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Foreword

The Geo-mapping for Energy and Minerals (GEM) program is laying the foundation for sustainable economic development in Northern Canada. 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 2015, the GEM program 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.

Introduction

The Canadian Cordillera is considered the world's type example of an accretionary orogen (ancient mountain belt) and comprises distinct tectonic blocks referred to as terranes, some of which are bounded by faults. Recent activities within GEM-1 have prompted the hypothesis that mineralization in the Cordillera is controlled by the complex internal architecture of the blocks, and not only by their bounding structures. As a test of this hypothesis, the *Ancient Faults and Their Controls on Mineralization in Northern BC and Southern Yukon* activity of the GEM 2 Cordilleran Project (Fig. 1), conducted detailed mapping of select target areas in the Yukon-Tanana, Slide Mountain, Quesnellia and Stikinia terranes to constrain regional controls on disposition of units and mineral deposits as well as the nature of the boundaries of these terranes with ancient North America (Laurentia) through time. This field-based project involves detailed mapping that is complemented by new geochronological, geophysical, and geochemical analyses of key crustal blocks and their bounding structures.

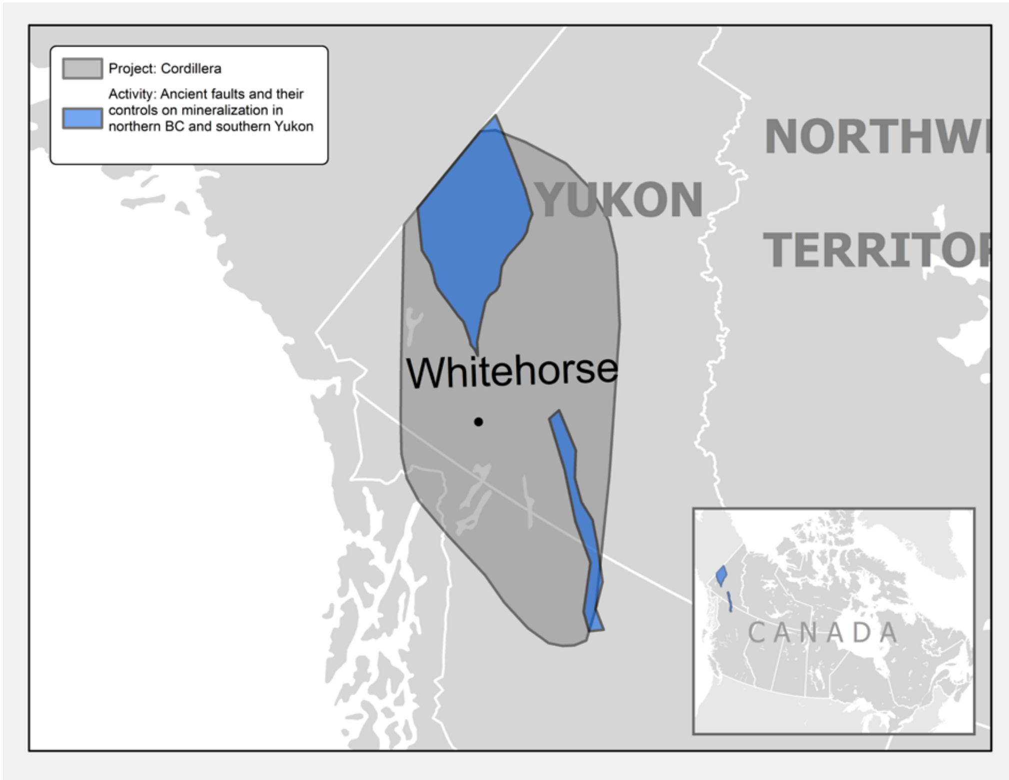

Figure 1: Overview map illustrating the footprint of the Cordillera project in northwest Canada. The footprint of the Crustal Blocks activity is highlighted in blue.

