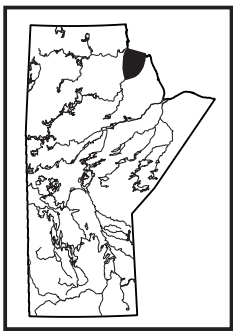
GS-13 Reconnaissance field mapping of Paleozoic rocks along the Churchill River and Churchill coastal area, northeastern Manitoba (parts of NTS 54E, L, K)

by M.P.B. Nicolas and G.A. Young[1]



Nicolas, M.P.B. and Young, G.A. 2014: Reconnaissance field mapping of Paleozoic rocks along the Churchill River and Churchill coastal area, northeastern Manitoba (parts of NTS 54E, L, K); *in* Report of Activities 2014, Manitoba Mineral Resources, Manitoba Geological Survey, p. 148–160.

Summary

The 2014 field component for phase 2 of the Geological Survey of Canada's Geo-mapping for Energy and Minerals program in Manitoba consisted of visits to key outcrop locations along the Churchill River and in the Churchill coastal area. Lithostratigraphic type sections for the Upper Ordovician Portage Chute, Surprise Creek, Caution Creek, Chasm Creek and Red Head Rapids formations are all located along the Churchill River and its tributaries. All the type section localities were visited by the authors, with the exception of the type locality for the Caution Creek Formation (for this formation, exposures at other sites were visited). The exposures visited around Churchill provide a comparative section, demonstrating the stratigraphic complexities caused by proximity to the Proterozoic Churchill quartzite, which stood out as islands during the Ordovician.

The Lower Paleozoic strata visited along the Churchill River correlate well with observations the authors have made in core from boreholes, and in field visits to other parts of the Hudson Bay Basin. Although there are broad similarities to strata of similar age in other parts of the basin, some of the sections visited in the Churchill coastal area exhibit features that are distinctly local in distribution and reflective of the diverse microenvironments characteristic of nearshore conditions.

Introduction

The Manitoba Geological Survey's (MGS) participation in the Hudson–Ungava Project of the Geological Survey of Canada's (GSC) second phase of Geo-mapping for Energy and Minerals program (GEM-2) has two primary components: field and core. The report by Nicolas et al. (GS-12, this volume) discusses the details of this GEM-2 project, plans for core work and some preliminary results, whereas this report describes the 2014 field component.

Following preliminary work in the 19th century (Bell, 1880; Tyrrell, 1897), scientists working with the GSC carried out mapping, stratigraphic and paleontological studies in the Manitoba part of the Hudson Bay Lowland (HBL) in the 1950s and 1960s (Nelson, 1963, 1964; Sanford et al., 1968; Norris and Sanford, 1969; Norford, 1971; Cumming, 1975). A regional synthesis by Norris (1993) summarizes this work, combining it with field research on other parts of the Hudson Bay Basin and drill cores. Recent research and advances in basin understanding are summarized in Lavoie et al. (2013).

Studies of Paleozoic strata and fossils along the Manitoba Hudson Bay coast include work by Johnson and Baarli (1987), Skinner and Johnson (1987), Johnson et al. (1988), Elias et al. (1999), Elias and Young (2000), Nelson and Johnson (2002), Rudkin et al. (2003), Young et al. (2003), Young et al. (2007), Rudkin et al. (2008), Young et al. (2012) and Robson and Young (2013). The MGS's Paleozoic reconnaissance mapping in the HBL had been limited, with some work done along the Nelson River (Bezys, 1990), and a brief visit to the Churchill River by H. McCabe in 1979 (H. McCabe, unpublished field notes, 1979).

In spite of all the previous work done in the area, certain questions remained. Reconnaissance mapping of the Churchill River was selected for 2014 field study because of the importance of this section to the Paleozoic stratigraphy of the Hudson Bay Basin and to help with long distance correlations. The lithostratigraphic type sections of the Upper Ordovician Portage Chute, Surprise Creek, Caution Creek, Chasm Creek and Red Head Rapids formations are located along the Churchill River (Nelson, 1963, 1964). The names of the Bad Cache Rapids Group and the Churchill River Group are also derived from sections along this river (Nelson, 1963, 1964).

The Churchill coastal area provides a comparative section, demonstrating the stratigraphic complexities caused by proximity to the Proterozoic Churchill quartzite, which stood out as islands during the Late Ordovician. The ridges formed by these ancient islands still dominate the landscape today. Along the coast, outcrops are mostly visible only at low tide. A stratigraphic succession from the Upper Ordovician Churchill River Group, which directly overlies the Churchill quartzite, up through the Red Head Rapids Formation (also referred to as the Port Nelson Formation in this area by some researchers) and into the Silurian Severn River Formation is preserved here (Elias et al., 1999; M.W. Demski, B.J. Wheadon, L.A. Stewart, R.J. Elias, G.A. Young, G.S. Nowlan and E.P. Dobrzanski, work in progress, 2014).

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Visits to these sites provided a much-needed frame of reference to assist in understanding 1) the complexities of the Churchill coastal area and 2) the long-distance correlations to subsurface core information from boreholes located in the southeastern half of the HBL in Manitoba (see Nicolas et al., Figure GS-12-2, this volume, for a map showing borehole locations).

Churchill River

With helicopter support, the authors visited key sites along the Churchill River (Figure GS-13-1) over the course of three days, with particular focus on type section locations as described by Nelson (1963, 1964; see also Cumming, 1975). Table GS-13-1 shows the list of field stations, locations, stratigraphy and site significance. Site

