\delta^{13}C_{VPDB}$ are shown in Figure 8. The vertical density of sampling is quite variable from one well to the other, reflecting the availability of carbonate mudstones in the stratal package. For the wells in the Moose River Basin (Fig. 8), samples were taken at the metric to submetric scale (Chow and Armstrong, 2015; Braun et al., 2016), whereas for wells in the Hudson Bay Lowland (Fig. 8), sampling frequency alternated between the submetric scale for some intervals to others where samples were metres to tens of metres apart (Armstrong et al., 2013; Nicolas, 2016b; Nicolas and Armstrong, 2017). This sampling strategy puts certain limits on the proposed correlations. Figure 8 is a simplified representation of the vertical carbon stable-isotope profiles. Oxygen stable-isotope ($\delta^{18}O_{VPDB}$) ratios were measured for all samples. Additionally, Sr radiogenic-isotope ($^{87}Sr/^{86}Sr$) ratios were collected from a small subset of samples. Neither the oxygen nor Sr ratios were used for correlation, but the data provide some information on the alteration conditions of the samples. In this study, $\delta^{13}C_{VPDB}$ ratios are reported in per mil relative to the Vienna Pee Dee Belemnite (VPDB) international standard.

Figure 8 reveals some interesting stratigraphic trends. The first one (trend 1, Fig. 8) is a significant positive isotopic excursion (+3 to +5 per mil) at the transition between the middle and upper members of the Kenogami River Formation. This positive excursion is traced in all wells that have intersected that section of the stratigraphy. A second, less obvious trend, consists of a minor negative isotopic excursion (−1 to −3 per mil) observed near the top of the upper member of the Kenogami River Formation in two wells from the Moose River Basin (trend 2, Fig. 8). This excursion is not observed in the Kaskattama Prov. No. 1 well, possibly due to the sampling mesh in that specific interval (40 m at the transition between the Stooping River and Kenogami River formations). Even with a submetric sampling mesh, this excursion is not observed in the Schlievert Lake well, casting some doubts on its significance. Another

Contents

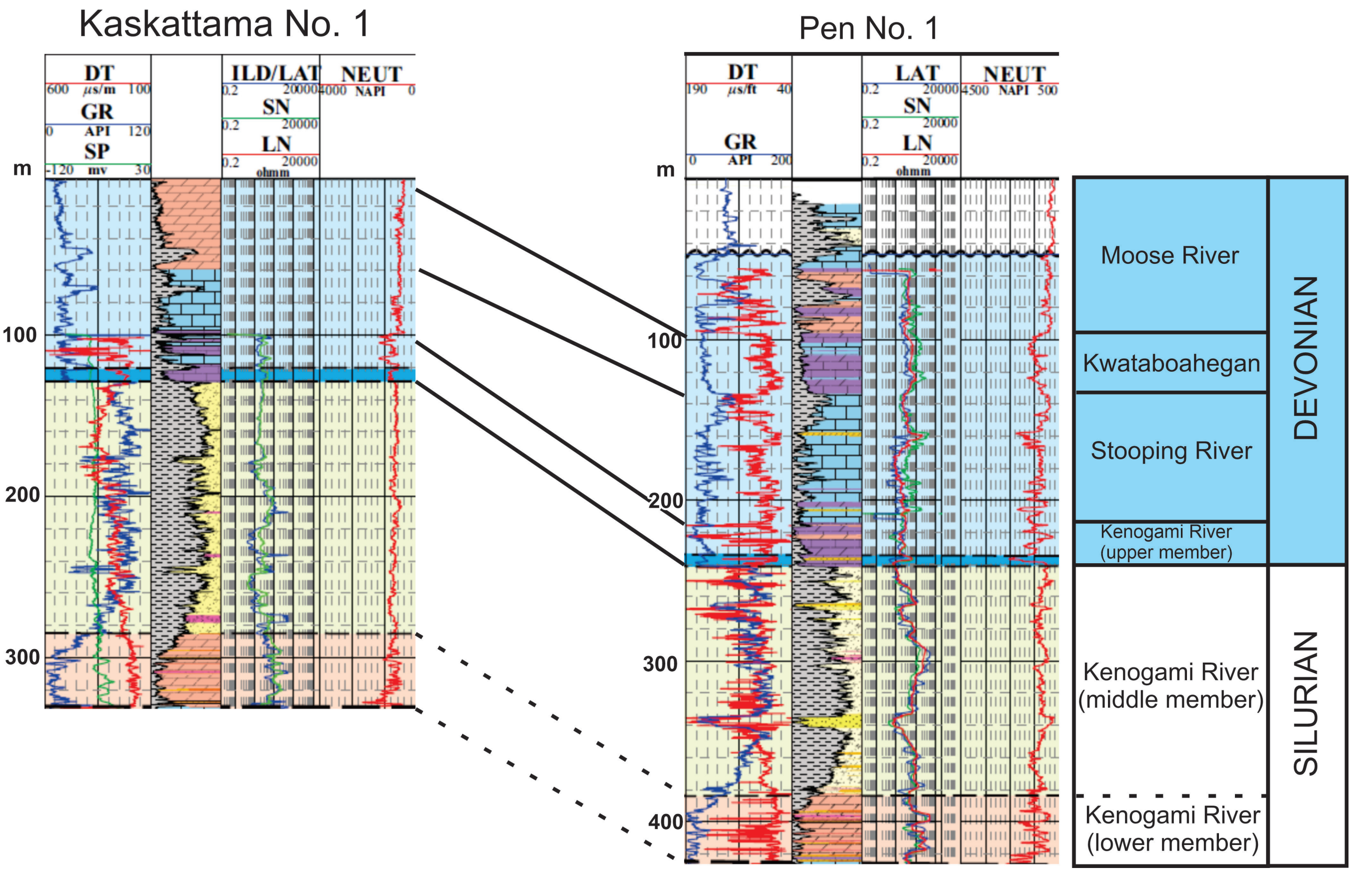


Figure 7. Log-based correlation between Kaskattama Prov. No. 1 and Pen No. 1 wells. Detailed log profiles and lithological interpretation are from K. Hu (pers. comm., 2015). Stratigraphic unit interpretation is from Nicolas and Armstrong (2017).

negative isotopic excursion (−2 to −4 per mil) is noted for the three wells that have intersected the middle section of the Stooping River Formation (trend 3, Fig. 8). There is insufficient carbon stable-isotope data gathered from post-Stooping River Formation strata to enable the recognition of local trends other than showing highly fluctuating ratios.

The discussion below supplements carbon stable-isotope correlations of Braun et al. (2016) with local and global interpretations of observed excursions.

DISCUSSION

Stratigraphic correlations of Devonian rocks in the three studied domains

The Devonian stratigraphy proposed by Sanford et al. (1968) from field sections in the Moose River Basin has been largely recognized in the offshore wells drilled in Hudson Bay. The upper part of the Devonian succession has been eroded in onshore sections of the Hudson Bay Lowland. The fence diagram in Figure 9 (*see* Fig. 1 for location) presents the stratigraphic correlation between the three studied areas (Pen No. 1 in northern Ontario, Walrus A-71 in the Hudson Bay Basin, and the Moose River Basin). The Moose River Basin section is a composite from field sections, where the maximum thickness of units is used for graphic representation. For the Hudson Bay Lowland, the Pen No. 1 well is used, as it contains a more complete succession compared to the Kaskattama Prov. No. 1 well. For the offshore Hudson Bay Basin, the Walrus A-71 well was chosen for its relative closeness to the onshore domain. Moreover, its stratigraphic succession is representative of the overall offshore succession and does not include the thick evaporite succession present in the Beluga O-23 well.

For the three areas shown on Figure 9, the basal section of the Devonian succession differs in the absence of the Kenogami River Formation in the Walrus A-71 well, which was drilled on a tectonic high (Hu et al., 2011). The clastic-dominated Sextant Formation is restricted to the eastern part of the Moose River Basin. The top of the stratigraphy in the Hudson Bay Lowland consists of the Moose River Formation, although thermal indicators from samples of that area indicate that a post-Middle Devonian succession was also deposited in the area but has been removed through postdepositional erosion (Lavoie et al., 2013, 2015). A thin interval assigned to the Murray Island Formation is present

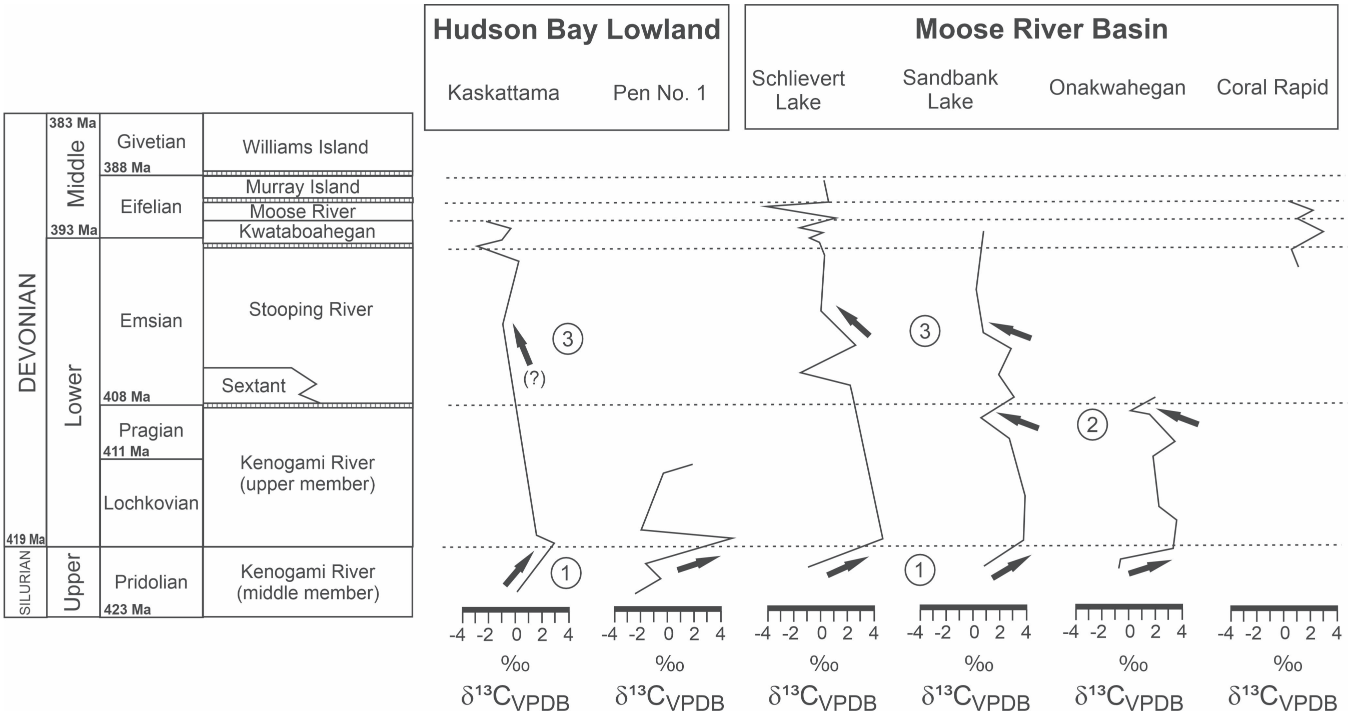


Figure 8. Vertical profiles of carbon stable isotopes ($\delta^{13}C_{VPDB}$) for sampled wells in the Hudson Bay Lowland and Moose River Basin. Details of the vertical profile (precise location of samples) are found in Armstrong et al. (2013), Chow and Armstrong (2015), Braun et al. (2016), Nicolas (2016b), and Nicolas and Armstrong (2017). Trends 1, 2, and 3 are discussed in the text; location of wells shown in Figure 1. Silurian–Devonian stratigraphy is *modified from* Braun et al. (2016) and Nicolas and Armstrong (2017). Time scale from Gradstein et al. (2012).

in the Moose River Basin and in the offshore. Additionally, the Middle to Upper Devonian Williams Island and Long Rapids formations are present in the Hudson Bay and Moose River basins. The thickness of the Williams Island Formation is substantial (greater than 120 m thick) in all offshore wells (Table 3). The Long Rapids Formation remaining post-erosion is present in all offshore wells, except the Narwhal O-58, and reaches thicknesses of over 200 m in the Walrus A-71 and Polar Bear C-11 wells (Table 3).