The main science questions being addressed by the Crustal Blocks activity are:

1) Where are the major suture zones in the northern Cordillera, what do they represent tectonically, and what is the resulting provinciality of mineral potential in the newly subdivided terranes?
2) What are the lithospheric and crustal scale controls on gold and base metal fertility?

The 2015 field program is the second of three planned field seasons wherein Geological Survey of Canada (GSC) geoscientists will collaborate with Yukon Geological Survey, British Columbia Geological Survey, and universities to conduct field activities in western and southern Yukon and northern British Columbia to investigate major structural breaks in the regional geology, and their potential role in controlling mineralization in this area which has significant but poorly understood mineral potential. This work complements concurrent research being carried out under the Porphyry Transitions and Cache Creek activities within the overall Cordillera project (see reports by Zagorevski et al., 2015 a, b).

During 2015, field investigations were carried out in two main areas in west central Yukon (Fig. 2) under the Crustal Blocks activity: the Mount Nansen – Nisling River area and Stewart River area.

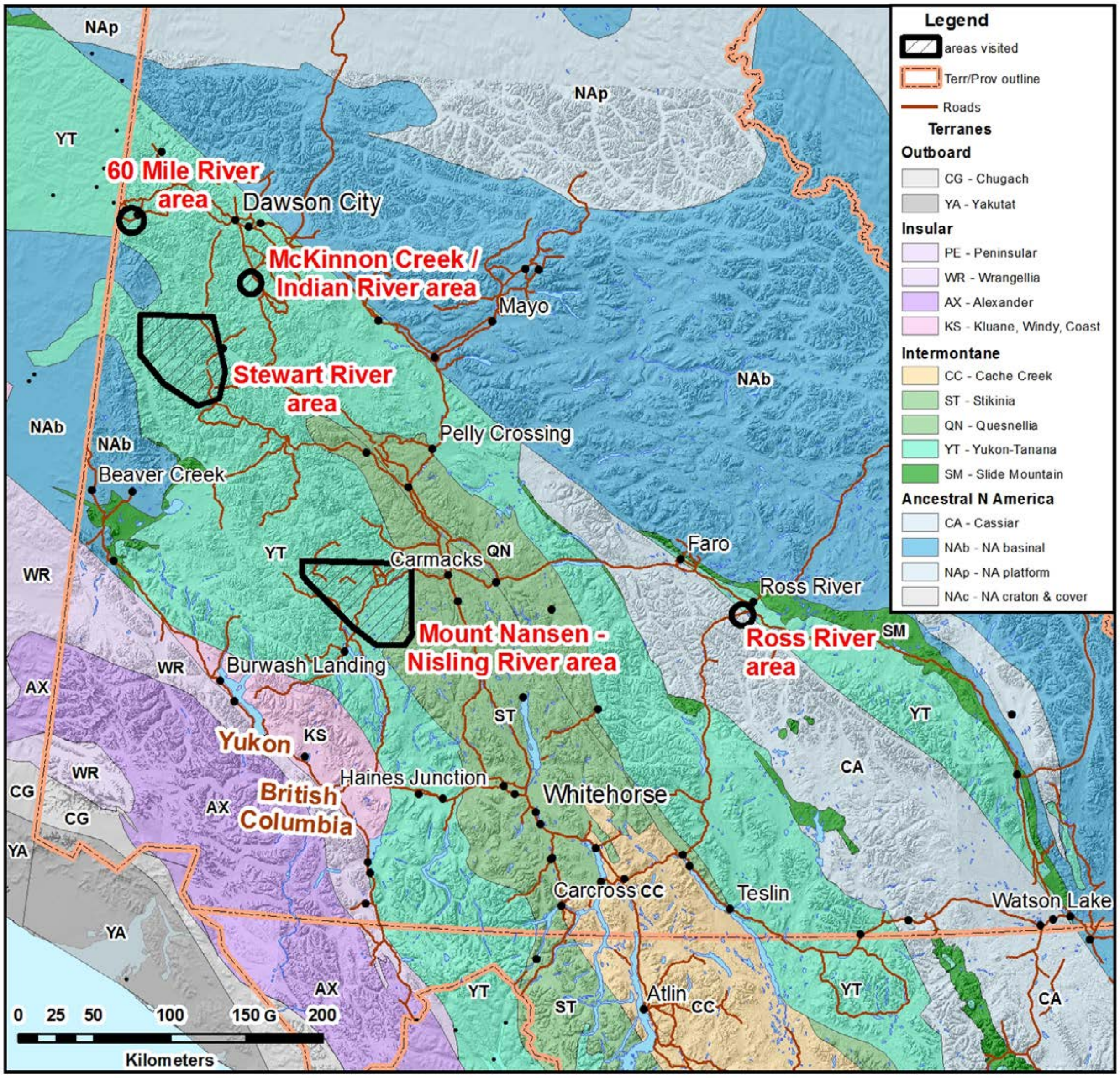

Figure 2: A simplified terrane map of the Northern Canadian Cordillera showing the location of the field areas visited during summer 2015 Crustal Blocks activity (modified from Colpron and Nelson, 2011).

Objectives of mapping in the Mount Nansen – Nisling River area included:

1) Update reconnaissance bedrock geology (Tempelman-Kluit, 1974, 1984; Carlson, 1987), and integrate it into modern tectono-stratigraphic framework of western Yukon (e.g., Colpron et al., 2006; Murphy et al., 2006; Ryan et al., 2014);
2) Determine the nature and significance ultramafic rocks (Schist Creek mafic-ultramafic complex);
3) Determine the nature of the contact between Early Jurassic plutonic suites and Yukon-Tanana terrane

4) Improve understanding of map distribution and mineral potential of Cretaceous to Tertiary magmatic suites
5) Refine the models of Permian metamorphism of Yukon-Tanana terrane in western Yukon through detailed metamorphic studies.
