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FOREWORD (supplied by GEM Coordination Office)

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 2016, the 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

Northern Mackenzie Mountains bedrock mapping and stratigraphic studies is a component of "Shield-to-Selwyn geo-transect: studying the evolution of sedimentary rocks of the northern mainland NWT to improve exploration success for petroleum resources and base metal deposits" (Figure 1). This activity will initiate the first regional integrated effort to place Proterozoic to Cenozoic strata of Mackenzie Platform, Selwyn Basin, and adjacent regions into a fully modern tectono-stratigraphic and metallogenic framework, and will better enable industry and Northerners to responsibly find and develop energy and mineral natural resources, maximizing their economic and societal impact.

The present report provides a brief account of field activities in the northern Mackenzie Mountains of the NWT during late July and early August, 2016. Preliminary results are presented that touch upon bedrock geological mapping, structural geology, and stratigraphy.

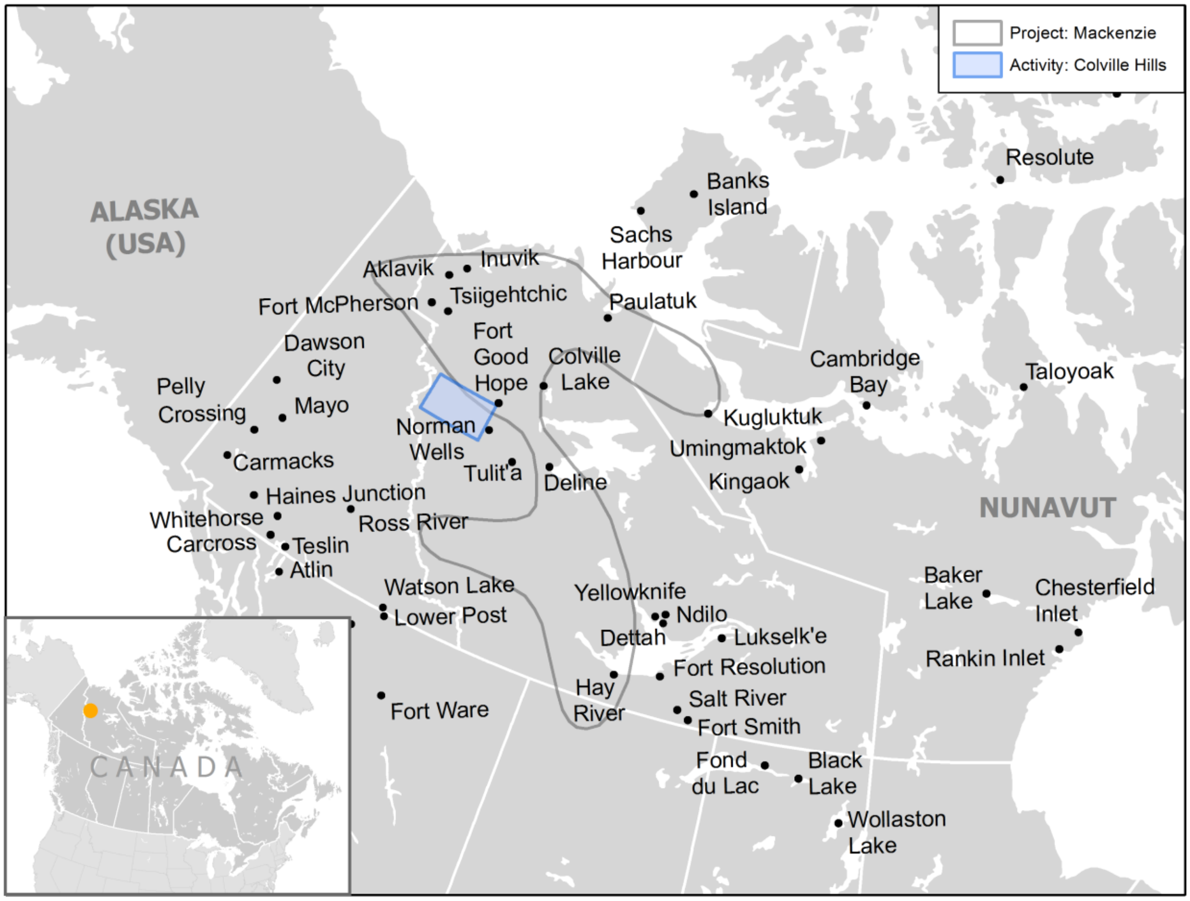

Figure 1: *Location of the GEM 2 Mackenzie project area (grey outline) in the Northwest Territories. Blue box indicates study area for 2016 field work in the northern Mackenzie Mountains as part of the 2015-2017 "Colville Hills activity". (This figure was prepared by the GEM Coordination Office.)*

INTRODUCTION

During the summer of 2016, 1:100 000 scale bedrock mapping was carried out in the northern Mackenzie Mountains of the Northwest Territories. The purpose of the work was to update the existing 1:250 000 scale maps for the region (Aitken and Cook, 1979a,b; Aitken et al., 1982), as part of the Shield to Selwyn geo-transect activity of the GEM Program (Figure 1). The region under study comprises the southern halves of NTS map areas 106G and 106H (Figure 2), with particular focus on the mountainous regions of the map sheets.

