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FOREWORD / CONTEXT

The Geo-mapping for Energy and Minerals (GEM) program is laying the foundation for sustainable economic development in the North. The Program provides modern public geoscience that will set the stage for long-term decision making related to investment in responsible resource development. Geoscience knowledge produced by GEM supports evidence-based exploration for new energy and mineral resources and enables northern communities to make informed decisions about their land, economy and society. Building upon the success of its first five-years, GEM has been renewed until 2020 to continue producing new, publically available, regional-scale geoscience knowledge in Canada's North.

During the summer of 2015, the GEM program has successfully carried out 14 research activities that include geological, geochemical and geophysical surveying. These activities have been undertaken in collaboration with provincial and territorial governments, northerners and their institutions, academia and the private sector. GEM will continue to work with these key collaborators as the program advances.

PROJECT SUMMARY

The Arctic is the last area with significant conventional hydrocarbon potential to be explored. A report by the United States Geological Survey indicates reserves of over 90 billion barrels of oil, 44 billion barrels of natural gas liquids and 1670 trillion cubic feet of natural gas (Bird et al., 2008), with a significant portion of these reserves located in the Canadian Arctic.

The Hudson Bay basin is one of these under explored sedimentary basins in the Canadian Arctic. The basin is the largest intracratonic basin in North America and if other similar basins in North America (Michigan, Illinois, Williston basins) are world-class hydrocarbon producers, the Hudson Bay basin has significant potential. To date, only nine exploration wells have been drilled in this large basin (4 onshore and 5 offshore) with no commercial discovery.

As part of the initial phase of the Geoscience for Energy and Minerals (GEM) program, a re-evaluation of historical exploration data and strategic acquisition of new hydrocarbon system data led to a preliminary positive evaluation of the hydrocarbon prospectivity of the basin (Lavoie et al., 2013, 2015a).

The Hudson Bay – Ungava project of the second phase of the GEM program aims to provide new information and models for the evolution of the Hudson Bay basin which will serve as the cornerstone for a modern appraisal of the hydrocarbon prospectivity of the largest sedimentary basin in Canada.

INTRODUCTION TO HUDSON-UNGAVA 2015 ACTIVITIES

Integrated regional stratigraphy of petroleum basins of the Hudson-Ungava Project

The integrated regional stratigraphic framework is the natural continuation of the work completed as part of the first phase of GEM where specific local frameworks were constructed (Lavoie et al., 2013). The fine-scale correlations of these frameworks (Ontario, Manitoba, offshore Hudson Bay, onshore Foxe basin, offshore Hudson Strait) is only possible through the use of a multidisciplinary approach that will combine detailed biostratigraphy, chemostratigraphy, sedimentology, petrophysics and geophysics.

This activity addresses two fundamental scientific questions:

1. How have geodynamic factors, such as faulting and/or variable burial and exhumation influenced the architecture and petroleum prospectivity of the Hudson Bay basin?

2. Can sub-basins with distinct hydrocarbon prospectivity be identified in the Hudson Bay basin?

In this report, 2015 field work on Akpatok Island (Ungava Bay) and a field trip to northeastern Manitoba will be discussed (Figure 1).

Understanding of hydrocarbon systems – source and reservoir rocks

The regional understanding of hydrocarbon systems (source and reservoir rocks, thermal maturation, hydrocarbon generation and expulsion, traps and seals) was initially addressed as part of the first phase of GEM with positive conclusions on the presence of all the above elements and events (Lavoie et al., 2013, 2015a) . The comprehension of hydrocarbon systems for the entire Hudson Bay and Strait area is a critical element of the second GEM program. This will be accomplished through detailed field work combined with laboratory analyses (organic and inorganic geochemistry, thermal indicators, marine geophysical works and remote sensing).

Like the integrated stratigraphy activity, this activity addresses the same fundamental scientific questions:

1. How have geodynamic factors, such as faulting and/or variable burial and exhumation influenced the architecture and petroleum prospectivity of the Hudson Bay basin?

2. Can sub-basins with distinct hydrocarbon prospectivity be identified in the Hudson Bay basin?

In this report, 2015 field work on Southampton Island (Hudson Bay) will be discussed (Figure 1).

