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# Report of activities for Ancient Faults and Their Controls on Mineralization in Northern British Columbia and Southern Yukon: GEM2 Cordillera Project

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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 2014, GEM's new research program has been launched with 14 field activities with six projects (Fig. 1) 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 is comprised of distinct tectonic blocks referred to as terranes, some of which are bounded by faults. Recent activities within GEM-1 have hinted that mineralization in the Cordillera is controlled by the complex internal architecture of the blocks, as well as their bounding structures. Building on these findings, the Crustal Blocks activity (*Ancient Faults and Their Controls on Mineralization in Northern BC and Southern Yukon*) of the GEM 2 Cordilleran Project (Fig. 1) involves detailed mapping of selected target areas in northern Cordilleran terranes of peri-Laurentian affinity: Yukon-Tanana, Slide Mountain, Quesnellia and Stikinia. Also of interest is the nature of their boundary with ancient North America (Laurentia) through time. This work is to be complemented by modern geochronological, geophysical, and geochemical analyses of key crustal blocks and their bounding structures.

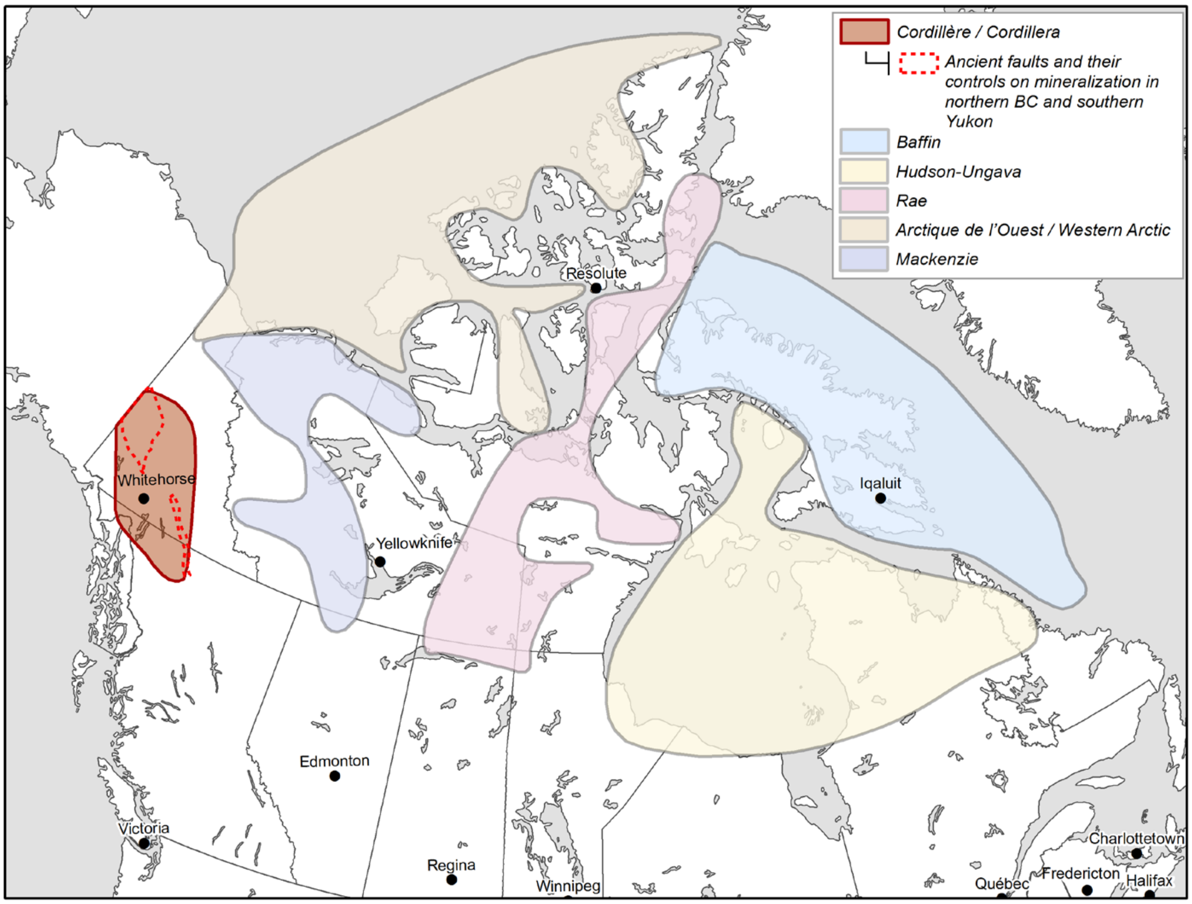


**Figure 1:** Overview map of the six GEM 2 project areas across northern Canada. The Cordillera Project is in highlighted in reddish colour, and the footprint of the current activity is highlighted with a dashed line.

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 2014 field program was the first of three planned field seasons wherein Geological Survey of Canada (GSC) geoscientists, together with partners from Yukon Geological Survey, British Columbia Geological Survey, and universities will conduct field activities in western and southern Yukon and northern British Columbia to investigate the major structural breaks in the regional geology, and their potential role in controlling mineralization in this area of significant but poorly understood mineral potential.