The region was previously mapped by GSC at reconnaissance scale as part of Operation Norman (1968-1970; Aitken et al., 1969, 1970; Cook and Aitken, 1971). The published bedrock geology maps for the study area are GSC "A" Series maps (Aitken and Cook, 1979a,b), which were published in conjunction with a GSC Memoir (Aitken et al., 1982). The northern edge of the study region was subsequently included in the Peel Project, a joint undertaking of the Northwest Territories Geoscience Office, Yukon Geological Survey, and Geological Survey of Canada (Pyle and Jones, 2009; Pierce and Jones, 2009), which generated new stratigraphic and petroleum systems data.

METHODOLOGY

Field activities took place between July 15 and August 4, not including time spent in travel to and from the study area. All work was staged from the Arctic Red River Outfitters base camp (Figure 2), on the Arctic Red River in the central part of NTS 106G. In total, 6 work days were lost to rain, snow, high winds, and low cloud ceilings, and 1 day was lost to helicopter repairs. Heavy smoke haze from forest fires was a significant impediment early in the field season. Field work was conducted jointly with a GSC team studying Devonian stratigraphy in the region (Kabanov et al., 2016).

Mapping activities in the study area were undertaken in pursuit of improved understanding of lithostratigraphy, intrusive relationships, and structural issues. Bedrock is moderately to very well exposed on peaks and ridges in the northern Mackenzie Mountains, although mapping efforts are hampered by steep terrain, extensive felsenmeer and scree slopes, and Quaternary cover in the valleys. In view of the size of the study area, the relatively brief field season, and weather delays, it was necessary to focus mapping efforts on geologic units and structures identified as problematic. The mapping itself consisted of a combination of helicopter spot-checking and foot traverses.

Prior to the field season, archival bedrock-mapping data from Operation Norman were incorporated into the project geodatabase, using procedures described by Fallas et al. (2015a). Selected public domain mineral exploration industry data were incorporated into the geodatabase using a modified set of procedures that will be documented in a separate report (T. Finley, work in progress). When overlain upon high-resolution satellite imagery, these archival mapping data were a useful resource for identifying areas needing detailed study.

A goal of the "Shield to Selwyn" activity is to interpret the Proterozoic to Silurian tectonostratigraphic framework along a geo-transect from the edge of the Brock Inlier to the northeastern edge of Selwyn Basin. To aid in the construction of the geo-transect, observations were made on Cambrian, Ordovician, and Silurian strata within the study area. In particular, partial or complete stratigraphic sections were measured and described through the Nainlin (Cambrian), Franklin Mountain (Cambrian-Ordovician), and Mount Kindle (Ordovician-Silurian) formations.