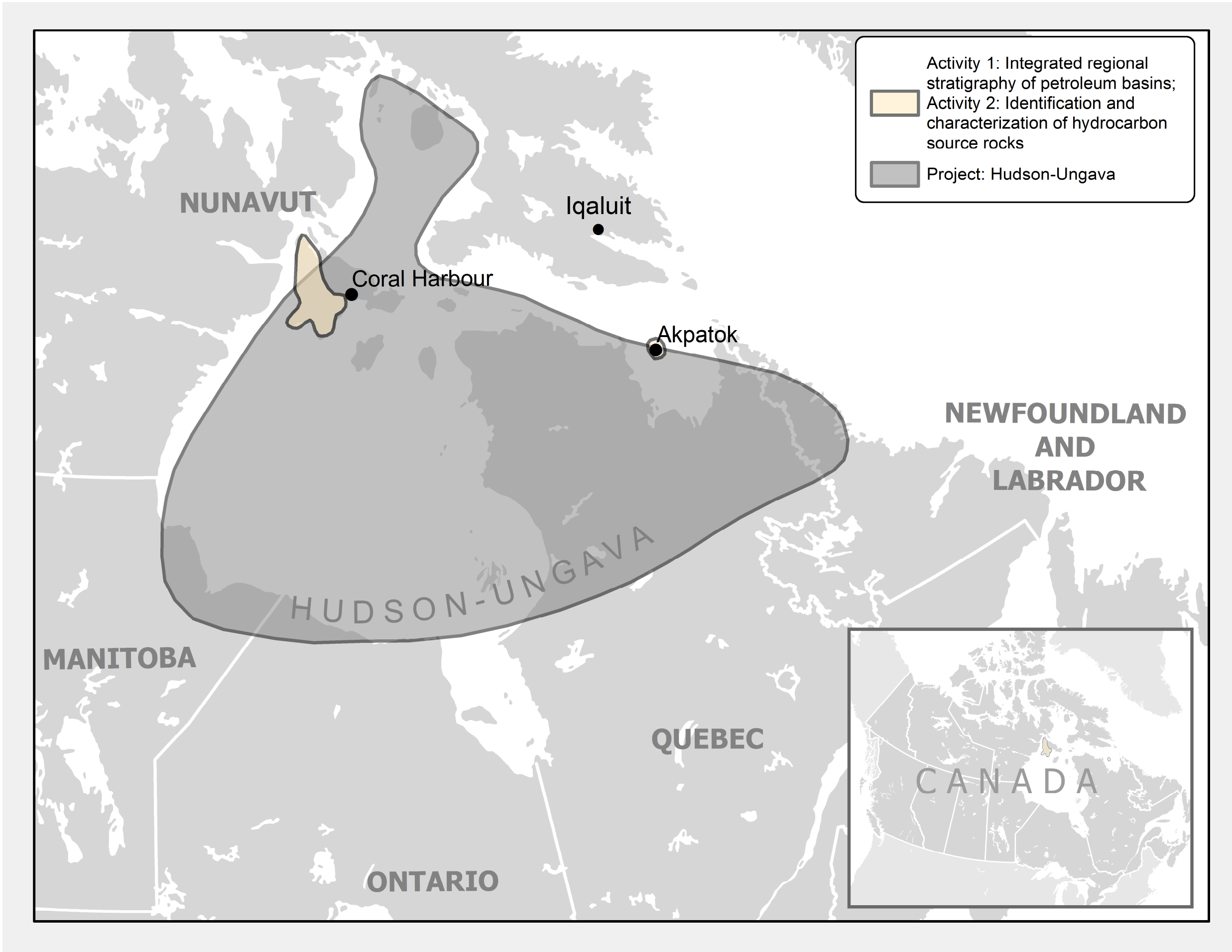

Figure 1: General location area of field activities on Akpatok and Southampton Islands

RADARSAT image acquisition, interpretation, and methods development for identification of potential oil slicks

This activity involves a multi-year acquisition plan and interpretation of RADARSAT images over Hudson Bay/ Strait and Foxe Basin in order to record repeat observations of potential oil slicks in the same zones. The GEM-01 supported activity provided intriguing initial results and established a collection of historic data that is ultimately required as a basis for any further investigation or monitoring in the region (Decker et al., 2013). This GEM-02 activity will build upon these results by strengthening the baseline data to support further targeted investigations and will aid in improving knowledge of the subsurface geology and hydrocarbon potential in the Hudson Bay / Strait and Foxe Basin. Additional observations of spatially coincident dark features using satellite imagery raises the probability that natural seep occurrences exist and will help provide valuable, unconventional geoscience information about hydrocarbon resources.

This activity addresses the following fundamental scientific question:

1. Can sub-basins with distinct hydrocarbon prospectivity be identified in the Hudson Bay basin?

In this report, images acquisition program for 2015 and development of algorithms for rapid treatment of RADARSAT images will be discussed.

METHODOLOGY

Akpatok and Southampton islands field work

For both Akpatok and Southampton islands, the field work was thematic in its approach and no systematic mapping was conducted or planned. On Akpatok Island, reconnaissance field work in 2014 (Zhang and Mate, 2015; Lavoie et al., 2015b) improved the regional stratigraphic framework and identified sites for future stratigraphic studies and biostratigraphic sampling (coast and creek sections). Key outcrop localities on Southampton Island that were briefly reported in Heywood and Sanford (1976) and Zhang (2010), as representing potential hydrocarbon reservoirs were also visited.

RADARSAT activity

An image acquisition plan for 2015 has been elaborated covering ice free conditions from August to the end of October. Over 1 350 000 Km2 of the study area has been imaged at multiple instances with over 575 images. Some areas are covered with multi-temporal stacks containing up to 10 dates. Figure 2 shows the distribution of the image footprints for 2015.