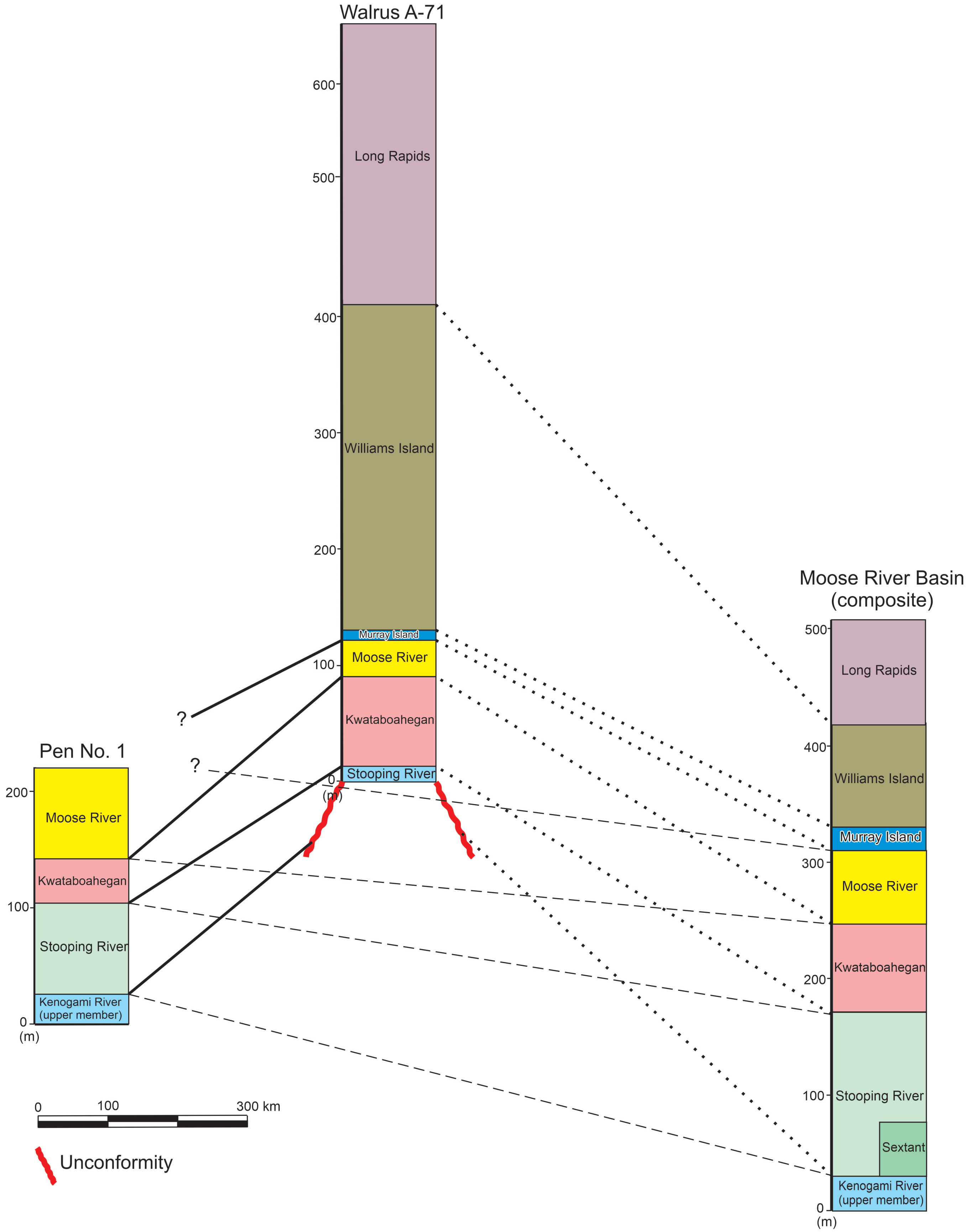
Kenogami River Formation

The Kenogami River Formation has been divided into three informal members (Sanford et al., 1968), with the lower and upper members composed of various carbonate and some evaporite units. The thicker middle member consists primarily of red and grey, fine- to coarse-grained clastic rocks and minor carbonate rocks. Some authors have proposed that the Silurian–Devonian boundary occurs in the middle member of the formation (Sanford and Norris, 1975; Norris et al., 1993). The base of the lower member is interpreted to conformably (Norford, 1971) or disconformably (Armstrong et al., 2013) overlie the lower Silurian (Llandovery) Attawapiskat and Ekwan formations. The upper member of the Kenogami River Formation is assumed to be disconformably overlain by the Emsian Stooping River Formation (Sanford and Norris, 1975).

Palynological studies of the upper member of the formation in the Moose River Basin exploration wells revealed the presence of spores of Lochkovian to Pragian (Gedinnian to Siegenian) age (McGregor et al., 1970; McGregor and Camfield, 1976). Assemblages of acritarchs, chitinozoans, and spores in the lower beds of the Stooping River Formation included Emsian forms (Robertson Research Canada Limited, 1986; Hu et al., 2011).

McGregor and Camfield (1976) reported the presence of two species of spores in the lowest beds of the middle member of the Kenogami River Formation. The interpretation of these nondiagnostic fauna suggests a potential (?) late Silurian or Early Devonian age. A more diverse spore assemblage was obtained near the top of the middle member. Based on limited insights into correlation between sections, McGregor and Camfield (1976) suggested that this assemblage indicates the late Silurian (Pridoli) or more likely Early

Figure 9. Stratigraphic correlation of the Devonian rock succession in the Hudson Bay Basin (Pen No. 1 and Walrus A-71 wells) and in the Moose River Basin. Location of the correlation fence diagram in Figure 1.


Walrus A-71
600
500
400
300
200
100
0
(m)
Long Rapids
Williams Island
Murray Island
Moose River
Kwataboahegan
Stooping River
?
?
Pen No. 1
200
100
0
(m)
Moose River
Kwataboahegan
Stooping River
Kenogami River (upper member)
Moose River Basin (composite)
500
400
300
200
100
0
(m)
Long Rapids
Williams Island
Murray Island
Moose River
Kwataboahegan
Stooping River
Sextant
Kenogami River (upper member)
0
100
300 km
Unconformity

Devonian (Lochkovian). McGregor and Camfield (1976) interpreted that the Silurian–Devonian boundary occurs within the middle member of the Kenogami River Formation. Subsequent attempts to accurately determine the position of this boundary using additional samples of diverse microfauna from new material collected both onshore and offshore were unsuccessful.

In the offshore domain, data from a carbonate interval assigned to the lower member of the Kenogami River Formation in the Polar Bear C-11 well are characterized by the presence of a mixed assemblage of late Silurian and Early Devonian chitinozoans (Société Nationale des Pétroles d'Aquitaine and Centre de Recherches de Pau, 1975a). Corroboration of this assignment is impossible, as the authors did not provide microphotographic plates (E. Asselin, pers. comm., 2019). Uyeno (T.T. Uyeno, unpub. GSC Paleontological Report 02-TTU-89, 1989) identified a Devonian conodont assemblage in the same interval. Lower Silurian chitinozoans were found 30 m below this assemblage in a dolostone succession assigned to the Attawapiskat Formation (Société Nationale des Pétroles d'Aquitaine and Centre de Recherches de Pau, 1975a), which suggests the potential for significant erosion or nondeposition of the upper Silurian succession. Zhang and Barnes (2007) and Barnes (2020) described lower Silurian (Telychian) conodonts in the Kenogami River Formation of the Narwhal O-58 well and proposed that the lower and middle members of the Kenogami River Formation are possibly of early Silurian age.

Based on biostratigraphy and seismic interpretation, researchers have proposed that a significant depositional hiatus occurred in the late Silurian to Early Devonian, at least locally in the offshore (Hu et al., 2011; Pinet et al., 2013), which is seemingly not observed in the onshore domain (Armstrong et al., 2013, 2018). The Kenogami River Formation is not recognized in well logs of the Netsiq N-01 and Walrus A-71 wells (Table 3), which were both drilled on structural highs in the central Hudson Bay Basin (Pinet et al., 2013). The unit was either eroded or not deposited on the paleotectonic highs during a global sea-level lowstand at the end of the Silurian (Ross and Ross, 1996). The Kenogami River Formation is present in the three other offshore wells in Hudson Bay that were not drilled on a structural high (Beluga O-23, Polar Bear C-11, and Narwhal O-58). In these wells, the formation consists of a 10 to 80 m thick lower carbonate unit overlain by a 20 to 90 m thick succession of evaporitic rocks, with intervening dolostone and minor shale. In this study, the offshore evaporite-dominated upper unit is considered the lateral equivalent of the red, nearshore to supratidal clastic succession and subtidal marine carbonate units that characterize the middle and upper members of the Kenogami River Formation in the onshore of the Hudson Bay Lowland and the Moose River Basin.

The carbon stable-isotope ($\delta^{13}C_{VPDB}$) chemostratigraphic profiles for the wells in the Hudson Bay Lowland and Moose River Basin all suggest a significant positive isotopic excursion at the transition between the middle and upper members of the formation (Fig. 8). This excursion has been interpreted by Braun et al. (2016) to represent the 'Klonk Event' (Saltzman, 2002; Buggisch and Joachimski, 2006), which marks the Silurian–Devonian boundary in many sedimentary basins worldwide (*see* 'Devonian $\delta^{13}C_{VPDB}$ chemostratigraphy' section). There are no unequivocal late-Silurian biostratigraphic data in the middle member; in fact, the interpretation by McGregor and Camfield (1976) is more suggestive of an Early Devonian age for the middle member. Given these uncertainties, the $\delta^{13}C_{VPDB}$ positive excursion at the transition between the middle and upper members could also be correlated with another positive excursion at the Lochkovian–Pragian transition (Buggisch and Joachimski, 2006), as discussed further below.

Sextant Formation

The Emsian Sextant Formation only occurs in the eastern sector of the Moose River Basin. It consists of a coarse-grained assemblage of red conglomerate and sandstone, with minor shale and siltstone. Fragments of plants are locally abundant, and the unit is interpreted as a nearshore facies laterally equivalent to the marine Stooping River Formation. Its unique location suggests the presence of an emerged land area in an easterly direction.

Stooping River Formation

The Emsian Stooping River Formation disconformably overlies the Kenogami River Formation and is, in turn, disconformably overlain by the Kwataboahegan Formation (Sanford et al., 1968). The Stooping River Formation is Emsian in age, based on spores (McGregor and Camfield, 1976) and chitinozoans (Hu et al., 2011). In the Moose River Basin, the Stooping River Formation is laterally equivalent to the Sextant Formation. For the onshore domain (Pen No. 1, Kaskattama Prov. No. 1, and field sections in the Moose River Basin), the formation consists of bioclastic limestone with crinoids, brachiopods, corals, and stromatoporoids, with minor dolostone, shale, and anhydrite beds. Two major lithofacies changes are observed in the offshore domain.

In the Beluga O-23 well, a thick (738 m; Fig. 5) succession of halite and anhydrite contains thin interbeds of limestone, dolostone, and sandstone. This occurrence of a thick evaporite succession was initially correlated with the Kenogami River Formation (Sanford and Grant, 1990) but is now assigned to the Stooping River Formation, based on the lithological character of the encasing units and presence of intervening limestones with Emsian microfauna (Robertson Research Canada Limited, 1986; Hu et al., 2011). The occurrence of a thick interval of interpreted deep-water evaporite units suggests the possible presence of a deeper marine, salinity-stratified subbasin.

In the Narwhal O-58 well, in the easternmost offshore sector of the preserved Devonian domain (Fig. 1), a 113 m thick succession of shale and sandstone is lumped together into the Stooping River and Kwataboahegan formations. This assignment is based on the typical rock units of the Kenogami River and Moose River formations below and above the clastic interval (Hu et al., 2011). Emsian microfauna have been recovered in the interval (Société Nationale des Pétroles d'Aquitaine and Centre de Recherches de Pau, 1975b). The eastward lateral transition from marine lithofacies to possible (yet to be confirmed) nearshore clastic units, as is the case of the Stooping River to Sextant formations in the eastern domain of the Moose River Basin, suggests that an emerged land area, the source of the coarse-grained clastic sediments, was also likely present in a general easterly direction during the Early Devonian.

