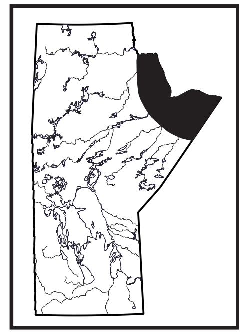
GS-14 Lithofacies analysis of the Silurian Attawapiskat Formation in the Hudson Bay Lowland, northeastern Manitoba

by A. Ramdoyal[1], M.P.B. Nicolas and N. Chow[1]



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Summary

The Hudson Bay and Foxe Basins Project of the Geo-mapping for Energy and Minerals Program has just completed its fifth and final year. This paper documents the portion of this program that details lithofacies analysis of the Lower Silurian Attawapiskat Formation[2] in the Hudson Bay Lowland in northeastern Manitoba. This study was completed in 2012 as part of a Bachelor of Science (Honours) thesis project in the Department of Geological Sciences at the University of Manitoba.

The Attawapiskat Formation extends over much of the Hudson Bay Basin and is interpreted to have been deposited on a shallow rimmed shelf where isolated and barrier reefs developed in an irregular concentric belt around the periphery of the basin. In the Hudson Bay Lowland, this formation consists of stromatoporoid- and coral-rich limestone and, to a lesser extent, dolostone beds. In this study, 10 lithofacies have been recognized in the Attawapiskat Formation, which are grouped into three lithofacies associations. The subtidal lithofacies association (LA 1) consists of eight lithofacies: A, mottled to nodular skeletal wackestone; B, stromatoporoid-coral framestone; C, stromatoporoid-coral rudstone; D, peloidal intraclastic wackestone to grainstone; E, skeletal mudstone to wackestone; F, peloidal intraclastic bindstone; G, interbedded skeletal wackestone and intraclastic rudstone; and H, graded oolitic grainstone to wackestone. The intertidal lithofacies association (LA 2) comprises lithofacies I—laminated skeletal mudstone to wackestone; and the supratidal lithofacies association (LA 3) comprises lithofacies J—laminated dolostone.

Due to its highly porous and reefal character, this formation has been identified as the best candidate for a potential conventional reservoir rock in the Hudson Bay Lowland of Manitoba.

Introduction

The Hudson Bay and Foxe Basins Project of the Geo-mapping for Energy and Minerals (GEM) Program has just completed its fifth and final year. The project objective is to document the potential hydrocarbon systems in the successions of the Hudson Bay and Foxe basins by reassessing available geoscience data and acquiring new data in areas or domains that have knowledge gaps (Nicolas and Lavoie, 2009). Led by the Geological Survey of Canada, partners in this project include the National Energy Board, Northern and Indian Affairs Canada, Canadian and international universities, and the Manitoba, Ontario and Nunavut governments. The Manitoba component of the project is located on land in the Hudson Bay Lowland (HBL) of northeastern Manitoba, on the southwestern rim of the Hudson Bay Basin.

There has been minimal exploration for hydrocarbons in the Hudson Bay Basin. The first round of exploration started in the early 1960s and the second round in the mid 1980s. Only nine hydrocarbon exploration wells were drilled and several thousands of kilometres of seismic data were acquired during these exploration efforts. Of these nine wells, three of them are located onshore in northeastern Manitoba. These wells are: 1) Sogepet Aquitaine Kaskattama Prov. No. 1 drilled in 1967, 2) Houston Oils et al. Comeault Prov. No. 1 drilled in 1968, and 3) Merland et al. Whitebear Creek Prov. drilled in 1970 (Figure GS-14-1). These wells will be referred to herein as the Kaskattama, Comeault and Whitebear, respectively. All three wells were dry, did not contain economic quantities of hydrocarbons, have been abandoned and were fully cored, from near surface to their termination in Precambrian basement rocks.

The Attawapiskat Formation is a Lower Silurian carbonate succession within the Hudson Bay Basin. In Manitoba, this formation subcrops below the Quaternary sediments in a northwest-trending band but has only been documented in the subsurface in the three petroleum exploratory wells listed above. The Attawapiskat Formation is visible in outcrop in northern Ontario, including along the Severn, Attawapiskat and Ekwan rivers (D. Armstrong, pers. comm., 2013). The Attawapiskat Formation is the one of the most prospective potential conventional reservoirs in the Hudson Bay Basin due to its locally highly porous and reefal character. A detailed sedimentological study of the Attawapiskat Formation in the Kaskattama, Comeault and Whitebear wells was completed in 2012 for a B.Sc. (Honours) thesis project in the Department of Geological Sciences at the

[1] Department of Geological Sciences, University of Manitoba, 125 Dysart Road, Winnipeg, MB R3T 2N2

[2] For the sake of consistency, the Manitoba Geological Survey has opted to make a universal change from capitalized to noncapitalized for the generic part of lithostructural feature names (formal stratigraphic and biostratigraphic nomenclature being the exceptions).

