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2016

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Report of Activities for the GEM-2 – Western Arctic Margins project, Banks Island, Northwest Territories

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2016

doi:10.4095/299294

This publication is available for free download through GEOSCAN (http://geoscan.nrcan.gc.ca/).

Recommended citation
Smith, I.R., Dewing, K., Galloway, J., and Piepjohn, K. 2016. Report of Activities for the GEM-2 – Western Arctic Margins project, Banks Island, Northwest Territories; Geological Survey of Canada, Open File 8150, 18 p. doi:10.4095/299294

Publications in this series have not been edited; they are released as submitted by the author.

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FOREWORD

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 2016, GEM program has successfully carried out 17 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

This report outlines the scope and objectives of the Banks Island bedrock, structural geology and kimberlite (diamond) indicator minerals research activities, and summarizes field work, sample collection, and data compilation carried out between September 2015 and August 2016.

Field activities on Banks Island in 2016 expands upon the previous year's field-based kimberlite indicator mineral activities (Smith, 2015), and provides a means for updating and expanding the bedrock geology compilation of Miall (1979) by employing new techniques, radiometric dating controls, and seismic records that were unavailable in the 1970s when mapping was conducted. Principal field-based objectives of this research were to: 1) obtain new sample suites for paleontological analysis for the purpose of refining biostratigraphic age control and paleoenvironment; 2) reconcile seismic images, which show abundant faulting, with surface mapping which shows relatively few faults; 3) obtain kinematic indicators from areas of surface faulting or folding; 4) obtain sample suites for other geochemical and geochronological studies; and 5) reconcile bedrock unit ages that are in apparent conflict with the age of the same units elsewhere in the region.

Kimberlite indicator mineral (KIM) studies were logistically limited to areas of principal bedrock geology operations, and thus were designed to continue investigating the potential of bedrock-inherited (Canadian Shield-origin) KIMs within the fluvial Upper Tertiary Beaufort and Lower Cretaceous Isachsen formations. Additional samples were also collected, where possible, to further resolve aspects of late Wisconsinan and older glacial dispersal of KIMs on Banks Island.

Fieldwork in July 2016 led to an improved understanding of the nature and structural history of Devonian to Tertiary strata on Banks Island. Scientists were able to retrace many previously documented associations, while making important new stratigraphic interpretations and sample collections that will refine the understanding of timing, depositional environment, and tectonic alterations, ultimately providimg new insight into the age and evolution of the offshore Canada Basin. Kimberlite indicator mineral sample collections will be used to continue investigating the potential for secondary bedrock-inherited KIMs on Banks Island and to follow up on two geographical areas where samples collected in 2015 yielded results that challenged previous reconstructions.

This past summer's fieldwork was the last of the GEM-2 Program planned for Banks Island. Research this fall/winter will focus on the preparation and submission of collected samples for various analyses and dating. Results will be compiled, interpreted, and released in forthcoming publications.

INTRODUCTION

The GEM-2 Western Arctic Margins project is mainly focussed on improving the understanding of bedrock geology and geological history along the western extents of the Canadian Arctic Archipelago (Fig. 1). Research will provide a regional geological framework based on correlation of onshore stratigraphy into offshore areas using new data acquired by UNCLOS and industry seismic surveys, and will integrate recent mapping projects on Ellef Ringnes, northwest Victoria, and northern Axel Heiberg and Ellesmere islands (Evenchick and Embry, 2012a, b; Dewing, 2015; Dewing et al., 2015; Williamson, 2016).

Field geological studies on Banks Island will address important scientific questions regarding the opening of the Canada Basin and Arctic Ocean, including:

- What is the stratigraphic and structural history of the margins of the Arctic Ocean?
- What is the structural and stratigraphic architecture of the Canada Basin and how does it compare to the onshore margins?
- How did the opening of the Arctic Ocean control deposition of source rocks, depth and timing of burial, and timing of uplift across the region?

This project also seeks to resolve the nature and distribution of KIMs documented by industry on northeastern Banks Island and in so doing, will determine whether Banks Island is prospective for hosting diamond-bearing kimberlite. KIMs recovered and analyzed from stream sediment, bulk sediment, and bedrock samples, along with geological assessments of various terrains will produce new regional geoscience data that will increase knowledge on the potential provenance of Banks Island KIMs. This will address knowledge gaps and facilitate decisions by industry to either renew diamond-bearing kimberlite exploration efforts on Banks Island, or determine that this is area is unlikely to host such mineral resources and thus focus exploration activities elsewhere.

Figure 1. Basemap showing the extents of the GEM 2 Western Arctic Margins project, and Banks Island, Northwest Territories, the focus of this summer's field activities.

FIELDWORK

Fieldwork carried out in July 2016 involved the collaboration of Karsten Piepjohn of the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR; German Federal Institute for Geosciences and Natural Resources) and Barrett Elliott of the Northwest Territories Geological Survey. Field operations involved Twin Otter (Aklak Air) and helicopter (Great Slave Helicopters) supported activities over the course of three weeks based out of the hamlet of Sachs Harbour (Fig. 1) and from two temporary base camps – Nelson Head on southeast Banks Island, and Polar Bear Cabin on north-central Banks Island. Much of the northern Banks Island fieldwork included operations within the bounds of Aulavik National Park.