Kwataboahegan Formation

The Middle Devonian (Eifelian) Kwataboahegan Formation is conformably overlain by the Moose River Formation. The unit is of a fairly consistent thickness over the area in which Devonian outcrops occur. The formation is characterized (except the Narwhal O-58 well as indicated above) by open-marine, thickly bedded bioclastic limestone units, with stacked, metre-thick stromatoporoid-coral biostromes and bioherms, which can locally be dolomitized and brecciated. The carbonate rocks are locally very vuggy and filled with coarse-grained calcite, celestite, and fluorite crystals that might indicate hydrothermal alteration. The formation is rich in bitumen, either as pore/vug filling or as millimetre- to centimetre-thick stringers impregnating the dolomitic facies (Chow and Armstrong, 2015). In the Walrus A-71 well, a 15 m interval near the top of the Kwataboahegan Formation has shown gas kicks and bitumen-impregnated dolostone. Based on log analyses, this interval is likely an oil reservoir (Hu and Dietrich, 2012; Lavoie et al., 2015).

Moose River Formation

The Eifelian Moose River Formation is disconformably overlain by the Murray Island Formation (Sanford et al., 1968). The formation consists of two major lithofacies assemblages: an alternating bioclastic limestone and vuggy dolostone with thick beds of gypsum, which dominates the onshore domain (Sanford et al., 1968; Nicolas and Armstrong, 2017); and a thick succession of evaporite units, with a few limestone and shale interbeds. The latter occurs near the top of the formation; this assemblage characterizes the offshore domain (Hu et al., 2011). The top of the unit, as exposed in the field, is marked by a thick interval of carbonate breccia, with a clastic mudstone matrix that most likely represents a collapse breccia caused by the dissolution of the evaporite units that dominate the onshore deposits (Sanford et al., 1968).

Murray Island Formation

The Eifelian Murray Island Formation is disconformably overlain by the Williams Island Formation (Sanford et al., 1968). The Murray Island Formation is the thinnest (3–20 m) of all units in the Hudson Bay Basin, including Ordovician and Silurian strata. The formation is almost entirely composed of brecciated and contorted bioclastic limestone and clastic mudstone beds, as attested by outcrops and cores. For onshore exposures, it seems that this relatively thin carbonate succession is affected by complex deformation from solution collapse after dissolution of the underlying evaporite units of the Moose River Formation.

Williams Island Formation

The Givetian Williams Island Formation is one of the thickest units of the Devonian succession (Tables 1, 3). For both the Moose River Basin and offshore Hudson Bay, the unit is unconformably overlain by the Long Rapids Formation (Sanford et al., 1968). Even if not formally divided into members, the formation is represented by a lower succession of varicoloured shale and mudstone, with minor bioclastic and muddy limestone interbeds; and an upper interval of bioclastic limestone, with local stromatoporoid boundstone and secondary interbedded shale. There are no sedimentological analyses of the clastic facies; hence, their depositional setting(s) is unknown. The presence of carbonate interbeds suggests a marine environment.

Long Rapids Formation

The Long Rapids Formation is the uppermost preserved Paleozoic unit in the study area. The age of the formation is assigned to the Frasnian–Famennian of the Late Devonian (Levman and Von Bitter, 2002). The measured thicknesses of the unit, from around 50 m onshore to up to 250 m offshore (except for Narwhal O-58 well), represent minimums, as erosion has removed an unknown number of strata. Based on various thermal indicators, Lavoie et al. (2013, 2015) have calculated that between 1.5 and 2.5 km of strata of unknown age has been eroded away.

In the offshore domain, the Long Rapids Formation is characterized by dark brown to grey shales, with minor limestone and dolostone interbeds. In the Moose River Basin, the formation is characterized by elevated organic-matter content, resulting in immature hydrocarbon source rock (Bezys and Risk, 1990).

DEVONIAN $\delta^{13}C_{VPDB}$ CHEMOSTRATIGRAPHY

Carbon stable-isotope ratios in carbonate (calcite and dolomite) mud is considered a good proxy of the $\delta^{13}C_{VPDB}$ value of ancient oceans. Over time, the marine carbon stable-isotope ratio has fluctuated as a result of complex Earth–hydrosphere–atmosphere interactions associated with the overall carbon cycle including, amongst others, variations in burial and storage of organic carbon, paleoproductivity, fluxes from surface weathering, and the release of organic carbon from various processes (Kump and Arthur, 1999). Global-scale variations of the carbon cycle should be recorded in the $\delta^{13}C_{VPDB}$ ratios of the carbonate sediments deposited during this time. If a specific event in the global-scale carbon cycle is somehow absent, then sampling intervals or local perturbations must be considered.

Marine biotic events and crises (extinctions) are commonly associated with an increase in the burial of organic carbon and a corresponding positive $\delta^{13}C_{VPDB}$ excursion (Talent et al., 1993; Caplan and Bustin, 1999; Kabanov, 2019). The Devonian is characterized by a number of significant biotic crises (i.e. the three important extinction events of the Late Devonian) and, consequently, also has one of the most dynamic global $\delta^{13}C_{VPDB}$ profiles (Fig. 10).

Figure 10 presents the overall variations of the $\delta^{13}C_{VPDB}$ ratios for the Lower and Middle Devonian, based on the work of Saltzman (2002); as well as Hess and Trop (2019) for the Pridoli to Lochkovian of North America; and Buggisch and Joachimski (2006) for the entire Devonian in Europe. No $\delta^{13}C_{VPDB}$ data are available for the Late Devonian of the Hudson Platform. The first positive carbon-isotope excursion in the global record is identified at the Silurian–Devonian transition (Pridoli to Lochkovian) and referred to as the 'Klonk Event' (Kaljo et al., 1996). The Klonk Event (+3 per mil in Europe) is associated with significant faunal turnover for conodonts (Barrick et al., 2018; Slavik and Hladil, 2020) and, to some extent, graptolites (Saltzman, 2002). In North America, the Klonk Event (average +5 per mil) is associated with a late Silurian sea-level lowstand (with local unconformities representative of subaerial exposures and peritidal carbonate sedimentation), followed by an Early Devonian sea-level rise correlated with an increase in organic productivity and nutrient input (Saltzman, 2002).

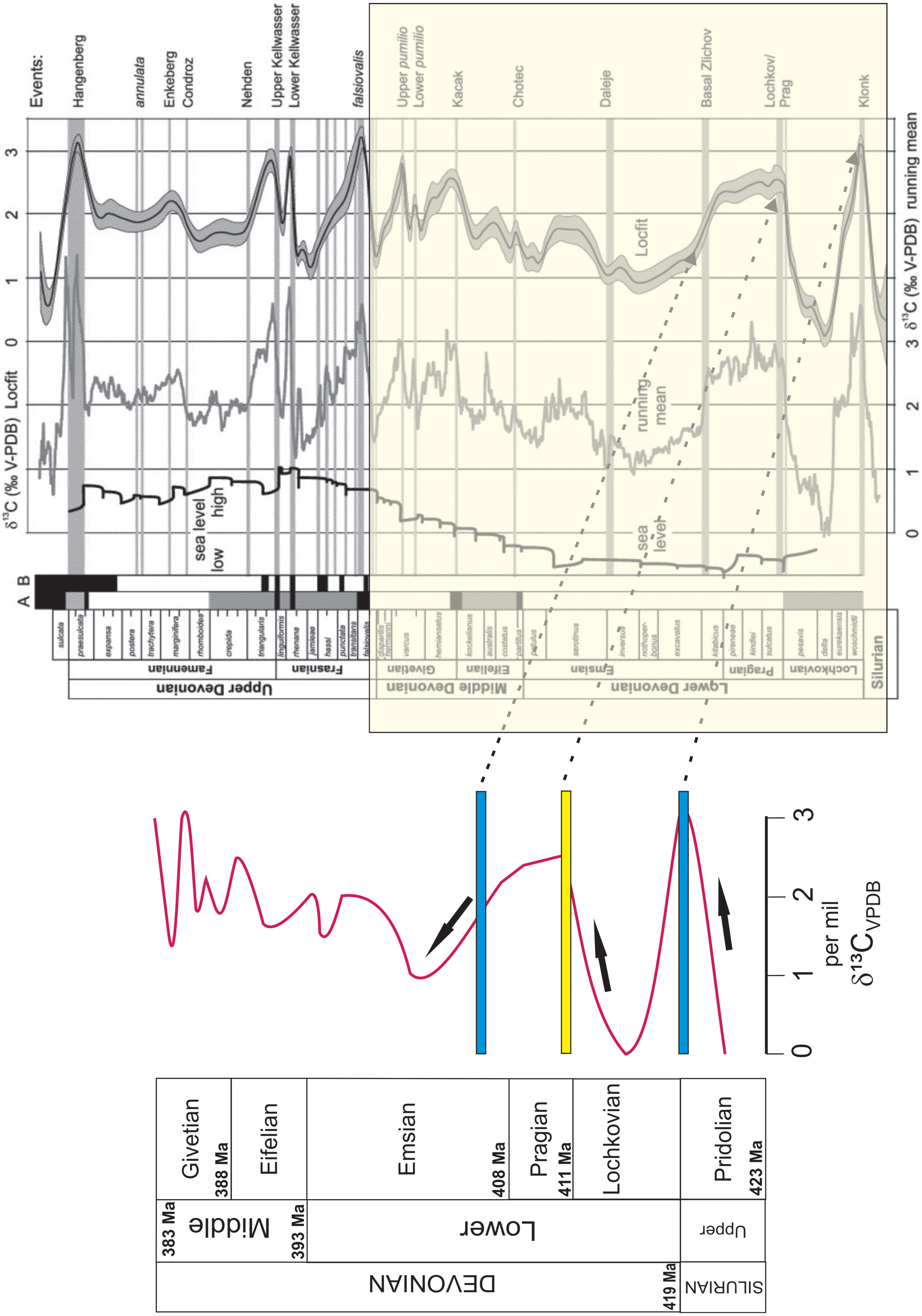
Braun et al. (2016) correlated the first positive $\delta^{13}C_{VPDB}$ excursion in the Moose River Basin to the Silurian–Devonian Klonk Event. A carbon-isotope excursion is also present at the same stratigraphic level (transition between the middle and upper members of the Kenogami River Formation) in wells of the Hudson Bay Lowland (Fig. 8). Given the lack of unequivocal biostratigraphic data in the middle member of the Kenogami River Formation and the Lochkovian–Pragian age of the upper member, this interpretation cannot be refuted. However, this implies that the significant global positive $\delta^{13}C_{VPDB}$ excursion at the Lochkovian–Pragian (Fig. 10) would not have been recorded in the Hudson Bay Lowland and Moose River basins (Fig. 8).

The isotopic excursion at the transition between the middle and upper members of the Kenogami River Formation could also be correlated with the global positive excursion (+3 per mil) at the Lochkovian–Pragian transition (Fig. 10; Buggisch and Joachimski, 2006). The latter assignment is also consistent with the presence of Lochkovian–Pragian spores in the upper member of the Kenogami River Formation (McGregor et al., 1970; McGregor and Camfield, 1976) and with the Emsian biostratigraphic data in the overlying Stooping River Formation. This second possibility reconciles the Silurian–Devonian chitinozoan assemblage in the lower member of the Kenogami River Formation in the Polar Bear C-11 well (Hu et al., 2011).

Armstrong et al. (2013) noted a significant +4 per mil $\delta^{13}C_{VPDB}$ excursion in a 10 m interval (393–383 m) at the transition between the lower and middle members of the Kenogami River Formation in the Pen No. 1 well. A similar +3 per mil $\delta^{13}C_{VPDB}$ excursion is noted for the correlative interval (310–285 m) in the Kaskattama Prov. No. 1 well (Nicolas and Armstrong, 2017). This lower to middle member transition in the Kenogami River Formation has not been intercepted in wells studied in the Moose River Basin, making it impossible to evaluate the regional extent of this isotopic excursion. This excursion could represent the Klonk Event; hence, the succession of thick continental to marginal marine strata of the middle member of the Kenogami River Formation would be Lochkovian in age.