Field investigations for the Crustal Blocks activity during 2014 were designed to address five principal objectives:

1) Evaluate known and critical localities of the Slide Mountain terrane and associated rocks in northern British Columbia, and southeast and western Yukon concerning their previously postulated rift origin and development of oceanic lithosphere, and the subsequent tectonic evolution of the terrane, the nature of its structural contacts with elements of the Yukon-Tanana terrane and the autochthonous North American (Laurentian) margin, and structural breaks within Yukon-Tanana terrane.
2) Evaluate the high strain zone within the Sylvester allochthon of northern British Columbia known as the Rapid River tectonite (RRT). We attempted to a) constrain the age of early deformation within the RRT, b) evaluate whether the RRT could be equivalent to the lower part of Yukon-Tanana terrane, and c) evaluate the kinematic history of the tectonite in an attempt to understand the emplacement direction of this structural slice
3) Complete reconnaissance-scale evaluation of existing geological mapping in western Dawson area of Yukon to evaluate the current geological knowledge base against newly-acquired aeromagnetic surveys of the area, and to assess whether the area warrants modern bedrock mapping.
4) Complete reconnaissance-scale field checking of existing regional geological mapping in the Nisling River - Aishihik Lake area (including much of the Aishihik batholith) and consider the need for updated mapping in the area.
5) Evaluate the sedimentology and paleontology of mid-Cretaceous sedimentary rocks in west-central Yukon (Indian River Formation) to constrain the paleotectonic environment of this region and reactivation of major structures, and to elucidate the mid-Cretaceous evolution of the greater Cordilleran orogen.

Figure 2 shows the four main locations of field work of Crustal Blocks activity in 2014 in the Cassiar Mountains of northern BC (objectives 1 and 2), the Finlayson Lake district of southeast Yukon (objective 1), the Dawson and Stewart River areas of western Yukon (objective 3 and 5), and the Aishihik Lake area of southwest Yukon (objective 4). 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., 2014 a, b).