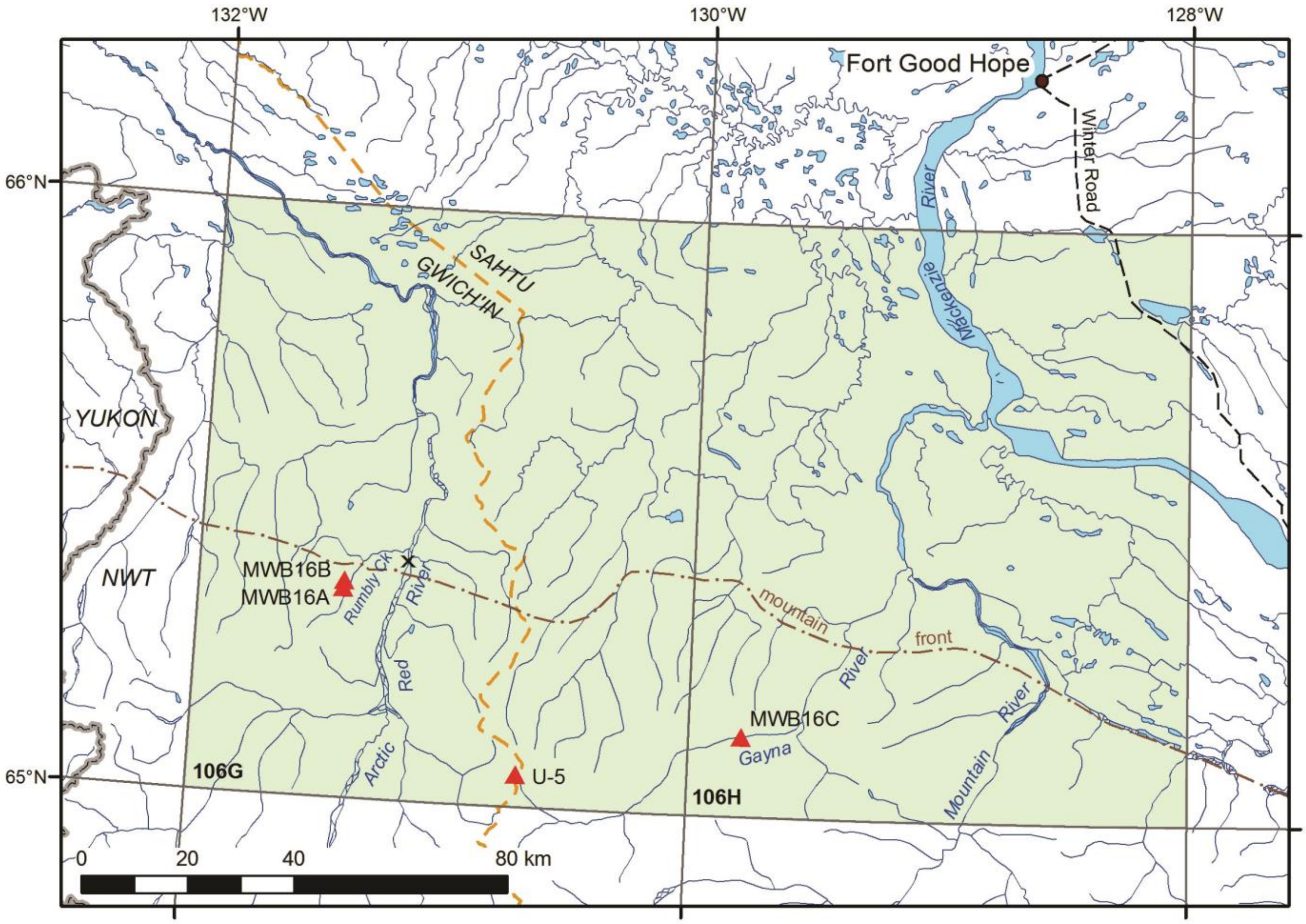

Figure 2: *Detailed location map of the area outlined in blue on figure 1. Red triangles are locations of measured sections referred to in the text; black X marks our base of operations at Arctic Red River Outfitters.*

RESULTS

Stratigraphic Mapping and Relationships

Bedrock map units exposed in the study area range in age from Neoproterozoic to Cretaceous (Figure 3). Improved understanding of Proterozoic, Cambrian, and Cretaceous stratigraphy (detailed below) has allowed for identification of map units at a greater level of detail than was previously possible (Aitken and Cook, 1979a,b). Published bedrock geology maps for the study area (Aitken and Cook, 1979a,b) reflect the stratigraphic knowledge that was current at the time of Operation Norman and in the following decade, as summarized by Aitken et al. (1983). A number of significant changes have been made to the region's lithostratigraphy since Operation Norman. These will be reflected in the new maps and are summarized briefly here.

Formation-level subdivisions of the Proterozoic Mackenzie Mountains Supergroup were extensively revised in the 1970s and 1980s (e.g., Aitken et al., 1978; Aitken, 1981), although these subdivisions were only formalized more recently (Long and Turner, 2011; Turner and Long, 2011). Updated formation terminology for units within the Mackenzie Mountains Supergroup is applied to the new mapping as follows (in ascending order): map unit H1 is now referred to as Tabasco Formation; the long-formalized Tsezotene Formation (Gabrielse et al., 1973) is unchanged; Katherine Group is subdivided into seven formations on the basis of alternating resistant (sandstone-rich) and recessive (shale-rich) intervals, where these can be delineated separately; and the Little Dal Group is subdivided into seven formations.

In the southwestern corner of the study area, Aitken et al. (1983) were able to apply formation names to some units within the Cryogenian to Ediacaran Windermere Supergroup (e.g., the Keele and Sheepbed formations of Gabrielse et al., 1973). However, the lowest Windermere unit in the study area consists of dark-weathering shale and lesser sandstone, assigned by Aitken et al. (1983) to the informal upper division of the Rapitan Group. More recent work has formalized the "upper Rapitan" as the Twitya Formation (Eisbacher, 1983). It is no longer considered to be part of the Rapitan Group (see the review provided by Turner et al., 2011) and these revisions will be reflected on the new maps. Also in the southwestern part of the study area, the transition between the Windermere Supergroup and overlying Cambrian strata proved to be very challenging to delineate on the ground, with strata previously assigned to Backbone Ranges Formation (?Ediacaran-Lower Cambrian) and Sekwi Formation (Lower Cambrian) by Aitken et al (1983) proving to be confusingly atypical of those units. Elucidation of this problem will require further study, expected to take place during summer, 2017.

Recent work has led to a clearer understanding of the extent and internal divisions of Cambrian map units in the northern and eastern Mackenzie Mountains (e.g., Serié et al., 2013; MacNaughton et al., 2013; MacNaughton and Fallas, 2014). During field work, distribution of Lower to Middle Cambrian units (Mount Clark and Mount Cap formations) was spot-checked and found to agree with the conclusions reached by Serié et al. (2013) and workers on the Peel Project (Pyle and Gal, 2009; Pierce and Jones, 2009).

