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P. Kabanov<sup>1</sup>, S.A. Gouwy<sup>1</sup>, and W.C. Chan<sup>1</sup>

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## **2016**

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Cover photo: Contact of Hume limestone and black shales of the Horn River Group at Rumbly Creek tributary waterfall section

## 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.

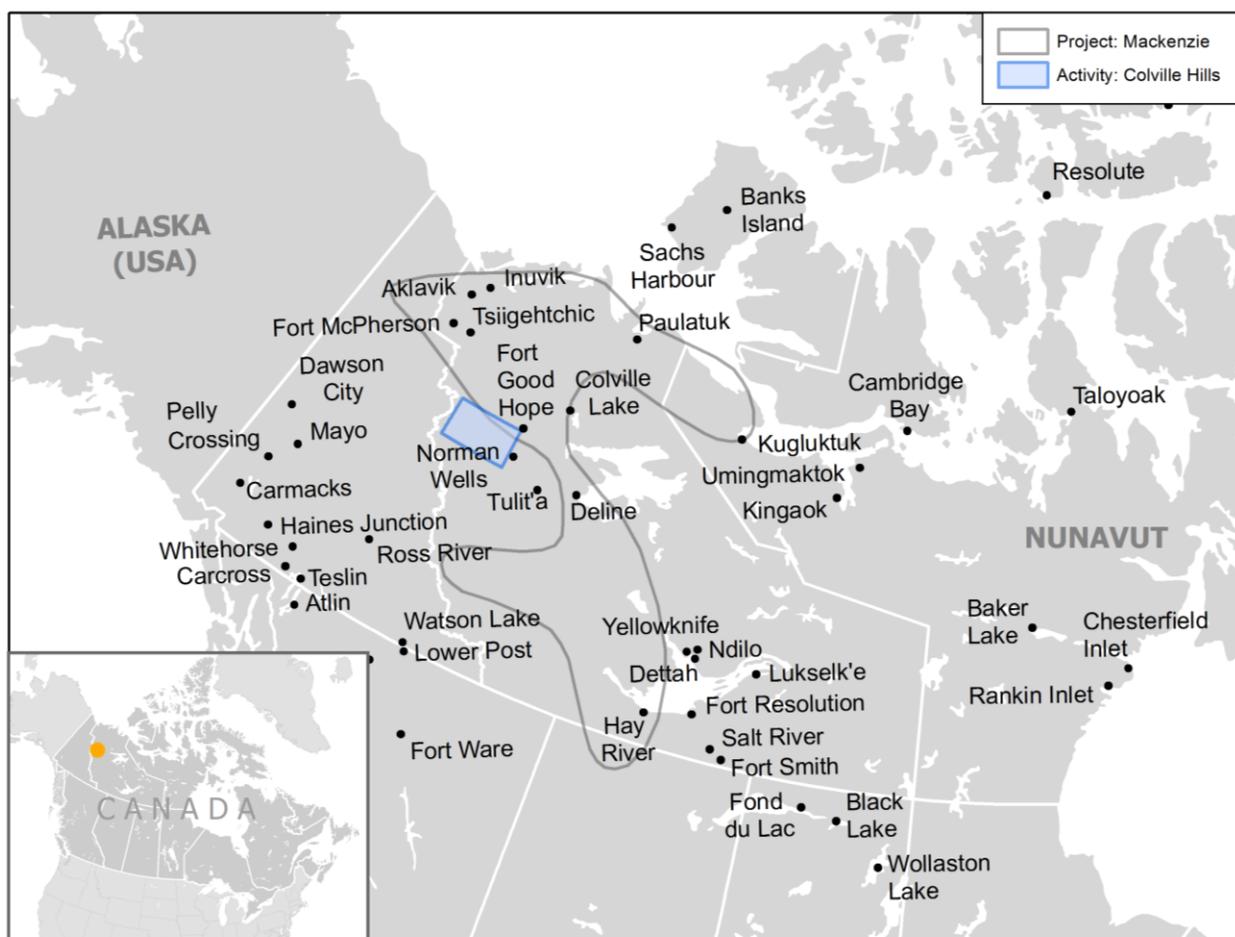


Figure 1. Location of the Gem 2 Mackenzie project area and the 2016 field work location for the Colville Hills activity.

## PROJECT SUMMARY

The Devonian Stratigraphic Framework study is part of the Mackenzie Project of GEM2, upgrading the multifaceted knowledge on the economically important Devonian strata of the region. The field work was conducted between July 12 - August 05, 2016, within NTS map areas 106G and 106 H. The Devonian team has measured 8 outcrop sections (974 m in total) located along the northern edge of the Mackenzie Mountains: Powell Creek (four sections), Rumbly Creek tributary waterfall, Rumbly Creek Canol, Turnabout Creek, and Rumbly Creek West Ridge. These sections cover the Devonian succession from its base to the basal part of the Imperial Formation. Most of the measured intervals were surveyed with spectral gamma-ray scintillometer for correlation with subsurface sections in Peel and Mackenzie plains. To strengthen the biostratigraphic framework, seventy-five samples for conodont biostratigraphy were collected from the studied formations.