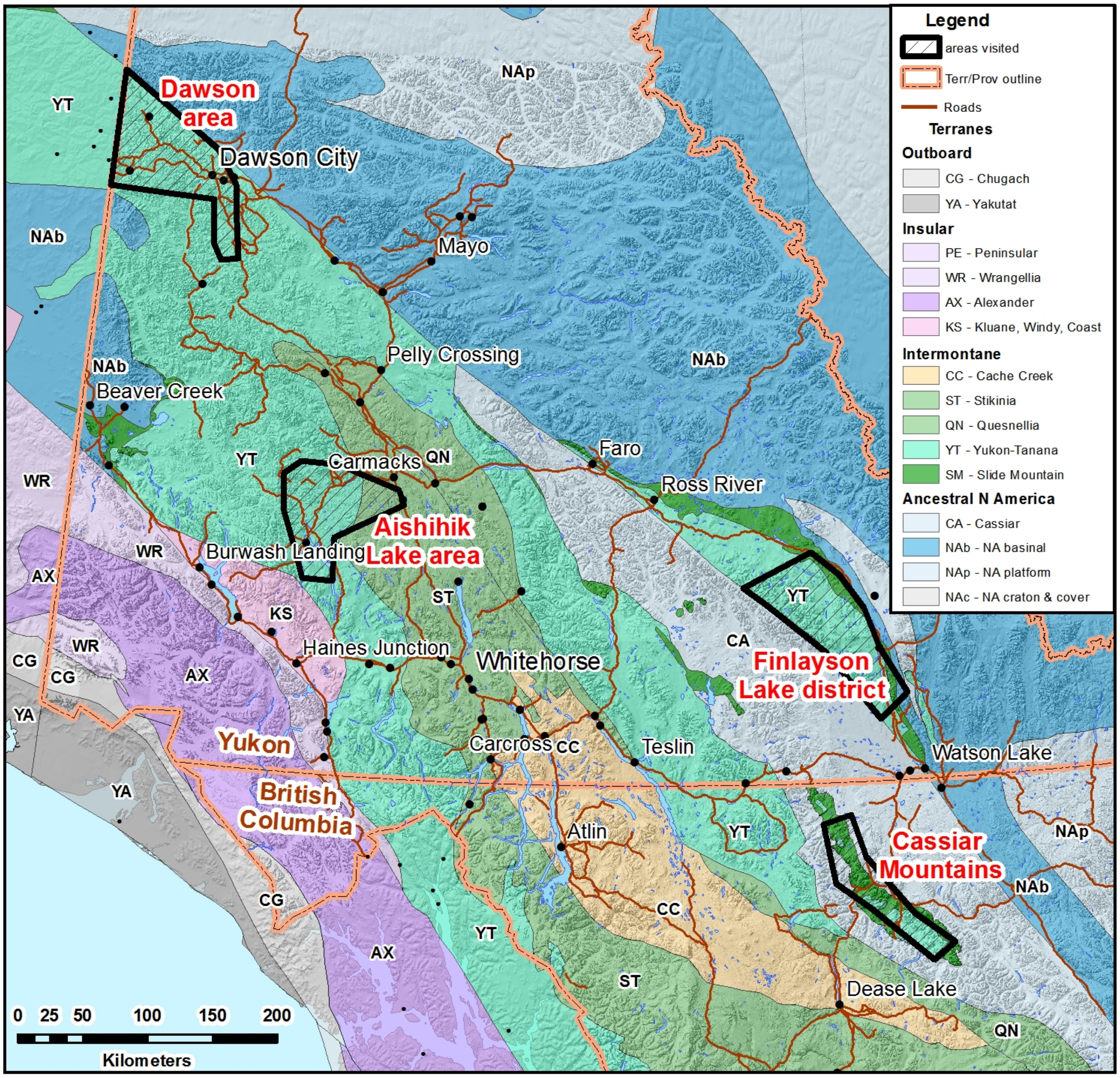


**Figure 2:** Location of the four main field locations visited during summer 2014 under the Crustal Blocks activity, illustrated on a simplified terrane map of northern Cordillera (modified from Colpron and Nelson, 2011).

## Methodology

Fieldwork as part of objectives 1 and 2 in the Cassiar Mountains of northern British Columbia (Fig. 2) was targeted and guided by questions raised from a synthesis of fieldwork projects carried-out in the 1980s and 1990s (Gabrielse, 1994, 1998; Gabrielse and Harms, 1989;

Gabrielse et al., 1993; Nelson et al., 1988; Nelson and Bradford, 1993). Four strategic areas were chosen for detailed field work, and this work was undertaken by remote fly camps (three to four days each) serviced by helicopter out of Watson Lake. Study areas were selected based on where key field relationships could be addressed by foot traverses and where bedrock exposure would lend itself to ease of collecting key samples for geochronology, lithogeochemistry, petrography, microstructural analysis, and thermochronology.