Recently, the Nainlin Formation was proposed by MacNaughton and Fallas (2014) to replace Middle to Upper Cambrian strata formerly assigned to the "basal Franklin Mountain red beds" (Aitken et al., 1973), as well as sandstone-rich red beds along the eastern flank of Mackenzie Arch that previously were assigned to the Saline River Formation (e.g., Aitken et al., 1973; Pyle and Gal, 2009). During the present field season, outcrop belts of Nainlin Formation were flown out to document their extent

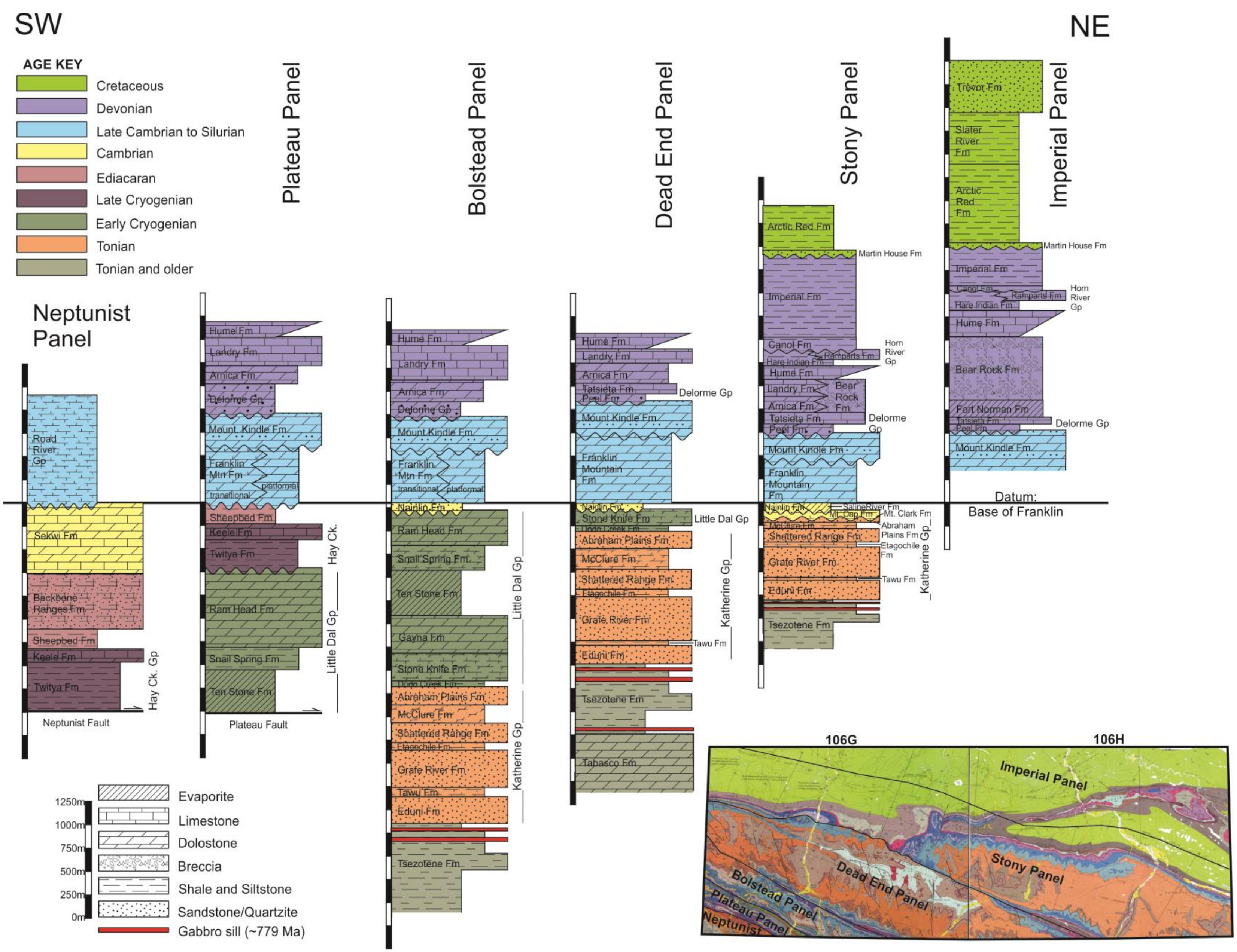

Figure 3: *Stratigraphic relationships in the northern Mackenzie Mountains. Each column shows the order and approximate thicknesses of units within structural domains as delineated in the map key (modified from Aitken and Cook, 1979a,b).*

within the study area. This will necessitate revising the unit's known distribution, as will be reflected in the new bedrock geology maps for the study area. Notably, the lateral transition between the Nainlin Formation and the Saline River Formation will be better constrained along the northern edge of the Mackenzie Mountains.

A section previously documented by Aitken et al. (1973; their section U-5) and referred to in their report as "basal Franklin Mountain red beds" was revisited, confirming the opinion of MacNaughton and Fallas (2014) that these strata should be reassigned to the Nainlin Formation. At this location, a visibly angular relationship exists between the base of Nainlin Formation and underlying strata of Little Dal Group. The vertical succession of Nainlin Formation reported by Aitken et al. (1973) for this section was confirmed to be as follows (in ascending order, with thicknesses converted from feet to metres): red-weathering, carbonate-clast conglomerate (up to 1.2 m); red shale and siltstone with minor dolostone (7.9 m); purple and grey argillaceous dolostone (4.2 m); quartz arenite (7.3 m); dolostone, dolomitic sandstone, and sandstone (7.3 m). The contact with the overlying pale grey limestone of the Franklin Mountain Formation is gradational.