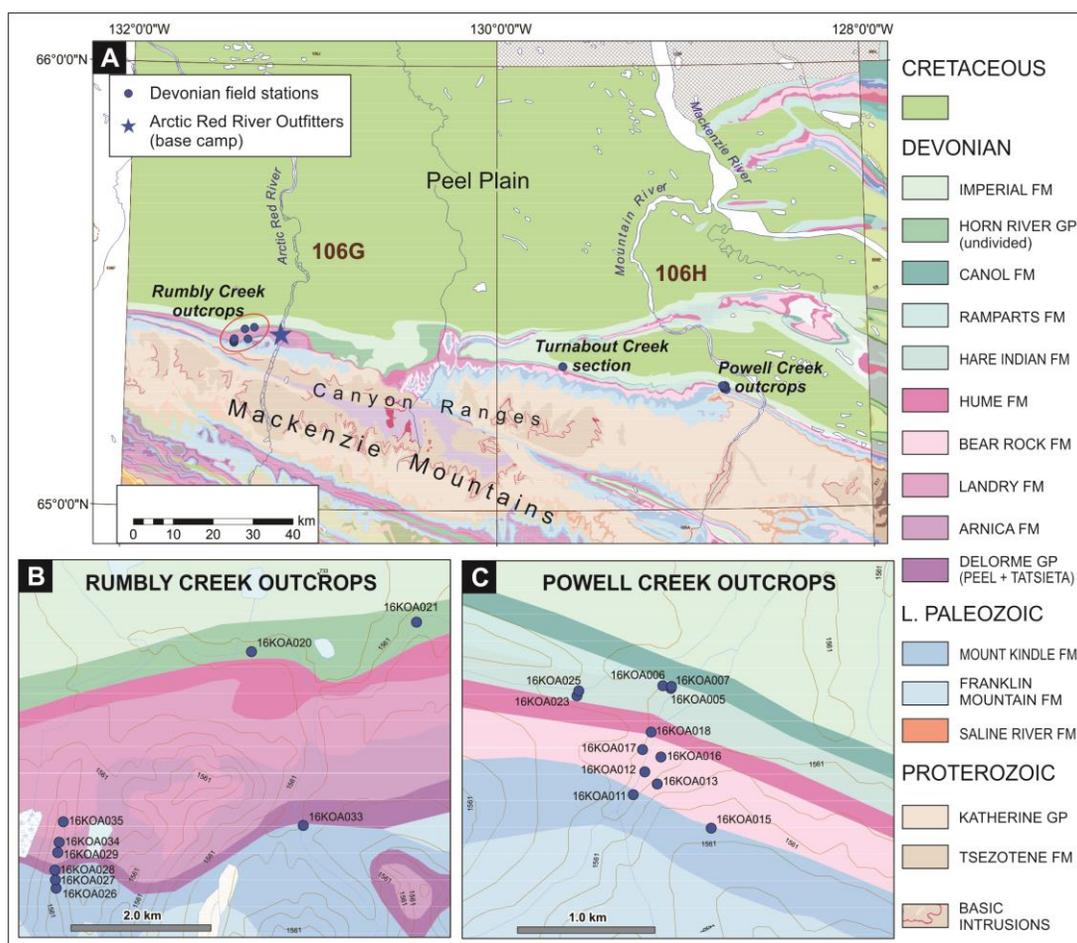
## RESUMÉ

L'étude sur le cadre stratigraphique du Dévonien, dans le cadre du projet Mackenzie du programme GEM-2, permet d'améliorer les connaissances à facettes multiples sur les strates du Dévonien de la région, lesquelles présentent un intérêt économique important. Les travaux sur le terrain ont été réalisés entre le 12 juillet et le 5 août 2016, dans les régions des cartes 106G et 106H du SNRC. L'équipe chargée de l'étude sur le Dévonien a mesuré huit coupes d'affleurements (totalisant 974 m) situés le long de la bordure nord des monts Mackenzie : ruisseau Powell (quatre coupes), chute de l'affluent du ruisseau Rumbly, Formation de Canol au ruisseau Rumbly, ruisseau Turnabout et crête ouest du ruisseau Rumbly. Ces coupes couvrent la succession du Dévonien depuis sa base jusqu'à la partie basale de la Formation d'Imperial. La plupart des intervalles mesurés ont fait l'objet de levés au moyen d'un scintillomètre gamma spectral, afin d'établir une corrélation avec les coupes de subsurface dans les plaines de Peel et de Mackenzie. Afin de renforcer le cadre biostratigraphique, soixante-quinze échantillons ont été prélevés dans les formations étudiées en vue d'une analyse biostratigraphique des conodontes.