Fieldwork as part of objective 2 in the Finlayson Lake district (Fig. 2) was undertaken by reconnaissance-scale spot checking by helicopter of key geological field localities where relationships would benefit from geochronology, lithogeochemistry, and petrography. Locations for field visits were determined largely from previous mapping by Don Murphy and Fionnula Devine in the late 1990s and early 2000s (Murphy et al., 2001, 2006; Devine, 2005; Devine et al., 2006).

Reconnaissance work as part of objective 3 in southwest Dawson and northern Stewart River map areas (Fig. 2) was undertaken by a combination of roadside work from truck along main and secondary roads, and strategic helicopter stops to remote sites, serviced out of Dawson City. To examine the quality of the regional geology map in southwest Dawson area, sites were chosen based on the existing compilation geology map (Gordey and Makepeace, 2000) and earlier geological compilation by Mortensen (1988; unpublished 1:50,000-scale maps). Sites to examine mafic-ultramafic localities were identified from Gordey and Makepeace (2000) and Gordey and Ryan (2005). Sites for examination of the Indian River Formation (objective 5) were based on previous work by Lowey (1984), Lowey and Hills (1988), Bond and Chapman (2007), and Gordey and Ryan (2005). Samples were collected for geochronology, lithogeochemistry, thermochronology, and paleontology.

Reconnaissance work under objective 4 in the Aishihik Lake area (Fig. 2) was conducted by helicopter spot checks serviced out of Carmacks. Stops were targeted based on existing geology by Dirk Tempelman-Kluit from the 1970s (Tempelman-Kluit, 1974, 1984), inspired and guided by new geological concepts and more refined mapping in the surrounding regions to the west (Israel and Westberg, 2011) and north (Ryan et al., 2014). Samples were collected for geochronology, petrography, lithogeochemistry, thermochronology, and isotopic analysis.

# Results

## Slide Mountain Terrane

Slide Mountain terrane is generally interpreted to represent the remnants of a mid- to late-Paleozoic marginal ocean basin that opened between Laurentia and the Yukon-Tanana terrane (eg., Murphy et al., 2006 and references therein). Occurrences of extensive mafic – ultramafic complex rocks, generally accepted as part of Slide Mountain terrane, were examined at several localities in the Cassiar Mountains of northern British Columbia, and in the Campbell and Simpson ranges of the Pelly Mountains in southeastern Yukon. We are attempting to better characterize the setting and origin of these rocks (e.g. intrusive crustal complexes versus an ophiolitic or ocean-continent-transition zone setting), and ultimately to re-evaluate the early rift evolution of the terrane as well as the nature of its structural contacts with Yukon-Tanana terrane and the ancient North American margin.

A consistent finding in these various ultramafic-mafic complexes is that the ultramafic portions are mainly composed of heavily serpentenized harzburgite to lherzolite, locally preserving bastite pseudomorphs after strongly stretched pyroxene crystals or aggregates (Fig. 3). Such rocks are typical of mantle tectonites. The rocks are commonly chromite-magnetite bearing, and patches and dykes of dunite and pyroxenite were observed locally. Small intrusive bodies of leucogabbro to trondhjemite were observed to be relatively common, but layered mafic-ultramafic cumulates and sheeted dykes typical of oceanic lower crust were notably absent. In general, the ultramafic bodies visited this summer have been interpreted as fragments of exhumed lithospheric mantle that became the substrate to the products of syn-rifting mafic magmatism, predominantly represented by mafic plutonic rocks. Locally the ultramafic-mafic complexes are overlain by thin units of mafic volcanic including pillow basalt (Fig. 4) and breccia, and chert. A strand of the Blue Dome fault (Nelson and Bradford, 1993) exhibits cataclastic brecciation of gabbro cut by basaltic dykes. The basalt dykes are probable feeders to the structurally overlying pillow basalts, and suggest that basaltic effusion was synchronous with cataclastic movement along this fault strand. Polymictic breccia and conglomerate deposits adjacent to a fault zone defined by cataclastic brecciation of the gabbro are interpreted as debris flows along a scarp formed during growth of the Blue Dome fault. The map relationship (Nelson et al., 1988) indicates that the Blue Dome fault is capped by the mafic volcanic rocks.