Consistent with assignment of the isotope excursion in the Moose River Basin of Braun et al. (2016) to the Klonk Event is the possibility that the $\delta^{13}C_{VPDB}$ excursion in the lower to middle member transition in the Pen No. 1 and Kaskattama Prov. No. 1 wells records the Ludfordian (Ludlow, late Silurian) Lau carbon isotope excursion, or Lau Event (Fig. 11; Martma et al., 2005; Lehnert et al., 2007; Spiridonov et al., 2020). This carbon-isotope excursion is one of the largest shifts of the Phanerozoic, with magnitudes commonly in the range of +7 to +9 per mil (up to +12 per mil in Australia; Jeppsson et al., 2007). This excursion is also recorded in the late Silurian reefal facies of the Gaspé Peninsula (+6 per mil; Bourque et al., 2001) and in the western United States (Saltzman, 2001). The two alternatives given above are presented on Figure 11. However, until more precise biostratigraphic information, or other time-constrained data, for the middle member of the Kenogami River Formation becomes available, the issue remains unresolved.

Figure 10. Summary of carbon stable-isotope ($\delta^{13}C_{VPDB}$) variations for the Pridoli (late Silurian) to Givetian (Middle Devonian). Events discussed in text are outline by the coloured bars. The blue bars are assignments based on Braun et al. (2016), whereas the yellow bar (Lochkovian–Pragian) is an alternative of the Pridoli–Lochkovian interpretation for the middle to upper member transition in the Kenogami River Formation (*modified from* Buggisch and Joachimski, 2006). Time scale from Gradstein et al. (2012).


Events:
Hangenberg
annulata
Enkeberg
Condroz
Nehden
Upper Kellwasser
Lower Kellwasser
falsiovalis
Upper pumilio
Lower pumilio
Kacak
Chotec
Daleje
Basal Zlichov
Lochkov/Prag
Klonk
δ13C (‰ V-PDB) Locfit
δ13C (‰ V-PDB) running mean
Locfit
running mean
sea level
sea level low high
A B
Upper Devonian
Middle Devonian
Lower Devonian
Silurian
Famennian
Frasnian
Givetian
Eifelian
Emsian
Pragian
Lochkovian
DEVONIAN
SILURIAN
Middle
Lower
Upper
Givetian
Eifelian
Emsian
Pragian
Lochkovian
Pridolian
383 Ma
388 Ma
393 Ma
408 Ma
411 Ma
419 Ma
423 Ma
δ13CVPDB per mil
0
1
2
3

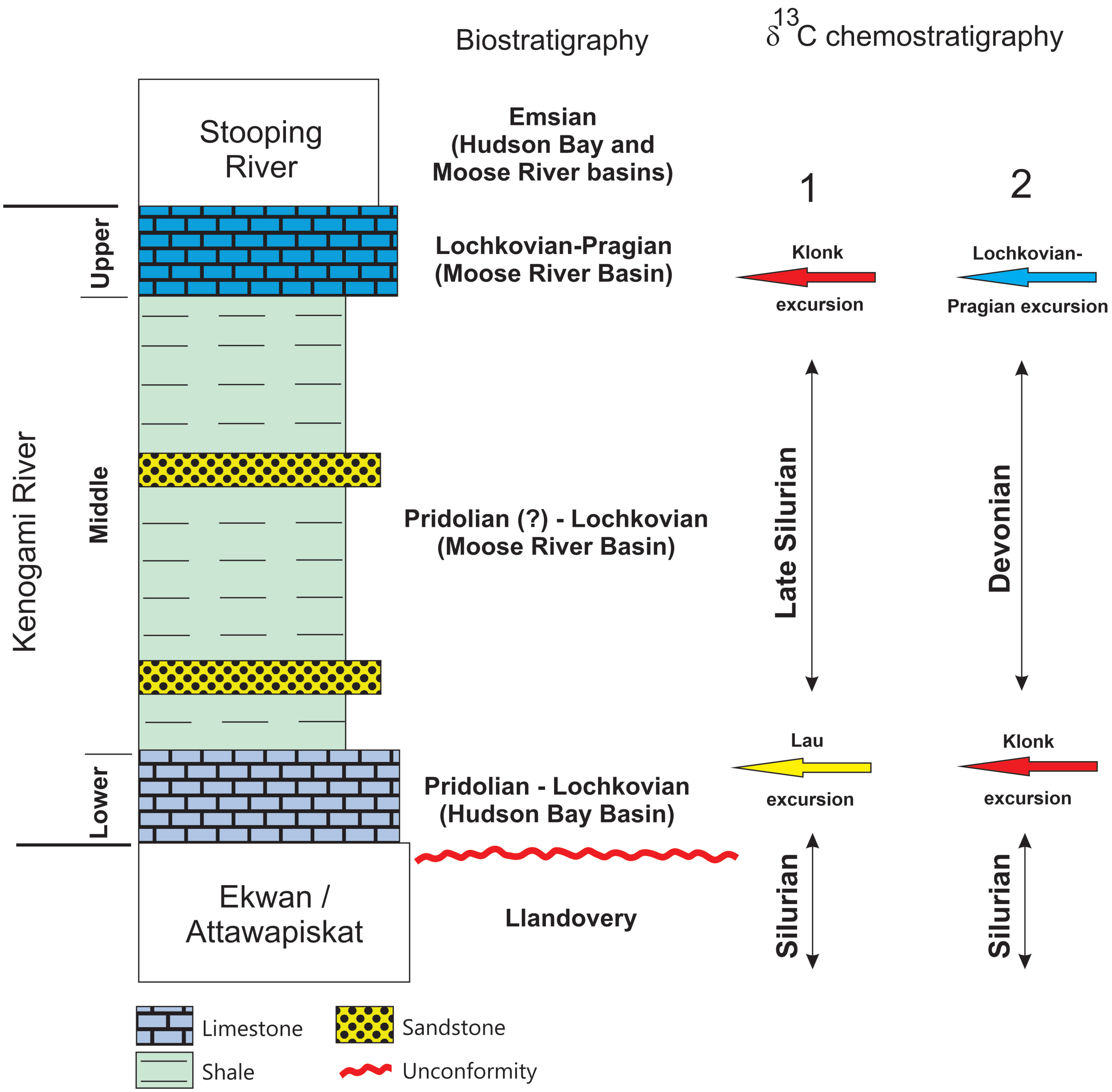


Figure 11. Two age scenarios for the Kenogami River Formation based on biostratigraphic and chemostratigraphic data. Biostratigraphic data for the Moose River Basin are from McGregor et al. (1970) and those for the Hudson Bay Basin, from Hu et al. (2011). Carbon stable-isotope ($\delta^{13}C_{VPDB}$) interpretation 1 is from Braun et al. (2016) and interpretation 2 is proposed in this study.

The second event for which a potential correlation exists between the global $\delta^{13}C_{VPDB}$ curve and the Hudson Platform data is the early Emsian 'Basal Zlichov' trend (Fig. 10; Buggisch and Mann, 2004). The Zlichov is a former stratigraphic stage of the upper Lower Devonian (now part of the Emsian) defined in the Czech Republic. Near the base of the actual Emsian, a sea-level rise is associated with a negative carbon stable-isotope shift, to which the 'Basal Zlichov' name has been given (Buggisch and Mann, 2004; Buggisch and Joachimski, 2006). This sea-level rise is reflected in a gradual change in the conodont fauna (Slavik and Hladil, 2020). In the Hudson Platform, the trend is associated with a transgressive transition from clastic and clastic-rich carbonate units (the lower Stooping River unit of Braun et al., 2016) to an open-marine carbonate facies in the Stooping River Formation (Braun et al., 2016).

COMPARISONS WITH OTHER INTRACRATONIC BASINS IN NORTH AMERICA

The concept of 'sequence' was defined in North America by Sloss (1963), who recognized thick (hundreds of metres) stratigraphic packages of sedimentary facies limited by significant tectonically driven unconformities. The definition and use of these unconformity-bounded stratigraphic packages have proven useful to correlate sedimentary-basin successions in North America. The Williston and Michigan intracratonic basins are neighbours of the Hudson Platform, and episodic intrabasin connections have been suggested (Sanford, 1987; Norris et al., 1993). A comparison of the Devonian stratigraphy of the Hudson Bay/Moose River (HBMR), Williston, and Michigan basins is presented in Figure 12. The Devonian belongs to the Kaskaskia Sequence (*sensu* Sloss, 1963) that encompasses rock units of Early–Middle Devonian to Middle Mississippian age. The magnitude of erosion at sequence boundaries is considered variable within and between basins. The unconformity at the base of the Kaskaskia Sequence, which separates it from the underlying Middle Ordovician–Early Devonian Tippecanoe Sequence, is present in these three basins. The unconformity between the Kaskaskia and Absaroka sequences is present in the Williston and Michigan basins but not preserved in the Hudson Bay Basin. In North American intracratonic basins, the Kaskaskia Sequence is characterized primarily by abundant shallow-water carbonate and evaporite units.

The duration of the basal unconformity of the Kaskaskia Sequence is highly variable in the HBMR basins (Fig. 11). In the offshore wells (Hu et al., 2011; Pinet et al., 2013), the basal unconformity is interpreted to cover parts of the upper (Pridoli–Ludlow) and lower (Wenlock) Silurian between the lower member of the Kenogami River and the top of the upper Llandoverian (lower Silurian) Attawapiskat/Ekwan formations. In the Hudson Bay Lowland, Armstrong et al. (2013) proposed a possible disconformable contact between the Llandoverian Attawapiskat Formation and the lower member of the Kenogami River Formation in the Pen No. 1 well based on a small negative $\delta^{13}C_{VPDB}$ anomaly of −1 to −2 per mil. More significantly, a major $\delta^{18}O_{VPDB}$ negative shift of −8 per mil is present in the uppermost 10 m of the Attawapiskat Formation. Such a negative shift of $\delta^{18}O_{VPDB}$ could indicate alteration of carbonate minerals in the presence of meteoric waters. The same interval in the Kaskattama Prov. No. 1 well does not show that $\delta^{18}O_{VPDB}$ negative shift (Nicolas and Armstrong, 2017), although that contact in the Comeault Prov. No. 1 well in Manitoba (Fig. 1) shows a negative trend of −7 per mil for the same interval (Nicolas and Armstrong, 2017). Even in the absence of clear evidence of subaerial exposure in the Hudson Bay Lowland wells, the local presence of a significant negative $\delta^{18}O_{VPDB}$ shift in the upper part of the Attawapiskat Formation most likely supports the occurrence of fresh meteoric-water circulation in the upper part of the formation and alteration of the primary $\delta^{18}O_{VPDB}$ marine signal. This is only possible if a nearby emerged meteoric-water recharge area is available.

As discussed previously, the current issue with respect to the precise age of the middle member of the Kenogami River Formation leaves the door open to the presence or absence of the continent-wide basal unconformity of the Kaskaskia Sequence in the HBMR basins. The base of the succession for the HBMR basins shown in Figure 12 offers the two alternatives for the interpretation of the Kenogami River Formation (Fig. 11; *see also* 'Devonian $\delta^{13}C_{VPDB}$ chemostratigraphy' section). The left side of the HBMR column is based on the Braun et al. (2016) interpretation of the Klonk Event (Silurian–Devonian) at the transition between the middle and upper members of the Kenogami River Formation; the right side relies on limited biostratigraphic data in the offshore section of the lower member of the Kenogami River Formation and the alternate interpretation for the position of the Klonk isotopic event at the transition between the lower and middle members of the Kenogami River Formation.

During the Emsian, sedimentation resumed in the Michigan Basin with deposition of basal sandstone transitioning to shallow-water marine limestone, and local sandstone and evaporite units. The lithofacies succession (Bois Blanc and Sylvania formations) in the Michigan Basin correlates with the assemblage of sandstone–limestone–evaporite units of the Sextant/Stooping River formations (Fig. 12).