## INTRODUCTION

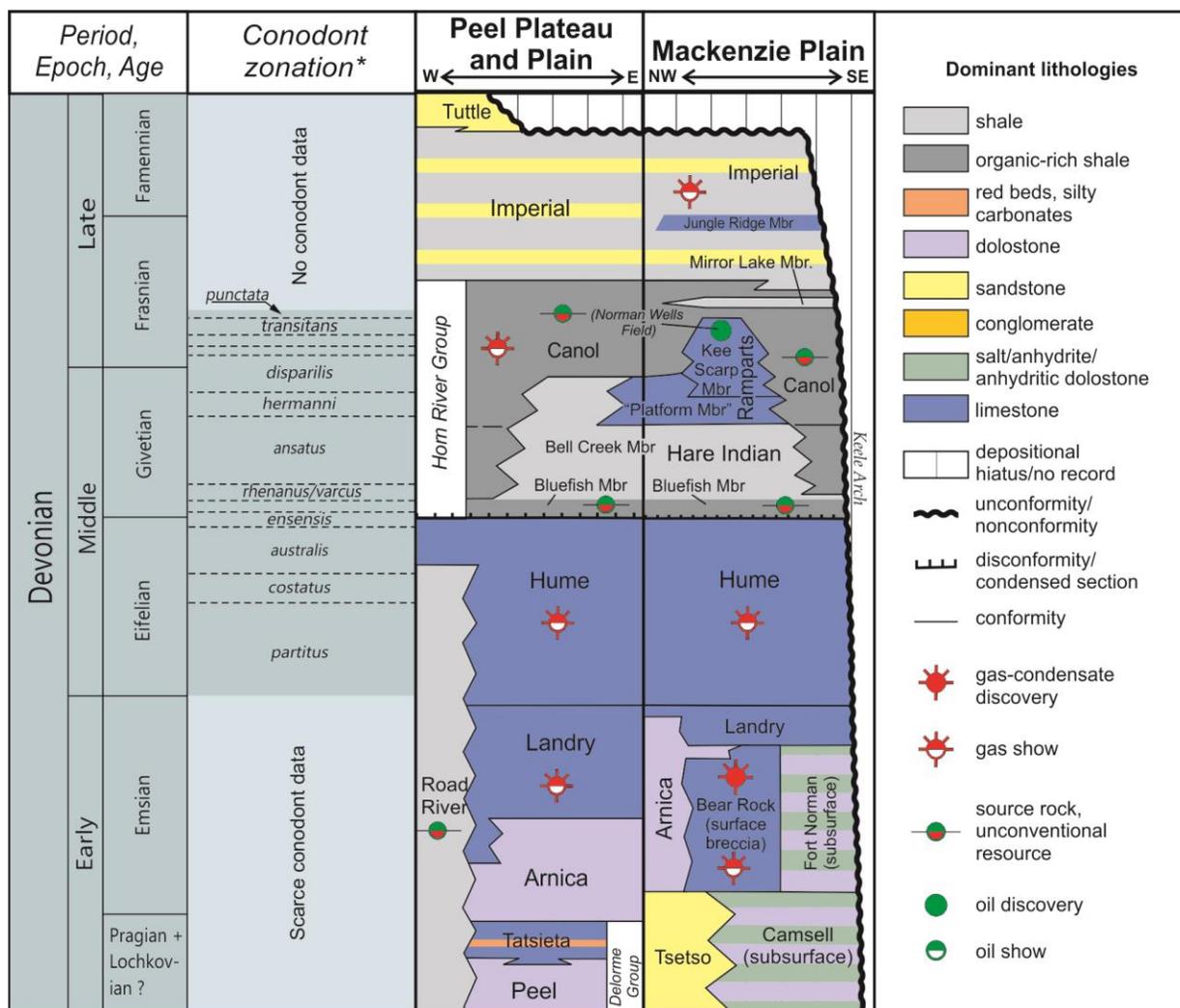
### Activity outline

The Mackenzie Project of the renewed GEM Program (2014-2020) includes the *Devonian stratigraphic framework* study focusing on the improvement of stratigraphic subdivision for the needs of bedrock mapping and frontier petroleum exploration. The Devonian in the Mackenzie project area (Figs. 1 and 2) is a thick (locally over 1 km) stratal succession composed of carbonates, evaporites, and siliciclastics recording the evolution of depositional environments from passive-margin shallow-water carbonate platform, through the sediment-starved epiplatform anoxic basin, to the foreland basin (Fig. 3). The study is focusing on the sub-Imperial Devonian strata as stratigraphy of the Late Devonian Imperial Formation is considered adequate and up to date (Hadlari et al., 2009; Dixon, 2012). Biostratigraphic and chronostratigraphic constraints on formations and members are the critical part of the study, with most significant results achieved to date in the Horn River Group (Fig. 4; Kabanov et al., 2016a; Kabanov and Gouwy, in press).