Bedrock Geology

Bedrock geology fieldwork involved 2 to 6 person crews on day traverses supported by helicopter. Sections were measured using a 1.5 m Jacob Staff and locations were determined by GPS. Samples were collected from surface outcrops and are 0.25 to 5 kg in weight. Location data, samples and analytical data are curated at the Geological Survey of Canada – Calgary.

Fieldwork and areas of investigation were guided by the excellent maps and report of Miall (1979). In the 36 years since the publication of this work, new ages of stratigraphic units from nearby areas and industry seismic lines have been released and new insights on biostratigraphic control and techniques for age-dating (e.g., U-Pb geochronology of zircon-bearing tuffs) have been developed. Checking outcrops to resolve inconsistencies between new data sets and the results of Miall (1979) was a goal of the 2016 fieldwork. There are also a number of analytical techniques that were not available to Miall in the 1970s, including geochronology and thermochronology analyses. Samples were taken specifically to employ these new types of analysis.

Nelson Head and the southeastern coast of Banks Island

The objective of fieldwork on southeastern Banks Island was to look for kinematic indicators on faults in the vicinity of the Nelson Head graben, measure and sample a section of the Lower Cretaceous Isachsen Formation, and to examine the extent of the Upper Cretaceous Kanguk Formation and sample tuffs within it (Figs. 2, 3A; Table 1).

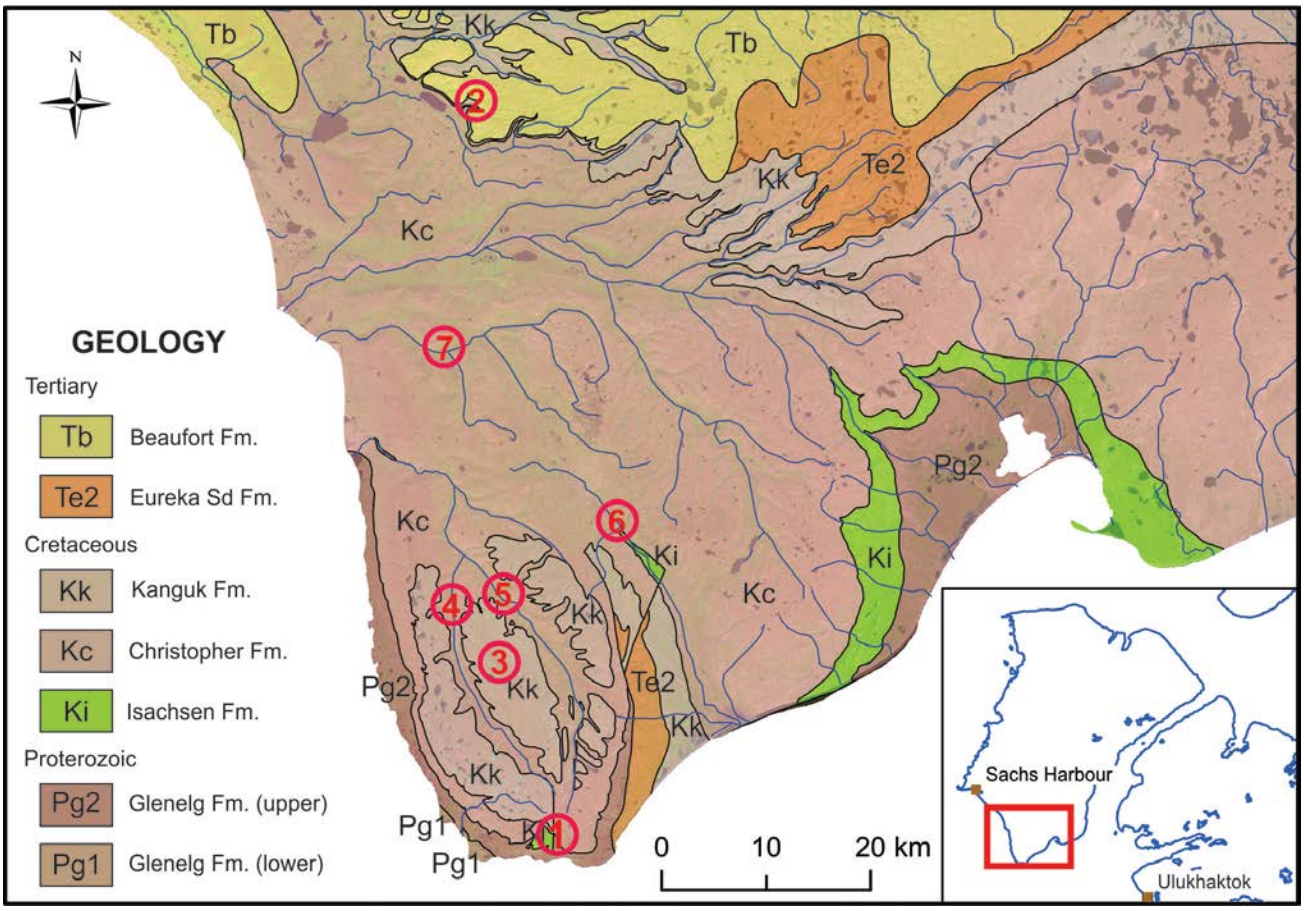

Figure 2. Areas of field investigation and sample collection in the Nelson Head region of southeast Banks Island. Station numbers and types of samples collected are identified on the accompanying Table 1. Geology after Miall (1979).