Along Gayna River, a newly discovered exposure of Nainlin Formation was documented. This exposure is unusual in providing essentially complete exposure through the unit (Figure 4). A measured section at this site (MWB16C) documented a succession of thin-bedded shale and sandstone, dominantly red-weathering with lesser green beds, with a basal conglomerate unit that is associated with a buried paleo-fault scarp. Salt casts and oscillation ripples are abundant at several levels and arthropod-produced trace fossils are locally present. The total thickness of Nainlin Formation in this section was 19.4 m.

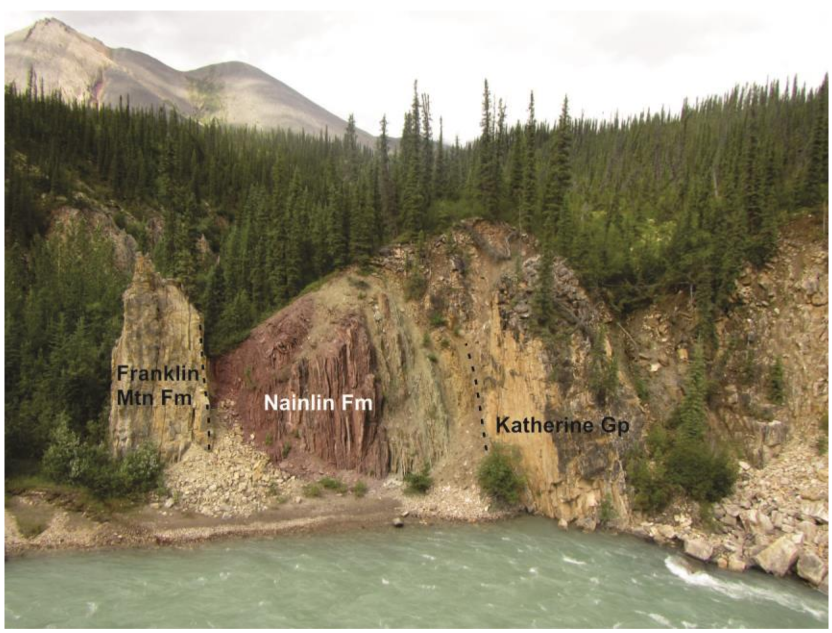

Figure 4: *View of measured section MWB16C through Nainlin Formation along Gayna River. Nainlin Formation at this location is 19.4 m thick.*

The lithostratigraphy of the carbonate deposits that make up the Upper Cambrian to Devonian succession (e.g., Norford and Macqueen, 1975; Morrow, 1991) in the study area was found to be robust, with no significant changes required to nomenclature. Detailed work on these strata by our party focused on pre-Devonian units: the Franklin Mountain and Mount Kindle Formations. See also the report by Kabanov et al. (2016) for observations on Devonian stratigraphy in the region.

The Cambrian-Ordovician Franklin Mountain Formation is dominated by dolostone and commonly is non-fossiliferous (e.g., Turner, 2011), although fossil localities have been reported locally within the present study area (Norford and Macqueen, 1975). During a reconnaissance traverse, a fossil rich locality was found in a ridge-crest exposure of the unit (figure 5A). This locality was subsequently collected for macrofossils and conodonts, and its stratigraphic position documented in a partial measured section (MWB16A) to permit comparison with other sections through the Franklin Mountain Formation. The fossil samples await study.