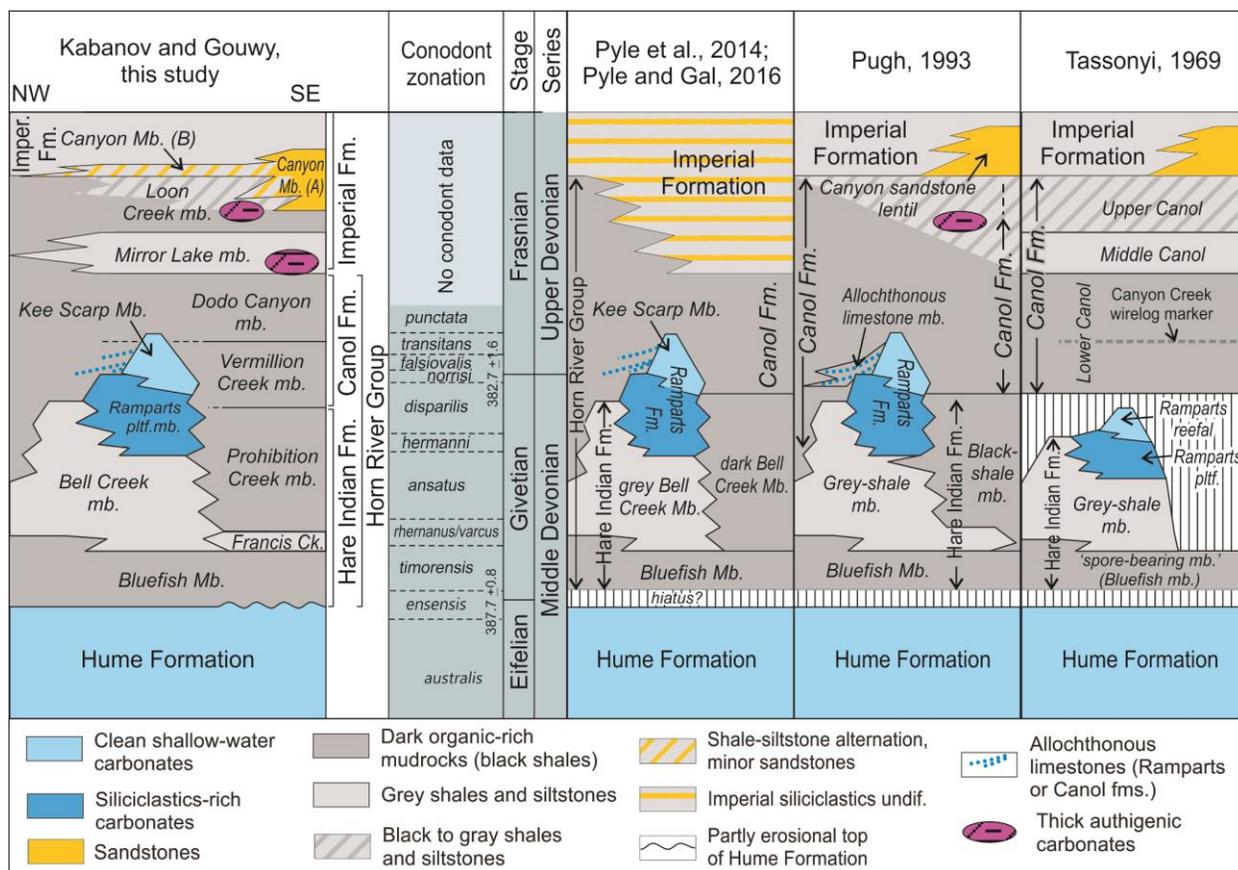


**Figure 2.** Study area and field stations on measured Devonian outcrops put on the bedrock geological map (A). GEM Mackenzie project updates and structural information not included. (B and C) Two close-ups with 250k topography. The GIS bedrock basemap is courtesy of K.M. Fallas.

The Givetian-Frasnian black shales of the Horn River Group host the giant, non-conventional prospect of gas and light oil (a.k.a. Canol Shale Play; AANDC, 2014). This prospect is considered a major future asset in fossil energy for Northwest Territories (Hayes, 2011), and constitutes the research focus of the multiproxy characterization of this stratal package (Fig. 4; Pyle and Gal, 2016; Kabanov and Gouwy, in press). Mudrocks of the Horn River Group, particularly the Canol Formation, also sourced conventional reservoirs at Norman Wells Oilfield and Summit Creek gas-condensate field (Snowden et al., 1987; Yose et al., 2001; Hannigan et al., 2011). Research on the Horn River Group addresses the GEM Mackenzie Project no. 1 question: *What controlled deposition of source rocks, depth and timing of burial, and timing of uplift across the region, and their impact on petroleum systems?*



**Figure 3. Devonian table of formations for the study area. Devonian stratigraphy of the field area 2016 is described by Peel Plateau and Plain subdivisions. Conodont zonation refers to the eastern Peel area and Mackenzie Plain (Kabanov and Gouwy, in press). Complete list of identified conodont zones is given on Figure 4. Lower Devonian stratigraphy adapted from Rocheleau and Fiess (2014).**



**Figure 4. Lithostratigraphy of the Horn River Group of the Mackenzie Plain, adjacent to the field study area of 2016, in comparison to previous lithostratigraphic subdivisions that involve subsurface correlations (Kabanov and Gouwy, in press). Conodont zonation also refers to the eastern Peel area.**

The other focus is the thick Lower to basal Middle Devonian succession of shallow-water platform carbonates and evaporites which historically has the least developed stratigraphic framework (Fig. 3). In this succession, the contacts of formations are lithological with a significant component of facies change or degree of dolomitization (Fig. 3) and no adequately defined sequence-stratigraphic bounding surfaces, except for the sub-Devonian unconformity. The top of the Lower Devonian package, at the contact of Landry and Hume formations, has been also interpreted controversially (Bassett, 1961; Morrow, 1991, 1999; Gal et al., 2009), and the need for more sedimentological detail in the regional context was recently demonstrated (Kabanov, 2014). The Lower Devonian succession contains distinctive allostratigraphic horizons such as thick deeper-water fossiliferous intervals inside peritidal successions and major disconformities with thick paleokarsts and paleosols (Kabanov, 2014, 2015), and the goal of this part of the study is to evaluate traceability of these horizons across the project area, from outcrops to the subsurface, to augment the conventional lithostratigraphy.

The Lower Devonian carbonates also host economic assets: numerous oil and gas shows in breccias, dolostones and limestones and one recently launched oil, gas, and condensate field at Summit Creek, with a reservoir in breccia of the Bear Rock Formation (Gal et al., 2009; Hannigan et al., 2011). To the south of the study area, in the Liard Basin, a chain of fourteen gas fields produces gas from catagenetic

hydrothermal dolomite reservoirs (Manetoe facies) developed in Devonian-age carbonates (Morrow et al., 1990; Hannigan et al., 2011; Morrow, 2012). The Lower Devonian carbonates of the Mackenzie Mountains host Pb-Zn mineralization along fault zones with best showings in limestones of the Landry Formation (Dewing et al., 2006).

### Field work 2016

The Field Party included two bedrock mapping teams and the Devonian stratigraphy team. All three teams operated with daily helicopter dispatch from the base camp at Arctic Red River Outfitters (Fig. 2). Our Devonian stratigraphy team also conducted a six-day fly camp to study several outcrops in Powell Creek (Figs. 2 and 5). The core activity was focused on bedrock surveying within NTS map areas 106G and 106H (Fig. 1), along the northern part of the Mackenzie Mountains arch and the adjacent portion of the Peel Plateau (Fallas et al., in press).

The goal of the Devonian stratigraphy team was obtaining information (biostratigraphic, sedimentologic and geophysical) crucial for characterization of lithostratigraphic units and their local and global correlation. The team measured 974 meters in eight stratigraphic sections (Table 1), and one station at the upper Rumbly Creek was accessed for conodont sampling of the Peel Formation, close to the base of the Devonian succession. Most intervals in measured sections were surveyed with a spectral gamma-ray scintillometer (SGR). Samples for biostratigraphy, a total of 75, were collected from all stratigraphic units except for the basal Imperial beds where no carbonate material suitable for dissolution was found. The contact between the Mount Kindle and Peel formations (sub-Devonian unconformity) in a dolostone section at Powell Creek was sampled for analytical studies. One bentonite clay seam was collected for absolute dating from the Lower Canol formation of Powell Creek Canol section.