6) Determine the stratigraphy and paleontology of mid-Cretaceous sedimentary rocks in west-central Yukon (Indian River Formation) to constrain the paleotectonic environment of the region and the mid-Cretaceous evolution of the greater Cordillera.
7) Reinterpret the deep crustal geophysical character of the northern Canadian Cordillera through geophysical modelling to investigate relationships between the accreted terranes and cratonic North America.

Methodology

Fieldwork in the Mount Nansen – Nisling River area, part of objectives 1 to 4, was conducted from a road accessible base camp, located at Mount Nansen in the northern limit of the map area. Refined mapping is available in the surrounding regions to the southwest (Israel and Westberg, 2011) and north (Ryan et al., 2014a), and reconnaissance work by Ryan et al. (2014b). Mapping at 1:50 000 scale mapping was conducted over five weeks by helicopter-supported foot traversing and supplemented by work from truck and all-terrain vehicles. Mapping was greatly assisted in this area of variable quality bedrock exposure by recently acquired 400 m resolution aeromagnetic data (e.g., Hayward et al., 2012), and high-resolution satellite imagery. The locations of traverses were chosen to target key geological problems, particular lithological units, or test geophysical anomalies evident in the geophysical data or existing mapping (Tempelman-Kluit, 1974, 1984). Samples were collected for geochronology, petrography, lithogeochemistry, thermochronology, and isotopic analysis.

As part of objective 5, fieldwork in the Stewart River map area southwest of Dawson (Fig. 2) was conducted over a three day period in early August. This study forms part of an M.Sc. thesis project (Morneau) at Carleton University to better resolve the age and specific conditions of metamorphism in western Yukon-Tanana terrane, currently thought to be Permian (e.g., Berman et al. 2007). The work was carried out through helicopter assisted spot checks and foot traverses in areas where metapelites contain diagnostic metamorphic mineral assemblages suitable for detailed metamorphic studies (Gordey et al., 2006). Samples collected during fieldwork, combined with those accessed from the GSC's archives, will be processed and analysed over the coming year by several methods:

- Thin section petrography will be used to identify metamorphic mineral assemblages and to identify samples suitable for quantitative studies.