Algorithms are in development in order to read, manipulate and visualise oil seep candidates identified on RADARSAT images within the Matlab programming environment. Scientific literature on state-of-the-art computer algorithms/approaches for automatic oil seep detection has been studied and the most relevant ones appropriate to this activity have been identified. Based on the dataset analyzed during GEM-1 and the literature survey, development of algorithms has been initiated for 1) dark target identification based primarily on a multiscale approach and mathematical morphology tools and 2) on the characterization of identified dark targets based on radiometric and spatial/contextual properties.

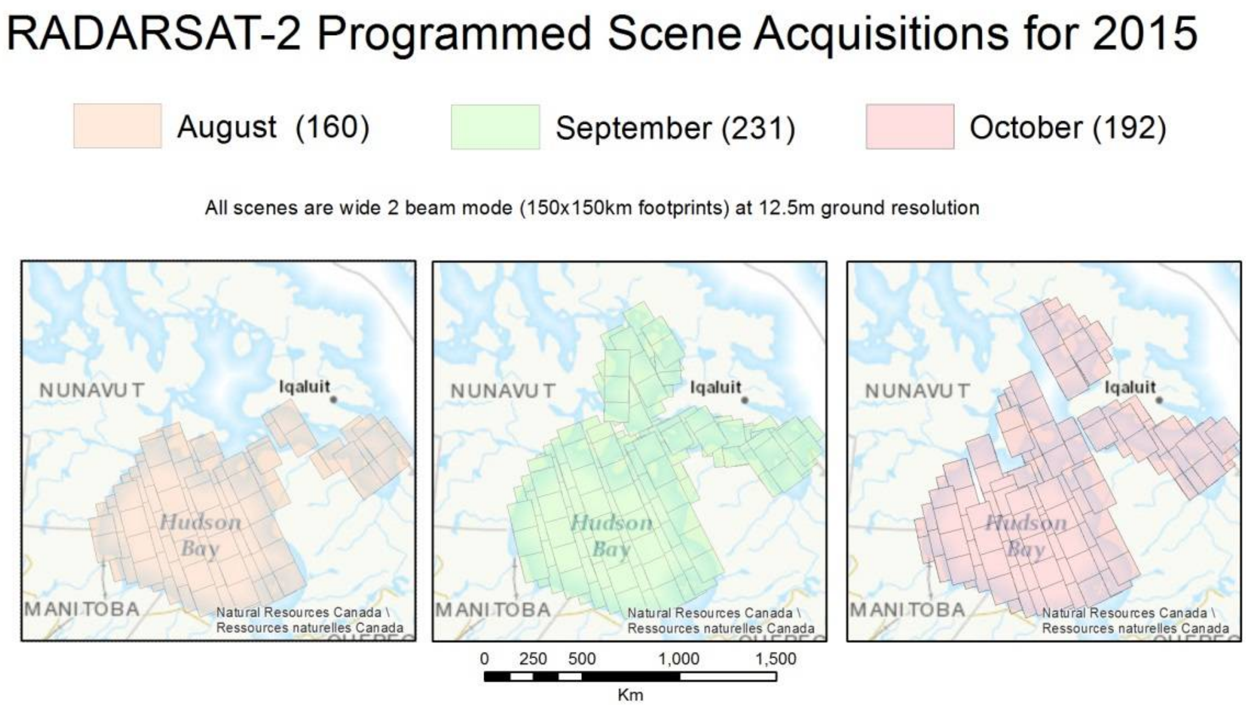

Figure 2: RADARSAT image coverage for 2015 over the Hudson Bay / Strait and Foxe basin.

RESULTS

Akpatok Island stratigraphic survey

Field work on Akpatok Island was carried out between July 18 and 23 (Fig. 3). A temporary camp was built on the island to accommodate the field crew which consisted of 2 geologists, 3 bear monitors, one camp manager and one helicopter pilot. The objectives of the field work as defined following the 2014 reconnaissance survey Geoscience for Energy and Minerals (GEM) program (Zhang and Mate, 2015; Lavoie et al., 2015b), were as follows:

1) Refine the stratigraphic succession and the distribution of the Amadjuak and Akpatok formations.
2) Collect samples for conodont biostratigraphy for a precise biostratigraphic zonation of the carbonate succession
3) Collect selective samples for chitinozoan study to complete the biostratigraphic framework of the succession
4) Identify and collect new sections of organic limy shales for organic geochemistry and biostratigraphy.

Stratigraphic succession

The most recent geological map of the island indicates that the surficial geology consists of the Akpatok Formation and an outlier of the Boas River Shale in the northwest corner of the island (Sanford and Grant, 1998). A core from a hydrocarbon exploration well (Akpatok L-26) drilled in 1970 near the coast on western Akpatok Island (Workum, 1976) intercepted a succession interpreted to belong, in descending order, to the Akpatok, Amadjuak, Frobisher Bay and Ungava Bay formations (Sanford and Grant, 1990). Some preliminary biostratigraphy and organic matter evaluation of the succession is reported in Zhang and Mate (2015). Our survey documented the presence of both the Akpatok and Amadjuak formations on the island (Fig. 4). Overall, a total of 79 samples for conodont and 10 samples for chitinozoan biostratigraphy were collected from 12 different localities.