	Powell Creek Canol	Powell Creek West	Powell Creek Lower Devonian	Powell Creek Landry-Hume	Rumbly Creek tributary waterfall	Rumbly Creek Canol	Turnabout Creek	Rumbly Creek West Ridge	Rumbly Creek Station
Station at section base	16KOA005	16KOA023	16KOA011	16KOA017	16KOA020	16KOA021	16KOA030	16KOA026	16KOA033
Latitude, longitude, (NAD83), ASL	65.27746N, 128.77364W, 351 m	65.27709N, 128.78831W, 415 m	65.27056N, 128.77983W, 378 m	65.27349N, 128.77824W, 354 m	65.40341N, 131.35967W, 660 m	65.40765N, 131.30914W, 570 m	65.32369N, 129.64431W, 508 m	65.37253N, 131.41802W, 1191 m	65.38127N, 131.34261W, 697 m
Imperial Fm. (lower)									
Canol Formation	8 sampl. 54.0 m					8 sampl. 93.5 m	2 sampl. 74.0 m		
Ramparts Fm. (platform)	4 sampl.						6 sampl.		
Hare Indian Fm.		5 sampl. 14.0 m			5 sampl. 31.0 m				
Hume Fm. (upper)	4 sampl.	9 sampl.			6 sampl.				
Hume Fm. (lower)									
Landry Fm.				2 sampl. 104.7 m				1 sampl.	
Bear Rock Fm.			6 sampl.						
Arnica Fm.								5 sampl.	
Tatsieta Fm.									
Peel Fm.								3 sampl. 374.0 m	1 sampl.
Mt. Kindle Fm. (top)			229.0 m						

**Table 1. Measured Devonian sections. Green boxes indicate lithostratigraphic units captured in the description; yellow boxes indicate samples taken for conodont biostratigraphy.**

## METHODOLOGY AND SAMPLING PROCEDURE

### *Section measurements*

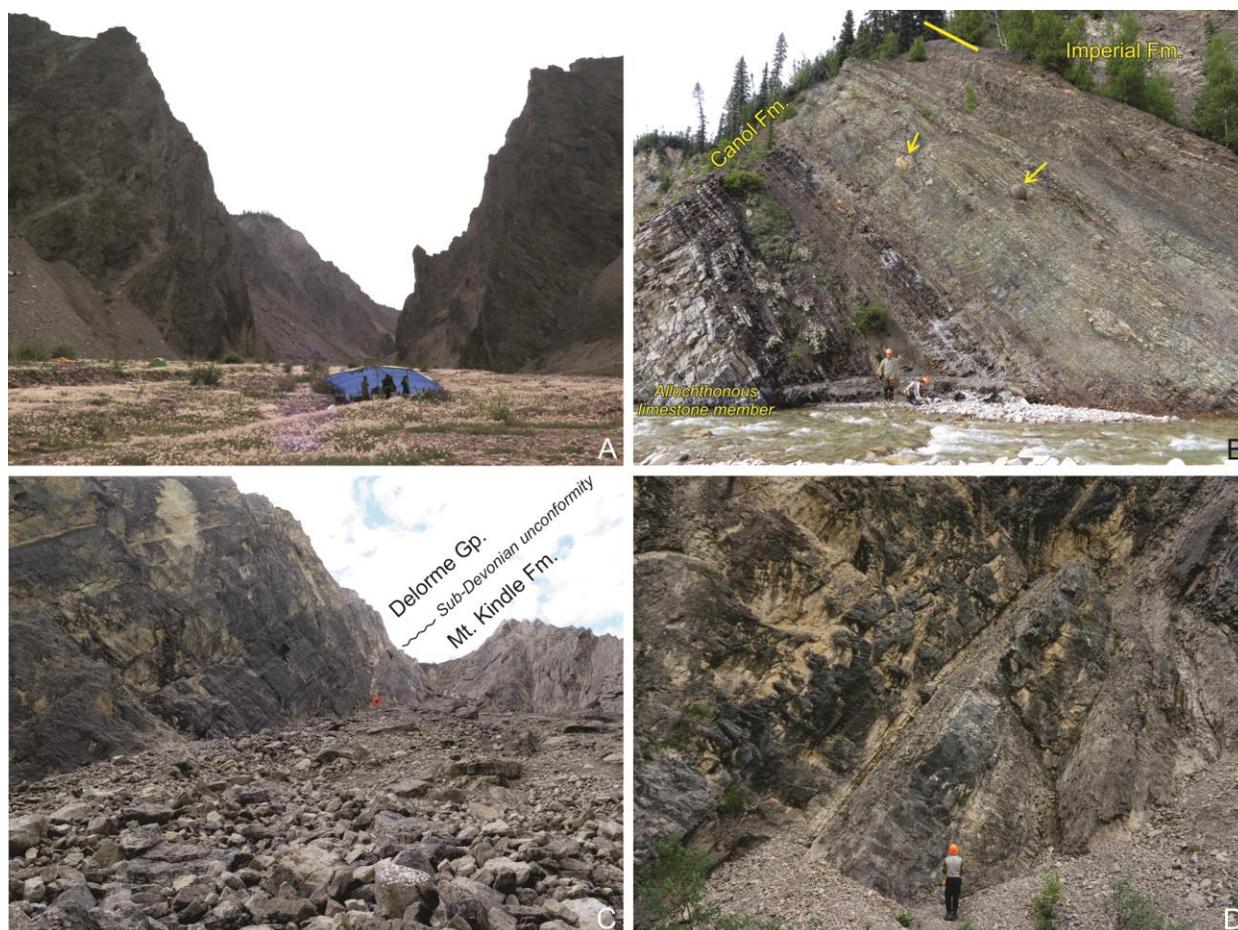
Outcrops selected for stratigraphic sections were georeferenced with field stations (Fig. 2 and Table 1) recorded on a Trimble Nomad 900 series handheld computer. Geological information for each field station was entered in GanFeld, a GSC custom application built on ESRI ArcPad mobile system. Stratigraphic thicknesses were measured with 1.6 m tall pogo stick graduated in 10 cm. Zero datums were chosen at recognizable horizons in basal parts of sections (e.g., lithological contacts, paleokarst tops at unconformities, or thin carbonate beds in mudrocks), but these horizons usually did not match bases of sections available for observation. Meterage was marked with flagging tape that then was removed after measurement and sampling were finished. Dip and strike were captured with right-hand rule on one or more reliable bedding planes in each section. Bed-by-bed section descriptions were accompanied with macro-photographing of key textures and structures.