The early Middle Devonian (Eifelian) carbonate and local evaporite succession in the HBMR (Kwataboahegan, Moose River, and Murray Island formations) is correlative with the similar alternating limestone and evaporite units of the Amherstburg, Lucas, and Dundee formations of the Michigan Basin (Fig. 12). The development of metazoan boundstones in the Kwataboahegan Formation is roughly coeval with those found in the upper Emsian–lowermost Eifelian Amherstburg Formation (Fig. 12; Formosa Reef Limestone of Uyeno et al., 1982).

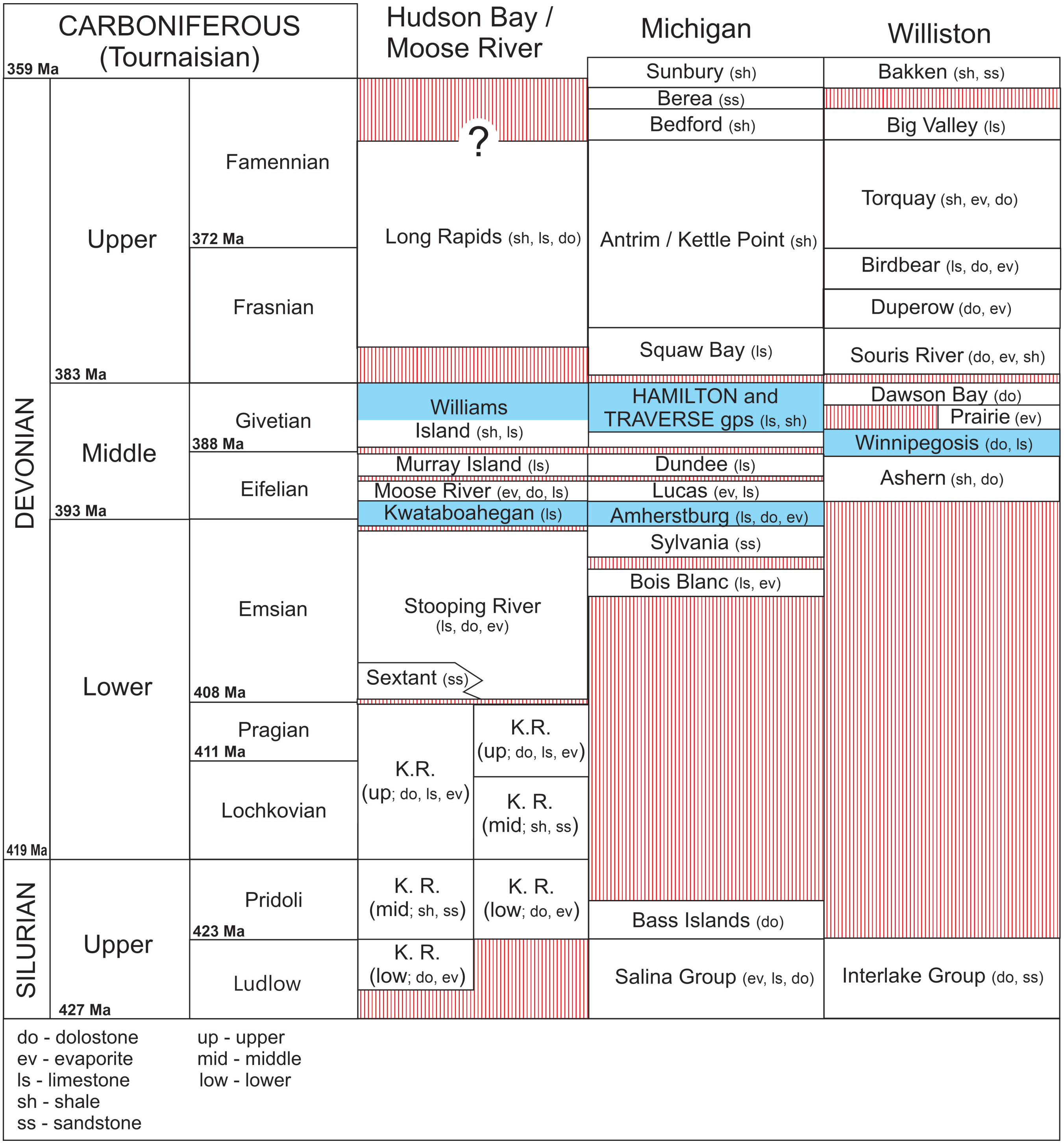


Figure 12. Comparative Devonian stratigraphic frameworks for the Hudson Bay/Moose River (HBMR) basins, the Michigan Basin (Sanford et al., 1993; Swezey, 2008; Carter et al., 2019), and the Williston Basin (Stott, 1991; Anna et al., 2013). All units at formation level, except for the Hamilton and Traverse groups. The two possible interpretations of the Kenogami River Formation (K.R.) stratigraphy are shown at the base of the HBMR section. Units with blue background contain metazoan reefs. Vertical, red-hatched pattern indicates an unconformity and/or disconformity. Time scale from Gradstein et al. (2012).

In the Williston Basin, the deposition of the Kaskaskia Sequence started with a Middle Devonian (Eifelian) shale unit (Ashern Formation; Fig. 12) and continued with a succession of carbonate and evaporite units of the Givetian Winnipegosis Formation. Metazoan bioclastic banks of the Winnipegosis Formation are roughly coeval with the boundstone facies of the upper part of the Williams Island Formation in the HBMR basins (Fig. 12). The Givetian of the Michigan Basin consists of a basal shale overlain by mixed carbonate and shale units of the Hamilton Group in Ontario. A similar succession, with the addition of metazoan reefs, occurs in the southern reach of the Michigan Basin in Michigan State (the Traverse Group). The latter is very similar to the Williams Island Formation of the HBMR basins (Fig. 12).

An unconformity separates the Long Rapids Formation from the Williams Island Formation in the HBMR basins; the time value of this hiatus is unknown. The Long Rapids Formation is characterized by organic-rich black shale in the Moose River Basin. To the immediate south, the Antrim Formation in the Michigan Basin (the Kettle Point Formation in Ontario; Bingham-Koslowski et al., 2016) is also an Upper Devonian organic-rich shale. However, in the offshore Hudson Bay Basin, the Long Rapids Formation is primarily a dark grey and red shale, with a few sandstone and dolostone interbeds devoid of well-log evidence of organic-rich intervals (Hu et al., 2011). In latest Devonian time, the succession in the Michigan Basin is largely dominated by clastic units (shale, sandstone), including the latest Devonian–Tournaisian Sunbury Formation black shales (Fig. 12). However, in the Williston Basin to the southwest, cyclic carbonate and evaporite units, with minor shale and thin beds of organic-rich argillaceous limestone, characterize the Frasnian–Famennian interval; organic-rich shales of the Bakken Formation were deposited during the latest Devonian (Famennian) to earliest Carboniferous (Tournaisian) (Fig. 12; Anna et al., 2013).

There are significant similitudes in the stratigraphic succession for the three major basins with an overall carbonate- and evaporite-dominated succession. The HBMR and Michigan basins share two coeval episodes of coral- and stromatoporoid-dominated reef/boundstone development: the first one at the Emsian–Eifelian transition and a second one in the Givetian. Given the duration of the basal unconformity for the Williston Basin, only one episode of metazoan-rich strata is known in that basin (early Givetian). Even if corals and stromatoporoids are ubiquitous in the Givetian Winnipegosis Formation, the structures are not described as rigid boundstone but rather as somewhat loose hydrodynamic accumulations of metazoans (Jones, 1965).

PETROLEUM SYSTEMS

Devonian petroleum systems are amongst the most prolific globally, for both conventional and unconventional resources. In the Western Canada Sedimentary Basin, the Frasnian Duvernay Formation is a major source rock (Creaney et al., 1994) and is currently under development as an unconventional reservoir (Preston et al., 2016), whereas the coeval and conventional target reefs in the Leduc Formation are host to major hydrocarbon reserves (Switzer et al., 1994). In the intracratonic Williston and Michigan basins, recent developments are focused on unconventional plays such as the prolific Famennian–Tournaisian Bakken Formation (Anna, 2013) and the Frasnian Antrim Formation (Swezey et al., 2015), respectively.

Source rocks and maturation

In the Williston Basin, other than the Bakken Formation, Devonian source rocks are present in the Givetian Winnipegosis and Frasnian Duperow formations (Anna et al., 2013), whereas in the Michigan Basin, other than the Antrim/Kettle Point formations, only some black shale intervals are found in the Frasnian Squaw Bay Formation (Swezey et al., 2015). All formations listed above are mature (oil to gas windows) and have generated hydrocarbons (Anna, 2013; Swezey et al., 2015).

In the Moose River Basin, Bezys and Risk (1990) have documented source-rock potential in the Frasnian–Famennian Long Rapids Formation. Zhang and Hu (2013) failed to recognize any potential for that formation in the Beluga O-23 well of the Hudson Bay Basin but have identified five narrow zones with source-rock potential in the upper part of the Stooping River up to the lower part of the Williams Island formations from gamma-ray logs and Rock-Eval analyses. In all cases, onshore and offshore shale intervals with source-rock potential are immature (Lavoie et al., 2013, 2015).

Reservoirs

For both the Williston and Michigan basins, production-proven Devonian conventional reservoirs are hosted by carbonate rocks and include porous reefs and dolomitized carbonate facies. These include the Givetian Winnipegosis and Frasnian Duperow formations in the Williston Basin (Anna et al., 2013); and the Eifelian Amherstburg, Lucas, and Dundee formations as well as the Givetian Traverse Group in the Michigan Basin (Swezey et al., 2015; Carter et al., 2019).

In the Moose River Basin, outcrops of porous reefs and dolomitized units abound in the Kwataboahegan and Williams Island formations. Detailed petrophysical analyses of logs from offshore wells in the Hudson Bay Basin confirm the porous nature of these two formations, and, from calculated water saturation in pore space, a significant number of intervals with hydrocarbon-charged porosity are documented; the thickest interval (15 m) occurs in the Kwataboahegan Formation in the Walrus A-71 well (Hu and Dietrich, 2012). Hydrocarbons in these carbonate rocks are not sourced from the immature Devonian shales but originate from the well documented Upper Ordovician source rocks (Lavoie et al., 2015).

CONCLUSIONS

The Hudson Bay Basin and adjacent satellite basins (Moose River and Foxe basins) are composed of lower to middle Paleozoic mixed carbonate- and evaporite-dominated successions. As part of both phases of the GEM program, litho-, bio-, and chemostratigraphic data were acquired for regional correlations from exploration wells and outcrops.

The Devonian stratigraphic succession in the type area (Moose River Basin) is recognized and used at the regional scale for correlation; some units are only locally present (e.g. Sextant Formation), whereas others have significant facies variations (e.g. Kenogami River, Stooping River, and Kwatabohegan formations). The restriction of the Lower Devonian coarse-grained clastic rocks within the eastern domain of the study area indicates they are derived from easterly located lands. Although several formations have a significant evaporite content, the Stooping River Formation stands out with the thickest succession of anhydrite and halite, indicating a local salinity-stratified deep subbasin.

The $\delta^{13}C_{VPDB}$ chemostratigraphic study of carbonate mudstone helped the correlation of Lower and Middle Devonian units from the Moose River Basin to the Hudson Bay Lowland strata. The trends in $\delta^{13}C_{VPDB}$ ratios for the study interval suggest two significant carbon-isotope excursions, with the first positive excursion occurring at the transition between the middle and upper members of the Kenogami River Formation and a negative shift in the middle section of the Stooping River Formation. In previous work, the positive isotope excursion in the Kenogami River Formation for both the Hudson Bay Lowland and Moose River Basin has been considered to correlate with the Klonk isotopic event that globally marks the Silurian–Devonian boundary. The isotopic excursion occurs at the top of the largely unfossiliferous middle member of the Kenogami River Formation. However, the positive isotopic excursion could also be correlated with another significant global positive excursion at the Lochkovian–Pragian boundary. Such an assignment is not in conflict with biostratigraphic data from the immediate overlying unit (Emsian Stooping River Formation) and is consistent with the presence of Lochkovian–Pragian spores in the upper member of the Kenogami River Formation in the Moose River Basin. From this hypothesis, the Silurian–Devonian Klonk Event could be observed in the +3 to +4 per mil $\delta^{13}C_{VPDB}$ excursion recorded at the transition between the lower and middle members of the Kenogami River Formation in the Hudson Bay Lowland wells. This part of the Kenogami River Formation has not been studied in the Moose River Basin.