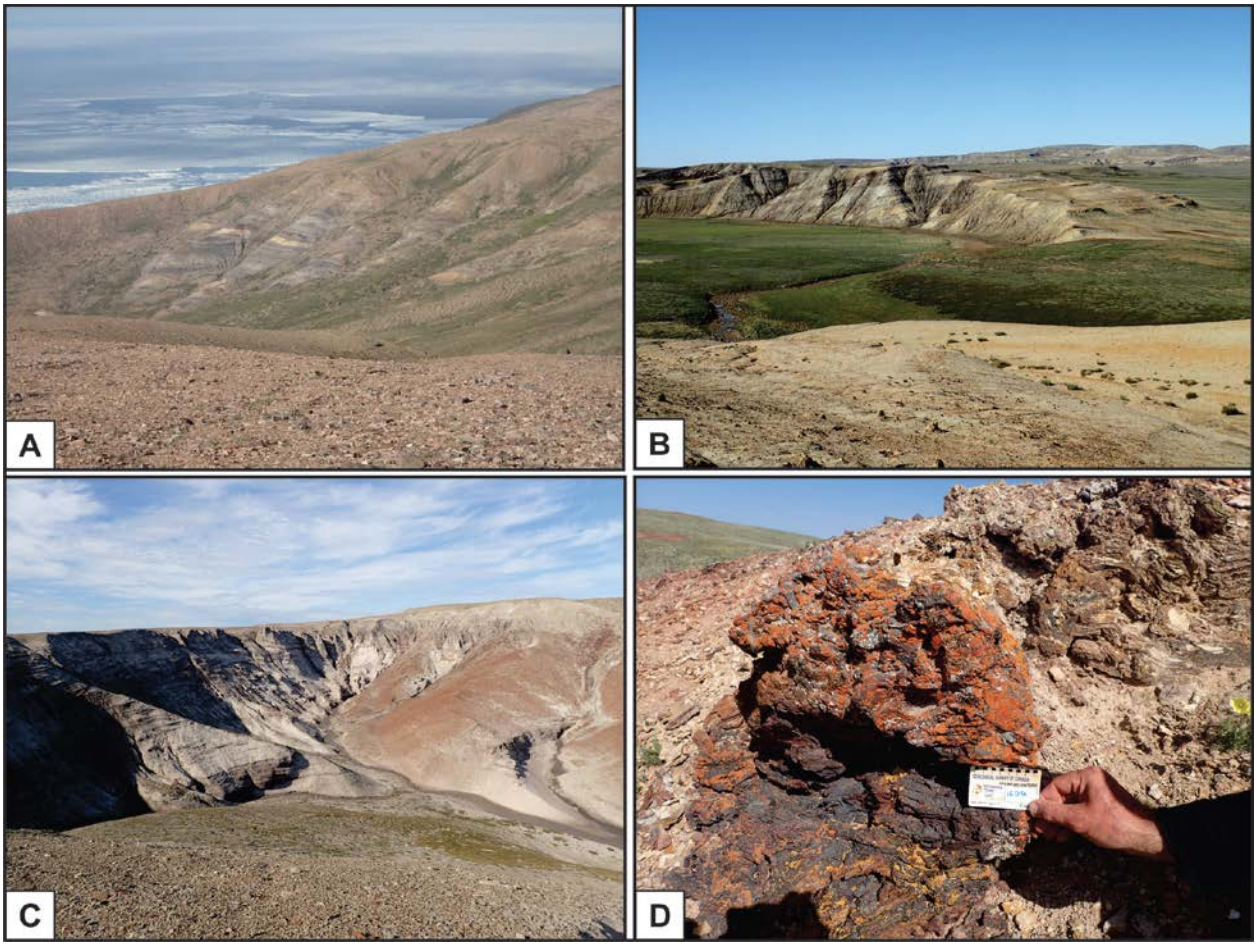

Figure 3. (**A**) Outcrop of Isachsen Formation, Nelson Head Graben. Site 1 on Fig. 2. (**B**) Typical outcrop of Tertiary Eureka Sound Formation. Looking SW, Muskox River is just to the right of the picture frame. Site 14 on Fig. 6. (**C**) Isachsen Formation near Cape Vessey Hamilton, Site 16 on Fig. 6. (**D**) Red weathering paralava and burnt shale (klinker) in the lower part of the Kanguk Formation, near Able River, Site 11 on Fig. 6.

	Station #	Detrital - Zr provenance	Tuff - Zr geochronology	Thermal Maturity	Biostratigraphy	Macrofossil	Kimberlite Indicator Minerals
NELSON HEAD							
	1	x		x	x		
	2		x				
	3						x
	4						x
	5						x
	6						x
	7						x
POLAR BEAR CABIN							
	8		x	x	x	x	
	9	x		x	x		x
	10		x				
	11		x		x		
	12	x		x	x		
	13	x			x		
	14				x		x
	15				x	x	
	16	x			x	x	x
	17				x	x	x
	18				x		
	19						x
	20						x

Table 1. July 2016 field station localities and sample collection sites, Banks Island, NWT

Faults in the Neoproterozoic Shaler Group along the east side of Nelson Head were measured. The kinematic indicators preserved on the fault surfaces will provide a sense and timing of motion on the faults.

At Nelson Head, a 59 m section of Isachsen Formation (Fig. 2, site 1) was measured and samples were collected for detrital zircon provenance analysis, thermal maturity analysis, and biostratigraphic age control (palynology; Table 1).