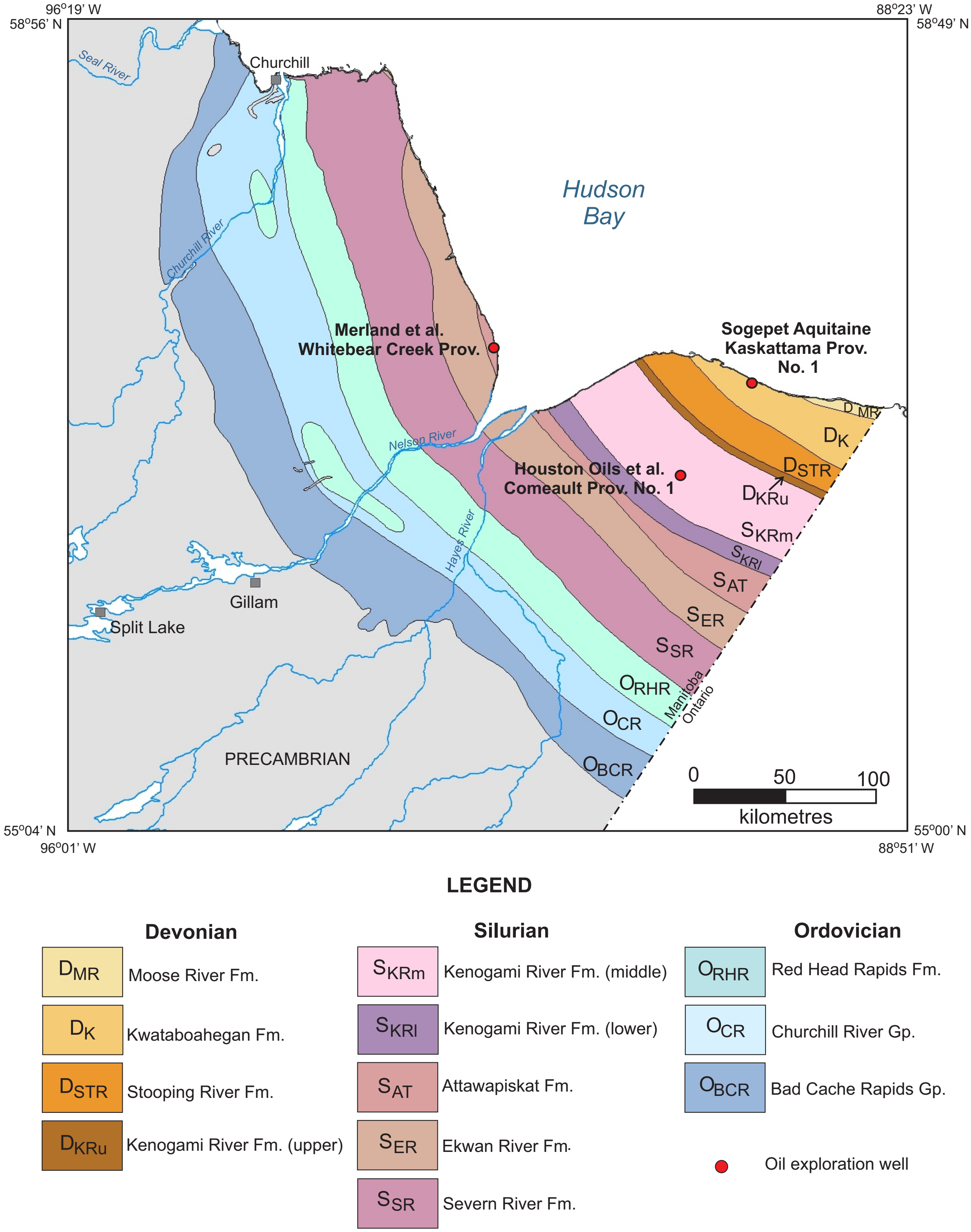

Figure GS-14-1: *Stratigraphy of the Hudson Bay Lowland showing the location of the three cores with Attawapiskat Formation sections recovered, northeastern Manitoba.*

University of Manitoba (Ramdoyal, 2012). The results of the lithofacies analysis are discussed herein.

Geological setting

The Hudson Bay Basin is a Phanerozoic intracratonic basin located in central northern Canada, which is approximately centred on the modern day Hudson Bay. It reaches a maximum thickness of 2.5 km and consists of Paleozoic and Cretaceous rocks, which unconformably overlie Proterozoic rocks (Sanford, 1987). Unlike the Williston Basin, the depocentre of the Hudson Bay Basin is thought to have moved over time (Pinet et al., 2013), however, in general, the maximum thickness of the sedimentary package occurs approximately in the centre of the basin and thins out toward its edges. The HBL portion of the basin is located along the southern end of the basin, occurring onshore in northeastern Manitoba and northern Ontario. The Paleozoic succession consists of Upper Ordovician, Lower Silurian and Lower Devonian carbonate, evaporitic and clastic successions. The formations show a concentric outcrop/subcrop map pattern (the Manitoba portion of which can be seen in Figure GS-14-1), which is dominantly controlled by erosion.

Stratigraphy

In the HBL, the Lower Silurian strata are composed of fossiliferous limestone and dolostone units, as well as anhydrite beds, which reach up to 200 m thick (Norford, 1971). The strata represent mainly shallow, open and restricted marine depositional environments. The Lower Silurian succession consists of the Severn River, Ekwan River, Attawapiskat formations and the lower and middle members of the Kenogami River Formation (Figure GS-14-2).

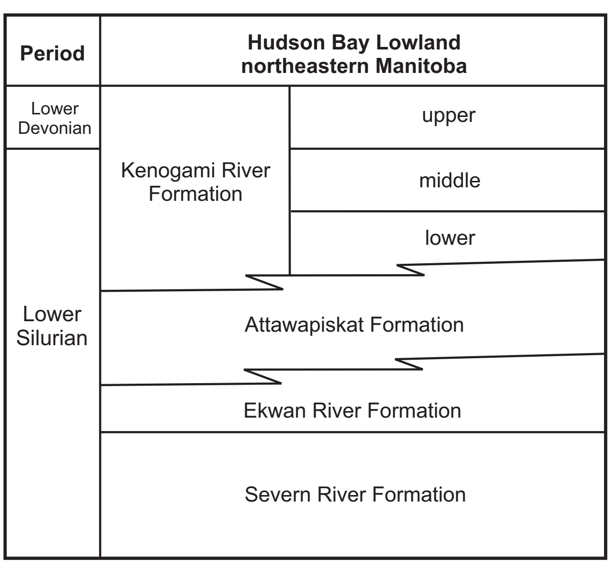

Figure GS-14-2: *Paleozoic stratigraphic column of the onshore Hudson Bay Lowland, northeastern Manitoba.*

The Attawapiskat Formation in the HBL consists of stromatoporoid- and coral-rich limestone and, to a lesser extent, dolostone beds. The formation has a thickness of 30, 37 and 66 m in the Whitebear, Comeault and Kaskattama wells, respectively. The Attawapiskat Formation extends over much of the Hudson Bay Basin and is interpreted to have been deposited over a shallow shelf where isolated and barrier reefs developed in an irregular concentric belt around the periphery of the basin (Sanford, 1987; Sanford and Grant, 1990; Norris, 1993). The Attawapiskat Formation and the uppermost part of the Ekwan River Formation have an interfingering relationship and are, therefore, interpreted to be coeval (Suchy and Stearn, 1992). The transition from the Ekwan River Formation to the Attawapiskat Formation follows a general trend of becoming more reefal upsection and thus the reefal beds are generally considered to be part of the Attawapiskat Formation. On gamma-ray well logs, the Attawapiskat Formation shows a slightly lower (cleaner or less shaly) and blockier signature than the underlying Ekwan River Formation. The uppermost part of the Attawapiskat Formation may also have an interfingering relationship with the lower part of the overlying Kenogami River Formation (Norford, 1971).

Methodology

Examination of the Attawapiskat Formation in the cores from the Whitebear, Kaskattama and Comeault wells was undertaken in August and September 2011 at the Manitoba Geological Survey's Rock Preparation and Core Storage Facility in Winnipeg. Dunham's (1962) classification scheme, as modified by Embry and Klovan (1972), was applied to name the carbonate rocks in this study. Representative photographs and samples of the core were taken. A total of 35 thin sections was prepared by Calgary Rock and Material Services Inc., 28 of which were from the Whitebear well and the remainder from the Kaskattama well. Thin sections were stained with Alizarin Red S to help distinguish calcite from dolomite, and with potassium ferricyanide to help distinguish ferroan carbonate minerals (Dickson, 1966). Thin sections were examined and photographed under transmitted light using a Nikon Optiphot-POL microscope with a Nikon DS-Fi1/LS2 digital camera. Modal abundances of the various components were visually estimated using comparison charts.