The Devonian succession of the Hudson Bay and Moose River basins is assigned to the North American Kaskaskia Sequence of Sloss (1963). The succession shares significant similitudes with the Williston and Michigan intracratonic basins that were at times likely connected. Carbonate and evaporite rocks dominate the stratigraphy in the three basins. Two major episodes of carbonate buildups are recorded in these basins, one at the Emsian–Eifelian transition and a second in the Givetian. For both episodes, corals and stromatoporoids are the dominant boundstone builders.

The Devonian succession of the Hudson Bay and Moose River basins encompasses a significant number of potential reservoir units consisting of porous metazoan reefs and dolomitized facies primarily present in the Kwataboahegan and Williams Island formations. Any hydrocarbon charge in these reservoirs is most likely derived from the Upper Ordovician source rocks, as known Devonian black shales in the area are immature.

ACKNOWLEDGMENTS

The authors sincerely thank all the GSC colleagues, provincial geologists, faculty members, and students who were involved in the mapping, stratigraphy, and geochemical characterization of the Devonian succession in the Hudson Platform over the 2008–2018 GEM-1 and -2 programs. Special thanks to Derek Armstrong (Ontario Geological Survey) and Michelle Nicolas (Manitoba Geological Survey) for their rigorous outcrop and core descriptions over the lifespan of the project. Kezhen Hu (GSC-Calgary) provided the critical log analyses for the Hudson Bay Basin wells, for which no core material was available, as well as for the Hudson Bay Lowland wells. Geological Survey of Canada colleagues Esther Asselin, Sofie Gouwy, and Sandy McCraken provided significant new biostratigraphic data for correlation of the Devonian rock successions. Special thanks to Marc Luzincourt (Delta Lab, GSC-Quebec) for his patient and diligent carbon-isotope work for the establishment of the chemostratigraphic framework for the Devonian interval in Manitoba. Finally, the authors are grateful to Nikole Bingham-Koslowski and Pavel Kabanov for much appreciated and detailed critical reviews of this report.

REFERENCES

Anna, L.O., 2013. Geologic assessment of undiscovered oil and gas in the Williston Basin Province, Montana, North Dakota, and South Dakota; Chapter 3 *in* Assessment of undiscovered oil and gas resources of the Williston Basin Province of North Dakota, Montana, and South Dakota, 2010 (ver. 1.1, November 2013), by U.S. Geological Survey Williston Basin Province Assessment Team; U.S. Geological Survey, Digital Data Series 69-W, 71 p.

Anna, L.O., Pollastro, R., and Gaswirth, S.B., 2013. Williston Basin Province — Stratigraphic and structural framework to a geologic assessment of undiscovered oil and gas resources; Chapter 2 *in* Assessment of undiscovered oil and gas resources of the Williston Basin Province of North Dakota, Montana, and South Dakota, 2010 (ver. 1.1, November 2013), by U.S. Geological Survey Williston Basin Province Assessment Team; U.S. Geological Survey, Digital Data Series 69-W, 17 p.

Aquitaine Company of Canada, 1969. Well report Walrus A-71; Canada Energy Regulator, 98 p. <https://www.cer-rec.gc.ca/en/about/library/north-offshore-data.html> [accessed May 5, 2021]

Armstrong, D.K., McCracken, A.D., Asselin, E., and Brunton, F.R., 2013. The Hudson Platform Project: stratigraphy of the Aquitaine Pen No. 1 core; *in* Summary of field work and other activities 2013; Ontario Geological Survey, Open File Report 6290, p. 34-1–34-21.

Armstrong, D.K., Nicolas, M.P.B., Hahn, K.E., and Lavoie, D., 2018. Stratigraphic synthesis of the Hudson Platform in Manitoba, Ontario, and Nunavut: Ordovician–Silurian; Geological Survey of Canada, Open File 8378, 48 p. https://doi.org/10.4095/308418

Barnes, C.R., 2020. Impacts of climate-ocean-tectonic changes on early Paleozoic conodont ecology and evolution evidenced by the Canadian part of Laurentia; Palaeogeography, Palaeoclimatology, Palaeoecology, v. 549, art. no. 109092, 22 p. https://doi.org/10.1016/j.palaeo.2019.02.018

Barrick, J.E., Kleffner, M.A., and Sungren, J.R., 2018. Conodont faunas across the Silurian–Devonian boundary and the Klonk isotope event in western Tennessee, and the appearance of endemic earliest Devonian *Icriodus* species; 2018 GSA North-Central Section, 52nd Annual Meeting, Geological Society of America, Ames, Iowa, April 16–17, 2018, Abstracts with Programs, v. 50, no. 4, paper 6-3.

Bell, J.M., 1904. Economic resources of the Moose River Basin; Ontario Bureau of Mines, no. XIII, Part 1, p. 134–179.

Bell, R., 1885a. Observations on the geology, mineralogy, zoology and botany of the Labrador Coast, Hudson's Strait and Bay, made in 1885; part DD *in* Geological and Natural History Survey of Canada, Annual Report v. 1 (1885), 32 p. https://doi.org/10.4095/297069

Bell, R., 1885b. Report of the second Hudson Bay's expedition under the command of Lieutenant A.R. Gordon, R.N., 1884; Canada Department of Marine Fisheries, 40 p.

Bezys, R.K., 1989. The Onakawana B drillhole (OGS 85D), District of Cochrane: report on drilling operations and preliminary geological findings; Ontario Geological Survey, Open File Report 5708, 94 p.

Bezys, R.K. and Risk, M.J., 1990. The Long Rapids Formation: an Upper Devonian black shale in the Moose River Basin, northern Ontario; Canadian Journal of Earth Sciences, v. 27, p. 291–305. https://doi.org/10.1139/e90-028

Bingham-Koslowski, N., Tsujita, C., Jin, J., and Azmy, K., 2016. Widespread Late Devonian marine anoxia in eastern North America: a case study of the Kettle Point Formation black shale, southwestern Ontario; Canadian Journal of Earth Sciences, v. 53, p. 837–855. https://doi.org/10.1139/cjes-2015-0227

Bourque, P.-A., Savard, M.M., Chi, G., and Dansereau, P., 2001. Diagenesis and porosity evolution of the upper Silurian–lowermost Devonian West Point reef limestone, eastern Gaspé Belt, Québec Appalachians; Bulletin of Canadian Petroleum Geology, v. 49, p. 299–326. https://doi.org/10.2113/49.2.299

Brand, U., 1989. Global climatic changes during the Devonian–Mississippian: stable isotope biogeochemistry of brachiopods; Palaeogeography, Palaeoclimatology, Palaeoecology, v. 75, p. 311–329. https://doi.org/10.1016/0031-0182(89)90192-2

Braun, M., Armstrong, D.K., Chow, N., and Gouwy, S.A., 2016. Preliminary lithostratigraphy, chemostratigraphy and lithofacies analysis of the Devonian succession, Moose River Basin, northern Ontario; *in* Summary of field work and other activities, 2016; Ontario Geological Survey, Open File Report 6323, p. 27-1–27-13.

Buggisch, W. and Joachimski, M.M., 2006. Carbon isotope stratigraphy of the Devonian of central and southern Europe; Palaeogeography, Palaeoclimatology, Palaeoecology, v. 240, p. 68–88. https://doi.org/10.1016/j.palaeo.2006.03.046

Buggisch, W. and Mann, U., 2004. Carbon isotope stratigraphy of Lochkovian to Eifelian limestones from the Devonian of central and southern Europe; International Journal of Earth Sciences, v. 93, p. 521–541. https://doi.org/10.1007/s00531-004-0407-6

Burgess, P.M., 2019. Phanerozoic evolution of the sedimentary cover of the North American Craton; *in* The sedimentary basins of the United States and Canada, (ed.) A.D. Miall; Elsevier, p. 39–75 (second edition).

Canterra Energy Ltd., 1985. Trillium SOQUIP Onexco et al. Beluga O-23 — final well summary; Canada Energy Regulator, 124 p. <https://www.cer-rec.gc.ca/en/about/library/north-offshore-data.html> [accessed May 5, 2021]

Canterra Energy Ltd., 1986. ICG Sogepet et al. Netsiq N-01 — final well summary; Canada Energy Regulator, 145 p. <https://www.cer-rec.gc.ca/en/about/library/north-offshore-data.html> [accessed May 5, 2021]

Caplan, M.L. and Bustin, R.M., 1999. Devonian–Carboniferous Hangenberg mass extinction event, widespread organic-rich mudrock and anoxia: causes and consequences; Palaeogeography, Palaeoclimatology, Palaeoecology, v. 148, p. 187–207. https://doi.org/10.1016/S0031-0182(98)00218-1

Carter, T.R., Brunton, F.R., Clark, J.K., Fortner, L., Freckelton, C., Logan, C.E., Russell, H.A.J., Somers, M., Sutherland, L., and Yeung, K., 2019. A three-dimensional geological model of the Paleozoic bedrock of southern Ontario; Geological Survey of Canada, Open File 8618, 45 p. https://doi.org/10.4095/315045

Chow, N. and Armstrong, D.K., 2015. Preliminary lithostratigraphy and chemostratigraphy of the Devonian Kwataboahegan Formation, Moose River Basin, northern Ontario; *in* Summary of field work and other activities, 2015; Ontario Geological Survey, Open File Report 6313, p. 33-1–33-12.

Creaney, S., Allan, J., Cole, K.S., Fowler, M.G., Brooks, P.W., Osadetz, K.G., Macqueen, R.W., Snowdon, L.R., and Riedeger, C.L., 1994. Petroleum generation and migration in the Western Canadian Sedimentary Basin; Chapter 31 *in* Geological atlas of the Western Canada Sedimentary Basin, (comp.) G.D. Mossop and I. Shetsen; Canadian Society of Petroleum Geologists and Alberta Research Council, p. 455–468. <http://ags.aer.ca/publications/chapter-31-petroleum-generation-and-migration> [accessed May 5, 2021]

Criss, R.E., 1995. Stable isotope distribution: variations from temperature, organic and water-rock interactions; *in* Global Earth physics: a handbook of physical constants, (ed.) T.J. Ahrens; American Geophysical Union, AGU Reference Shelf, v. 1, p. 292–307. https://doi.org/10.1029/RF001p0292

Cumming, L.M., 1975. Ordovician strata of the Hudson Bay Lowland; Geological Survey of Canada, Paper 74-28, 93 p. https://doi.org/10.4095/102500

Dowling, D.B., 1901. The west side of James Bay; *in* Summary report on the operations of the Geological Survey (1901), Part A; Geological Survey of Canada, Annual Report, v. 14, p. 109–117. https://doi.org/10.4095/297202

Dyer, W.S., 1928. Geology and economic deposits of the Moose River Basin; Ontario Department of Mines, v. XXXVII, pt. 6, p. 1–69.

Dyer, W.S., 1930. Paleozoic geology of the Albany River and certain of its tributaries; Ontario Department of Mines, v. XXXVIII, p. 47–60.

Eaton, D.W. and Darbyshire, F., 2010. Lithospheric architecture and tectonic evolution of the Hudson Bay region; Tectonophysics, v. 480, p. 1–22. https://doi.org/10.1016/j.tecto.2009.09.006

Fritz, M.A., Lemon, R.R.H., and Norris, A.W., 1957. Stratigraphy and palaeontology of the Williams Island Formation; Geological Association of Canada, Proceedings, v. 9, p. 21–47.