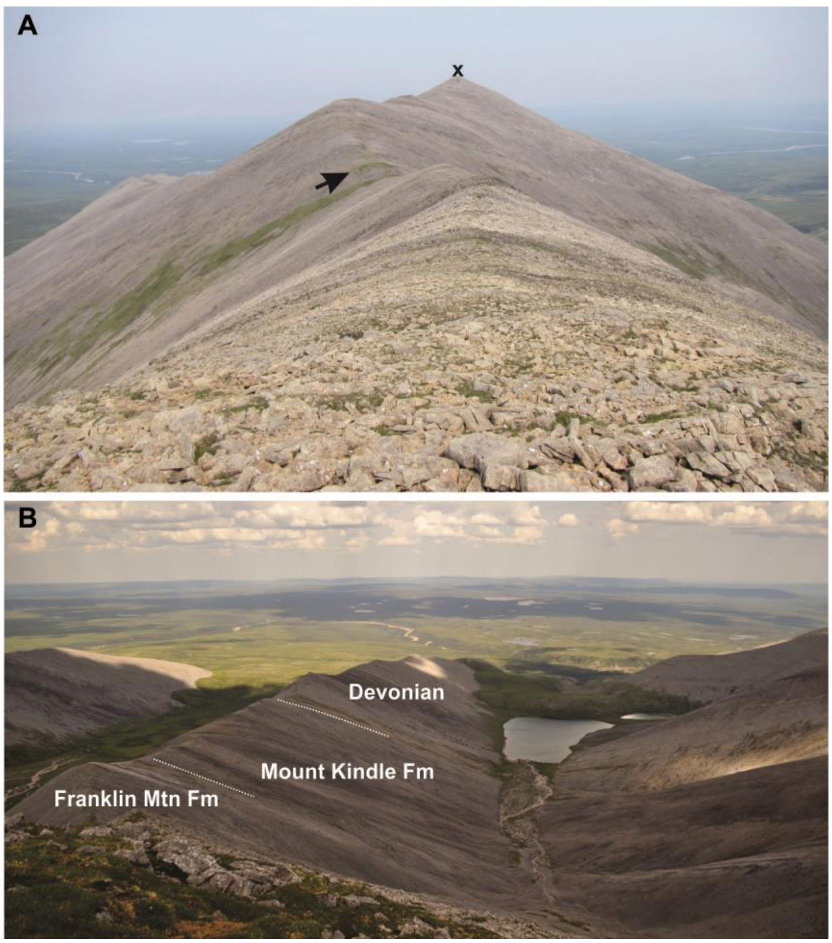

Figure 5: *(A) Overview of dolostone-dominated Franklin Mountain Formation, as seen in measured section MWB16A. Photograph taken from a point 4.5 m above base of formation, looking northward and upsection. Arrow points to top of macrofossil-bearing interval, 184.5 m above base of formation. Far extension of ridge, seen at left, is shown in Figure 4B. The top of the highest point seen along the ridge (marked by "x") is the approximate location from which the photograph in Figure 4B was taken. (B) View of ridge along which section MWB16B through Mount Kindle Formation was measured. Mount Kindle Formation in this section is 226 m thick.*

In support of ongoing efforts to document lateral trends within the Ordovician-Silurian Mount Kindle Formation (Pope and Leslie, 2013; Fallas et al., 2015b), a detailed section (MWB16B) was measured through this unit along a ridge at the northern edge of the Mackenzie Mountains, near Rumbly Creek, just west of Arctic Red River (figure 5B). Detailed sampling for conodont biostratigraphy and stable-isotope chemostratigraphy was carried out, and the results will appear in future reports. The total measured thickness of Mount Kindle Formation in this section is 226 m. The unit is dominated by dolostone and locally is extremely rich in silicified macrofossils. It forms a regional-scale unconformity-bounded depositional sequence (Pope and Leslie, 2013) and evidence for karst was found at both its basal contact with the underlying Franklin Mountain Formation and its upper contact with overlying Devonian strata. This measured section lies immediately beneath Devonian strata documented by Kabanov et al. (2016); together, these sections comprise the "Rumbly Creek, West Ridge" reference section for much of the Ordovician to Devonian succession in the study region.

The undivided Cretaceous succession shown on previous maps of the area (Aitken and Cook, 1979a,b) can be subdivided into formations on the basis of more recent measured sections in the Peel Plateau and Peel Plain region (Pyle and Jones, 2009). The presence of these units was confirmed by observations during the present work, and mapping will be supplemented with observations from petroleum wells and reflection-seismic data in the study area.

Intrusive Relationships

Intrusive mafic (gabbro) sills have previously been documented within the Tsezotene Formation along with a set of dykes known to cross-cut most units of the Mackenzie Mountains Supergroup (Aitken and Cook, 1979a,b; see figure 6). Cross-cutting relationships between sills and associated dykes were examined to determine if the intrusive event constituted one phase of intrusion or multiple phases (figure 6C,D). Close association between dykes and steeply-dipping faults within Proterozoic strata has been noted by previous workers (Aitken and Cook, 1974), and examples were sought in the field to evaluate structural controls on the intrusive event (figure 6B). Samples were collected from sills and dykes for geochemical analysis and for attempted radiometric dating. Results of these studies will appear in separate reports.

Structural Studies

Structures in the study area record multiple phases of deformation involving Neoproterozoic to Cretaceous strata and intrusive rocks. Aitken and Cook (1974) documented the existence of antecedent faults whose initial phase of extensional motion occurred in the Neoproterozoic, affecting only strata assigned to the Mackenzie Mountain Supergroup and older units (figures 6A,B, and 7A). Recent work by MacNaughton and Fallas (2014) showed that some antecedent faults within the Mackenzie Mountains recorded an additional phase of extensional motion in the Cambrian, similar to steeply-dipping faults documented beneath Mackenzie Plain (MacLean et al., 2014) and Colville Hills (MacLean and Cook, 1992). Field work during 2016 included further examination of the antecedent faults to look for additional evidence of Cambrian fault motion.

Subsequent Cordilleran deformation in Cretaceous to Eocene time generated younger compressional folds and thrust faults, as well as reactivating antecedent faults. Aitken and Cook (1974) suggested that map relationships in this study area showed reactivation of antecedent faults as reverse faults and strike-slip faults (figure 7B). Various faults and segments of faults were examined to constrain structural relationships that might clarify the nature and magnitude of the reactivation.