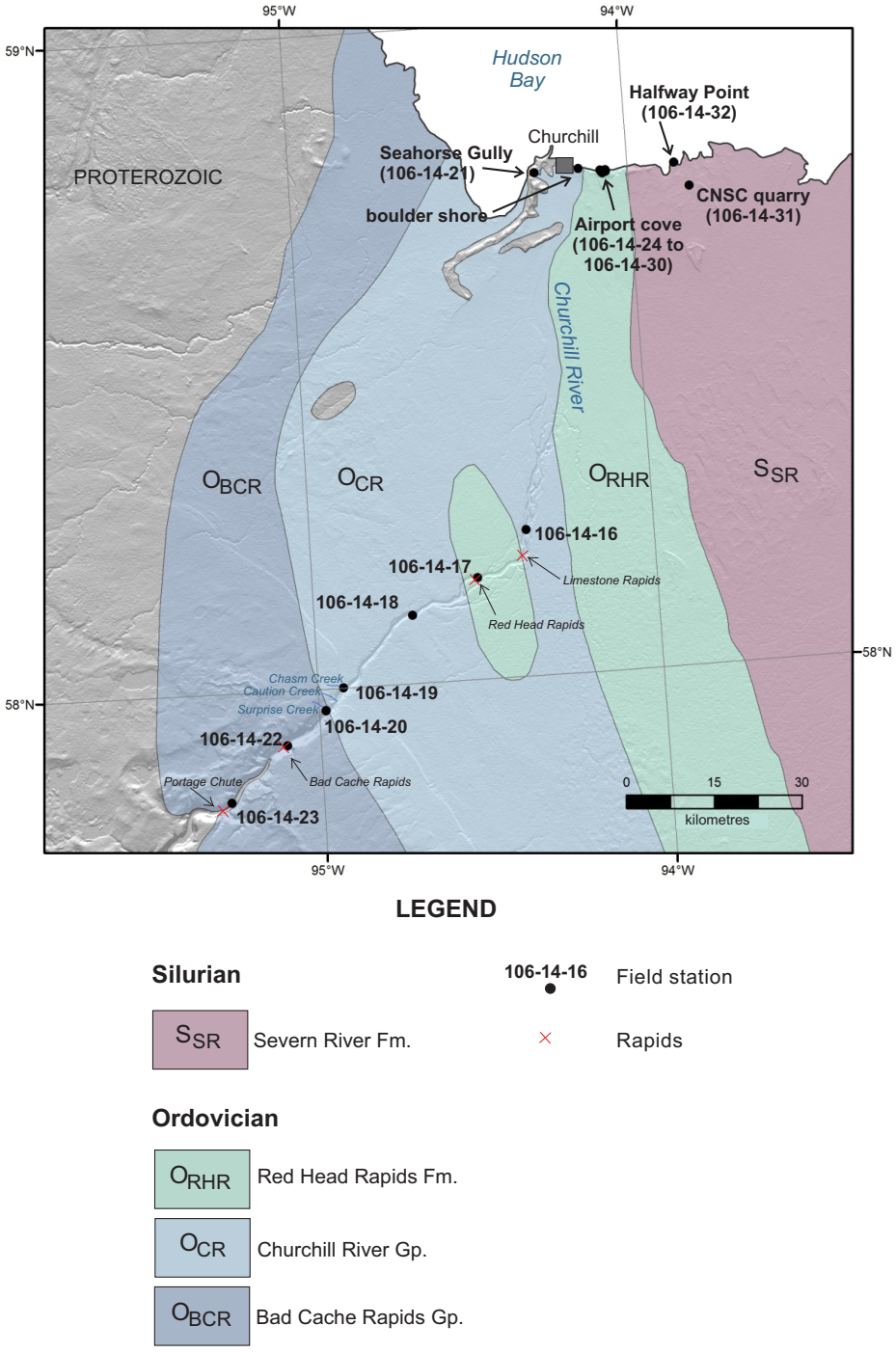

Figure GS-13-1: *Paleozoic geology of the Churchill River and Churchill coastal area, northeastern Manitoba, showing the locations and names of field stations. Geology from Nicolas et al. (Figure GS-12-2, this volume). Background image, with hillshaded underlay, was generated using digital elevation data (United States Geological Survey, 2002). Abbreviations: Fm., formation; Gp., group; CNSC, Churchill Northern Studies Centre.*

Table GS-13-1: List of field stations visited along the Churchill River and in the Churchill coastal area, northeastern Manitoba.

Field station	Easting (NAD 83, Zone 15)	Northing (NAD 83, Zone 15)	Latitude	Longitude	Ground elevation* (m asl)	Stratigraphic unit	Comment
106-14-16	419517	6454508	58.22436299	-94.37023899	18.72	Chasm Creek Fm.	
106-14-17	410616	6447083	58.15597898	-94.51887201	40.94	Red Head Rapids Fm.; Chasm Creek Fm.	Contact between Red Head Rapids and Chasm Creek formations is visible
106-14-18	398962	6441662	58.104803	-94.71446922	48.00	Chasm Creek Fm.	
106-14-19	386114	6430316	57.99983704	-94.92684698	56.77	Chasm Creek Fm.; Caution Creek Fm.	Chasm Creek; type section for Chasm Creek Fm.
106-14-20	382828	6426687	57.96640196	-94.98061697	63.70	Portage Chute Fm.; Surprise Creek Fm.	Surprise Creek; type section for Surprise Creek Fm.
106-14-20	382827	6426782	57.96725398	-94.98067204	84.73	Surprise Creek Fm.; Caution Creek Fm.	Surprise Creek; type section for Surprise Creek Fm.; located at the falls
106-14-21	426306	6514949	58.76825899	-94.27420098	26.45	Churchill River Gp.	Seahorse Gully; Precambrian–Ordovician unconformity
106-14-22	375768.5	6421362	57.91669308	-95.09706457	NA	Bad Cache Rapids Gp., Portage Chute Fm.	Bad Cache Rapids; type section for Bad Cache Rapids Gp.
106-14-23	365417	6412418	57.83341301	-95.26659703	98.23	Portage Chute Fm.	Downstream from Portage Chute; type section for Portage Chute Fm.
106-14-24	437640	6514181	58.76315600	-94.07806202	10.00	Severn River Fm.	Airport cove west
106-14-25	438445	6514171	58.76318098	-94.06414303	6.66	Red Head Rapids (Port Nelson) Fm.	Airport cove east
106-14-26	437894	6513944	58.76106204	-94.07360301	5.45	Red Head Rapids (Port Nelson) Fm.	Airport cove west
106-14-27	437873	6514005	58.76160099	-94.07397601	2.17	Red Head Rapids (Port Nelson) Fm.	Airport cove west
106-14-28	438460	6514379	58.76504503	-94.06392996	2.51	Churchill River Gp.	Airport cove east; Precambrian island
106-14-29	438497	6514261	58.76399201	-94.06327198	1.70	Churchill River Gp. to Red Head Rapids (Port Nelson) Fm.	Airport cove east
106-14-30	437552	6514438	58.76544502	-94.07964603	4.13	Severn River Fm.	Airport cove west
106-14-31	452490	6510501	58.73199603	-93.82059501	26.12	Severn River Fm.	Location of M-4-2003 drillhole (Young et al., 2003)
106-14-32	450203	6514613	58.76866702	-93.86099503	-1.27	Severn River Fm.	Site describe in Norford (1971)

* Ground elevation reading as determined on hand-held GPS.

descriptions, joint azimuth measurements, samples and photos were taken at each site. The lithological samples collected will be analyzed for $\delta^{13}C$ and $\delta^{18}O$ stable isotopes (using the same methodology described in Nicolas et al. [GS-12, this volume]), and select samples may be analyzed for conodonts. In situ macrofossil specimens were collected with hammer and chisel at each site; where in situ material could not be readily extracted, specimens in sharp scree blocks were collected from below vertical cliffs. Fossil specimens will be deposited in the collections of The Manitoba Museum. In this report, macrofossil names for the Churchill River sites are based largely on field identifications. Macrofossil identifications for Churchill area sites are based partly on material in the collections of The Manitoba Museum.

The stratigraphic sections exposed along the banks of the Churchill River and its tributaries represent the Ordovician formations, from the Portage Chute Formation and its contact with the underlying Proterozoic granitic rocks, up through to the Red Head Rapids Formation (Figure GS-13-2).

Portage Chute Formation

The Upper Ordovician (lower Katian) Portage Chute Formation of the Bad Cache Rapids Group was visited at three field stations: 106-14-20, 106-14-22 and 106-14-23 (Figure GS-13-1). Exposures of this formation line the Churchill River for several kilometres, from Portage Chute to Bad Cache Rapids, but the vertical steep cliffs and near absence of helicopter-accessible landing sites makes viewing these outcrops difficult. Station 106-14-22 is the Bad Cache Rapids Group type section, whereas station 106-14-23 (Figure GS-13-3) is the type section for the Portage Chute Formation (located downstream from Portage Chute; Figure GS-13-1). This station features an exposure of Proterozoic granite that forms the base of the river bed. The Portage Chute Formation unconformably overlies the granite, and forms steep vertical cliffs along the river (Figure GS-13-3a).