The tuffaceous beds noted by Miall (1979; GSC site C-30528) within the basal Kanguk Formation at upper Sachs River (Fig. 1, site 2; Fig. 4) were re-visited to collect samples for detrital zircon geochronology; samples from intervening mudstone beds were collected for biostratigraphy. There were 26 individual tuff deposits within an outcrop of Kanguk Formation, spanning 3.4 m of an exposed faulted and deformed section, that range in thickness from 2-15 cm and average ~5 cm thick. North of this locality, several valleys incised into the “bituminous shale member” of the Kanguk Formation expose what Miall (1979) described as bright red, blocky-weathering shale with cindery streaks (Fig. 5A). It is suspected that these sites are examples of burnt shale/coal deposits (cf., Piepjohn et al., 2007; Estrada et al., 2009), as was investigated on northern Banks Island (Fig. 3D). Southwest of here, also within the Kanguk “bituminous shale member,” a greeny-blue mineral spring deposit was discovered (Fig. 5B). The mineral has provisionally been identified as halotrichite (Grasby, pers. comm., 2016), a hydrous Fe Al sulphate associated with pyritic shale. Discussion with community members in Sachs Harbour revealed that this site was unknown, and no other such deposits are known of on Banks Island. Analytical testing of the mineral precipitate and spring waters is ongoing.

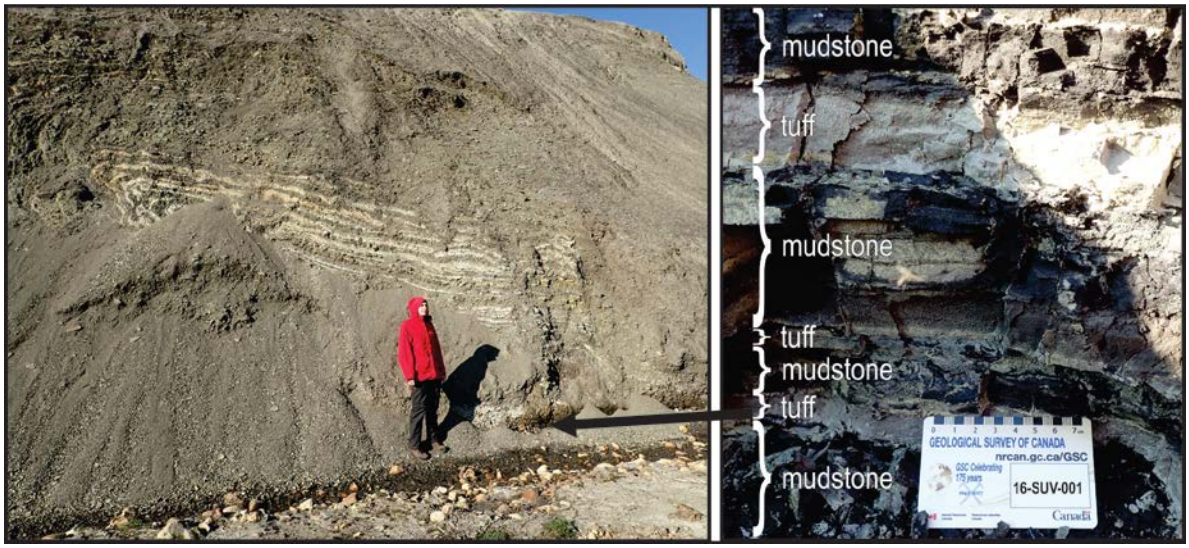

Figure 4. Abundant tuffaceous beds exposed over 3.4 m of section within basal Kanguk Fm., upper Sachs River (Fig. 1, site 2). Section was excavated right of where the person (A. Durbano) is standing. Image at right shows detail of lowermost exposed tuff beds.

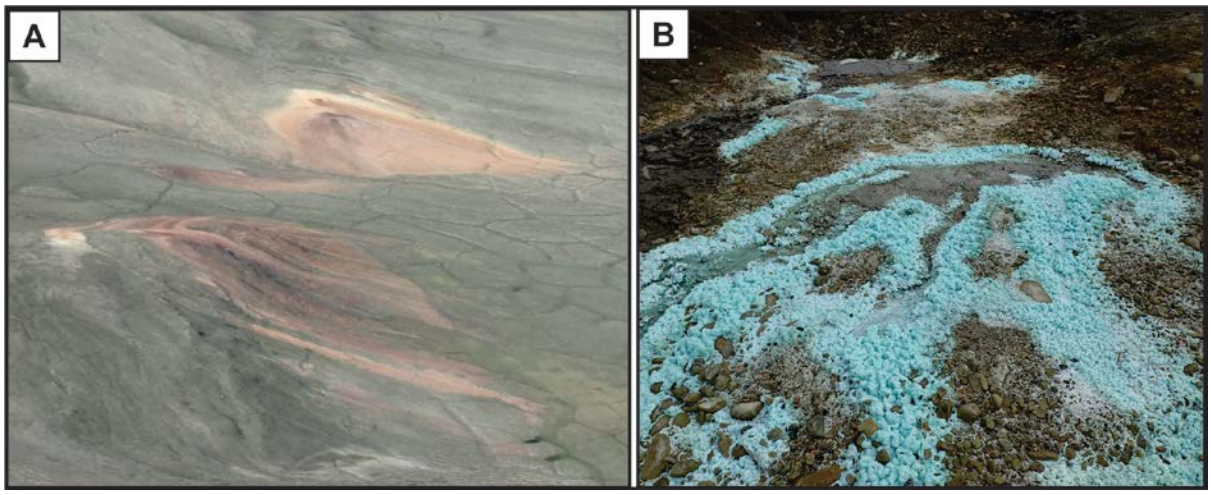

Figure 5. (**A**) Red and orange-weathering exposure of presumed burnt shale/coal (klinker) within the "bituminous member" of the Kanguk Fm., upper Sachs River, Banks Island. (**B**) Halotrichite efflorescent deposits from mineral springs in Kanguk Fm., upper Sachs River area.