Galloway, J.M., Armstrong, D.A., and Lavoie, D., 2012. Palynology of the INCO-Winisk #49204 core (54°18′30″N, 87°02′30″W, NTS 43L/6); Geological Survey of Canada, Open File 7065, 51 p. https://doi.org/10.4095/290985

Gao, C., McAndrews, J.H., Wang, X., Menzies, J., Turton, C.L., Wood, B.D., Pei, J., and Kodors, C., 2012. Glaciation of North America in the James Bay lowland, Canada, 3.5 Ma; Geology, v. 40, p. 975–978. https://doi.org/10.1130/G33092.1

Gradstein, F.M., Ogg, J.G., Schmitz, M., and Ogg, G. (ed.), 2012. The geologic time scale 2012; Elsevier, Amsterdam, 2 volumes, 1144 p. (first edition). https://doi.org/10.1016/C2011-1-08249-8

Hamblin, A.P., 2008. Hydrocarbon potential of the Paleozoic succession of Hudson Bay Bay/James Bay: preliminary conceptual synthesis of background data; Geological Survey of Canada, Open File 5731, 12 p. https://doi.org/10.4095/225183

Hanna, M.C., Lister, C.J., Kublik, K., King, H.M., Kung, L.E., McCarthy, W.M., McDannell, K.T., and Jassim, Y., 2018. Qualitative petroleum resource assessment of western Hudson Bay, Foxe Channel, and Repulse Bay, Manitoba, Nunavut, Ontario, and Quebec; Geological Survey of Canada, Open File 8434, 31 p. https://doi.org/10.4095/311260

Hanna, M.C., King, H.M., and Lyster, C.J., 2019. Qualitative petroleum resource assessment of eastern Hudson Bay and James Bay, Nunavut, Ontario and Quebec; Geological Survey of Canada, Open File 8344, 21 p. (revised edition). https://doi.org/10.4095/313398

Hess, A.V. and Trop, J.M., 2019. Sedimentology and carbon isotope ($\delta^{13}C$) stratigraphy of Silurian–Devonian boundary interval strata, Appalachian Basin (Pennsylvania, USA); Palaios, v. 34, p. 405–423. https://doi.org/10.2110/palo.2019.020

Hogg, N., Satterly, J., and Wilson, A.E., 1953. Drilling in the James Bay Lowland: Part 1 — Drilling by the Ontario Department of Mines; Ontario Department of Mines, Annual Report 1952, vol. LXI, Part 6, p. 115–140.

Hu, K. and Dietrich, J., 2012. Reservoir characterization of five offshore wells in the Hudson Bay Basin, Northern Canada; Geological Survey of Canada, Open File 7052, 36 p. https://doi.org/10.4095/290119

Hu, K., Dietrich, J., Dewing, K., Zhang, S., Asselin, E., Pinet, N., and Lavoie, D., 2011. Stratigraphic correlations for five offshore wells in the Hudson Bay Basin, northern Canada; Geological Survey of Canada, Open File 7031, 1 poster. https://doi.org/10.4095/289545

Jeppsson, L., Talent, J.A., Mawson, R., Simpson, A.J., Andrew, A., Calner, M., Whitford, D., Trotter, J.A., Sandström, O., and Cladon, H.J., 2007. High-resolution late Silurian correlations between Gotland, Sweden and the Broken River region, NE Australia: lithologies, conodonts and isotopes; Palaeogeography, Palaeoclimatology, Palaeoecology, v. 245, p. 115–137. https://doi.org/10.1016/j.palaeo.2006.02.032

Jones, L., 1965. The Middle Devonian Winnipegosis Formation of Saskatchewan; Saskatchewan Department of Mineral Resources, Geological Sciences Branch, Sedimentary Geology Division, Report no. 98, 191 p.

Kabanov, P., 2019. Devonian (*c.* 388–375 Ma) Horn River Group of Mackenzie Platform (NW Canada) is an open-shelf succession recording oceanic anoxic events; Geological Society of London, Journal, v. 176, p. 29–45. https://doi.org/10.1144/jgs2018-075

Kaljo, D., Boucot, A.J., Corfield, R.M., Le Herisse, A., Koren, T.N., Kriz, J., Männik, P., Märss, T., Nestor, V., Shaver, R.H., Siveter, D.J., and Viira, V., 1996. Silurian bio-events; *in* Global events and event stratigraphy in the Phanerozoic, (ed.) O.H. Walliser; Springer-Verlag, Berlin, p. 173–224.

Kaminski, E. and Jaupart, C., 2000. Lithospheric structure beneath the Phanerozoic intracratonic basins of North America; Earth and Planetary Science Letters, v. 178, p. 139–149. https://doi.org/10.1016/S0012-821X(00)00067-4

Kindle, E.M., 1924. Geology of a portion of the northern part of Moose River Basin, Ontario; *in* Summary report 1923; Geological Survey of Canada, Part CI, p. 21–41. https://doi.org/10.4095/100595

Kump, L.R. and Arthur, M.A., 1999. Interpreting carbon-isotope excursions: carbonates and organic matter; Chemical Geology, v. 161, p. 181–198. https://doi.org/10.1016/S0009-2541(99)00086-8

Lavoie, D., Pinet, N., Dietrich, J., Zhang, S., Hu, K., Asselin, E., Chen, Z., Bertrand, R., Galloway, J., Decker, V., Budkewitsch, P., Armstrong, D., Nicolas, M., Reyes, J., Kohn, B.P., Duchesne, M.J., Brake, V., Keating, P., Craven, J., and Roberts, B., 2013. Geological framework, basin evolution, hydrocarbon system data and conceptual hydrocarbon plays for the Hudson Bay and Foxe basins, Canadian Arctic; Geological Survey of Canada, Open File 7363, 210 p. https://doi.org/10.4095/293119

Lavoie, D., Pinet, N., Dietrich, J., and Chen, Z., 2015. The Paleozoic Hudson Bay Basin in northern Canada: new insights into hydrocarbon potential of a frontier intracratonic basin; The American Association of Petroleum Geologists, Bulletin, v. 99, p. 859–888. https://doi.org/10.1306/12161414060

Lehnert, O., Fryda, J., Buggisch, W., Munnecke, A., Nützel, A., Kriz, J., and Manda, S., 2007. $\delta^{13}C$ records across the Late Silurian Lau Event: new data from middle paleolatitudes of northern peri-Gondwana; Palaeogeography, Palaeoclimatology, Palaeoecology, v. 245, p. 227–244. https://doi.org/10.1016/j.palaeo.2006.02.022

Levman, B.G. and Von Bitter, P.H., 2002. The Frasnian–Famennian (mid-Late Devonian) boundary in the type section of the Long Rapids Formation, James Bay Lowland, northern Ontario, Canada; Canadian Journal of Earth Sciences, v. 39, p. 1795–1818. https://doi.org/10.1139/e02-073

Low, A.P., 1887. Preliminary report on an exploration of country between Lake Winnipeg and Hudson Bay; Geological Survey of Canada, Annual Report, v. 2 (1886), pt. F, 18 p. https://doi.org/10.4095/296713

Marshall, J., 1992. Climatic and oceanographic isotopic signals from the carbonate rock record and their preservation; Geological Magazine, v. 129, p. 143–160. https://doi.org/10.1017/S0016756800008244

Martison, N.W., 1953. Petroleum possibilities of the James Bay Lowland area; Ontario Department of Mines, Annual Report, v. 61 (1952), pt. 6, p. 1–58.

Martma, T., Brazauskas, A., Kaljo, D., Kaminskas, D., and Musteikis, P., 2005. The Wenlock–Ludlow carbon isotope trend in the Vidukle core, Lithuania, and its relations with oceanic events; Geological Quarterly, v. 49, p. 223–234.

McArthur, J.M., Howarth, R.J., and Bailey, T.R., 2001. Strontium isotope stratigraphy: LOWESS version 3: best fit to the marine Sr-isotope curve for 0–509 Ma and accompanying look-up table for deriving numerical age; The Journal of Geology, v. 109, p. 155–170. https://doi.org/10.1086/319243

McGregor, D.C. and Camfield, M., 1976. Upper Silurian? to Middle Devonian spores of the Moose River Basin, Ontario; Geological Survey of Canada, Bulletin 263, 63 p. https://doi.org/10.4095/103961

McGregor, D.C., Sanford, B.V., and Norris, A.W., 1970. Palynology and correlation of Devonian formations in the Moose River Basin, northern Ontario; Geological Association of Canada, Proceedings, v. 22, p. 45–54.

Mutti, M., John, C.M., and Knoerich, A.C., 2006. Chemostratigraphy in Miocene heterozoan carbonate settings: applications, limitations and perspectives; Geological Society of London, Special Publications, v. 255, p. 307–322. https://doi.org/10.1144/GSL.SP.2006.255.01.18

Narbonne, G.M., Kaufman, A.J., and Knoll, A.H., 1994. Integrated chemostratigraphy and biostratigraphy of the Windermere Supergroup, northwestern Canada: implications for Neoproterozoic correlations and the early evolution of animals; Geological Society of America, Bulletin, v. 106, p. 1281–1292. https://doi.org/10.1130/0016-7606(1994)106%3c1281:ICABOT%3e2.3.CO%3b2

Nelson, S.J., 1952. Ordovician palaeontology and stratigraphy of the Churchill and Nelson rivers, Manitoba; Ph.D. thesis, McGill University, Montréal, Quebec, 190 p.

Nelson, S.J., 1963. Ordovician paleontology of the Hudson Bay lowland; Geological Society of America, Memoir, v. 90, 152 p. https://doi.org/10.1130/MEM90-p1

Nelson, S.J., 1964. Ordovician stratigraphy of northern Hudson Bay lowland, Manitoba; Geological Survey of Canada, Bulletin 108, 36 p. https://doi.org/10.4095/100625

Nelson, S.J. and Johnson, R.D., 1966. Geology of Hudson Bay Basin; Bulletin of Canadian Petroleum Geology, v. 14, p. 520–578.

Nicolas, M.P.B., 2016a. Carbon and oxygen stable-isotope profiles of Paleozoic core from the Hudson Bay Basin, northeastern Manitoba (parts of NTS 54B7, 8, 54F8, 54G1); *in* Report of activities 2016; Manitoba Growth, Enterprise and Trade, Manitoba Geological Survey, p. 142–149.

Nicolas, M.P.B., 2016b. Carbon and oxygen stable-isotope results from three petroleum-exploration Paleozoic cores from the Hudson Bay Basin, northeastern Manitoba (parts of NTS 54B7, 8, 54F8, 54G1); Manitoba Growth, Enterprise and Trade, Manitoba Geological Survey, Data Repository Item DRI2016002, Microsoft® Excel® file. <https://www.manitoba.ca/iem/geo/mgstracker/hudbaylowland_gemenergy.html> [accessed December 15, 2016]

Nicolas, M.P.B. and Armstrong, D.K., 2017. Update on Paleozoic stratigraphic correlations in the Hudson Bay Lowland, northeastern Manitoba and northern Ontario; *in* Report of activities 2017; Manitoba Growth, Enterprise and Trade, Manitoba Geological Survey, p. 133–147.

Norford, B.S., 1970. Ordovician and Silurian biostratigraphy of the Soguepet-Aquitaine Kaskattama Province no. 1 well, northern Manitoba; Geological Survey of Canada, Paper 69-8, 44 p. https://doi.org/10.4095/102285

Norford, B.S., 1971. Silurian stratigraphy of northern Manitoba; *in* Geoscience studies in Manitoba, (ed.) A.C. Turnock; Geological Association of Canada, Special Paper 9, p. 199–207.

Norris, A.W. and Sanford, B.V., 1968a. Operation Winisk, Hudson Bay Lowland, Ontario, Manitoba, Quebec, District of Keewatin; *in* Report of activities, Part A; Geological Survey of Canada, Paper 68-1A, p. 207–208. https://doi.org/10.4095/106381

Norris, A.W. and Sanford, B.V., 1968b. Paleozoic and Mesozoic geology of the Hudson Bay Lowland; *in* Earth Science Symposium on Hudson Bay, (ed.) P.J. Hood; Geological Survey of Canada, Paper 68-53, p. 169–205. https://doi.org/10.4095/119794

Norris, A.W., Grant, A.C., Sanford, B.V., and Cowan, W.R., 1993. Hudson Platform — geology; Chapter 8 *in* Sedimentary cover of the craton in Canada, (ed.) D.F. Stott and J.D. Aitken; Geological Survey of Canada, Geology of Canada, no. 5, p. 655–700 (also Geological Society of America, The geology of North America, v. D-1). https://doi.org/10.4095/192378

Parks, W.A., 1904. Devonian fauna of Kwataboahegan River; Ontario Bureau of Mines, v. 13, p. 180–191.