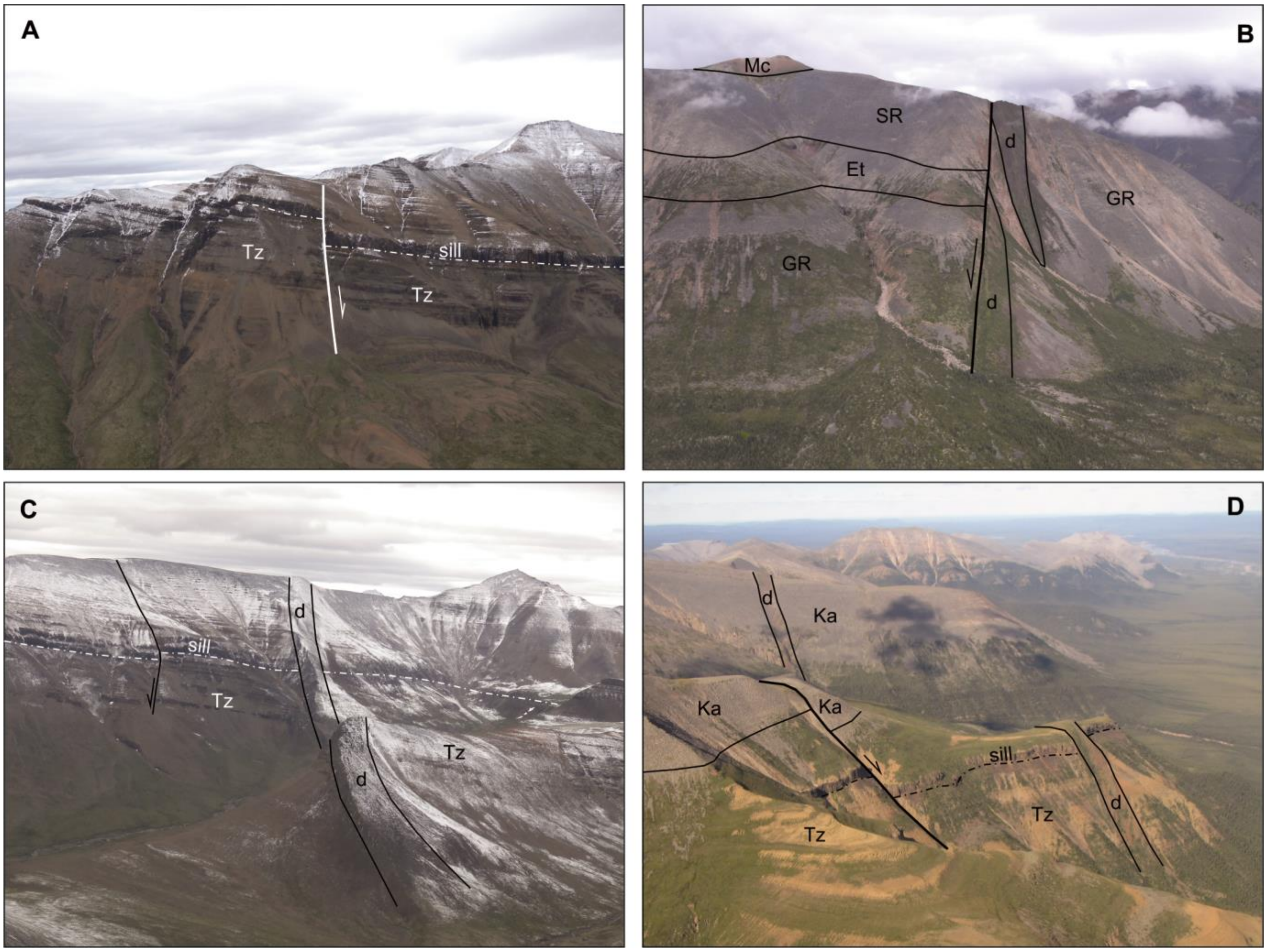

Figure 6: *Intrusive mafic igneous rocks in the study area. A) Gabbro sill within Tsezotene Formation offset by apparent normal fault (half arrow indicates relative movement) at 65.1904, -130.7208 looking southeast. B) Gabbro dykes associated with apparent normal fault within strata of the Katherine Group at 64.9933, -130.2732 looking north. C) Intersection of dyke and sill (base marked by dash-dot line) at 65.2367, -130.8290 looking south-southeast. Although partly obscured by snow cover, the dyke appears to intrude through the sill. D) Intersection of another dyke and sill at 65.2564, -131.3536 looking north. Note the dyke continues upsection into Katherine Group. Abbreviations: Tz=Tsezotene Formation, Ka=Katherine Group, GR=Grafe River Formation, Et=Etagochile Formation, SR=Shattered Range Formation, Mc=McClure Formation, d=dyke.*