The extent of Kanguk Formation atop Nelson Head is likely considerably less than is indicated on the maps of Miall (1979). Much of the area around the eastern extents of Nelson Head that was mapped as Kanguk Formation was instead found, upon site visits, to consist of thick glaciofluvial and till deposits with no bedrock exposed. Miall's (1979) mapped relationship of faults cutting the Isachsen and Christopher formations and overlain by unfaulted Kanguk Formation may not be correct. Large (>1 m) ellipsoid mudstone concretions were found outcropping along bedrock exposures and accumulating at the base of slopes in the lower parts of incised valleys 25 km inland of Nelson Head. These are correlated with the "basal bituminous shale member" of the Kanguk Formation (Miall, 1979).

Northern Banks

The work on northern Banks Island was completed while working from the Polar Bear Cabin basecamp.

A 60 m section was logged near Thomsen River of Christopher Formation (Fig. 6, site 8) up to the overlying contact with Hassel Formation. Samples were collected for invertebrate macrofossils (ammonites), thermal maturity analysis, and biostratigraphic age control. Thin tuff beds were present in the section and collected for geochronological age dating. Samples for detrital zircon provenance analysis were collected from the basal Hassel Formation at this locality.

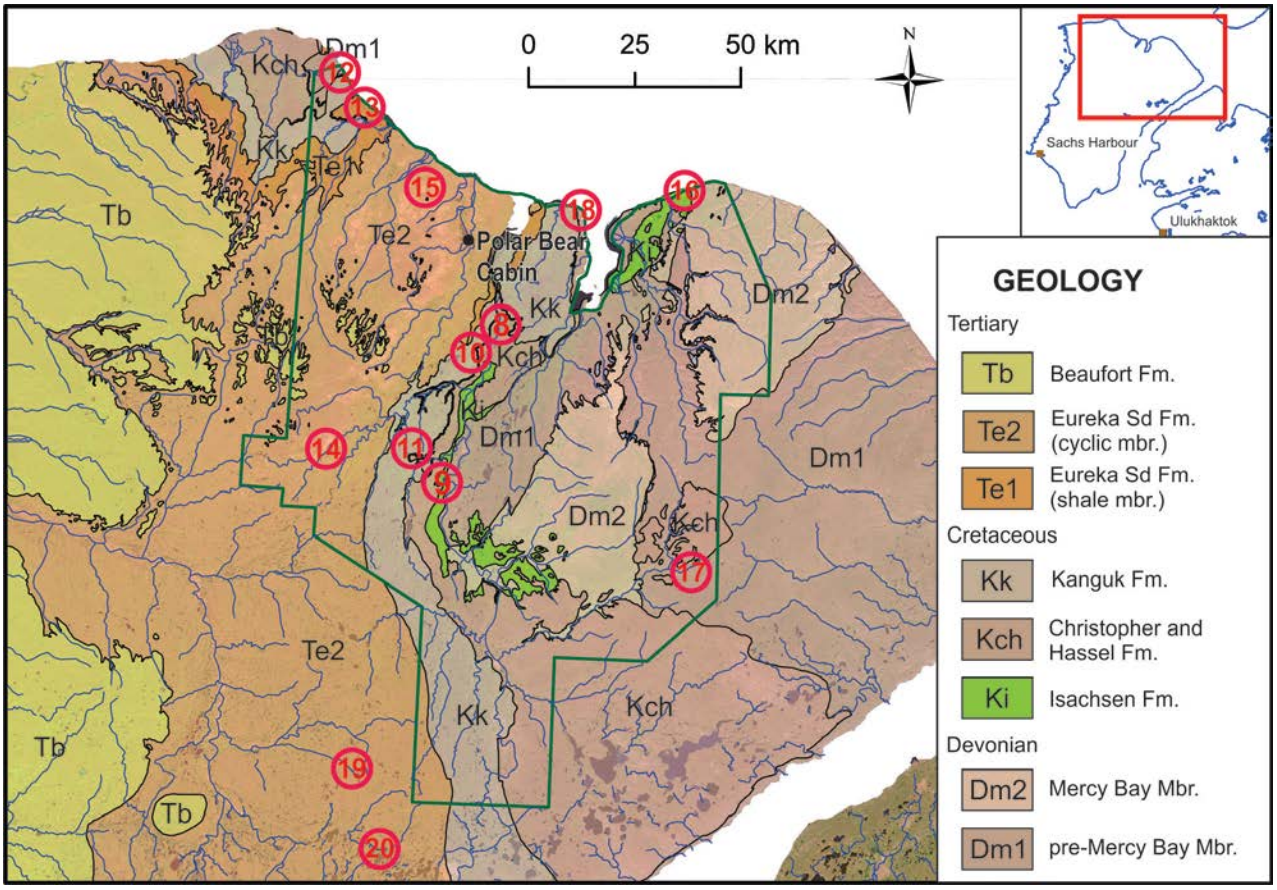

Figure 6. Areas of field investigation and sample collection in the Polar Bear Cabin region, northern Banks Island. Station numbers and types of samples collected are identified on the accompanying Table 1. Geology after Miall (1979). Green outline delineates the boundary of Aulavik National Park.