The Portage Chute Formation consists of two members: a lower sandstone and an upper limestone. The lower member (member 1 of Nelson, 1964) consists of a light grey to dark rusty brown, quartz-rich, poorly sorted,

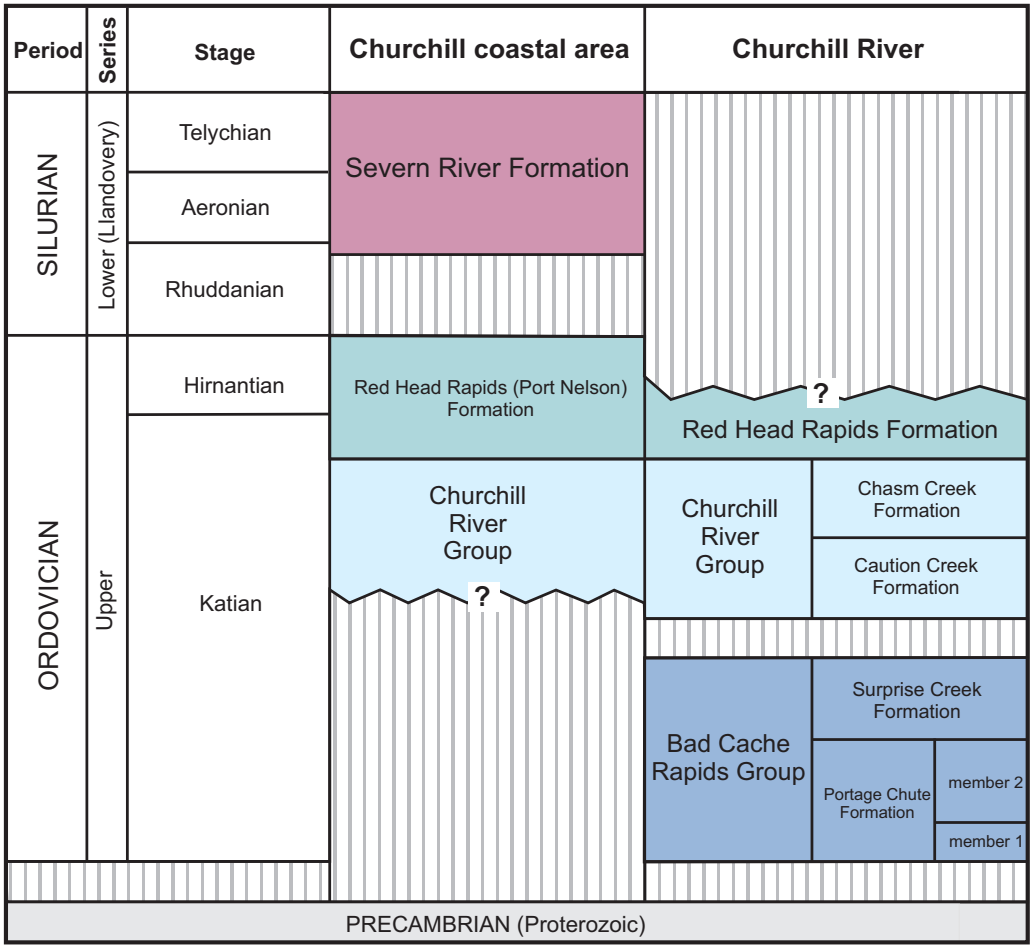

Figure GS-13-2: *Stratigraphic chart for the Hudson Bay Lowland along the Churchill River and Churchill coastal area, northeastern Manitoba. Stage usage is from Norris (1993), Norford (1997), Zhang and Barnes (2007), M.W. Demski, B.J. Wheadon, L.A. Stewart, R.J. Elias, G.A. Young, G.S. Nowlan and E.P. Dobrzanski (work in progress, 2014), and International Commission on Stratigraphy (2014).*

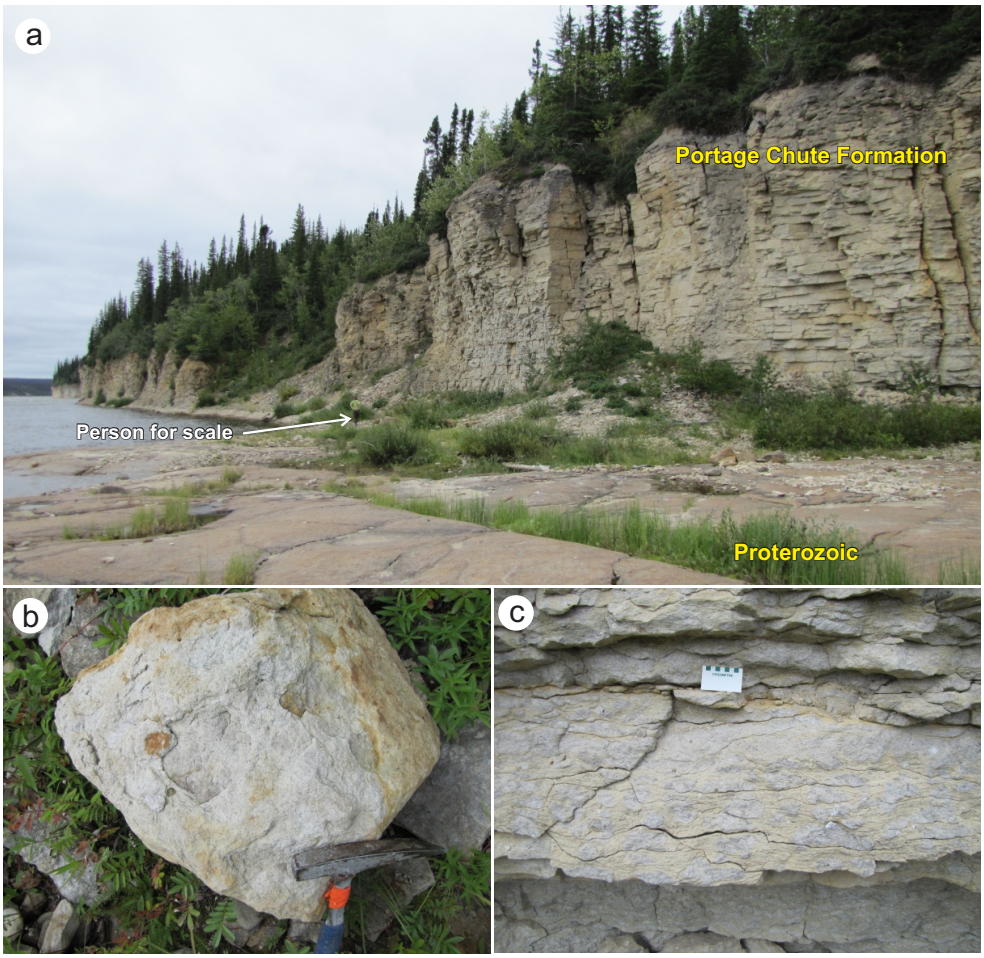

Figure GS-13-3: *Exposure just downstream from Portage Chute at station 106-14-23 showing* ***a)*** *the vertical cliffs of the Portage Chute Formation directly overlying the Proterozoic granitic surface;* ***b)*** *close-up of a sandstone boulder from member 1 of the Portage Chute Formation; and* ***c)*** *close-up of nodular and argillaceous wackestone of member 2 of the Portage Chute Formation. Location of station 106-14-23 is shown in Figure GS-13-1.*

variably consolidated sandstone (Figure GS-13-3b). The authors attempted to locate this member, but all bedrock exposures of the sandy lithology at the section visited were hidden by an extensive apron of rubble at the base of the riverbank cliffs. Large boulders at station 106-14-23 were the only evidence that this member occurred nearby. The thickness of the lower member is estimated to be <1 m at this station. This member represents the initial flooding of the Hudson Bay Basin by the sea during the Ordovician.