Lithofacies associations

Detailed core and petrographic examinations of the Attawapiskat Formation in this study have resulted in the recognition of 10 lithofacies. These lithofacies are grouped into three lithofacies associations, forming part of a shallow shelf succession: a subtidal lithofacies association (LA 1), an intertidal lithofacies association (LA 2) and a supratidal lithofacies association (LA 3). The lithofacies in each association are summarized in Table GS-14-1. Figures GS-14-3 to -5 show detailed lithofacies subdivisions of the three cores logged for this study. Limitations of the present study preclude a detailed examination of the relationships between the lithofacies, but preliminary correlations between the Whitebear and Kaskattama cores suggest lateral continuity of the majority of lithofacies associations. More details on the lithofacies can be found in Ramdoyal (2012).

Lithofacies association 1: subtidal

The subtidal lithofacies association (LA 1) comprises lithofacies A (mottled to nodular skeletal wackestone), B (stromatoporoid-coral framestone), C (stromatoporoid-coral rudstone), D (peloidal intraclastic wackestone to grainstone), E (skeletal mudstone to wackestone), F (peloidal intraclastic bindstone), G (interbedded skeletal wackestone and intraclastic rudstone) and H (graded oolitic grainstone to wackestone). Figure GS-14-6 shows examples of these lithofacies in core. This lithofacies association represents the majority of the Attawapiskat Formation examined in this study.

Lithofacies A, D, E and G share similar lithological characteristics, notably abundant micrite and bioturbation, diverse skeletal allochems and thin intraclast beds. These lithofacies are interpreted to represent deposition between storm and fair-weather wave base where low-energy conditions were punctuated by episodic storms. Lithofacies A and E may have been deposited in slightly deeper environments than lithofacies D and G, as suggested by the more abundant micrite, fewer and thinner storm beds and smaller intraclasts in lithofacies A and E.

Lithofacies B and C, which commonly occur together, are interpreted to represent stromatoporoid-coral patch reefs and associated reef flank deposits, respectively. The units are relatively thin (less than 4 m) suggesting that they are laterally restricted buildups. The lithofacies are underlain and overlain by lithofacies A, D and E suggesting that the patch reefs developed under relatively low-energy conditions. The generally enveloping nature of the individual bulbous and irregular stromatoporoids further suggests relatively low sedimentation rates (cf. James and Bourque, 1992). Outcrop studies of Attawapiskat Formation reefs in the adjacent Moose River Basin document patch reefs that are interpreted to have developed in shallow subtidal conditions and had at least 8–10 m of syndepositional relief (Chow and Stearn, 1989; Suchy and Stearn, 1993).

Lithofacies F is composed of stromatolites, which are 2–20 cm thick and characterized by stacked hemispheroids with constant diameter domes (SH-C; after Logan et al., 1964) and closely spaced, laterally linked hemispheroids (LLH-C; after Logan et al., 1964). The association of the SH-C and LLH-C forms with lithofacies A, C, E and G supports a subtidal origin for the stromatolites. Lithofacies H was observed once in each of the Whitebear and Kaskattama cores as a single bed. It is interpreted to represent ooid sand shoals in a shallow subtidal setting with intermittent high- and low-energy conditions.

Lithofacies association 2: intertidal

The intertidal lithofacies association (LA 2) consists only of lithofacies I, laminated peloidal-skeletal mudstone to wackestone (Figure GS-14-7). This lithofacies is characterized by discontinuous, wavy or crinkled laminations, which are interpreted to be microbial in origin, and has desiccation cracks, horizontal and vertical burrows, and laminoid fenestral and clotted micrite fabrics. These features, along with the low faunal diversity and abundance of peloids, support an intertidal interpretation (Pratt, 2010). Intraclastic-peloidal packstone laminae with erosional lower and gradational upper bedding contacts, are interpreted to have formed by episodic storm events that reworked intertidal deposits. Lithofacies association 2 represents a very small portion of the overall Attawapiskat Formation section in the study area.

Lithofacies association 3: supratidal

The supratidal lithofacies association (LA 3) is composed only of lithofacies J, laminated dolostone (Figure GS-14-8). This lithofacies has abundant microbial laminations, fenestrae and detrital quartz and feldspar silt, minor laminae and thin beds of shale and skeletal packstone (Figure GS-14-8a). Porosity is 35–45% and predominantly intercrystalline and fenestral. Dolomicrite and microbial laminations are common in supratidal settings (Flügel, 2010; Pratt, 2010). The abundant siliciclastic silt and shale partings (Figure GS-14-8b) are attributed to eolian transport from a land source. Episodic storm conditions are reflected by skeletal beds with erosional basal contacts and fining-upward trends. Similar to the intertidal association, this supratidal association represents a very small portion of the overall Attawapiskat Formation section in the cores examined.

Cyclicity and sea-level changes

The three lithofacies associations recognized in the Attawapiskat Formation in the Whitebear and Kaskattama cores are arranged into metre- to decametre-scale shallowing-upward cycles (Figures GS-14-3, -5). Each complete cycle consists of a lower subtidal lithofacies association (LA 1) that is gradationally overlain by the intertidal lithofacies association (LA 2) that, in turn, is overlain by the supratidal lithofacies association (LA 3).

In the Whitebear core, three cycles are recognized. These cycles range from 3.7 to 15.1 m thick; the beginning of a fourth cycle occurs at the top of the formation and continues into the overlying Kenogami River Formation (Figure GS-14-3). In the Kaskattama core, three cycles are recognized and these cycles range from 5.5 to 42.1 m

Table GS-14-1: Summary of the lithofacies of the Attawapiskat Formation, northeastern Manitoba (modified from Ramdoyal, 2012).