Figure 3: Google Earth map of Akpatok Island in Ungava Bay. The star locate the base camp for the field work

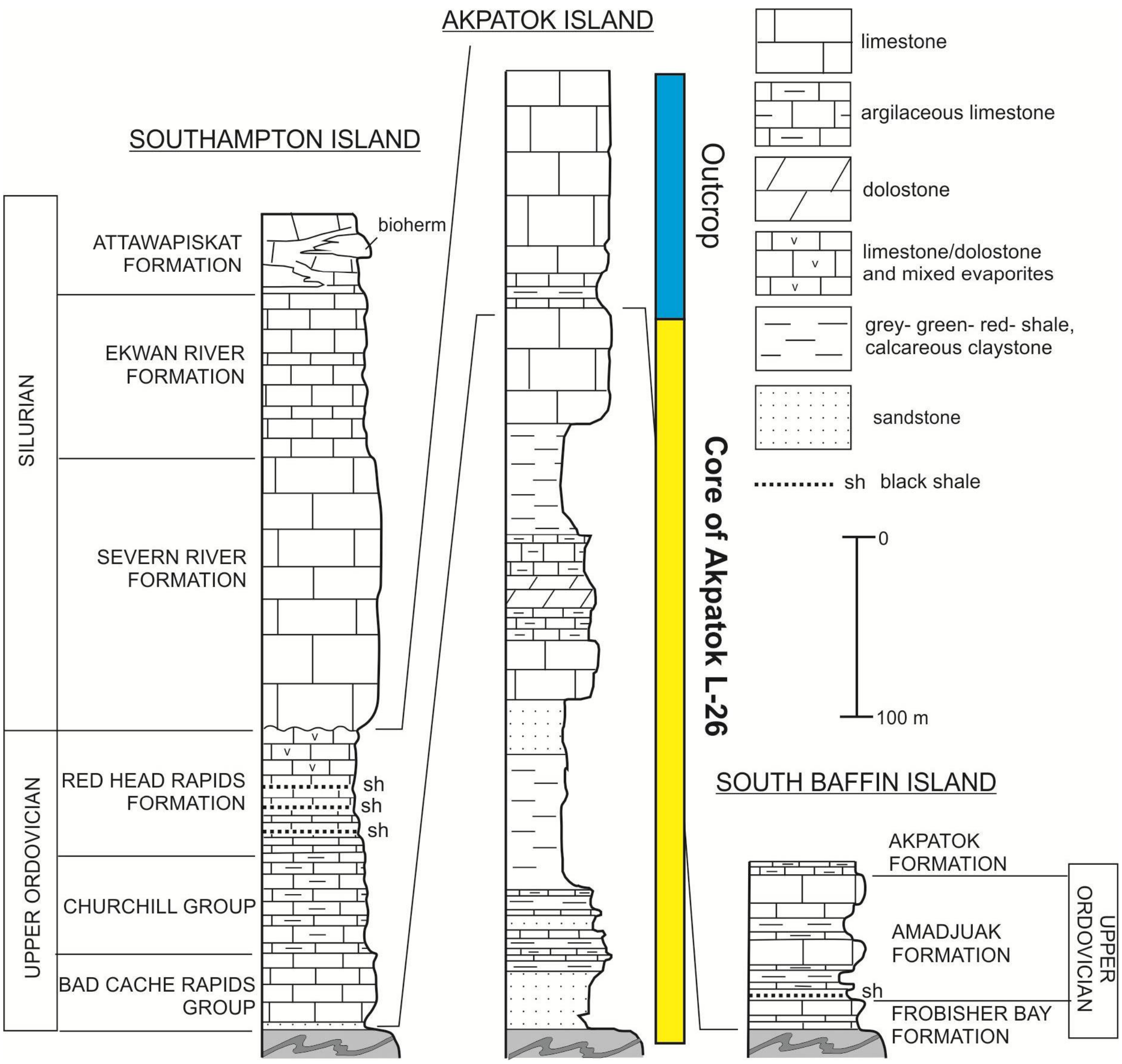

Figure 4: Preliminary stratigraphic synthesis for the Lower Paleozoic of northern Hudson Bay and Strait areas. The Akpatok section is from the Akpatok L-26 core; over 150 m more of field section is likely. Modified from Pinet et al (submitted).

Figure 5: Thin beds of lime mudstone with sutured contacts; these are interpreted to belong to the Akpatok Formation.

The Akpatok Formation consists predominantly of micrite beds ranging from 2 to 10 cm in thickness (Fig. 5), the unit is largely devoid of significant macrofauna except few crinoids and bryozoans. The micrite is locally wavy-bedded and has sutured contacts with no interbeds. At some localities, the micrite has a strong condensate smell when freshly broken.

The Amadjuak Formation consists of fosssiliferous wackestone to packstone in beds ranging from 5 to 20 cm in thickness (Fig. 6). The dominant macrofauna consists of gastropods, brachiopods, trilobites, pelecypods and echinoderms; trace fossils are particularly abundant on bedding plane surfaces. As is the case of the Akpatok Formation, the bed contacts are mostly sutured with no interbeds. A 10 m thick interval with up to 15% of chert nodules in a wackestone-dominated facies is, however, present (Fig. 6). The chert nodules are elongated with a long axis of 5 to 15 cm long.