Near the Thomsen River section, several grab samples were recovered for biostratigraphic age control (Fig. 6, site 8).

Eleven samples were collected across a 20 m measured section of the Isachsen to Christopher formational transition near Baker Creek (Fig. 6, site 9). Samples were collected for biostratigraphic age control, thermal maturity study, and detrital zircon provenance analysis (Table 1). The “silty shale member” of the Kanguk Formation, south of Baker Creek, was visited and sampled for age control (Fig. 6, site 10; Table 1).

Grab samples were obtained from the “bituminous member” of the Kanguk Formation, a red-weathering unit near Able Creek for various analyses (Figs. 3D and 6, site 11). Textures in the red-weathering unit indicate at least partial melting of the rock, presumably a ‘bocanne’ formed by a process similar to that now active at the Smoking Hills, southeast of Banks Island, and similarly documented in Tertiary strata on Ellesmere Island (Mathews and Bustin, 1984; Piepjohn et al., 2007; Estrada et al., 2009).

Approximately 17 m of section were logged and sampled of the Hassel (?) and Kanguk formations (Fig. 6, site 11). Fifteen samples were collected for biostratigraphic age control, and an approximately 10 cm thick tuff was sampled for geochronological analysis.

On the northern coast of Banks Island between Cape M’Clure and Antler Cove, 31 m of exposed Mesozoic strata were logged (Fig. 6, site 12). The rocks are mapped as uppermost Hassel Formation and lower Kanguk Formation including the “bituminous member” and part of the overlying “silty shale member.” Eighteen samples were collected for geochronological age control, biostratigraphic age dating and thermal maturation study (Table 1).

Samples were collected from what was mapped by Miall (1979) to be a Tertiary section on the northern coast of Banks Island (Fig. 6, site 13). Numerous glendonite rosettes were collected from the weathered bedrock surface and in-situ within consolidated strata from this locality (Fig. 7). Glendonites are believed to form within cold shallow marine environments, possibly in association with methane seeps (Selleck et al., 2007; Herle et al., 2015), which would be incompatible with the prevailing understanding of the paleoenvironment during deposition of this Tertiary-aged strata. Mudstone samples were collected for biostratigraphic age dating.

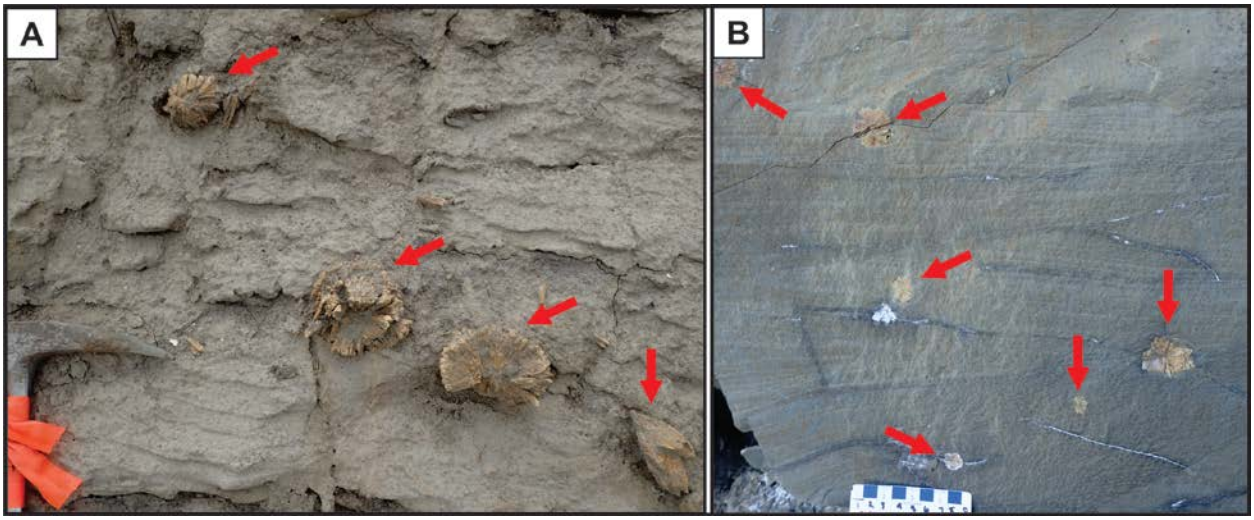

Figure 7. Glendonites exposed at surface in (**A**) poorly-lithified, and (**B**) well-lithified sandstones. Rock hammer for scale in (A).

An outcrop of Kanguk Formation “upper sand unit” of Miall (1979) was visited on the northern coast of Banks Island (Fig. 6, site 13). A conglomerate within the “upper sand unit” contains abundant clasts of silicified crinoidal grainstone. At least one clast is from an Upper Paleozoic unit as it contains fusulinids. Samples were taken for detrital zircon provenance analysis and a mudstone sample was collected for biostratigraphic age control.

A section assigned to the Eureka Sound Formation, cyclic member, was visited near the Muskox River (Fig. 3B and 6, site 14). Samples were collected from the lowermost ~35 m of section for biostratigraphic age control.