Lithofacies		Thickness	Lithology	Major allochems	Calcite cement (CC) Dolomite (DOL)	Porosity	Lithofacies association
A	Mottled to nodular skeletal wackestone	1.46–2.13 m	Skeletal wackestone interbedded with intraclastic and skeletal packstone; ostracod packstone to grainstone	Peloids, brachiopods, echinoderms, stromatoporoids	CC, fine to very coarse crystalline, <5% DOL, fine to medium crystalline, 10%	<5–25%; microvuggy, vuggy, mouldic	LA 1: subtidal
B	Stromatoporoid-coral framestone	2.1–3.7 m	Stromatoporoid-coral framestone; local intraclast-stromatoporoid packstone to grainstone beds ± shale	In situ wafer, bulbous, irregular stromatoporoids; rugose and tabulate corals; brachiopods; echinoderms	CC, very fine to medium crystalline, 2–3% DOL, fine crystalline, 55%	10–40%; interparticle, microvuggy, intraparticle, vuggy	
C	Stromatoporoid-coral rudstone	0.30–3.44 m	Stromatoporoid-coral rudstone with skeletal packstone to grainstone matrix	Wafer, bulbous, irregular stromatoporoid fragments; rugose and tabulate corals; brachiopods; echinoderms	CC, very fine to very coarse crystalline, 2–8% DOL, medium to coarse crystalline, 25%	20–40%; microvuggy, interparticle, intraparticle, mouldic	
D	Peloidal intraclastic wackestone to grainstone	1.13–1.40 m	Peloidal intraclastic wackestone with interbedded skeletal peloidal and intraclastic grainstone and packstone	Intraclasts, peloids, stromatoporoid fragments	CC, very fine to medium crystalline, 3–15% DOL, very fine to fine crystalline, 5%	<5–40%; microvuggy, mouldic, vuggy	
E	Skeletal mudstone to wackestone	0.73–4.63 m	Skeletal mudstone and wackestone, peloidal intraclastic grainstone to packstone, stromatoporoid-coral floatstone	Peloids, echinoderms, brachipods, trilobites, stromatoporoid fragments	CC, very fine to medium crystalline, <10% DOL, fine crystalline, 5–15%	<20%, locally up to 60%; microvuggy, mouldic, vuggy	
F	Peloidal intraclastic bindstone	0.61–0.82 m	Stromatolites with peloidal intraclastic wackestone matrix; intraclastic packstone	Peloids, intraclasts	CC, very fine to very coarse crystalline, 5–10%	5–10%; microvuggy, mouldic, vuggy	
G	Interbedded skeletal wackestone and intraclastic rudstone	0.21–1.04 m	Skeletal wackestone and interbedded intraclastic rudstone ± shales	Intraclasts, crinoids, echinoderms	CC, fine to very coarse crystalline, 5–25% Dolostone/dolomitic intraclasts	~5%; microvuggy	
H	Graded oolitic grainstone to wackestone	0.52 m	Oolitic grainstone to wackestone	Radial-concentric and composite ooids, aggregate grains, peloids	CC, very fine to very coarse crystalline, 25%	~30%; microvuggy, mouldic	
I	Laminated skeletal mudstone to wackestone	1.1–4.3 m	Microbially laminated mudstone to wackestone; peloidal intraclastic packstone laminae ± shales	Peloids, intraclasts	CC, very fine to very coarse crystalline, 2–3% DOL, very fine to fine crystalline, up to 45%	<5%; microvuggy, fenestral, vuggy	LA 2: intertidal
J	Laminated dolostone	0.03–0.12 m	Laminated dolostone ± shales	Crinoids, brachiopods	DOL, fine to medium crystalline, >50–65%	35–45%; intercrystalline	LA 3: supratidal

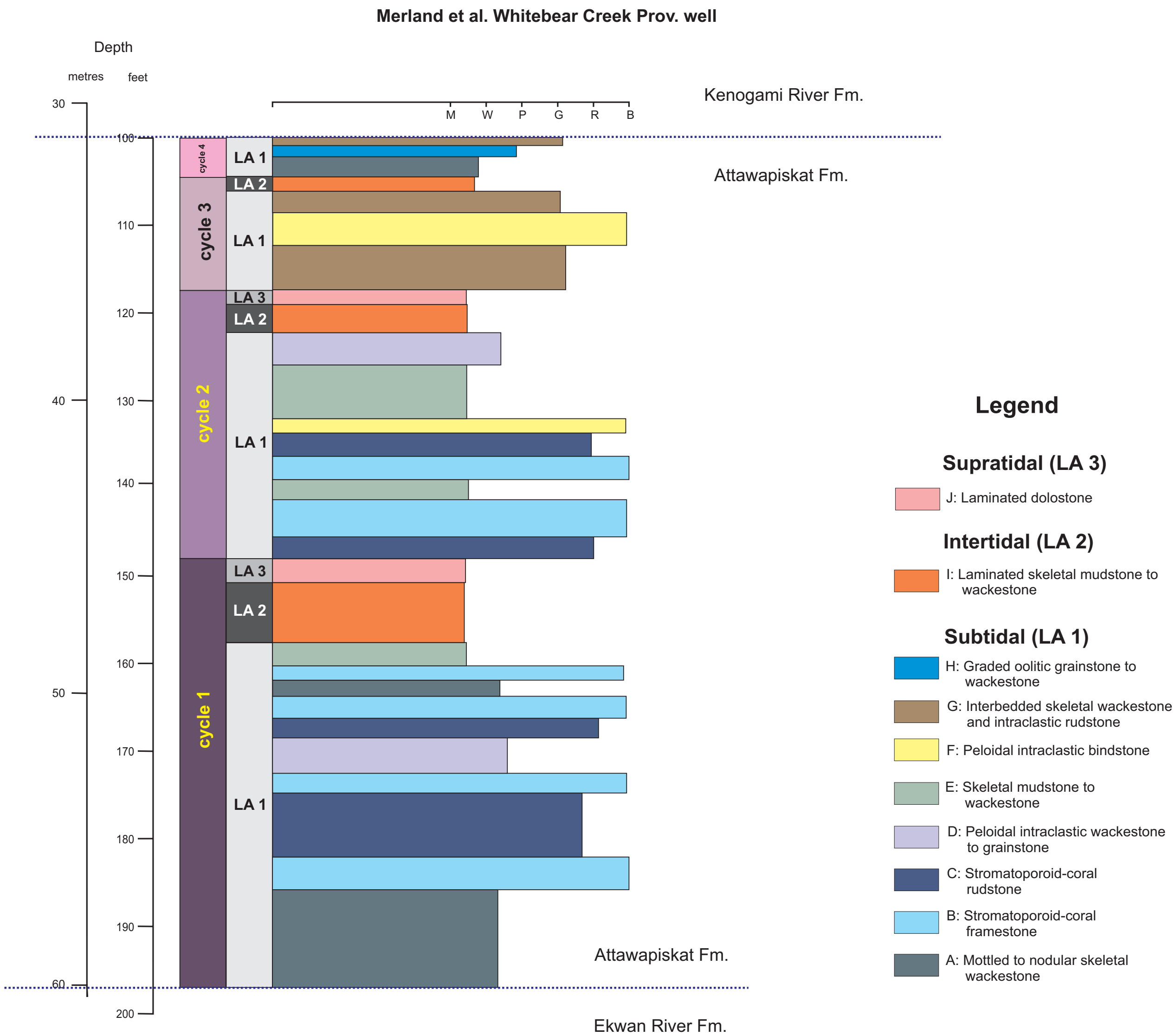

***Figure GS-14-3:** Stratigraphic section of the Attawapiskat Formation in the Merland et al. Whitebear Creek Prov. core showing the lithofacies, lithofacies associations and cyclicity (modified from Ramdoyal, 2012). Abbreviations: Fm., Formation; LA, lithofacies association; M, mudstone; W, wackestone; P, packstone; G, grainstone; R, rudstone; B, boundstone.*

thick (Figure GS-14-5). The Comeault well had poor core recovery through the Attawapiskat Formation section but at least two cycles are recognized (Figure GS-14-4), these cycles range from ~15 to ~21 m thick.