The Boas River Shale of Sanford and Grant (1990), now reassigned to the Amadjuak Formation (Zhang, 2012) was only visible at one locality (Zhang and Mate, 2015), there a *circa* 12 m thick interval of slightly displaced thin-bedded, dark colored micrite beds is visible. One sample for chitinozoan biostratigraphy was collected at that locality. Abundant fragments of this very distinctive facies are observed on the low-lying rubble in the foreshore on the western side of the island, however, no other occurrence of the unit was observed in the numerous surveyed creeks on the western side of the island.

Figure 6: Left: Thick beds of fossiliferous wackestone of the Amadjuak Formation. Right: Chert nodules and silicified bands in the Amadjuak Formation.

As part of the stratigraphy survey, we have identified three localities as highly brecciated intervals, discordant to the stratigraphy in the Amadjuak Formation (Fig. 6). These exposed breccias are between 2 and 4 m thick and are made up of unsorted, non-imbricated angular limestone fragments of the Amadjuak Formation. The fragments make up 80% of the breccia and range from a few millimetres to up to 20 cm (Fig. 7). Locally, up to 15% vuggy open space is noted and carbonate cement crusts with calcite and dolomite are present between some of the clasts. Overlying the breccia, beds fill irregular depressions (Fig.7). The breccias, based on field occurrence and the relationship with under and overlying beds, are preliminary interpreted as hydrothermal in origin. They are similar to breccias documented on Southampton Island (Lavoie et al., 2011) for which a hydrothermal origin was proposed based on petrography and stable isotope characterization of cements. One sample for further petrographic and geochemical characterization was collected.

Southampton Island hydrocarbon reservoir survey

Field work on Southampton Island was carried out between August 1 and 9 (Fig. 8). The field crew based in Coral Harbour consisted of 2 geologists, 1 graduate student, 1 bear monitor and one helicopter pilot. The objectives of the field work were to evaluate the porous reefs of the Upper Ordovician Red Head Rapids as a potential hydrocarbon reservoir in the subsurface. The study of the reef facies forms the basis of a M.Sc. thesis at the University of Ottawa. The precise objectives of the reservoir survey were as follows:

1- Visit known localities of the reef facies of the Red Head Rapids Formation as identified by Heywood and Sanford (1976) and Zhang (2010).

2- Describe the internal lateral and vertical facies architecture of the mound-shaped bioconstructions.
3- Systematically sample the reef facies for depositional and diagenetic features.

Fig 7: Top left: A 3 m-high exposed massive breccia with preserved zones of bedded limestones. Top right: Unsorted limestone clasts in the breccia, no internal texture preserved. Lower: Deformed bedded limestone on top of breccia, the limestones are part of elongated small sag-like features as shown at the hammer head.

Figure 8: Google Earth view of Southampton Island with the location of the three localities discussed in the text.

Red Head Rapids Formation

Heywood and Sanford (1976) divided the Red Head Rapids formation into three units, a lower stromatolitic and micritic unit, a middle fossiliferous biostromal limestone and dolostone unit with abundant stromatoporoids and corals, and an upper algal-rich mound-shaped unit poor in macrofauna. Heywood and Sanford (1976) reported the presence of dead oil in the pore space of some of the algal bioherms. The Upper Ordovician (late Richmondian, Zhang, 2008) succession conformably overlies the Churchill Group carbonates and is disconformably overlain by packstone and grainstone of the lower Silurian Severn River Formation. Recently, Zhang (2010) confirmed the presence of these three units with the addition of a fourth; a breccia interval, located between the units 1 and 2 of Heywood and Sanford (1976). These breccias were later interpreted to be hydrothermal and not sedimentary in origin (Lavoie et al., 2011).

The field crew visited several localities identified in Heywood and Sanford (1976), most of them consist of poorly outcropping mound-shaped circular zones. The best exposed locality (1 on Fig. 8 and locality 13 in Zhang, 2010) consists of an elongated (300 m by 100 m) mound-shaped structure with a preserved vertical relief of 8 meters (Fig. 9). The mound (unit 3 of Heywood and Sanford (1976) or 4 of Zhang (2010)) consists of three major facies including, in order of abundance: i) massive micrite-dominated facies (Fig. 9) with localized calcite cement coatings, ii) stratiform micrite-dominated facies (Fig. 9), and iii) and a thin-bedded (5 to 10 cm thick) micritic facies locally interbedded with the other facies. The massive and stratiform facies are locally porous (Fig. 10). Unabundant bitumen coatings are present in all three facies. A total of 87 samples from six representative sections along the mound margins were collected.