A section containing rocks of Tertiary age according to previous mapping (Miall, 1979) was visited and trace fossils sampled (*Ophiomorpha* sp. predominantly; Figs. 6, site 15 and 8). A second locality of Tertiary strata was visited and small samples of siderized rock and wood were sampled for macrofossil analysis and biostratigraphic age control (Fig. 6, site 15). This location has a clearly visible fault at surface that is also seen on the seismic line that crosses this area.

Figure 8. Ophiomorpha sp. burrow trace fossils exposed within wind-deflated, unconsolidated sandstone, Muskox River valley, Banks Island, NWT.

An outcrop of Isachsen Formation was visited near Cape Vessey Hamilton (Figs. 3C and 6, site 16). Nine samples were collected for plant macrofossils, biostratigraphic age control and detrital zircon provenance analysis. Two levels of conglomerate were sampled for clast composition. Most carbonate clasts seem to have been derived from the nearby Mercy Bay member of the Devonian Weatherall Formation. No silicified carbonate clasts were seen.

Thirteen grab samples were collected from Tertiary strata in the interior of east-central Banks Island. This was a locality previously identified for further study (Smith, 2015; Fig. 6, site 17). The purpose of sample collection is for biostratigraphic age control and to confirm the map unit. One grab sample was collected from a nearby outcrop of sandstone containing visible crinoid fossils.

A section of Christopher and/or Kanguk formations was visited at Investigator Point (Fig. 6, site 18). Three grab samples were collected for biostratigraphic age control to help resolve mapping issues. A nearby exposure of Hassel and Kanguk formations was also sampled.

Structural Geology

Structural geology field work was carried out in Devonian, Late Cretaceous and Paleogene sediments, largely on northern Banks Island. This work included the location of faults at surface which have previously been indicated on seismic surveys. Kinematic studies were undertaken on some of these fault zones and within outcrops outside the faults. Although the preservation of structures in the unconsolidated bedrock was poor, and the determination of the senses of displacements difficult, it can be stated that Banks Island has been more affected by tectonic movements than previously thought.

Kimberlite Indicator Minerals

Over the past 20 years, Banks Island has been the subject of kimberlite exploration by three companies – Monopros, Diamonds North Resources Ltd., and Rio Tinto Exploration Canada Inc. Numerous and varied KIMs have been documented on northeast Banks Island, for which the kimberlitic source is unknown. This area was the subject of field exploration and sample collection by the GEM 2 Western Arctic Margins project in July 2015 (Smith, 2015). This year's KIM sample collections were opportunistically made where bedrock geology-focussed logistics permitted. While the intention was to collect additional samples from areas and deposits on northeastern Banks Island not sampled in 2015, helicopter mechanical issues prevented several days of flying when such work had been planned. KIM samples were thus focussed in areas and deposits outside of known industry collections.

In 2015, discovery of unidentified unconsolidated Upper Tertiary Beaufort Formation fluvial deposits within catchments on northeastern Banks Island where industry samples had reported KIMs, led to their investigation as a potential source of bedrock-inherited KIMs (Smith, 2015). Following this same line of inquiry, the southeastern-most identified Beaufort Formation deposit (Vincent, 1990), which occurs in the Nelson Head area, was investigated and sampled (Fig. 2, site 3). This deposit, however, was determined instead to be a large, ice-contact glaciofluvial terrace, up to 10 thick, containing many angular to subrounded clasts, including abundant gabbro and local sandstone lithologies and lesser granite, gneiss, and Paleozoic carbonates, numerous of which were striated. Four stream sediment samples were also collected in the Nelson Head area (Fig. 2, sites 4-7), in order to broadly

characterize the regional bedrock catchments and glacial deposits in terms of potential KIM contents, and to compare and contrast these with collections from northeastern Banks Island.

Duck Hawk Bluffs, situated 14 km west of the hamlet of Sachs Harbour is an 8 km long and up to 60 m high bluff of largely unconsolidated sediments. It was previously asserted that Duck Hawk Bluffs contained preglacial sediments (i.e., Beaufort Formation) overlain by deposits from 3 glacials and 2 interglacials spanning >780 ka (cf., Vincent, 1983; Vincent et al., 1983; Barendregt and Vincent, 1990). Recent detailed and methodical investigations by Evans et al. (2014) reveal instead that this site is largely a thrust-block moraine comprising a stratigraphy recording 3 glacial intervals and one prominent interglacial, the base of which is glaciofluvial outwash that reworked Beaufort Formation sediments. Evans et al. (2014) documented extensive glaciotectonic deformation within the bluffs, and the incorporation of large rafts of intact and deformed Kanguk Formation bedrock. Samples for KIM analyses were collected from two sites in the lowermost glaciofluvial outwash (LFA 1 of Evans et al., 2014), and from two sites within the "old" (>780 ka) till (LFA 3 of Evans et al., 2014). Were KIMs to be recovered from these deposits, they would be compared to those collected from a similar pre-late Wisconsinan stratigraphy exposed at Morgan Bluffs on east-central Banks Island (Smith, 2015), and could reveal a palimpsest glacial dispersal of KIMs on Banks Island.