In the Whitebear core, the lowermost cycle 1 is the thickest and consists of subtidal lithofacies A, B, C, D and E (LA 1), which are overlain by intertidal lithofacies I (LA 2) and then supratidal lithofacies J (LA 3). In the Kaskattama core, cycle 1 is the thickest and consists of subtidal lithofacies A, B, C, D, E and G (LA 1) and supratidal lithofacies J (LA 3); the intertidal lithofacies I (LA 2) was not observed. Cycle 1 in the Comeault core consists of subtidal lithofacies B, C and E (LA 1) overlain by intertidal lithofacies I (LA 2).

In the Whitebear core, cycle 2 is composed of the same lithofacies association pattern as that seen in cycle 1 and is thus repeated in full with subtidal lithofacies B, C, D, E and F (LA 1), overlain by intertidal lithofacies I (LA 2) and capped by supratidal lithofacies J (LA 3). In the Kaskattama core, cycle 2 is composed of subtidal lithofacies A and H (LA 1) and capped by intertidal lithofacies I (LA 2); the supratidal lithofacies was not observed in this cycle. Cycle 2 in the Comeault core consists only of the subtidal lithofacies association (LA 1), however large sections of core are missing, particularly near the top of the section.

The third and uppermost cycles in the Whitebear and Kaskattama cores both consist of subtidal lithofacies association (LA 1) at the bottom of the cycle, capped by the intertidal lithofacies association (LA 2) at the top (Figures GS-14-3, -5); the supratidal lithofacies association (LA 3) was not observed in these cycles. In the Whitebear

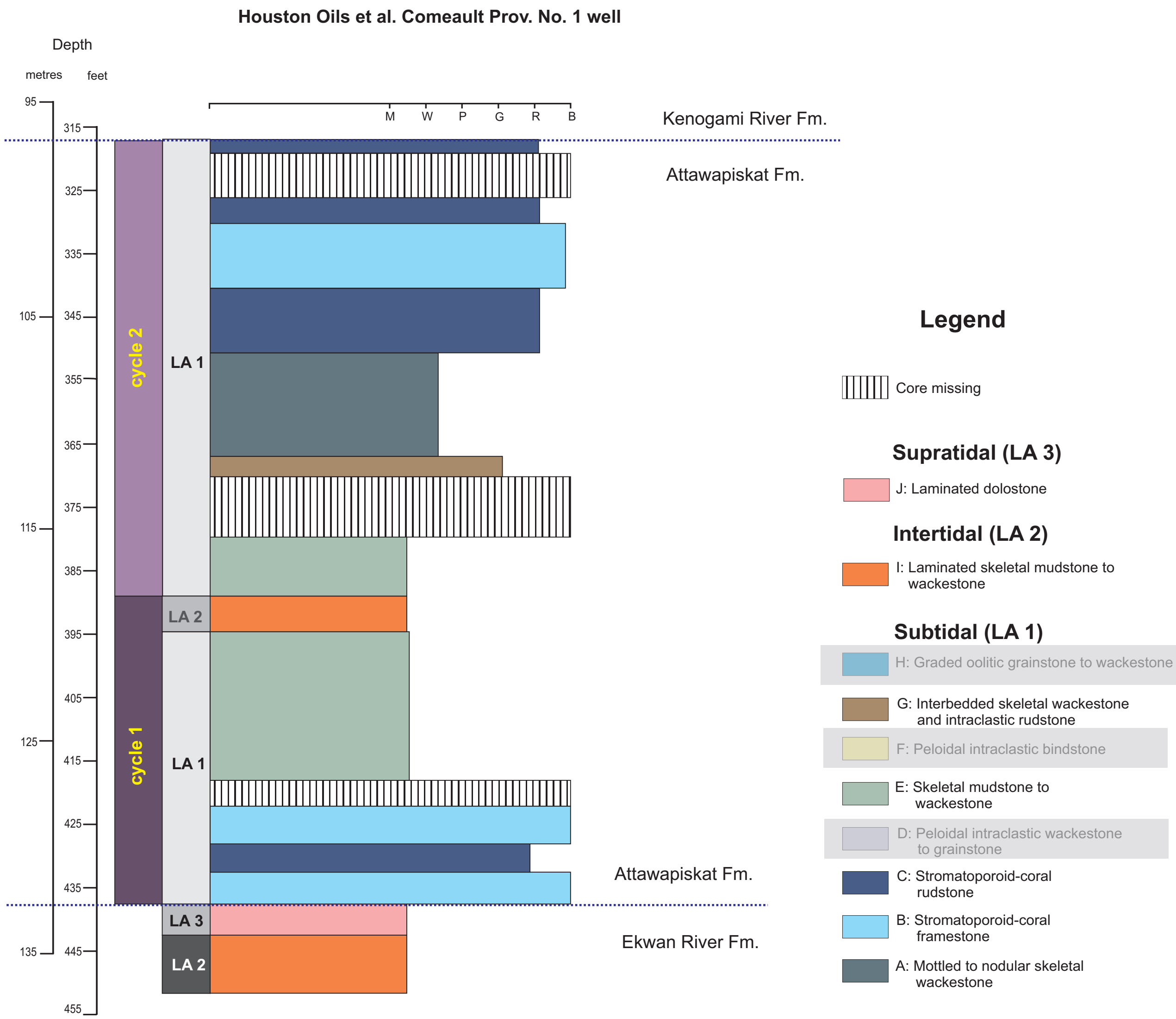

Figure GS-14-4: *Stratigraphic section of the Attawapiskat Formation in the Houston Oils et al. Comeault Prov. No. 1 core showing the lithofacies, lithofacies associations and cyclicity (modified from Ramdoyal, 2012). Lithofacies that are greyed out in the legend were not observed in this core. Abbreviations: Fm., Formation; LA, lithofacies association; M, mudstone; W, wackestone; P, packstone; G, grainstone; R, rudstone; B, boundstone.*

core, LA 1 consists of interbedded lithofacies F and G, while in Kaskattama it consists of lithofacies A, D and F.

The three cycles recognized in the Whitebear core are tentatively correlated to the three cycles in the Kaskattama core (Figure GS-14-9). Correlations to the Comeault core were not attempted due to the poor core recovery. Cycle 1 in the Whitebear core has significantly thinner subtidal lithofacies and thinner reefal intervals than cycle 1 in the Kaskattama core. In contrast, cycles 2 and 3 in both cores are of comparable thickness, but the supratidal lithofacies association is absent in both cycles in the Kaskattama core, and in cycle 3 in the Whitebear core. The three cycles are part of an overall shallowing-upward succession in the Attawapiskat Formation. These observations are consistent with the paleogeographic reconstruction of Suchy and Stearn (1992).The Whitebear well is located near the basin rim where sedimentation would have been more responsive to relative sea-level fluctuations in comparison to the Kaskattama well, which is located further basinward. The three Attawapiskat Formation cycles recognized in this study were also described by Suchy and Stearn (1992) in their sequence stratigraphic study of Lower Silurian strata in the Hudson Bay and Moose River basins. Cycle 1 of this study corresponds to their parasequences A1 to A3, cycle 2 to parasequences A4 and A5, and cycle 3 to parasequence A6. These cycles are interpreted to represent the more significant relative sea-level changes recorded in the Attawapiskat Formation.