A second well-exposed locality was studied south of Mount Minto on Bell Peninsula (2 on Fig. 8); a locality reported in Heywood and Sanford (1976). The succession exposed along the floor of a small creek consists of more or less displaced blocks of the porous massive micrite facies described above. A 7 m high cliff adjacent to the floor of the creek is made up of non-porous thick-bedded buff-colored dolomitic lime mudstone and packstone (about 6 m thick) with some stromatoporoid and coral rudstone at its top. This interval was interpreted by Heywood and Sanford (1976) as an inter-mound facies (Fig. 11). 11 samples were collected from this interval. The interval is disconformably overlain by thinner-bedded packstone and grainstone interpreted to belong to the lower Silurian Severn River Formation.

Further down the creek (3 in Fig. 8), a unit was observed in the cliff exposure that was not previously described in Heywood and Sanford (1976). The succession consists of complex assemblage of breccias laterally equivalent to well-bedded dolomitic lime mudstone and wackestone (Fig. 12). The base of the succession consists of thin beds of finely laminated micrite facies in which layers of vertical calcite cement crusts are present. This lower unit is overlain by clast-supported breccias made up of angular fragments of unsorted lime mudstone and wackestone encased in a calcarenite matrix. The breccia locally fills meter-wide pipes that cut through the well-bedded lime mudstone and wackestone facies. The vertical extension of the exposed breccia-filled pipes is at minimum 2 m (Fig. 12). At the contact between the vertical pipes or within the well bedded facies, well-rounded nodules are noted (Fig. 12), the nodules are between 5 and 25 cm in diameter and are commonly coalescent.

Figure 9: Elongated carbonate mound. The top ridge is outline in white. This specific locality is stop 13 of Zhang (2010). Helicopter for scale.

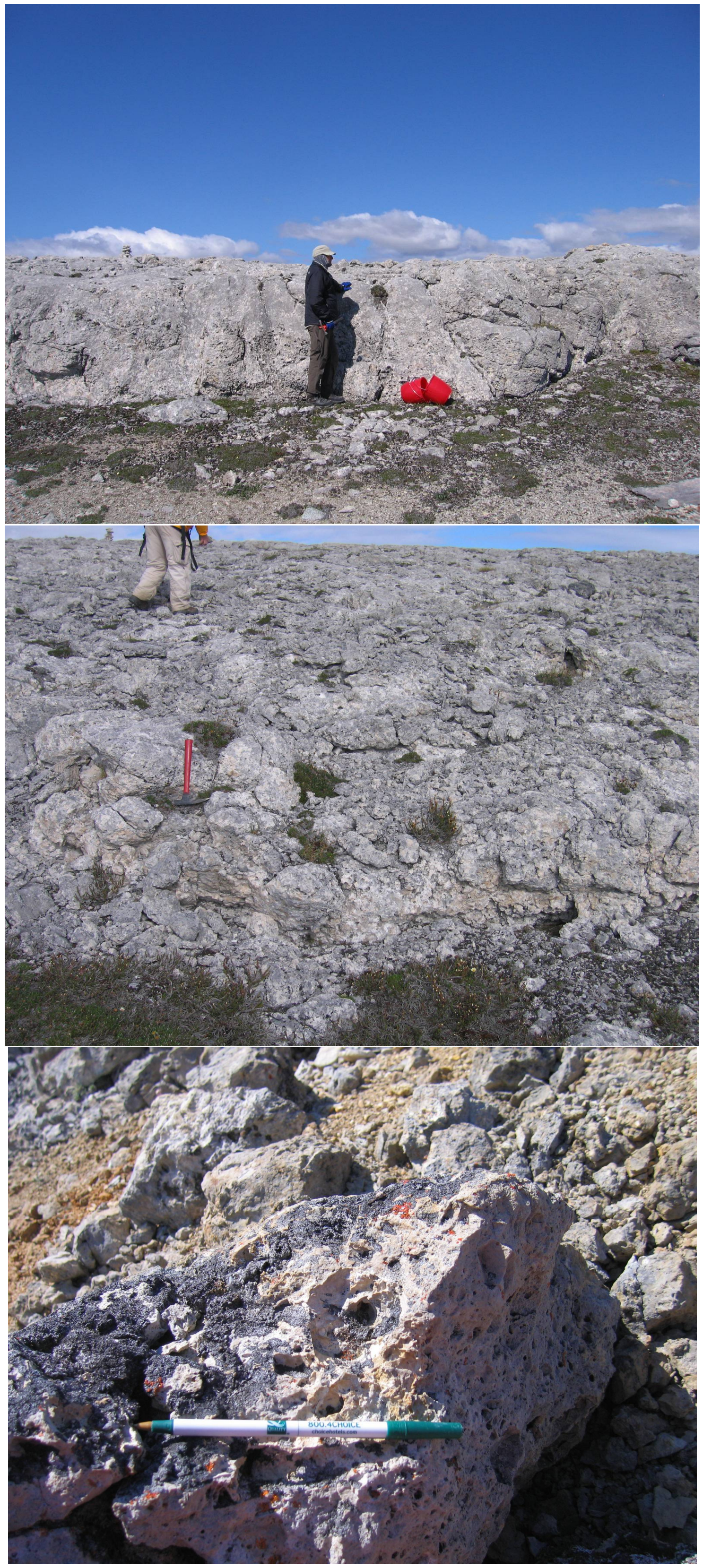

Figure10: Top: Massive micrite mound facies with adjacent stratiform facies. Center: Irregular stratiform micrite facies. Lower: Porous micrite with dark coatings and cements at the margin of vugs.