The upper member consists of a light grey, slightly dolomitic, bioclastic to argillaceous and nodular wackestone to packstone. Finely bedded, this member has a characteristic burrow-mottled appearance with *Thalassinoides*-like mottles and a very light green to yellow argillaceous matrix (Figure GS-13-3c). Fossils are common to sparse through the section, and include solitary rugose corals, tabulate corals (*Catenipora*, *Calapoecia*?), strophomenid brachiopods, gastropods (*Maclurina, Hormotoma*?), cephalopods, trilobites and receptaculitids (probably *Fisherites*). Floating, poorly sorted, angular, quartz sand grains are common but decrease in abundance upsection. Open vertical joints are common, with occasional joints lined with calcite crystals. This member represents the continued flooding of the basin under normal marine conditions (Lavoie et al., 2013).

The contact with the overlying Surprise Creek Formation is seen near the mouth of Surprise Creek, at its confluence with the Churchill River (station 106-14-20; Figure GS-13-4a). The contact is gradational (Figure GS-13-4a, transitional beds), with a transition occurring over approximately 1 m of section. This is marked mostly by the gradual disappearance of yellow burrow mottles upsection, and a change from thicker beds to thin and platy beds.

Surprise Creek Formation

The Upper Ordovician (Katian) Surprise Creek Formation of the Bad Cache Rapids Group was visited only

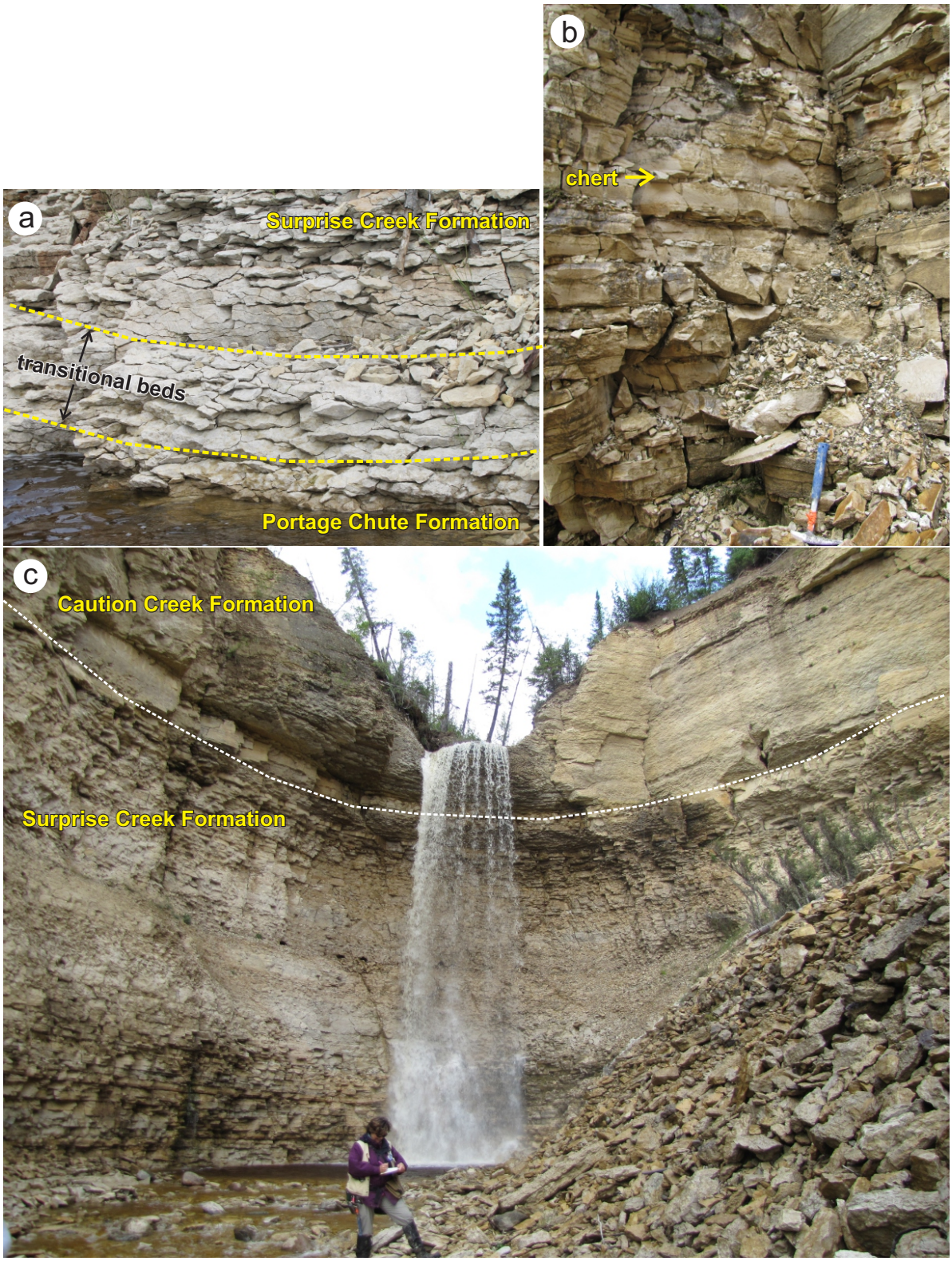

Figure GS-13-4: *Exposures on Surprise Creek at station 106-14-20 showing* ***a)*** *the transitional beds making up the contact between the Portage Chute and Surprise Creek formations;* ***b)*** *a close-up of laminated mudstone of the Surprise Creek Formation with abundant chert lenses; and* ***c)*** *the contact between the Surprise Creek and Caution Creek formations at the waterfall. Location of station 106-14-20 is shown in Figure GS-13-1.*

at station 106-14-20 on Surprise Creek (Figure GS-13-4). This is the type section for this formation (Nelson, 1964). The lower beds (equivalent to member 1 of Nelson, 1964), located near the mouth of the creek at the Churchill River, are dominantly light to medium brown, bioclastic, interbedded wackestone and packstone, finely bedded and often breaking off in thin plates. Open vertical joint sets are common. Macrofossils are mostly fragmented, but occasional well-preserved intact fossils can be found; fossils include solitary rugose corals, strophomenid and rhynchonellid brachiopods, the orthid brachiopod *Dinorthis*(?), gastropods, trilobites, crinoid fragments and receptaculitids (probably *Fisherites*). In these lower beds, strophomenid brachiopods are occasionally abundant, covering bedding-plane surfaces. This formation represents a period of shallowing in the basin leading to a more restricted evaporitic environment (Lavoie et al., 2013).