Reservoir potential

The Attawapiskat Formation is present throughout most, if not all, of the Hudson Bay Basin. It was found to

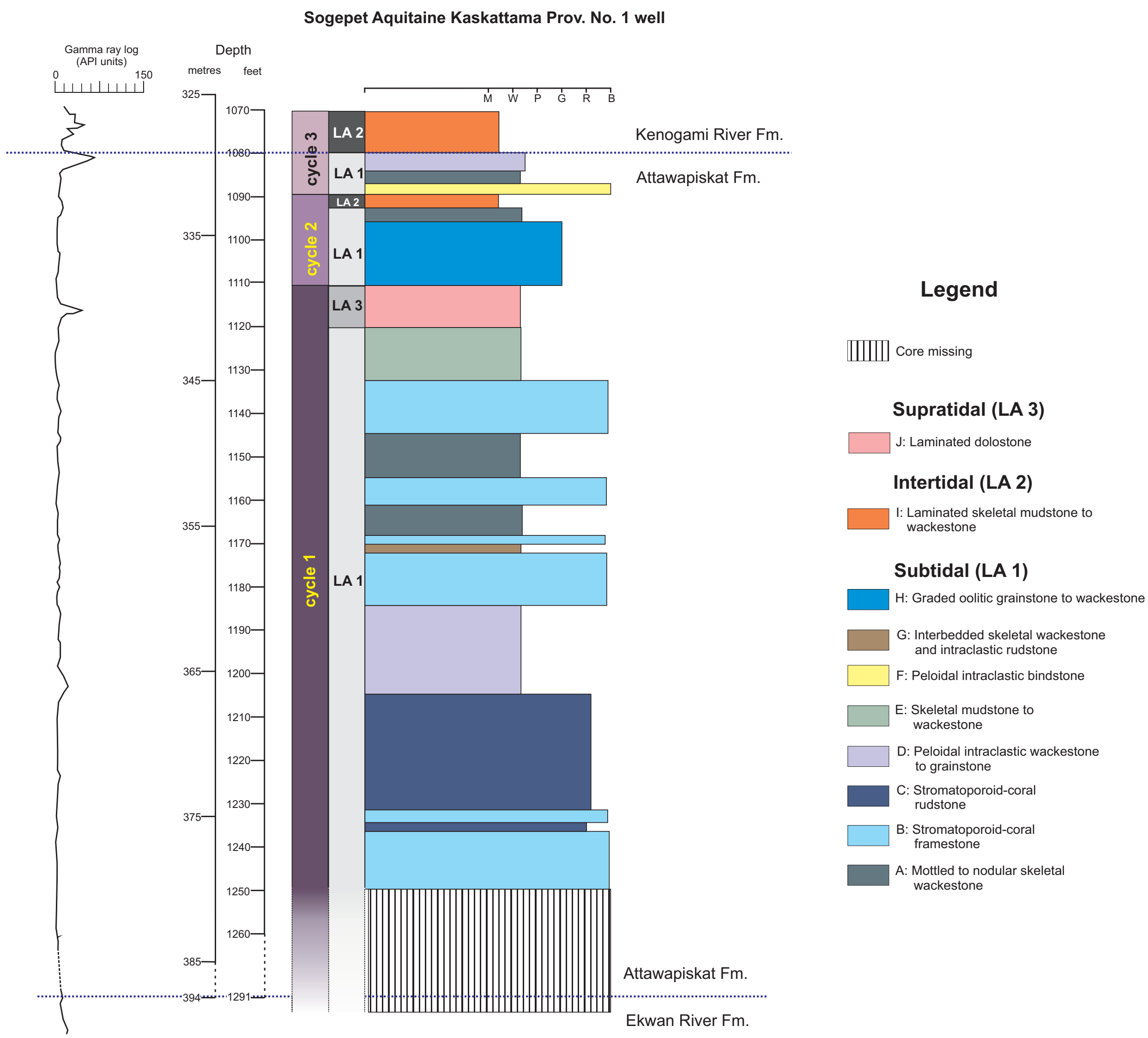

Figure GS-14-5: *Stratigraphic section of the Attawapiskat Formation in the Sogepet Aquitaine Kaskattama Prov. 1 core showing the lithofacies, lithofacies associations and cyclicity (modified from Ramdoyal, 2012). Abbreviations: Fm., Formation; LA, lithofacies association; M, mudstone; W, wackestone; P, packstone; G, grainstone; R, rudstone; B, boundstone.*

be the best potential conventional reservoir candidate in the Paleozoic sequence due to its porous and reefal nature. Primary porosity was found to range from 5 to 40%, and includes interparticle, intraparticle and fenestral porosity. Secondary dissolution porosity is generally higher, ranging from 5 to 55%, and consists of predominantly microvuggy porosity and localized intercrystalline, vuggy and mouldic porosity. The lithofacies considered to have the best reservoir potential are lithofacies C (stromatoporoid-coral rudstone), E (skeletal mudstone to wackestone), H (graded oolitic grainstone to wackestone), I (laminated skeletal mudstone to wackestone) and J (laminated dolostone).

Lithofacies J, which has intercrystalline porosity of 20–40%, is considered to have the highest reservoir potential. These high porosity values are in line with classic dolomicrite reservoirs (Choquette and Pray, 1970; Roehl and Choquette, 1985; Moore, 2001). Locally, high porosity in lithofacies I (15– 40%) is due to laminoid fenestrae. The interconnectedness of the fenestrae may facilitate fluid and gas migration. The reef flank lithofacies (lithofacies C) also has high reservoir potential with porosity ranging from 20 to 40%, which is largely interparticle and microvuggy. Interparticle pores have a wide range of shapes and sizes due to the variable shape and size of the reef detritus. Intraparticle porosity is also significant within stromatoporoids, tabulate and rugose corals. Microvuggy dissolution porosity affects skeletal allochems, micrite matrix, syntaxial calcite overgrowths and blocky calcite cement. Minor vugs, up to 1.3 cm in diameter occur, as well as moulds of skeletal allochems, dolomite and fluorite.