### *Gamma-ray spectrometry*

Measured outcrops were surveyed with the RS-230 BGO scintillometer (Radiation Solutions Inc.). SGR logs were made mostly in 0.5 m increments in mudrock-dominated sections and 1.0 m steps in Lower Devonian carbonates. Measurements across stratigraphic contacts and intraformational disconformities were made with more frequent increments. Signal acquisition time was set to 90 seconds.

Decomposition of gamma radiation into U, Th and K spectra is widely used to interpret lithology and depositional environments. Potassium and thorium are relatively stable and mostly bound in detrital siliciclastics, whereas uranium is more soluble and tends to be trapped by organic matter. Hence K and Th are usually better correlated to each other than K/U and Th/U, and are often used together as uranium stripped K-Th gamma ray proxy for siliciclastic supply, also known as the computed gamma ray (CGR). Potassium is bound in detrital micas and also more involved in weathering mineral transformations than thorium resulting in its fixation in clays. Thorium is very stable near the Earth surface and preferentially resides in detrital mineral grains (ilmenite and others).

The  $\gamma$ -ray (Gamma-ray) spectrometry is based on the fact that natural radioactivity in pre-Cenozoic rocks mostly results from three isotopes,  $^{232}\text{Th}$ ,  $^{40}\text{K}$ , and  $^{238}\text{U}$ , having half-lives comparable to the age of the Earth crust. Other radioactive isotopes decay faster with diminutive significance back in the pre-Quaternary geological record. Thorium and uranium both decay through two different series of a dozen or more intermediate isotopes to a stable isotope of lead. These decays produce complicated gamma-ray spectra with energy emission lines characteristic for each series. Radioactive potassium  $^{40}\text{K}$  decaying to stable  $^{39}\text{K}$  has only one characteristic gamma energy of 1.46 meV (Ellis and Singer, 2008).

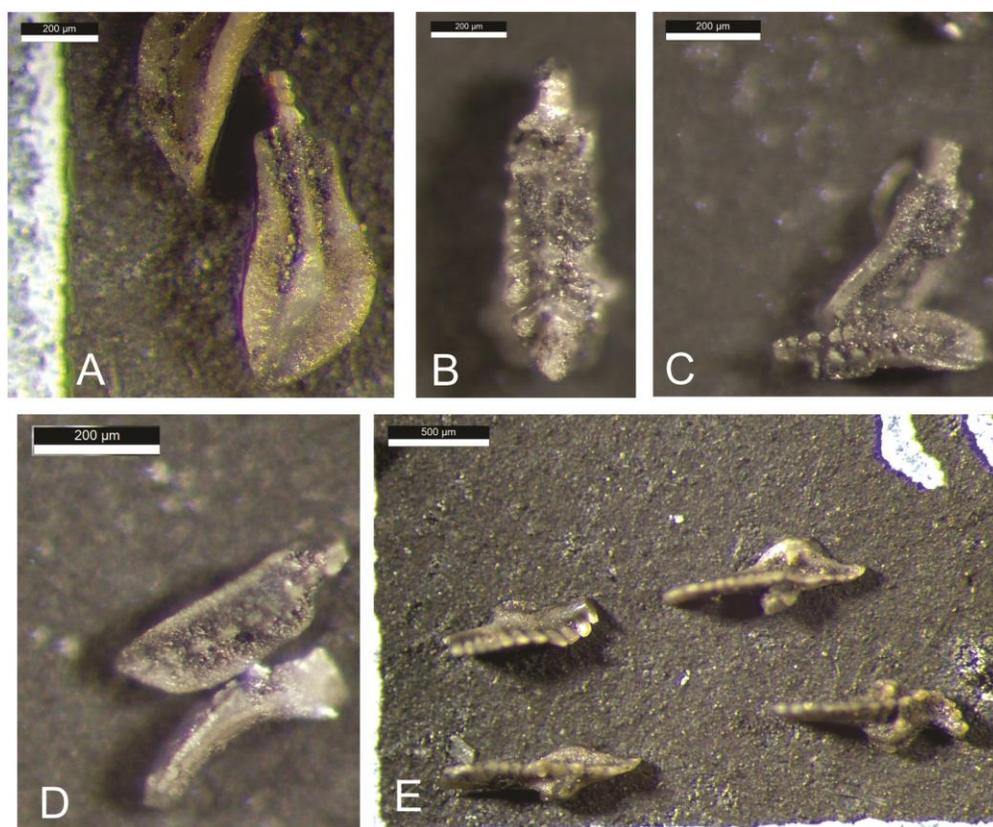


**Figure 5. Powell Creek: A: Fly camp with the Bear Rock cliffs on the background; B: Powell Creek Canol section, the type section for the Canol Formation; note large pyritic-calcareous nodules (arrowed); C: Base of Devonian dolostones, Station 16KOA011, geologist for scale in red circle; D: Geologist assessing part of the Bear Rock / Arnica Formation with stratified dolostones to the right and brecciated dolostones to the left, between stations 16KOA011 and 16KOA012.**