Bulk sediment KIM samples were collected from interpreted Beaufort Formation deposits on northern Banks Island from two localities. The first represents a prominent upland peneplain bordering the Muskox River valley (Fig. 6, site 14). The surface is covered by a conspicuously orange-stained, coarse pebble-cobble lag of sub-angular to well-rounded clasts, including abundant quartzites, sandstones, and red, green and black chert, many of which display a high degree of desert varnish, supporting the assertion of greater antiquity. Only very rare glacial erratic boulders were found across this broad surface, and there is no indication of any till deposit suggesting this region has only ever been inundated by cold-based ice since its formation (cf., Lakeman and England, 2013). A second sample of Beaufort Formation deposits was collected in an area where a stream sediment sample collected in 2015 returned several KIMs including a G10 garnet (Fig. 6, site 17). Here, a prominent incised valley is shouldered by 2-15 m thick, incised terraces of Beaufort Formation sandy-gravel that cap the underlying bedrock. A second KIM sample was collected from the apex of an alluvial fan in the valley west of where the 2015 sample returned a G10 garnet.

KIM samples were also collected in two locations of unconsolidated Isachsen Formation sand and gravel deposits (Fig. 6, sites 9 and 16). Site 9 is comprised of planar angle-bedded, fine to medium, quartz-rich sands, approximately 1 m thick, underlain by a coarse quartz sand lag with shale clasts. The unit is capped by a mud ripple underlying ripple and trough-cross bedded fine sand. Site 16 was sampled within two prominent pebble-boulder conglomerate beds (5-30 cm thick) of angular to sub-rounded sandstone and rare carbonate cobbles and boulders up to 40 cm in diameter. These unconsolidated conglomerate beds are situated within large-scale planar cross beds and trough-cross bedded sand.

A final two KIM samples were collected from stream sediments at and beyond the distal western margins of the Jesse moraine belt (Lakeman and England, 2012) in the headwaters of the Thomsen River valley (Fig. 6, sites 19 and 20). Site 19 is situated west of the Jesse moraine belt, within the zone of warm-based glacier ice that flowed northward down the Thomsen River valley during the late Wisconsinan deglacial Thomsen phase (~14 cal ka BP; Lakeman and England, 2012). Ice feeding this

flow would have originated in northwestern Victoria Island. The catchment around site 20 is marked by at least 5 large kames and associated outwash deposits, and would relate to the later deglacial Prince of Wales phase where ice sourced from central and eastern Victoria Island became increasingly topographically confined, flowing northward up Prince of Wales Strait. Differences in KIMs recovered from these two samples may help differentiate potential distal kimberlitic sources.

CONCLUSIONS

Bedrock Geology

A total of 154 samples were collected for a variety of analyses from bedrock exposed on Banks Island. These analyses will include geochronology age dating of tuff and detrital zircon provenance study (if possible), biostratigraphy (with a focus on palynology), and thermal maturation studies. We anticipate that analyses and emerging results will provide new insight into the age of lithostratigraphic units.

Numerous previously unmapped structures were identified during the field program. These will be examined in conjunction with seismic records to provide new insight into structural evolution of the region.

Kimberlite Indicator Minerals

A total of 16 sediment samples have been submitted for processing and KIM recovery. Recovered KIMs will be submitted for geochemical analysis, and results will be compiled with those samples collected in 2015 and released as an Open File report in 2017. Comparison of these results with existing industry KIM data from Banks and neighboring Victoria islands will help to resolve the potential source of the Banks Island KIMs, including the potential for bedrock inheritance of KIMS. Collaborative research initiated on hafnium (Hf) age determinations of ilmenites from Banks Island will be expanded to include any ilmenite minerals recovered in this year's sample collections.

Future Work

No additional fieldwork is planned for Banks Island under the GEM 2 Western Arctic Margins project. Resources will now be focused on the analysis and interpretation of samples collected over the two years of fieldwork. Additional research will be conducted using reprocessed on-shore and recently acquired industry offshore seismic data. Fault and kinematic indicator measurements will be analyzed and compared with structural studies in other areas of the Canadian passive continental margin. Future field studies are proposed for 2018 in the Smoking Hills area west of Paulatuk, following the same Cretaceous and Tertiary strata on Banks Island to their southernmost outcrop. Results will ultimately be synthesized with those gathered from the mainland, Banks Island, and Sverdrup Basin GEM-related field activities.

ACKNOWLEDGEMENTS

The research reported on in this publication is part of the GEM 2 Western Arctic Margins Project, which is under the scientific leadership of Keith Dewing and Jennifer Galloway, activity leader Rod Smith, and with GSC management support from Carl Ozyer and Lila Chebab. This research is being conducted in collaboration with researchers from Germany's Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Northwest Territories Geological Survey, and University of Alberta. Logistical

support was expertly managed by Polar Continental Shelf Project (PCSP), and operators Aklak Air and Great Slave Helicopters (René Gysler, Joe Gourd) who are thanked for their professional staff and service. The Sachs Harbour Hunters and Trappers Committee and wildlife monitors John Lucas, Sr., Trevor Lucas and Kim Lucas are thanked for their assistance and participation in field activities. Andrew Durbano provided field assistance to J. Galloway. Christine Deblonde (GSC Calgary) has provided GIS and digital data support to the project. Sean Eagles (GSC Ottawa) produced the basemap figure.

This research is conducted under Northwest Territories Scientific Research Licence 15800, Inuvialuit Land Administration Right to Access Land # ILA16SN002, Parks Canada Research and Collection Permit # AUL-2016-21396 and approval of the Sachs Harbour HTC. Assistance of N. Perry, Parks Canada, Western Arctic Branch is greatly appreciated. Access and use of Polar Bear Cabin was granted by NWT Department of Environment and Natural Resources.

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