Figure 11: A 7 m-high vertical cliff of the inter-mound facies (buff-colored unit), Red Head Rapids Formation. The recessive beds at the top of the section are interpreted as Severn River Formation.

Figure 12: Top: Breccia filling a pipe (outline in black) cutting through a well bedded lime mudstone facies (right of the hammer). Middle: Coalescent carbonate nodules distributed in the well-bedded facies and at the margin of the pipe. Lower: Large burrows in lime mudstone and wackestone, the burrows are surrounded by calcite cement.

These nodules are abundant (up to 50% over some metric intervals), and when freshly broken, the interior is massive and structureless although when weathered, a concentric fabric is noted. A large number of nodules have calcite-filled cracks on their exterior whereas calcite crusts also coat the outside of the nodules. Laterally, a 75 cm-thick bed of sandy dolomitic lime mudstone is exposed and is overlain by thick beds of wackestone with cm-wide burrows locally lined with calcite cement (Fig. 12). The carbonate lithologies, including the nodules, have a very strong petroliferous smell when freshly broken. Pedogenesis and meteoric diagenesis is proposed as a preliminary interpretation of the breccia – nodule association with a return to shallow subtidal conditions in the heavily burrowed interval capping the succession. 17 samples were collected from this locality for further sedimentological and diagenetic studies.

Hudson Bay platform field trip in the Churchill area, northeastern Manitoba

The formal stratigraphic nomenclature of the Ordovician succession of the Hudson Bay platform was proposed by Nelson (1963, 1964) from outcrops along the coast of Hudson Bay and as exposed on the shores of Nelson River and its tributaries in northeastern Manitoba. One of the main objectives of the Hudson Bay / Ungava GEM project is to propose a unified stratigraphic framework for the entire onshore and offshore domains.

As would be expected in a large depositional basin covering three distinct jurisdictions, stratigraphic nomenclature is variable (see Lavoie et al., 2013 for details). Some of the nomenclature problems lie in the difficult correlation of stratigraphic units that record local variations in depositional environments compared to the formal type section. In order to address these discrepancies, geologists from the Manitoba and Ontario geological surveys involved in the Hudson Bay project are organizing collaborative core workshops in their respective provinces. At this stage of the research project, it was decided that a joint field trip to the classic sections in northeastern Manitoba was the next logical step in the collaboration process.

In the Hudson Bay Lowlands of Manitoba, most of the Paleozoic lithostratigraphic units are represented onshore. The oldest formation is the Ordovician Portage Chute Formation (Bad Cache Rapids Group), and the youngest is the Devonian Moose River Formation. The field trip covered the succession from the base of the Ordovician strata up to the middle beds of the Silurian Severn River Formation.

From August 11 to 18, a group of 9 geologists involved in various aspects of the geology of the Hudson Bay platform gathered in Churchill (Manitoba). The group visited several type sections of the Ordovician succession (Fig. 13) in order to develop a common understanding if not a common language for the stratigraphic nomenclature. Two helicopters provided air support for sections inland and ground logistics was provided by the Churchill Northern Study Center for the access to Hudson Bay shore sections.

Twelve sections (6 along Churchill River and 6 along the Hudson Bay coast; Fig. 13 and Table 1) were visited, the details can be found in Nicolas and Young (2015).