### ***Sampling for conodonts***

An important part of the Devonian study involves producing detailed biostratigraphic information that could support regional and global correlation of the studied stratigraphic interval. The most frequently used and most detailed biostratigraphic framework for the Devonian is based on conodonts, an extinct group of marine chordates with phosphatic teeth-like element (Blieck et al., 2010). The fast morphologic evolution of these conodont elements (Fig. 6) through geologic time allows for a detailed subdivision of the studied time interval into conodont biozones that has seen most success in high-resolution correlations of Paleozoic marine rocks (Fig. 3). Earlier publications and GSC internal reports on the local conodont biostratigraphy (McCracken, 2008, 2011a, b; Uyeno, 1971, 1972, 1979, 1986, 2008) provide a good basis (Fig. 3, left side), but also indicate the need for further investigation to complete the detailed framework by precisely positioning the bases of the biozones in the local lithology, locate the bases of the stages in outcrops and complete the framework where no data were available.

For conodont studies, usually about 2.5kg of limestone or dolostone is sampled in the field and processed in the lab. Depending on the goal of the study, different strategies are used in the sampling. In the Lower Devonian carbonates (Peel, Tatsieta, Arnica, Landry, and Bear Rock formations, dominated by dolostones, rare preserved sedimentary textures indicate strong dominance of very shallow water, often cyclic peritidal facies) previous sampling had very limited success (McCracken, 2008, 2011a,b; Uyeno, 2008). The new samples were taken from fossiliferous highstand facies for better chance in obtaining biostratigraphic information. Sampling density was higher below and above the contact of the Hume/Hare Indian formations with the intention of precisely locating the base of the Givetian Stage (Fig. 6). In the basinal mudrocks of the Horn River Group (Hare Indian and Canol formations), the total amount of stratigraphic levels that can be sampled for conodonts is rather limited. Due to the specific processing technique, only material dissolvable in acetic acid can be sampled. In those black shale formations, the sampling was restricted to the few dolomitic beds, dolomitic nodule levels or calcareous authigenic nodule levels that might contain the necessary biostratigraphic information.



**Figure 6.** Examples of conodont elements used in biostratigraphy. A: *Polygnathus pseudofoliatus*, B: *Icriodus difficilis*, C: *Polygnathus ensensis*, D: *Polygnathus xylus*, E: *Tortodus* sp. (newly discovered species, not named yet) from the Hare Indian Formation at Dodo Canyon (NWT).

## FIELD ACHIEVEMENTS

### *Conodont biostratigraphy*

The Lower Devonian carbonates were sampled in four sections (18 samples, Table 1): Rumbly Creek West Ridge, Powell Creek Lower Devonian, Powell Creek Landry-Hume and the Rumbly Creek station. Sampling was restricted to deeper water fossiliferous intervals identified in shallower water stratigraphic successions.

The base of the Horn River Group, the contact between the Hume and the Hare Indian formations was sampled in more detail (Fig. 7) to locate the base of the Givetian Stage (first occurrence of *Polygnathus hemiansatus*). This was accomplished in two sections: Powell Creek West (14 samples, Figs. 7 and 8D) and Rumbly Creek tributary waterfall (11 samples).

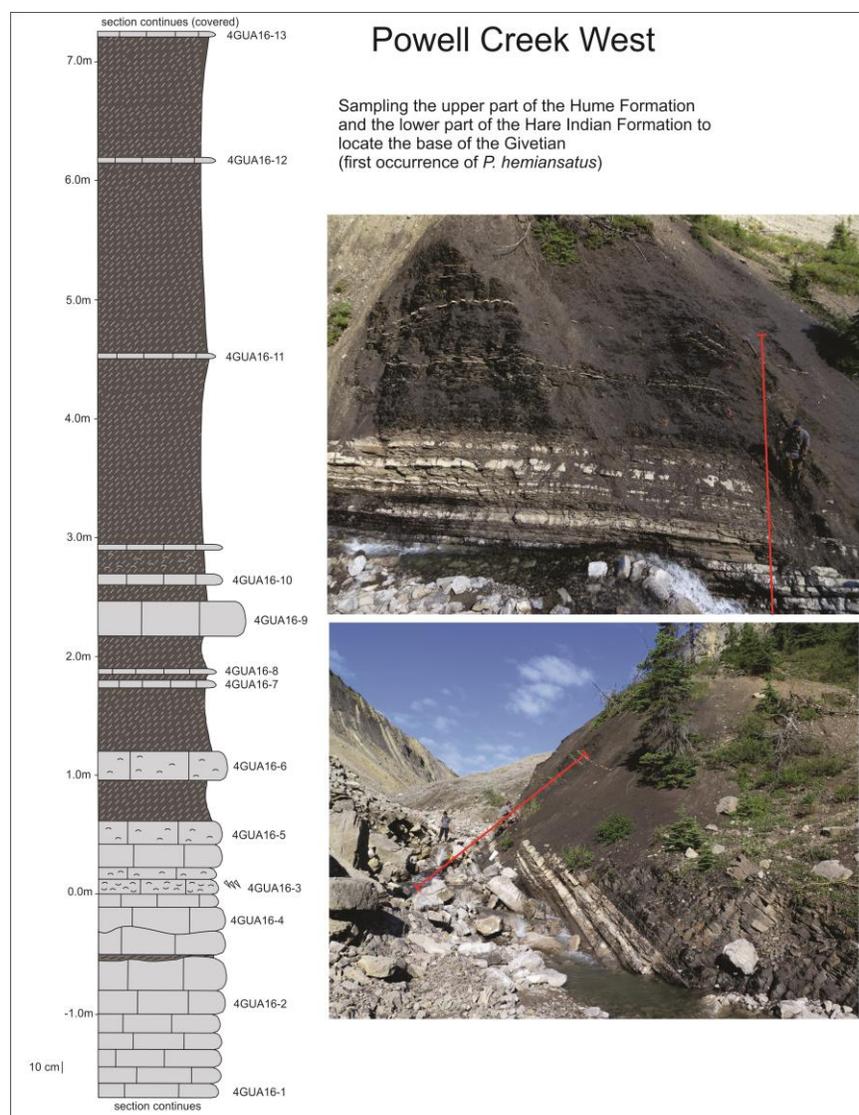


Figure 7. Detailed sampling for conodont biostratigraphy at Powell Creek West.