- Whole-rock geochemical analysis will be conducted to constrain numerical modelling of metamorphic mineral assemblages.
- X-ray computed micro-tomography work will be done in order to quantify metamorphic mineral phase distribution and size and to target cutting of the samples for mineral analysis and modelling
- Appropriate samples will undergo in situ U-Th-Pb SHRIMP dating of monazite to provide timing constraints on garnet growth as well as constraints on associated deformation.

Under objective 6, a review of various widespread and geographically-restricted clastic successions of southern Yukon assigned to the Cretaceous Indian River Formation (Lowey and Hills, 1988) is being carried out to assess the stratigraphic ages and depositional environments represented in the Cretaceous strata. These include exposures in the 60 Mile River area of western Yukon, scattered outcrops along the Top of the World Highway, exposures in the Indian River region and Henderson Dome area to the south, and presumed correlative strata exposed in the area of Ross River, south-central Yukon that were visited during 2014 fieldwork. For objective 7, a reconstruction of the Tintina fault was applied to regional geophysical and topographic data, facilitating the interpretation of west-trending lineaments within the lower crust and/or mantle lithosphere that have been identified as having been continuous across the region prior to later tectonic events (Hayward, in press). Gravity, magnetic, seismic reflection and refraction, topographic, geological and geochemical data, were interpreted with the aid of geophysical modelling in order to define spatial relationships between and the character of the structural lineaments.

Results

Mount Nansen - Nisling River area mapping

A number of key findings resulted from field mapping in the Mount Nansen–Nisling River area (Fig. 2). These findings significantly update the known geology from the existing reconnaissance maps by Tempelman-Kluit (1974). Utilizing the advances made in the understanding of Yukon-Tanana terrane and related rocks over the last 15 years, we were able to correlate many of the older, more deformed and metamorphosed rocks in the area into established units within Yukon-Tanana terrane. The new findings for the geology of this area will be described in more detail in an upcoming report and accompanying new map (Ryan et al., in prep). The main highlights include subdividing the geology on existing compilation maps into distinct tectono-stratigraphic units: the pre-Devonian Snowcap assemblage, metavolcanic and metasedimentary rocks of the early Mississippian Finlayson assemblage, metaplutonic rocks of the Early Mississippian Simpson Range plutonic suite, and minor possible metaplutonic and metavolcanic rocks of the middle Permian Klondike assemblage.

The Snowcap assemblage in this area is dominated by siliciclastic rocks composed mainly of quartzite, micaceous quartzite and psammitic quartz-muscovite-biotite (± garnet) schist. Locally, amphibolite is interlayered with the siliciclastic rocks on the cm to dm scale. The Snowcap assemblage locally contains marble bands varying in scale from decimeter, to 10's of metres. We recognized a separate, more carbonaceous unit dominantly comprising charcoal grey, finely laminated quartzite interlayered at the mm to cm scale with black phyllitic schist that is distinct from the Snowcap assemblage. We correlate these carbonaceous rocks with the siliciclastic member the Finlayson assemblage, referred to by Ryan et al. (2014a) as the Stevenson Ridge schist in the Stevenson Ridge area to the northwest, and the Nasina assemblage in the Klondike region about 200 km to the north (Mortensen, 1992; Gordey and Ryan, 2005). The nature of the contact between the carbonaceous Finlayson unit and the Snowcap assemblage is ambiguous; because these units locally appear to grade into each other, we infer it to be a transposed unconformity.

Finlayson assemblage metavolcanic rocks in the map area are dominated by amphibolite containing hornblende-plagioclase±epidote or garnet-hornblende-plagioclase±quartz mineral assemblages, and locally have a chlorite-biotite retrograde metamorphic overprint. Fine- to coarse-grained amphibolite and garnet amphibolite is locally interlayered with marble and siliciclastic metasedimentary rocks. A felsic metavolcanic(?) schist is locally associated with the amphibolite. Future geochronological studies conducted on the felsic schist may provide age control on the carbonaceous and amphibolitic assemblages in the Nisling River area. Unlike in the Finlayson lake district of southeast Yukon (see Murphy et al., 2006), Mississippian felsic volcanic rocks are very rare in west central Yukon.