Going upstream along Surprise Creek, the exposures change from 2 m creek walls to vertical cliffs at the mouth of a roughly 15 m high waterfall (Figure GS-13-4c). Upsection, the lithology changes to one with very few to no fossils, but dominated by chert nodules and lenses within a massive to finely laminated beige mudstone (Figure GS-13-4b). This represents members 2 to 7 of Nelson (1964). The chert nodules are grey to brown and commonly have tripolitic rims. Some chert nodules exhibit well-developed burrow mottling.

The contact with the overlying Caution Creek Formation was only seen at Surprise Creek (Figure GS-13-4c); it is exposed high in vertical cliffs beside the creek and near the waterfall. From a distance this contact appears fairly sharp, marked by a thin, dark brown, argillaceous, mudstone bed and by a change in bedding character from thin and platy bedding of the Surprise Creek Formation to the thicker bedded, blockier Caution Creek Formation.

Caution Creek Formation

The Upper Ordovician (Katian) Caution Creek Formation of the Churchill River Group was seen at station 106-14-19 (Figure GS-13-5), at the base of the section on Chasm Creek, and at station 106-14-20, at the top of the section on Surprise Creek (Figure GS-13-4c). The best outcrop is on Chasm Creek, where it is exposed at and above the creek water level. It consists of a light brown packstone, bioclastic and fossiliferous throughout. Open vertical joint sets are common. Fossils include solitary rugose corals, colonial corals, rhynchonelliformean brachiopods, gastropods, cephalopods, trilobites (including *Isotelus* sp. and calymenines), and abundant crinoid ossicles, which are occasionally articulated. Porosity within the unit is moderate to good, mostly pinpoint in size but with well-developed mouldic and vuggy porosity in places; vugs are occasionally filled to partially filled with white calcite crystals. The Caution Creek Formation was deposited in normal marine subtidal conditions. The crinoid grains are sufficiently abundant that some of the beds may represent a crinoid shoal environment.

The upper contact with the Chasm Creek Formation was only visited at Chasm Creek, where it is located high on the vertical cliff (Figure GS-13-5a). From a distance, this contact appears fairly sharp and is distinguished mostly by the change in character from the thin and platy beds characteristic of the Caution Creek Formation at this location, to the blockier and thicker bedded appearance the Chasm Creek Formation has at this location.

The type section of the Caution Creek Formation is located along the banks of Caution Creek, which meets the Churchill River on the north bank between Chasm Creek and Surprise Creek (Figure GS-13-1). This site was not visited; an aerial helicopter survey by the authors indicated that access to the outcrop would be very difficult due to the steepness and vegetative overgrowth of the creek banks.

Chasm Creek Formation

The type section of the Upper Ordovician (Katian) Chasm Creek Formation of the Churchill River Group was visited at station 106-14-19 (Figure GS-13-5) on Chasm Creek, slightly upstream from where the creek meets the Churchill River (Figure GS-13-1). This formation is also exposed at stations 106-14-16, 106-14-17 (Figure GS-13-6) and 106-14-18. This formation consists predominantly of interbedded fossiliferous wackestone and packstone, commonly bioclastic, with occasional mudstone and light green argillaceous mudstone beds (Figure GS-13-6b). The calcareous lower half of the formation can be seen at station 106-14-16, whereas the more dolomitic mid to upper beds are visible at station 106-14-18. At station 106-14-17, the exposure consists entirely of dolostone, where it represents the uppermost beds of the formation. Open vertical joint sets are common at all sites.

This formation is mottled with *Thalassinoides* burrows, has intraformational breccia dominated by ripped-up pebble-sized algal fragments, and commonly has well preserved fossils, including solitary rugose corals (*Lobocorallium*?), colonial corals (including the rugosan *Palaeophyllum* and the tabulates *Calapoecia, Paleofavosites* and *Catenipora*), rhynchonelliformean brachiopods, large cephalopods (including endocerids), trilobites, and crinoid fragments. Some corals are in growth orientation. This formation represents the last Ordovician normal marine subtidal deposition, before the onset of restricted marine conditions during deposition of the overlying Red Head Rapids Formation. The upper contact with the overlying Red Head Rapids Formation (Figure GS-13-6a) is sharp.

Red Head Rapids Formation

The Upper Ordovician Red Head Rapids Formation was only visited at one location (station 106-14-17) where it directly overlies the Chasm Creek Formation (Figure

Figure GS-13-5: *Exposure along Chasm Creek at station 106-14-19 showing* ***a)*** *the contact between the Caution Creek Formation and the overlying Chasm Creek Formation; and* ***b)*** *close-up of the Caution Creek Formation. Location of station 106-14-19 is shown in Figure GS-13-1.*

GS-13-6a). This outcrop is part of an outlier from the formation edge, as see in Figure GS-13-1. At this location, the formation consists of thin to medium bedded, beige to buff dolomudstone with interbeds containing faint blue-grey mottles and faint light to medium brown fine laminae, with no visible porosity and no fossils (Figure GS-13-6c). Open vertical joint sets are common. The lower contact with the Chasm Creek is moderately sharp. The Red Head Rapids Formation represents a shallow-water, restricted intertidal to supratidal marine environment.

This formation got its name from the exposures along the Churchill River on a stretch from Red Head Rapids to just below Limestone Rapids (Nelson, 1964). The lithology at site 106-14-17 is consistent with reports of this formation in other parts of the basin, including on Southampton Island (Nunavut; Zhang, 2010; Lavoie et al., 2013), and in various cores in Manitoba and Ontario (Wong, 2011; Duncan, 2012; Lavoie et al., 2013).

Exposures in the Churchill coastal area

Upper Ordovician and Lower Silurian units in the Churchill coastal area are distinctly different from that anywhere else in Manitoba's HBL, due to the paleotopography that dominated and controlled deposition in this area. Outcrops visited along the Churchill coastal area show a cross-section through the Upper Ordovician to Lower Silurian formations, with varying rock types and