The Carcajou Member of the Ramparts Formation was sampled in the Turnabout Creek section (6 samples, Fig. 8E). The upper part of the Horn River Group was sampled in three sections: Powell Creek Canol (Fig. 7B), Rumbly Creek Canol (Fig. 8A) and Turnabout Creek (Fig. 8B). Hopefully these samples will provide the most desired biostratigraphic information for the Canol Formation.

Since the samples taken for conodont biostratigraphic research need to be processed in the lab to release the phosphatic micro remains from the limestone or dolomite and processing time takes up to two months once samples have arrived at the lab, new data are not available at this moment. The results will be reported in GSC paleontological reports and in peer-reviewed publications.

Samples from earlier publications on the deposits in the area contained a satisfying amount of rather well-preserved material to work on, so the amount of conodont material that should come out of the new samples is expected to be good.



Figure 8. A: Cliff-forming Canol Formation at Rumbly Creek; B: SGR signal capturing on transition from Canol to Imperial formations, Turnabout Creek; C: Geologists at work near Hare Indian / Canol contact, Rumbly Creek tributary waterfall; D: SGR signal capturing and describing the lithology at Powell Creek west section; E: Measuring and sampling the Ramparts/Canol contact at Turnabout Creek.

### ***Horn River Group***

The field goal for the Horn River Group was achieved by measuring four sections (Table 1). The two sections at Rumbly Creek (stations 16KOA020 and 16KOA021) overlap and bear a recognizable recessive interval with dolostone beds in the lower Canol Formation allowing for construction of a composite section that would serve as reference for the western off-bank area (west of the offshore edge of the grey-shale Hare Indian and Ramparts formations). Canol sections at Powell and Turnabout creeks typify the Canol Formation as it occurs on top of thick grey-shale Hare Indian and Ramparts platform units. Lithofacies descriptions and correlation based on SGR logs will be reported in succeeding publications.

### ***Lower Devonian carbonates***

Two sections measured from the sub-Devonian unconformity to the Landry or Bear Rock formations are Rumbly Creek west ridge (Fig. 9) and the Lower Devonian section (mostly Bear Rock breccia) in the lower Powell Creek canyon (Table 1; Fig. 5). The first section is weathered by the harsh winter conditions into felsenmeer (field of blocks) with some resistant bedrock ribs; limestones of Tatsieta Formation there are more resistant and form low towers (Fig. 9).



**Figure 9.** Rumbly Creek west ridge section: A: Transport by helicopter; B: Geologists at work on the felsenmeer section of the cyclic (zebra) unit of the Arnica Formation; C: Making fire in a shelter, background view on the Arnica Formation and Peel Plateau; D: Acquiring SGR signal from the felsenmeer on the upper Arnica Formation, south (mountain) view; tower of resistant Tatsieta limestone is arrowed.

At Powell Creek, the section across the creek to the fly camp (stations 16KOA017 and 16KOA018) shows the details of the lower contact of Hume Formation. Between the Bear Rock breccias and the base of the fossiliferous and marly Hume Formation, about 60 m of cyclically repeating resistant, variably brecciated calcareous dolostones and recessive marly dolostones with fetid odor were assigned to the Landry Formation based on microbial lamination textures and lack of macrofossils. The Landry/Hume contact was shown to be gradational and conformable, which is consistent with observations in Kugaluk N-09 well (Kabanov, 2014). Previously the contact of Landry and Hume formations (or Bear Rock and Hume formations) was controversially described as sharp and probably unconformable (Bassett, 1961), conformable, or a “possible disconformity” (Morrow, 1999; Gal et al., 2009). Inside the Lower Devonian carbonate succession, a number of thick paleokarst profiles and fossiliferous intervals without shallow-water peritidal features (highstand intervals) have been identified.

### **FUTURE WORK**

Materials from the 2016 field work will be integrated into the Devonian stratigraphic framework research of the Mackenzie River Corridor. The Canol Formation in the western off-bank area of the Peel Plain and Plateau is up to 100 m thick and has underexplored hydrocarbon potential possibly comparable with the southern off-bank area in the Mackenzie Valley between Norman Wells and Tulita. The Rumbly Creek section of the Horn River Group should be developed into a reference section for the southern Peel area. It will also help to shed light on the correlation of the Mackenzie Valley succession (Kabanov and Gouwy, in press) with the Richardson Mountains (Hutchison and Fraser, 2015).

Ongoing work on the Devonian biostratigraphy of the Mackenzie Mountains will focus on the biostratigraphic study of the field samples processed for conodonts, the integration of biostratigraphic results with other data obtained during this fieldwork and correlation of the field results with data collected in earlier field work studies from the Mackenzie Plain and Peel area. These new samples will likely provide the clue to the recognition and correlation of global oceanic events in the project area. Samples collected during earlier field work in the Mackenzie area revealed new species endemic to the area suggesting new discoveries are also possible in the newly collected samples. The new information will be used to refine and strengthen the Devonian biostratigraphic framework of the area.

### **ACKNOWLEDGEMENTS**

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