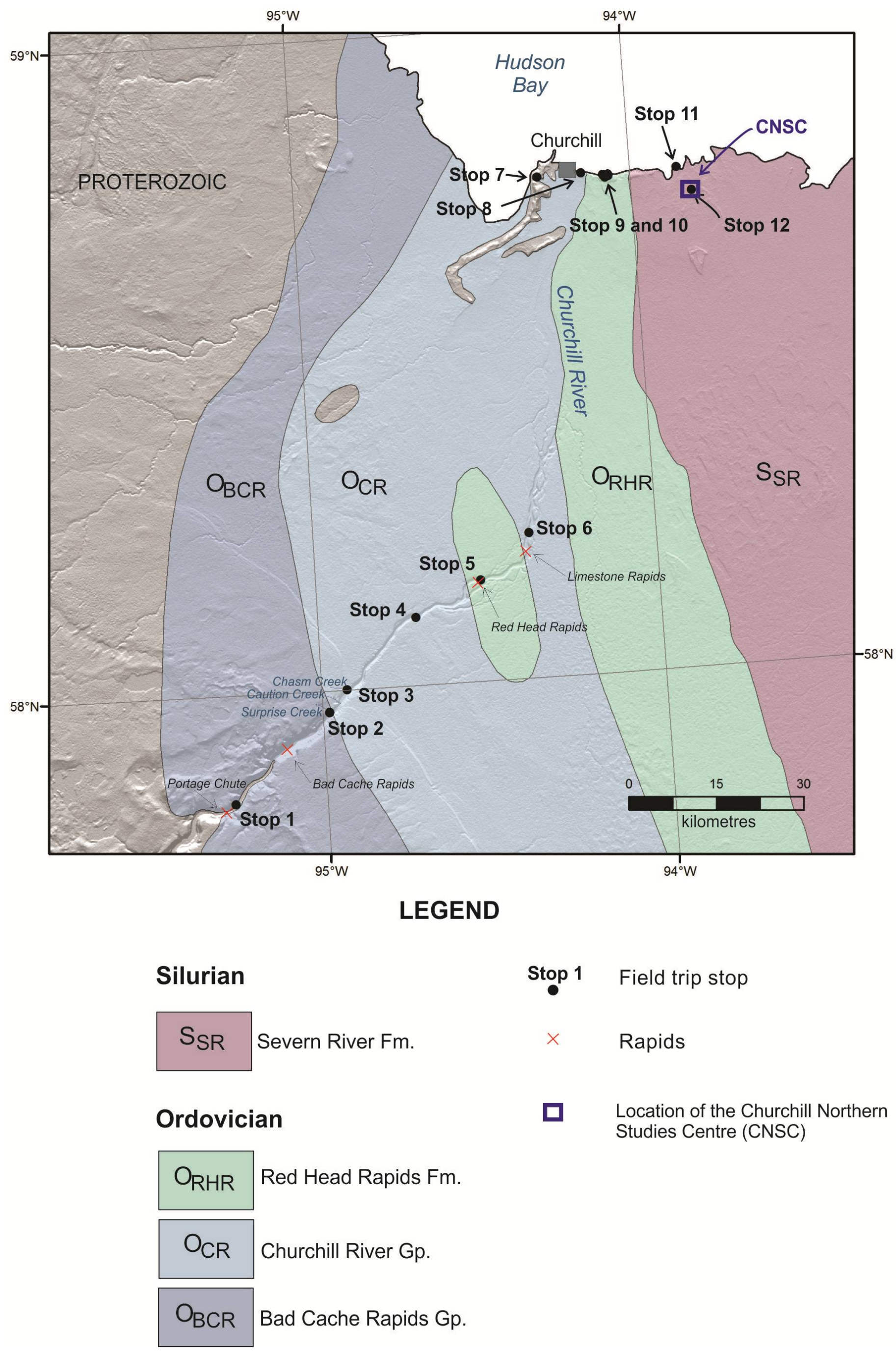

Figure 13: Paleozoic geology of the Hudson Bay platform in northeastern Manitoba with the stops of the field trip. Background image, with hillshaded underlay, was generated using digital elevation data (United States Geological Survey, 2002). Abbreviations: Fm.,formation; Gp., group; CNSC, Churchill Northern Studies Centre. (Modified from Nicolas and Young, 2014).

Table 1: List of field trip stops visited (including optional stops) along the Churchill River (Stops 1 to 6) and in the Churchill coastal area (Stops 7 to 12), northeastern Manitoba. From Nicolas and Young (2015).

Stop Number	Stop Name	Stratigraphy
1	Portage Chute	Portage Chute Formation Precambrian granite
2	Surprise Creek	Caution Creek Formation Surprise Creek Formation Portage Chute Formation
3	Chasm Creek (optional)	Chasm Creek Formation Caution Creek Formation
4	Chasm Creek Formation upstream	Chasm Creek Formation
5	Red Head Rapids	Red Head Rapids Formation Chasm Creek Formation
6	Chasm Creek Formation downstream	Chasm Creek Formation
7	Seahorse Gully	Churchill River Group
8	Churchill rocky shore	Churchill River Group
9	Airport cove, lower section	Red Head Rapids/Port Nelson Formation Churchill River Group
10	Airport cove, upper section	Severn River Formation Red Head Rapids/Port Nelson Formation
11	Halfway Point (Norford site)	Severn River Formation
12	CNSC quarry	Severn River Formation

A detailed sampling of Ordovician stops along the Churchill (1 to 5 on Fig. 13) will lead to a detailed sedimentological and isotope chemostratigraphic post-doctoral study at Laurentian University, the latter study to tie with current isotope chemostratigraphy in Ontario and from wells in Manitoba.

CONCLUSIONS

The three field activities under the GEM energy component of the Hudson Bay – Ungava project successfully met all the planned objectives.

A total of 79 samples for conodont biostratigraphy and 10 samples for chitinozoan biostratigraphy from Akpatok Island will be submitted for laboratory analysis and interpretation in this research year. Moreover, one sample of breccia cement will be analysed through the new clumped isotope technique.

A total of 117 samples for detailed sedimentological and diagenetic studies of the Upper Ordovician Red Head Rapids reefs and older breccia-nodule facies will be petrographically and geochemically studied as part of M.Sc. and B.Sc. research projects respectively at the University of Ottawa.

Fives sections were systematically sampled along the Churchill River for detailed sedimentological and isotope chemostratigraphy at Laurentian University. The Laurentian post-doctoral project aim at correlation of Upper Ordovician units between Ontario and Manitoba.

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