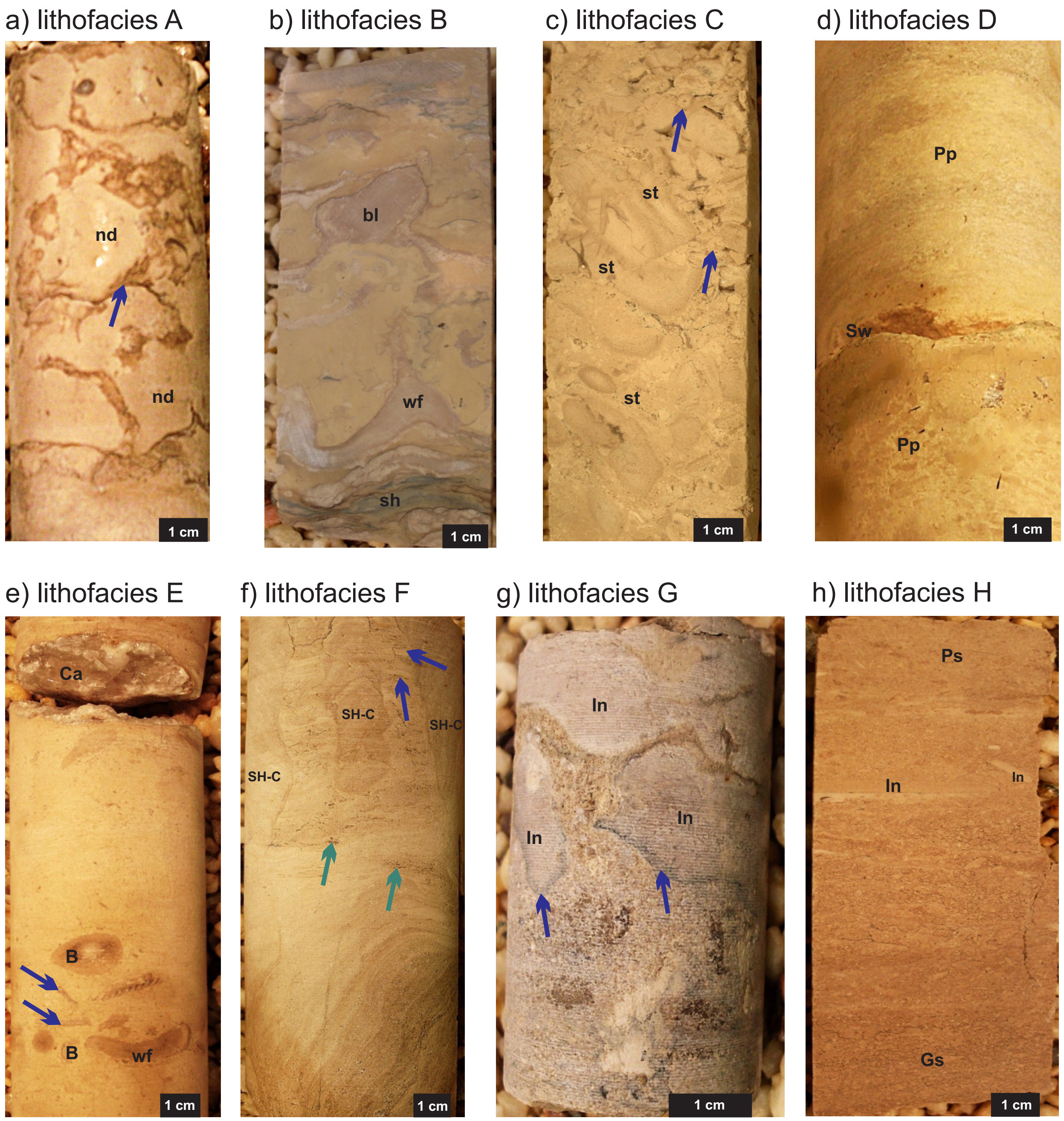

Figure GS-14-6: *Core from the Merland et al. Whitebear Creek Prov. well showing the subtidal lithofacies association:* ***a)*** *lithofacies A (mottled to nodular skeletal wackestone), showing skeletal wackestone nodules (nd) separated by dark brown internodular lime mudstone matrix (blue arrow), from a depth of 61.54 m;* ***b)*** *lithofacies B (stromatoporoid-coral framestone), showing fragmented and in situ wafer (wf) and bulbous (bl) stromatoporoids in a skeletal wackestone matrix overlying a shaly lamina (sh), from a depth of 59.77 m;* ***c)*** *lithofacies C (stromatoporoid-coral rudstone), showing fragments of stromatoporoids (st) and crinoids (blue arrows), from a depth of 41.79 m;* ***d)*** *lithofacies D (peloidal intraclastic wackestone to grainstone), showing peloidal packstone (Pp) interbedded with skeletal wackestone (Sw), from a depth of 54.86 m;* ***e)*** *lithofacies E (skeletal mudstone to wackestone), showing a skeletal wackestone with brachiopod fragments (B and blue arrows), wafer stromatoporoid (wf), and a coarse-crystalline, blocky calcite filling fractures (Ca), from a depth of 50.14 m;* ***f)*** *lithofacies F (peloidal intraclastic bindstone), showing stromatolites consisting of stacked hemispheroids with constant diameter domes (SH-C), intraclasts (blue arrows) and small vugs (green arrows), from a depth of 34.90 m;* ***g)*** *lithofacies G (interbedded skeletal wackestone and intraclastic rudstone), showing large skeletal wackestone intraclasts (In) rimmed with oxide staining (blue arrows) in a crinoidal grainstone matrix, from a depth of 34.78 m; and* ***h)*** *lithofacies H (graded oolitic grainstone to wackestone), showing an oolitic grainstone (Gs) bed with intraclasts (In) grading upward to an oolitic packstone (Ps), from a depth of 31.25 m (modified from Ramdoyal, 2012). Top direction of core is top of image.*

Lithofacies E locally displays high microvuggy porosity in the micrite matrix (up to 55%), whereas lithofacies H displays the same type of porosity (up to 30%) in ooids, peloids, aggregate grains and intraclasts. These lithofacies would likely not serve as a primary target on their own, but could serve to extend a potential pay zone.

Hydrocarbon exploration

The Attawapiskat Formation presents itself as an excellent reservoir rock. While hydrocarbon exploration has yet to be successful, the location of exploratory sites has been based on little data and with limited knowledge on the history of this basin's evolution. The detailed work done in this study supports Suchy and Stearn's (1992) paleogeographic reconstruction and provides a better understanding of the evolution of the Attawapiskat Formation, particularly the locations of productive reefal growth. With this in mind, the best locations to explore for onshore hydrocarbons within the Attawapiskat Formation in Manitoba is where younger Devonian and Upper Silurian rock outcrop to the northeast of the Comeault well. Of course, this area of good potential is not restricted to the onshore portion, but would also continue offshore, rimming the basin, as shown by the reef growth geometry in Suchy and Stearn (1992, Figure 18c).

Figure GS-14-7: *Core from the Merland et al. Whitebear Creek Prov. well showing examples of lithofacies I (laminated peloidal-skeletal mudstone to wackestone) from the intertidal lithofacies association:* ***a)*** *microbially laminated mudstone showing fissile, argillaceous laminae, with desiccation cracks (blue arrows), from a depth of 37.19 m;* ***b)*** *microbially laminated mustone with thin bed of peloid-intraclast packstone (green arrow), from a depth of 36.24 m (modified from Ramdoyal, 2012). Top direction of core is top of image. Abbreviations: ag, argillaceous laminae.*

Economic considerations

The Attawapiskat Formation is a dominantly reefal unit that is present throughout the Hudson Bay Basin.