A sparse number of leucogabbro to trondhjemite intrusions have been dated previously from similar rocks and have mainly yielded Permian ages between 274 and 265 Ma (Nelson and Friedman, 2004; Murphy et al., 2006; van Staal et al., 2012 and unpublished results), which are a proxy for the time of mantle exhumation and associated mafic magmatism during early seafloor development. These ages are surprising in regard to the present tectonic models for the opening of the Slide Mountain ocean, which supposedly took place during Late Devonian-Mississippian time. In addition, detailed examination of radiolaria and conodont paleontological data (Nelson and Bradford, 1993) suggest that oceanic sedimentation was not continuous from early Mississippian to Permian. Rather, separate Mississippian and Late Pennsylvanian-Early Permian pulses are indicated, separated by a notable gap during the Early to Middle

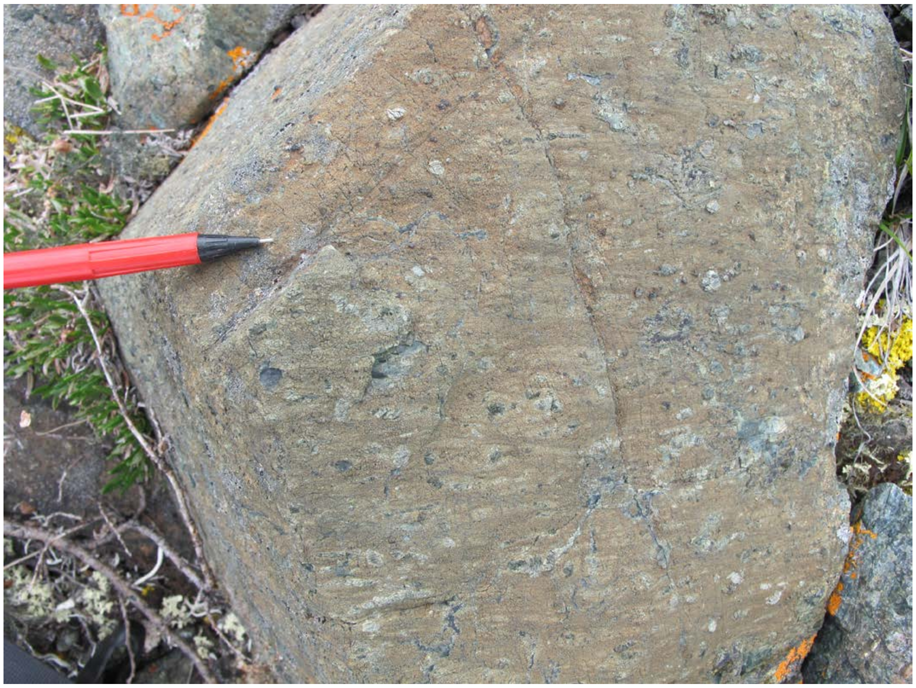

**Figure 3:** Chromite-bearing serpentinized lherzolite with a well-developed, high-temperature foliation defined by deformed olivine and orthopyroxene; the texture and composition allow interpretation of the rock as a mantle tectonite.