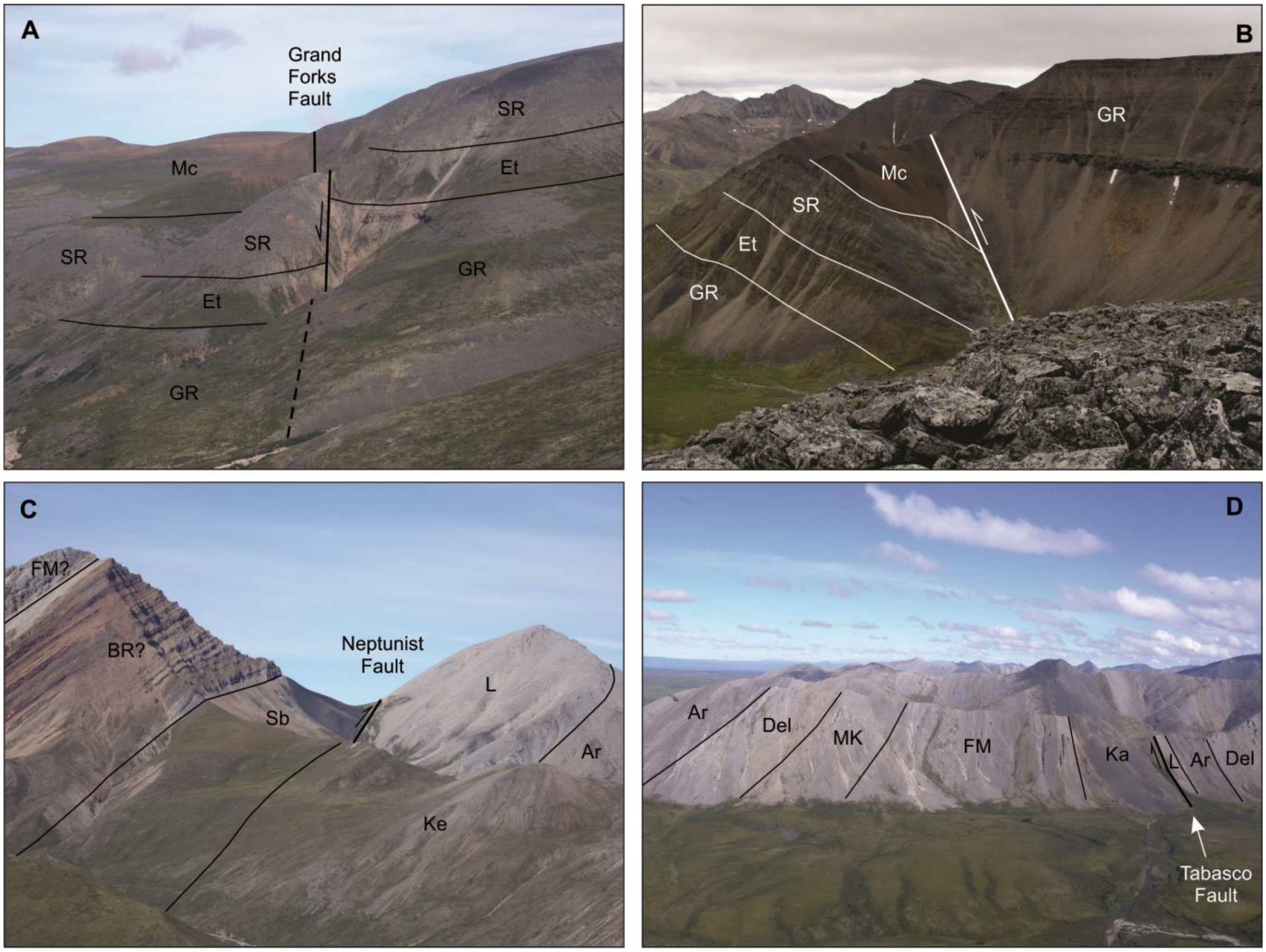

Figure 7: *Fault types found within the study area. A) Segment of the steeply-dipping Grand Forks Fault passing through Katherine Group at 65.1811, -131.3622, looking north-northwest, showing apparent normal motion on the fault where it cuts through bedding at high angle. B) Reverse fault (steep dip at high angle to bedding) within Katherine Group at 65.2910, -131.9389 looking south. C) Thrust fault (sub-parallel to bedding in footwall and hanging wall) in southwest 106G (see figure 2) at 65.0716, -131.9047 looking west. Formation assignments above Sheepbed shale are uncertain. D) Near-vertical to overturned Tabasco Fault back-thrust at 65.4274, -131.8874 looking east. Katherine Group is thrust southwards towards the mountains (to the right) over Devonian strata. Abbreviations: GR=Grafe River Formation, Et=Etagochile Formation, SR=Shattered Range Formation, Mc=McClure Formation, Ka=Katherine Group, Ke=Keele Formation, Sb=Sheepbed Formation, BR=Backbone Ranges Formation, FM=Franklin Mountain Formation, MK=Mount Kindle Formation, Del=Delorme Group, Ar=Arnica Formation, L=Landry Formation.*

Thrust faults associated with Cordilleran deformation (figure 7C,D) were well mapped by Aitken and Cook (1979a,b) despite sparse ground observations and challenges with stratigraphic identifications. Additional observations from the present work will require some revisions to previously interpreted structures; these revisions will be captured in new bedrock maps.

CONCLUSIONS

Field work in the northern Mackenzie Mountains during the summer of 2016 confirmed that gross-scale map patterns on published maps (Aitken and Cook, 1979a,b) were largely correct, but that updating of lithostratigraphic terminology is appropriate for several Proterozoic, Cambrian, and Cretaceous units. Recent revisions to Cambrian lithostratigraphy (e.g., Serié et al., 2013; MacNaughton and Fallas, 2014) were found to be valid within the study area. Detailed stratigraphic sections were measured through the Nainlin Formation (Middle to Upper Cambrian) and Mount Kindle Formation (Ordovician-Silurian), and a fossil locality in the Franklin Mountain Formation (Cambrian-Ordovician) was documented and collected.

Field observations of intrusive relationships, combined with geochemical and geochronological studies, are expected to better constrain the timing and nature of the intrusive event(s) and any associated structures. Revisions to mapped structures are expected to improve our overall understanding of how different types of structures interact and link when studied during subsequent structural analysis. Results of each of these studies will appear in future reports.

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