The early Mississippian Simpson Range suite comprises a suite of moderately to strongly foliated, locally gneissic, hornblende-biotite and biotite granodiorite. Minor monzogranite, diorite, gabbro and recrystallized amphibolite of uncertain protolith were also observed to occur within the Simpson Range suite. This suite locally dominates the map area and in places appears to intrude the Finlayson assemblage metavolcanic rocks. Locally, a particularly porphyritic member of the suite constitutes a rather striking augen granite (Fig. 3).

In the north central part of the map area, minor occurrences of metafelsite and moderately foliated porphyritic granite are similar to the middle Permian Klondike assemblage rather than the hornblende-biotite bearing Simpson Range suite (Ryan et al., 2014a). An attempt was made to determine if these rocks were in structural or stratigraphic separation from the adjacent Simpson Range suite. Pending geochronological analysis, we currently interpret the probable Permian rocks to be a successor sequence on the Mississippian rocks. This contrasts with the relationship noted in the northern Stevenson Ridge area (Ryan et al., 2014a) where Permian rocks were mapped as being in structural separation from the Mississippian rocks.

Figure 3: Potassium feldspar augen textured hornblende granodiorite of the Mississippian Simpson Range suite. Eraser for scale.

A complex of mafic and ultramafic rocks occur in the Schist Creek area in the northwest part of the map area and is herein informally referred to as the *Schist Creek complex*. The Schist Creek complex is dominated by serpentinite, that typically preserves bastite pseudomorphs after strongly stretched orthopyroxene (Fig. 4), and metagabbro (Fig. 5). The Schist Creek complex appears to be bound by a structural break in the geology; however, the true significance of the structure is unknown at present. It may represent an outlying klippe of Slide Mountain terrane (i.e. correlative to Harzburgite Peak - Eikland Mountain ophiolite (Escayola, et al. 2012), or a fragment of exhumed continental lithospheric mantle (i.e. correlative of the Buffalo Pitts peridotite; see Johnston et al., 2007).

The Mount Nansen-Nisling River map area covers a large part of the western portion of the Aishihik batholith, which is being targeted by detailed studies by Yukon Geological Survey (Patrick Sack and Maurice Colpron) and Porphyry Transitions activity under the GEM2 – Cordillera (Zagorevski et al., 2014, 2015a). The Aishihik batholith in the study area comprises several phases of the Long Lake suite (see also Chapman 2015) which range in age between ca. 188 Ma and ca. 181 Ma (N. Joyce, unpublished data, 2014). Mapping within the current project set out to investigate if the Aishihik batholith was structurally emplaced via thrusting towards the northwest with Yukon-Tanana terrane, or if it preserves an intrusive contact. Although the batholith's northwest contact is not exposed everywhere, at least 2 locations exhibit an intrusive contact between the Long Lake suite and the Mississippian Simpson Range

Figure 4: Magnetite-bearing serpentinite lacking a strong foliation. Light coloured crystals are bastite pseudomorphs after orthopyroxene. Pencil tip for scale.

Figure 5: Layered hornblende-plagioclase amphibolite that is interlayered within serpentinite, and is interpreted as metagabbro. Pencil for scale.

plutonic suite (Fig. 6). Thus we conclude that the northwestern margin of the Aishihik batholith is an intact intrusive contact. This interpretation is consistent with observations made at the batholith's eastern margin during additional high-resolution mapping conducted by Chapman and Sack under the Porphyry Transitions activity (Chapman, 2015).

Figure 6: Unfoliated monzogranitic dyke cross-cutting foliated hornblende granodiorite of the Mississippian Simpson Range suite. 30 cm hammer for scale.