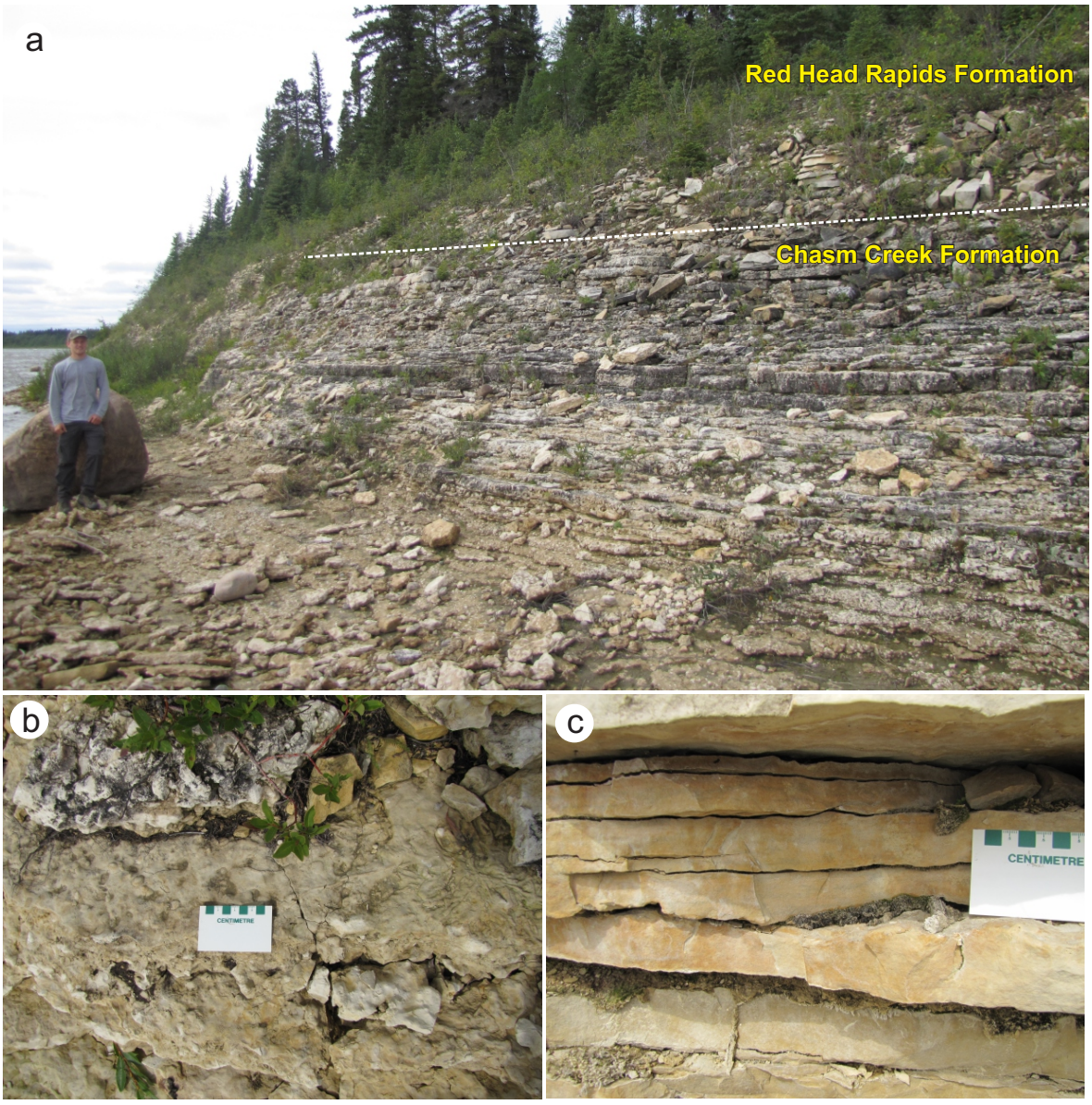

Figure GS-13-6: *Exposure along the Churchill River at Red Head Rapids at station 106-14-17 showing* ***a)*** *the contact between the Chasm Creek Formation and the overlying Red Head Rapids Formation;* ***b)*** *a close-up of the mottled wackestone to packstone of the Chasm Creek Formation; and* ***c)*** *a close-up of the blue-grey mottled and laminated mudstone of the Red Head Rapids Formation. Location of station 106-14-17 is shown in Figure GS-13-1.*

depositional environments typical of nearshore environments. The famous Ordovician rocky shoreline site near Churchill (boulder shore shown on Figure GS-13-1; see also Johnson et al., 1988; site 1 of Elias et al., 1999), assigned to the Churchill River Group, was not visited during this trip due to the presence of polar bears on the outcrop.

Airport cove

The section represented at Airport cove begins with the Upper Ordovician Churchill River Group, where it is directly in contact with the Proterozoic Churchill quartzite, up through the Red Head Rapids Formation (in this area, the Red Head Rapids Formation has been referred to by researchers as the Port Nelson Formation; see Lavoie et al. [2013] and Norford et al. [1998] for a discussion on the complexities associated with this stratigraphic assignment) to the Lower Silurian Severn River Formation (Figure GS-13-7a). The Bad Cache Rapids Group is not present in this area. Most of the section can only be seen at low tide. This cove was the site for three MGS boreholes: M-1-2003, M-2-2003 and M-3-2003 (locations shown on Figure GS-12-2, Nicolas et al., this volume; Young et al., 2003). Other research on Airport cove has included stratigraphic work by Elias et al. (1999) and