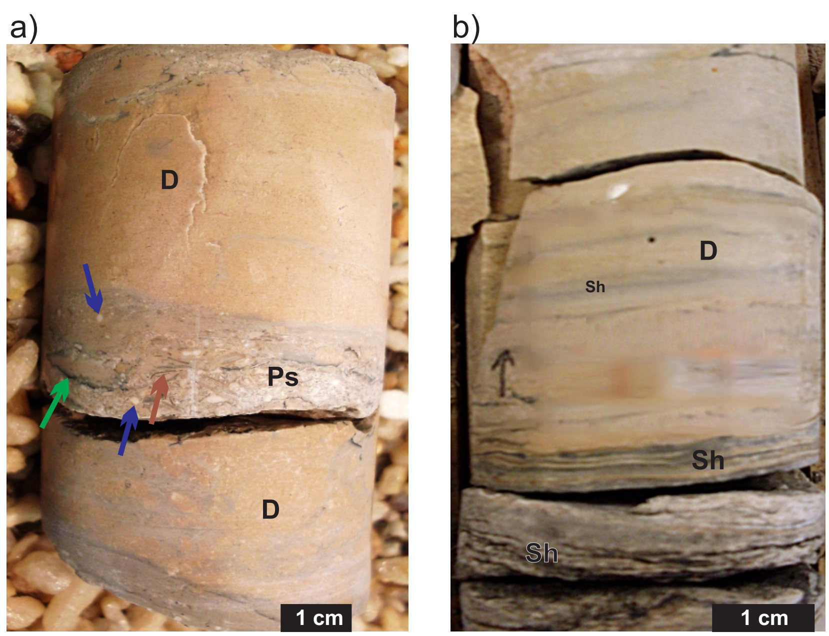

Figure GS-14-8: *Core from the Merland et al. Whitebear Creek Prov. well showing examples of lithofacies J (laminated dolostone) from the supratidal lithofacies association:* ***a)*** *dolostone (D) with a skeletal packstone (Ps) bed rich in crinoids (blue arrows) and inarticulate brachiopod shells (brown arrow), bitumen residue in subhorizontal fractures (green arrow), from a depth of 38.05 m;* ***b)*** *dolostone (D) with shaly intervals (Sh) along which fissility is pronounced, from a depth of 32.67 m (modified from Ramdoyal, 2012). Top direction of core is top of image.*

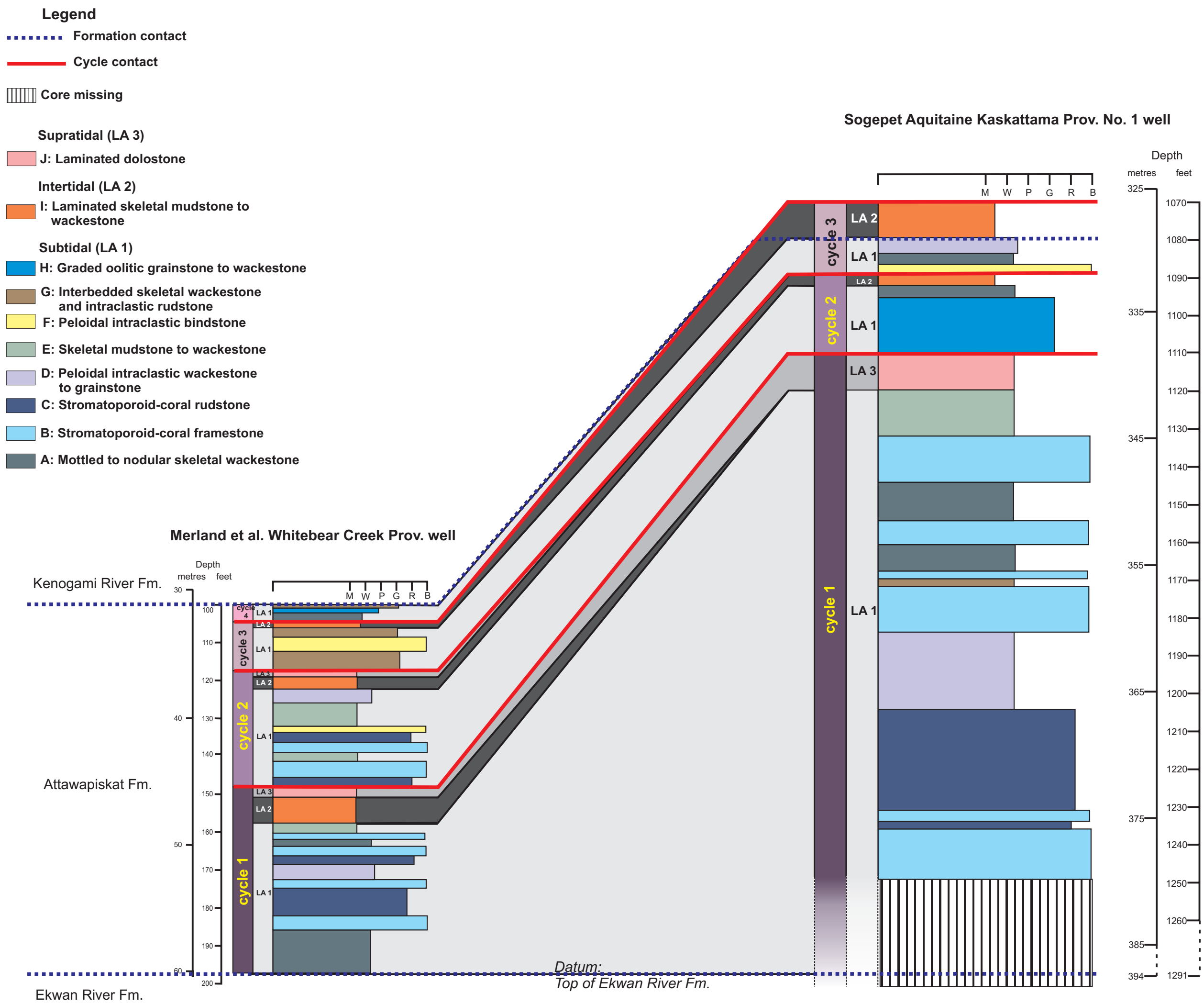

Figure GS-14-9: *Correlation of lithofacies associations and depositional cycles (modified from Ramdoyal, 2012). Abbreviations: Fm., Formation; LA, lithofacies association; M, mudstone; W, wackestone; P, packstone; G, grainstone; R, rudstone; B, boundstone.*

This formation has excellent potential as a reservoir rock. While there is currently no hydrocarbon production within the Hudson Bay Basin, understanding the detailed stratigraphy of the formation and the distribution of the different units in space and time will help to decipher the environmental setting in which this formation was deposited. This in turn, will allow specific high-porosity lithofacies to be targeted and exploration strategies to be developed to help locate oil traps. Hopefully, the information presented in this paper will aid in maximizing potential hydrocarbon production, while also reducing exploration and development costs.

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