During mapping, we also set out to distinguish younger (middle Cretaceous to Tertiary) volcanic and hypabyssal rock sequences in order better understand their map distribution, and their potential for mineralization (e.g., the Late Cretaceous Casino Suite; see Allan et al., 2013; Morris et al., 2014). This is a difficult task because the younger suites are often indistinguishable in the field, and follow-up geochronological analysis is required to distinguish between the suites with certainty. From field results alone, we are confident in distinguishing rocks around Mount Nansen as belonging to the middle Cretaceous Mount Nansen Group (Carlson, 1987). These are dominated by volcanic breccia of andesite to dacite composition (Fig. 7), and locally massive layers of plagioclase-phyric dacite. The complex appears to preserve a good horizontal stratigraphy. These volcanic rocks were intruded by cogenetic plutonic rocks of the Dawson Range batholith (Fig. 8), which dates regionally between about 105 to 99 Ma (Allan et al., 2013; Joyce, unpublished data 2011).

A particularly interesting porphyry suite observed to have intruded the Mount Nansen group constitutes a unit of quartz-feldspar porphyry, which we correlate with the last Cretaceous (ca. 78-73 Ma) Casino suite (Ryan et al., 2013). At Mount Nansen, the suite appears to be

Figure 7: Volcanic breccia of the Mount Nansen Group. Angular fragments of more dacitic composition floating in an andesite matrix. Pencil tip for scale.

Figure 8: Photo of hornblende porphyritic granodiorite of the Dawson Range batholith. Pencil tip for scale.

hypabyssal intrusive rather than volcanic. Key characteristics of this porphyry suite include the occurrence of grey blebby quartz phenocrysts (Fig. 9), locally intense limonite alteration and an abundance of calcite veining (Fig. 10). The alteration appears to be restricted to the porphyry itself. The rock bears striking similarity to a phase of the Patton porphyry at the Casino deposit in the central Dawson Range some 100 km to the northwest. Other occurrences of the Casino suite are known to occur in the region at least as far south as the southern end of Aishihik Lake (see Morris et al., 2014). This porphyritic suite should therefore be considered an exploration target for porphyry and epithermal mineralization potential.

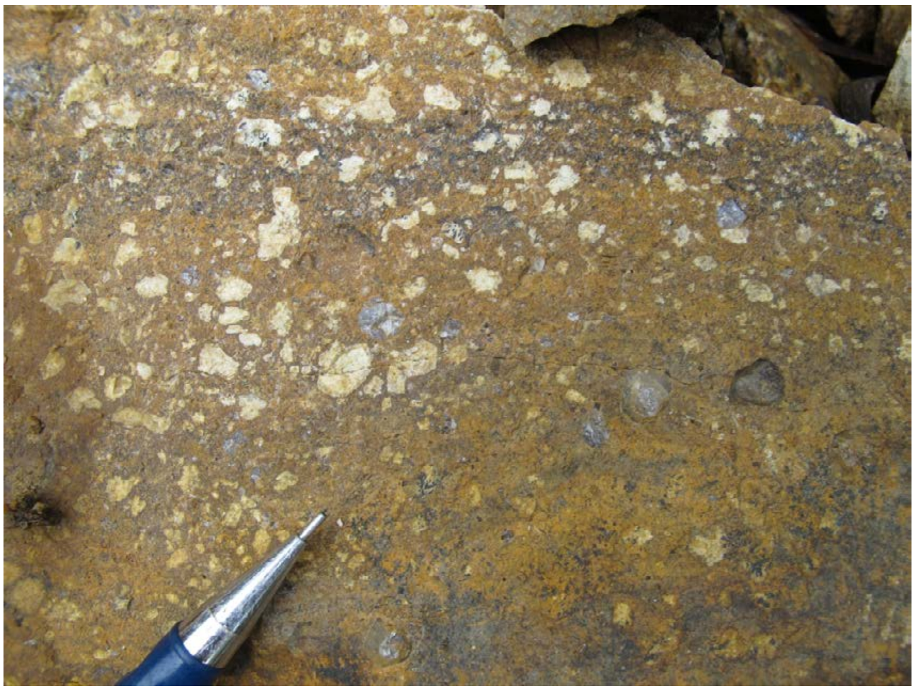

Figure 9: Quart feldspar porphyritic rhyolite of the Casino suite. The quartz phenocrysts show characteristic blebby texture, and the matrix is limonite altered. Pencil tip for scale.