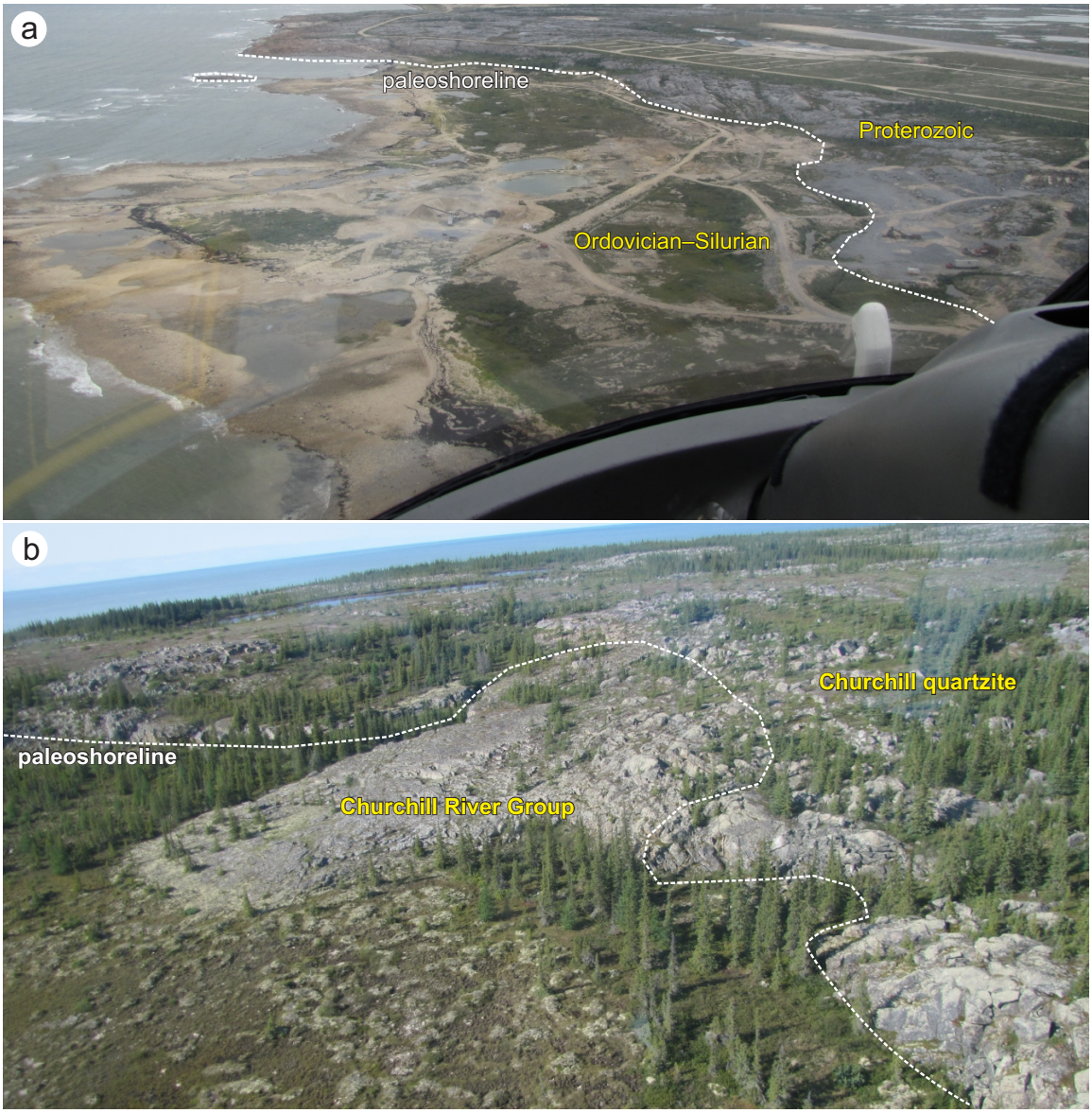

Figure GS-13-7: *Aerial photograph showing the paleoshorelines at* ***a)*** *Airport cove (stations 106-14-24 to 106-14-30) where there are exposures of the Churchill River Group, Red Head Rapids (Port Nelson) Formation and Severn River Formation; and* ***b)*** *Seahorse Gully (station 106-14-21) where the basal sandstone of the Ordovician Churchill River Group is lapping up directly onto the Proterozoic Churchill quartzite.*

M.W. Demski et al. (work in progress, 2014), and paleontological studies by Young et al. (2007, 2012) and Rudkin et al. (2008).

Airport cove is a broad embayment in a large ridge of Churchill quartzite; this ridge was one island within a paleoarchipelago in the Churchill area during the Ordovician (Nelson and Johnson, 2002). In the cove, the bottom of the section is characterized by a sandy dolomudstone (Elias et al., 1999) of the Churchill River Group directly lapping up against and overlying the Churchill quartzite, which formed a small resistant paleoisland within the cove (station 106-14-28). Changing microenvironments in proximity to the paleoshorelines are reflected in the variable and quick-changing lithologies seen at this locality. The basal sandy dolostone is medium grained, poorly sorted and medium grey with occasional dark blue–grey mottling. This grades into a medium brown dolomudstone with occasional floating sand grains, which then grades into a blue-grey and light brown laminated dolomudstone with occasional mottling consistent with a somewhat restricted paleoenvironment.

Upward, the lithologies undergo a transition to mottled dolostone consistent with normal marine environments (station 106-14-29). Open vertical joint sets are common. Fossils are common in some of these beds and include cephalopods (*Discoceras, Winnipegoceras,*

Westonoceras, Endoceras, Bickmorites, Ephippiorthoceras, Kochoceras, Richardsonoceras?), gastropods (*Maclurina, Hormotoma*), rhynchonelliformean brachiopods, aulacerid stromatoporoid sponges, tabulate corals and trilobites (including *Isotelus* sp.).

Above this, the lithologies and fossils are indicative of shallow, variable and generally restricted marine conditions. Strata assigned to the Red Head Rapids (Port Nelson) Formation include massive to laminated dolomudstone. Fossils are generally very rare in this unit, but it does include the Airport cove lagerstätte, the source for remarkable biota characterized by horseshoe crabs (*Lunataspis aurora*), eurypterids and green algae (seaweeds; Young et al., 2007, 2012; Rudkin et al., 2008). There were also brief intervals of normal marine conditions during Red Head Rapids (Port Nelson) Formation deposition, as evidenced from a fossil biota collected from a small quarry within the cove (station 106-14-26). This biota includes tabulate corals (*Calapoecia, Catenipora*), solitary rugose corals, cephalopods, strophomenid brachiopods and trilobites (*Isotelus*? and *Stenopareia*?). A short distance above the beds containing this fossil biota, a distinct grey clay horizon, also exposed in quarry sections, is considered to be associated with the Ordovician–Silurian boundary (station 106-14-27; see Elias et al., 1999).

The overlying Severn River Formation is best exposed on the tidal flat near the western end of the cove (station 106-14-30). Large bedding planes consist of light brown to beige bioclastic dolowackestone to packstone, often weathering to a light orange-brown, with fossils common throughout and abundant in some beds. These include tabulate corals, solitary rugose corals and numerous examples of the brachiopod *Virgiana decussata.*

Seahorse Gully

The Ordovician section at Seahorse Gully (station 106-14-21, shown in Figure GS-13-1) consists of basal sandstone assigned to the Churchill River Group (Figure GS-13-7b). This laps directly onto the edge of a paleoisland of Churchill quartzite, with the dip of the beds likely representing the original angle of deposition against the quartzite paleoshore. The Ordovician sandstone is coarse grained, poorly sorted, consolidated and grey with common cephalopod fossils (siphuncles of *Armenoceras* and discosorids) and occasional aulacerid stromatoporoids (*Aulacera*). Depositionally, this sandstone is similar to the basal sandstone (member 1) of the Portage Chute Formation, but biostratigraphy and geographic position are consistent with the interpretation that this sandstone is younger and was deposited during Churchill River Group deposition.

Halfway Point

The section exposed at low tide at Halfway Point (station 106-14-32, shown in Figure GS-13-1) is assigned to the Lower Silurian Severn River Formation, and has been described in detail by Norford (1971). Unfortunately, during the 2014 visit most of the section was covered by modern sand deposits, obscuring the bedrock geology (exposure at this site has been much better in the past). Exposed beds are light brown to light grey burrow-mottled dolowackestone, with occasional fossils. Of particular note is the abundance of *Virgiana decussata* brachiopod fossils seen in boulders in this area, suggesting the in-place beds are nearby. Open vertical joint sets are common.

Churchill Northern Studies Centre quarry

The section represented at the CNSC quarry (station 106-14-31, shown in Figure GS-13-1) is assigned to the Lower Silurian Severn River Formation. This quarry is adjacent to the drill site for borehole M-4-2003, drilled by MGS in 2003 (Young et al., 2003). The quarry is overgrown and partly water filled, but exposes approximately 1 m of the Severn River Formation. At this location, the succession consists, from bottom to top, of a bioclastic wackestone, a mottled mudstone, a peloidal packstone and an argillaceous mudstone. Fossils include ostracodes, rhynchonelliformean brachiopods and solitary rugose corals. Open vertical joint sets are common.

Discussion

The exposures of the Lower Paleozoic strata visited along the Churchill River correlate well with observations the authors have made in core from boreholes located in the southeastern half of the HBL (see Nicolas et al., Figure GS-12-2, this volume), and on Southampton Island (Zhang, 2010). This bodes well for successful long-distance lithostratigraphic correlation and definition of large-scale depositional trends in a large basin that has a minimal amount of subsurface information available.

In contrast to the river sections, the strata observed in the exposures around Churchill are different from those of similar age in other parts of the basin. This is due to the distinct microenvironments that formed around the Proterozoic paleoarchipelago and the resulting paleotopography, which delayed the start of marine deposition. An example of this is the presence of sandstone beds at the base of the Churchill River Group; in other parts of the basin sandstones have been restricted to the base of the older Bad Cache Rapids Group. Such differences suggest that definition of local stratigraphic members in the Churchill area may help to differentiate and understand them, permitting more accurate correlation with other parts of the basin.