Pearce, T.J. and Jarvis, I., 1995. High-resolution chemostratigraphy of Quaternary distal turbidites: a case study of new methods for the analysis and correlation of barren sequences; Geological Society of London, Special Publications, v. 89, p. 107–143. https://doi.org/10.1144/GSL.SP.1995.089.01.07

Pearce, T.J., Besly, B.M., Wray, D.S., and Wright, D.K., 1999. Chemostratigraphy: a method to improve interwell correlation in barren sequences — a case study using onshore Duckmantian/Stephanian sequences (West Midlands, UK); Sedimentary Geology, v. 124, p. 197–220. https://doi.org/10.1016/S0037-0738(98)00128-6

Pelechaty, S.M., Kaufman, A.J., and Grotzinger, J.P., 1996. Evaluation of $\delta^{13}C$ chemostratigraphy for intrabasinal correlation: Vendian strata of northeast Siberia; Geological Society of America, Bulletin, v. 108, p. 992–1003. https://doi.org/10.1130/0016-7606(1996)108%3c0992:EOCCFI%3e2.3.CO%3b2

Pinet, N., Lavoie, D., Dietrich, J., Hu, K., and Keating, P., 2013. Architecture and subsidence history of the intracratonic Hudson Bay Basin, northern Canada; Earth-Science Reviews, v. 125, p. 1–23. https://doi.org/10.1016/j.earscirev.2013.05.010

Preston, A., Garner, G., Beavis, K., Sadiq, O., and Stricker, S., 2016. Duvernay reserves and resources report: a comprehensive analysis of Alberta's foremost liquids-rich shale resource; Alberta Energy Regulator, 75 p. <https://aer.ca/documents/reports/DuvernayReserves_2016.pdf> [accessed September 22, 2019]

Price, L.L., 1978. Mesozoic deposits of the Hudson Bay lowlands and coal deposits of the Onakawana area, Ontario; Geological Survey of Canada, Paper 75-13, 45 p. https://doi.org/10.4095/103384

Quinlan, G.M., 1987. Models of subsidence mechanisms in intracratonic basins, and their applicability to North American examples; *in* Sedimentary basins and basin-forming mechanisms, (ed.) C. Beaumont and A.J. Tankard; Canadian Society of Petroleum Geologists, Memoir 12, p. 463–481.

Racey, A., Love, M.A., Bobolecki, R.T., and Walsh, J.N., 1995. The use of chemical element analyses in the study of biostratigraphically barren sequences: an example from the Triassic of the central North Sea (UKCS); Geological Society of London, Special Publications, v. 89, p. 69–105. https://doi.org/10.1144/GSL.SP.1995.089.01.06

Ratcliffe, L.M. and Armstrong, D.K., 2013. The Hudson Platform Project: 2013 field work and drill-core correlations, western Moose River Basin; *in* Summary of field work and other activities, 2013; Ontario Geological Survey, Open File Report 6290, p. 36-1–36-19.

Renard, M., 1986. Pelagic carbonate chemostratigraphy (Sr, Mg, ^{18}O, ^{13}C); Marine Micropaleontology, v. 10, p. 117–164. https://doi.org/10.1016/0377-8398(86)90027-7

Robertson Research Canada Limited, 1986. The micropaleontology, palynology and stratigraphy of the Trillium et al. Beluga O-23 well; Exploration Report 2300; Canada Energy Regulator, 21 p. <https://www.cer-rec.gc.ca/en/about/library/north-offshore-data.html> [accessed May 5, 2021]

Ross, C.A. and Ross, J.R.P., 1996. Silurian sea-level fluctuations; *in* Paleozoic sequence stratigraphy: views from the North American Craton, (ed.) B.J. Witzke, G.A. Ludvigson, and J. Day; Geological Society of America, Special Paper 306, p. 187–192.

Saltzman, M.R., 2001. Silurian $\delta^{13}C$ stratigraphy: a view from North America; Geology, v. 29, p. 671–674. https://doi.org/10.1130/0091-7613(2001)029%3c0671:SCSAVF%3e2.0.CO%3b2

Saltzman, M.R., 2002. Carbonate isotope ($\delta^{13}C$) stratigraphy across the Silurian–Devonian transition in North America: evidence for a perturbation in the global carbon cycle; Palaeogeography, Palaeoclimatology, Palaeoecology, v. 187, p. 83–100. https://doi.org/10.1016/S0031-0182(02)00510-2

Sanford, B.V., 1987. Paleozoic geology of Hudson Platform; *in* Sedimentary basins and basin-forming mechanism, (ed.) C. Beaumont and A.J. Tankard; Canadian Society of Petroleum Geologists, Memoir 12, p. 483–505.

Sanford, B.V. and Grant, A.C., 1990. New findings relating to the stratigraphy and structure of the Hudson Platform; *in* Current research, Part D; Geological Survey of Canada, Paper 90-1D, p. 17–30. https://doi.org/10.4095/131335

Sanford, B.V. and Grant, A.C., 1998. Paleozoic and Mesozoic geology of the Hudson Bay and southeast Arctic platforms; Geological Survey of Canada, Open File 3595, scale 1:2 500 000. https://doi.org/10.4095/210108

Sanford, B.V. and Norris, A.W., 1973. The Hudson platform; *in* Future petroleum provinces of Canada — their geology and potential, (ed.) R.G. McCrossan; Canadian Society of Petroleum Geologists, Memoir 1, p. 387–409.

Sanford, B.V. and Norris, A.W., 1975. Devonian stratigraphy of the Hudson Platform; Geological Survey of Canada, Memoir 379, 369 p. https://doi.org/10.4095/127033

Sanford, B.V., Norris, A.W., and Bostock, H.H., 1968. Geology and bibliography of the Hudson Bay Lowlands (Operation Winisk); Geological Survey of Canada, Paper 67-60, 118 p. Preliminary Map 17-1967, scale 1:1 000 000. https://doi.org/10.4095/100932

Sanford, B.V., Cowan, W.R., and Currie, K.L., 1993. St. Lawrence platform — geology; Chapter 11 *in* Sedimentary cover of the craton in Canada, (ed.) D.F. Scott and J.D. Aitken; Geological Survey of Canada, Geology of Canada, no. 5, p. 725–786 (also Geological Society of America, The geology of North America, v. D-1). https://doi.org/10.4095/192381

Satterly, J., 1953. Drilling in the James Bay Lowland, Part 2 — Results of other drilling; Ontario Department of Mines, Annual Report, v. 61 (1952), pt. 6, p. 141–157.

Savage, T.E. and Van Tuyl, F.M., 1919. Geology and stratigraphy of the area of Paleozoic rocks in the vicinity of Hudson and James bays; Geological Society of America, Bulletin, v. 30, p. 339–378. https://doi.org/10.1130/GSAB-30-339

Scholle, P.A. and Arthur, M.A., 1980. Carbon isotope fluctuations in Cretaceous pelagic limestones: potential stratigraphic and petroleum exploration tool; American Association of Petroleum Geologists, Bulletin, v. 64, p. 67–87.

Slavik, L. and Hladil, J., 2020. Early Devonian (Lochkovian–early Emsian) bioevents and conodont response in the Prague Synform (Czech Republic); Palaeogeography, Palaeoclimatology, Palaeoecology, v. 549, art. no. 109148, 14 p. https://doi.org/10.1016/j.palaeo.2019.04.004

Sloss, L.L., 1963. Sequences in the cratonic interior of North America; Geological Society of America, Bulletin, v. 74, p. 93–114. https://doi.org/10.1130/0016-7606(1963)74[93:SITCIO]2.0.CO%3b2

Société Nationale des Pétroles d'Aquitaine and Centre de Recherches de Pau, 1975a. Aquitaine et al. Polar Bear C-11 (Hudson Bay, Canada) geological and geochemical study; Canada Energy Regulator, 31 p. <https://www.cer-rec.gc.ca/en/about/library/north-offshore-data.html> [accessed May 5, 2021]

Société Nationale des Pétroles d'Aquitaine and Centre de Recherches de Pau, 1975b. Aquitaine et al. Narwhal South O-58 (Hudson Bay, Canada) geological and geochemical study; Canada Energy Regulator, 33 p. <https://www.cer-rec.gc.ca/en/about/library/north-offshore-data.html> [accessed May 5, 2021]

Spiridonov, A., Samsoné, J., Brazauskas, A., Stankevič, R., Meidla, T., Ainsaar, L., and Radzevičius, S., 2020. Quantifying the community turnover of the uppermost Wenlock and Ludlow (Silurian) conodonts in the Baltic Basin; Palaeogeography, Palaeoclimatology, Palaeoecology, v. 549, art. no. 109128, 18 p. https://doi.org/10.1016/j.palaeo.2019.03.029

Stott, D.F. (comp.), 1991. Geotectonic correlation chart, Sheet 2, Prairie provinces and British Columbia; *in* Chapter 8 of Sedimentary cover of the craton in Canada, (ed.) D.F. Stott and J.D. Aitken; Geological Survey of Canada, Geology of Canada, no. 5, p. 655–700 (also Geological Society of America, The geology of North America, v. D-1). https://doi.org/10.4095/192378

Switzer, S.B., Holland, W.G., Christie, D.S., Graf, G.C., Hedinger, A.S., McAuley, R.J., Wierzbicki, R.A., and Packard, J.J., 1994. Devonian Woodbend–Winterburn strata of the Western Canada Sedimentary Basin; Chapter 12 *in* Geological atlas of the Western Canada Sedimentary Basin, (comp.) G.D. Mossop and I. Shetsen; Canadian Society of Petroleum Geologists and Alberta Geological Survey, p. 165–202.

Talent, J.A., Mawson, R., Andrew, A.S., Hamilton, P.J., and Whitford, D.J., 1993. Middle Palaeozoic extinction events: faunal and isotopic data; Palaeogeography, Palaeoclimatology, Palaeoecology, v. 104, p. 139–152. https://doi.org/10.1016/0031-0182(93)90126-4

Tillement, B.A., Peniguel, G., and Guillemin, J.P., 1976. Marine Pennsylvanian rocks in Hudson Bay; Bulletin of Canadian Petroleum Geology, v. 24, p. 418–439.

Uyeno, T.T., Telford, P.G., and Sanford, B.V., 1982. Devonian conodonts and stratigraphy of southwestern Ontario; Geological Survey of Canada, Bulletin 332, 55 p. https://doi.org/10.4095/119432

Veizer, J., Ala, D., Azmy, K., Bruckschen, P., Buhl, D., Bruhn, F., and Jasper, T., 1999. ^{87}Sr/^{86}Sr, δ^{13}C and δ^{18}O evolution of Phanerozoic seawater; Chemical Geology, v. 161, p. 59–88. https://doi.org/10.1016/S0009-2541(99)00081-9

Verma, H.M., 1982. History of geological exploration in the James Bay lowland; *in* Mesozoic geology and mineral potential of the Moose River Basin, (ed.) P.G. Telford and H.M. Verma; Ontario Geological Survey, Study 21, p. 1–21.

Weissert, H., Joachimski, M., and Sarnthein, M., 2008. Chemostratigraphy; Newsletters on Stratigraphy, v. 42, p. 145–179. https://doi.org/10.1127/0078-0421/2008/0042-0145

White, T.S., Witzke, B.J., and Ludvigson, G.A., 2000. Evidence for an Albian Hudson arm connection between the Cretaceous western interior seaway of North America and the Labrador Sea; Geological Society of America, Bulletin, v. 112, no. 9, p. 1342–1355. https://doi.org/10.1130/0016-7606(2000)112%3c1342:EFAAHA%3e2.0.CO%3b2

Wilson, W.J., 1903. Reconnaissance surveys of four rivers south-west of James Bay; *in* Geological Survey of Canada, Annual Report, v. 15 (1902–1903), pt. A, p. 222A–243A. https://doi.org/10.4095/297451

Zhang, S. and Barnes, C.R., 2007. Late Ordovician–Early Silurian conodont biostratigraphy and thermal maturity, Hudson Bay Basin; Bulletin of Canadian Petroleum Geology, v. 55, p. 179–216. https://doi.org/10.2113/gscpgbull.55.3.179

Zhang, S. and Hu, K., 2013. Recognition of Devonian hydrocarbon source rocks in Beluga O-23 well, Hudson Bay Basin; Geological Survey of Canada, Open File 7433, 18 p. https://doi.org/10.4095/292867