The Carmacks group volcanic rocks also occur in the map area, most prominently at the northeast limit, and are dominated by basaltic andesite flows. The flows vary from massive to brecciated, and aphanitic to weakly plagioclase-phyric. There are numerous occurrences of volcanic rocks along the west and southwest margin of the map area that we interpret as the Rhyolite Creek complex. These range in composition from quartz-feldspar porphyry, to dacite, to andesite. The felsic porphyries are broadly similar in appearance to the Casino suite but are less altered and quartz tends to be more euhedral and smoky in colour. Ultimately, confident discrimination between various younger volcanic and hypabyssal rocks of similar character in the area requires additional geochronological analyses and geochemical evaluation, which are currently underway.

Figure 10: Photo of heavily altered and carbonate veined meta-rhyolite of the Casino suite. The rock has fine grained disseminated pyrite. Pencil tip for scale.

Indian River Formation

Analysis of paleontological samples collected in 2014 from surface exposures of the Indian River Formation along McKinnon Creek, around Henderson Dome, in the valley of Indian River (Bond and Chapman, 2007), and in the valley of 60 Mile River, are underway to assess age and depositional environment. In addition, approximately 30 new paleontological samples were collected in 2015 from cores drilled through the Indian River Formation at McKinnon Creek for placer prospectivity in the 1970s. The cores constitute the type locality of the formation (Lowey and Hills, 1988), and the samples will provide important constraints on the age of the sedimentary succession and the paleoenvironments represented in the strata.

Chert pebbles were collected from conglomerates of the Indian River Formation exposed along McKinnon Creek, in the valley of 60 Mile River, along Top of the World Highway, and from the type locality drill core, with the objective of analyzing the pebbles for their radiolarian content. This work is presently underway at Université Claude Bernard, Lyon, France, and is anticipated to provide information on the provenance of chert pebbles, and aid in tectonostratigraphic interpretation.

Geophysical modelling

Preliminary results for objective 7 suggest that west-trending lineaments within the lower crust may be related to the Liard transfer zone, a zone that divided the lower and upper plates during late Proterozoic-Cambrian rifting of the Laurentian margin. The transfer zone divides bimodal mantle xenolith suites to the south from unimodal suites to the north and 3D gravity models show a density increase to the north. Results suggest that extended North American basement, related to Laurentian margin rifting, underlies a thin carapace of accreted terranes in western Yukon and eastern Alaska. The interpreted continuity of North American basement reaffirms that if oroclinal bending of the Intermontane terranes occurred, then it was prior to its emplacement upon the rifted basement. Examination of the spatial relationships between mineral occurrences and the lineaments suggests that they influenced Mesozoic mineralization through influence on the development of the shallow crustal structure, location of igneous intrusions, and exhumation and erosion.

Next steps

It is clear that major crustal breaks transect the study area. We will continue to evaluate their regional significance by analyzing the lithological and tectonometamorphic differences between the rocks they separate and by attempting to delineate age domains through relevant geochronological techniques.

Ongoing petrological and geochronological investigation of samples from the Schist Creek mafic-ultramafic body will better elucidate its genesis and setting, and its role in the complex tectonic evolution of these Yukon-Tanana and Slide Mountain terranes.

Future work under the Crustal Block activity will continue to identify, define, and elucidate the history and metallogenic importance of major crustal breaks through the Intermontane terranes of the northern Cordillera.

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