Economic considerations

An improved understanding of the geological evolution, architecture and economic potential of the Hudson Bay Basin will depend on a good comprehension of the

stratigraphy of the Hudson Bay Lowland. The visiting and sampling of outcrops by researchers from the GEM team helps to bring continuity to the new scientific questions brought forward by GEM-2. The large multiyear collaborative GEM-2 project brings together geoscientists with different areas of expertise, encouraging a better understanding of the Hudson Bay Basin. This allows for different perspectives to be focused toward one common goal, all the while providing an opportunity for the researchers to learn from each other.

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References

Bell, R. 1880: Report on explorations on the Churchill and Nelson rivers and around Gods and Island Lakes; Geological Survey of Canada, Report of Progress for 1878–79, pt. IV, p. 1C–44C.

Bezys, R.K. 1990: Stratigraphic mapping (NTS 63G) and core hole program 1990; *in* Report of Activities 1990, Manitoba Energy and Mines, Minerals Division, p. 140–151.

Cumming, L.M. 1975: Ordovician strata of Hudson Bay Lowlands; Geological Survey of Canada, Paper 74-28, 93 p.

Duncan, B.J. 2012: Stratigraphy and facies analysis of uppermost Ordovician to lowermost Silurian strata in the Whitebear core, Hudson Bay Basin, northern Manitoba; B.Sc. thesis, University of Manitoba, Winnipeg, Manitoba, 192 p.

Elias, R.J. and Young, G.A. 2000: Enigmatic fossil encrusting an Upper Ordovician rocky shore on Hudson Bay, Canada, is a coral; Journal of Paleontology, v. 74, no. 1, p. 179–180.

Elias, R.J., Young, G.A. and Rudkin, D.M. 1999: Ordovician–Silurian boundary section discovered near Churchill, Manitoba: preliminary report; Acta Universitatis Carolinae Geologica, v. 43, no. 1/2, p. 229–232.

International Commission on Stratigraphy 2014: International chronostratigraphic chart v.2014/02; International Commission on Stratigraphy, URL <http://www.stratigraphy.org/ICSchart/ChronostratChart2 014-02.pdf> [September 2014].

Johnson, M.E. and Baarli, B.G. 1987: Encrusting corals on a latest Ordovician to earliest Silurian rocky shore, southwest Hudson Bay, Manitoba, Canada; Geology, v. 15, no. 1, p. 15–17.

Johnson, M.E., Skinner, D.F. and Macleod, K.G. 1988: Ecological zonation during the carbonate transgression of a Late Ordovician rocky shore (northeastern Manitoba, Hudson Bay, Canada); Palaeogeography, Palaeoclimatology, Palaeoecology, v. 65, no. 1–2, p. 93–114.

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.P.B., 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.

Nelson, S.J. 1963: Ordovician paleontology of the northern Hudson Bay Lowland; Geological Society of America, Memoir 90, 152 p.

Nelson, S.J. 1964: Ordovician stratigraphy of northern Hudson Bay Lowland, Manitoba; Geological Survey of Canada, Bulletin 108, 36 p.

Nelson, S.J. and Johnson, M.E. 2002: Jens Munk Archipelago: Ordovician–Silurian islands in the Churchill area of the Hudson Bay Lowlands, northern Manitoba; Journal of Geology, v. 110, no. 5, p. 577–589.

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

Norford, B.S. 1997: Correlation chart and biostratigraphy of the Silurian rocks of Canada; Geological Survey of Norway, International Union of Geological Sciences Publication No. 33, 77 p.

Norford, B.S., Nowlan, G.S., Haidl, F.M. and Bezys, R.K. 1998: The Ordovician–Silurian boundary interval in Saskatchewan and Manitoba; *in* Eighth International Williston Basin Symposium, J.E. Christopher and C.F. Gilboy (ed.), Saskatchewan Geological Society, Special Publication No. 13, p. 27–45.

Norris, A.W. 1993: Hudson Platform - geology; *in* Chapter 8, Sedimentary Cover of the Craton in Canada, D.F. Stott and J.D. Aitken (ed.), Geological Survey of Canada, Geology of Canada Series no. 5, p. 653–700.

Norris, A.W. and Sanford, B.V. 1969: Paleozoic and Mesozoic geology of the Hudson Bay Lowland (Operation Winisk); Geological Survey of Canada, Paper 68-53, p. 169–205.

Robson, S.P. and Young, G.A. 2013: Late Ordovician conulariids from Manitoba, Canada; Journal of Paleontology, v. 87, no. 5, p. 775–785.

Rudkin, D.M., Young, G.A., Elias, R.J. and Dobrzanski, E.P. 2003: The world's biggest trilobite - *Isotelus rex* new species from the Upper Ordovician of northern Manitoba, Canada; Journal of Paleontology, v. 77, no. 1, p. 99–112.

Rudkin, D.M., Young, G.A. and Nowlan, G.S. 2008: The oldest horseshoe crab: a new xiphosurid from late Ordovician Konservat-Lagerstaetten deposits, Manitoba, Canada; Palaeontology, v. 51, pt. 1, p. 1–9.

Sanford, B.V., Norris, A.W., Bostock, H.H. and Bell, R.T. 1968: Geology of the Hudson Bay Lowlands: Operation Winisk; Geological Survey of Canada, Paper 67-60, p. 1–46.

Skinner, D.F. and Johnson, M.E. 1987: Nautiloid debris oriented by long-shore currents along a Late Ordovician–Early Silurian rocky shore; Lethaia, v. 20, no. 2, p. 157–164.

Tyrrell, J.B. 1897: Report on the Dubawnt, Kazan and Ferguson rivers and the northwest coast of Hudson Bay, and on two overland routes from Hudson Bay to Lake Winnipeg; Geological Survey of Canada, Annual Report, v. 9, pt. F, 218 p.

United States Geological Survey 2002: Shuttle Radar Topography Mission, digital elevation model, Manitoba; United States Geological Survey, URL <ftp://edcsgs9.cr.usgs.gov/pub/data/srtm/>, portions of files N48W88W.hgt.zip through N60W102.hgt.zip, 1.5 Mb (variable), 90 m cell, zipped hgt format [March 2003].

Wong, M.E. 2011: Lithofacies analysis and stratigraphic correlation of the Upper Ordovician Red Head Rapids Formation, Hudson Bay Basin, northeastern Manitoba; B.Sc. thesis, University of Manitoba, Winnipeg, Manitoba, 72 p.

Young, G.A., Elias, R.J. and Dobrzanski, E. 2003: Paleozoic drillcore from the Churchill area, northern Manitoba: preliminary results (NTS 54K and 54L); *in* Report of Activities 2003, Manitoba Industry, Economic Development and Mines, Manitoba Geological Survey, p. 171–177.

Young, G.A., Rudkin, D.M., Dobrzanski, E.P., Robson, S.P., Cuggy, M.B., Demski, M.W. and Thompson, D.P. 2012: Late Ordovician Konserval-Lagerstätten in Manitoba; Geological Survey of Canada, Annual Report, v. 9, pt. F, 218 p.

Young, G.A., Rudkin, D.M., Dobrzanski, E.P., Robson, S.P. and Nowlan, G.S. 2007: Exceptionally preserved Late Ordovician biotas from Manitoba, Canada; Geology, v. 35, no. 10, p. 883–886.

Zhang, S. 2010: Upper Ordovician stratigraphy and oil shales on Southampton Island - field trip guidebook; Geological Survey of Canada, Open File 6668, 44 p.

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.