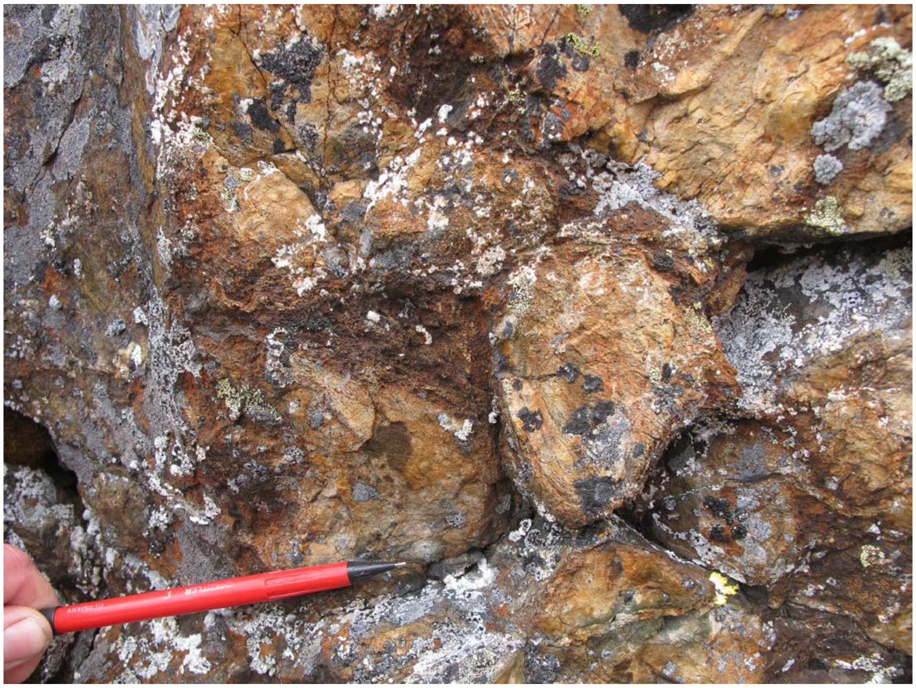

**Figure 4:** Thin selvedges on small pillow structures in mafic volcanic rocks of the Slide Mountain terrane, with good hyaloclastite (the brown patches) preserved in the pillow interstices; metamorphic rank appears to be prehnite-pumpellyite facies.  Concentric zoning apparent in pillows.

Pennsylvanian. Combined, these data suggests that the existing tectonic models are in need of modification. Particularly the evidence for Middle Permian hyperextension and the onset of proto-oceanic crust formation conflicts with models that promote a much earlier Late Devonian-Mississippian opening followed by a Middle-Late Permian closure. It is possible that there are distinct Mississippian and Permian basins currently lumped together in the Slide Mountain terrane, separated by at present poorly defined pulses of basin inversion and associated orogenesis.

## Rapid River Tectonite

Our field work in the RRT within the Cassiar Mountains of northern British Columbia (Fig. 2) yielded good preliminary results. Rocks included in the RRT were described by Harms (1990) and Gabrielse (1994, 1998) as dominated by siliceous tectonite, and correlated with the Dorsey complex by Nelson and Friedman (2004). However, we observed this rock package to be dominated by meta-igneous rocks. A large proportion comprises mafic tectonite, characterized by heterogeneous amphibolite (Fig. 5). The latter that is tentatively interpreted to represent fragmental volcanic to volcaniclastic rocks, which may have been deposited during formation of an Upper Devonian primitive magmatic arc. The other major component of the RRT is intensely foliated to mylonitized tonalite (Fig. 6) that is widely exposed in the Cry Lake and Dalton – Four Mile areas. We interpret highly siliceous bands within these mylonitic rocks as metamorphic segregations and/or veins, and not of sedimentary origin. Hence, because the RRT is principally not siliciclastic in origin, we do not believe it forms part of the Dorsey complex, and therefore probably does not correlate with the Snowcap assemblage of the lower Yukon-Tanana terrane. The high strain ductile foliation that is characteristic of the RRT is indicative of strong non-coaxial deformation, consistent with formation in a major ductile fault zone. What remains uncertain is whether this is a zone of contractional or extensional deformation, and exactly what geological domains would have been juxtaposed across it. The sample suites we have collected for geochronology will help constrain the early ductile component of this deformation, as well as the end of the deformation event. Elsewhere in the area, the RRT is known to be crosscut by a 362 Ma pluton (Gabrielse, 1998). We speculate that the high strain deformation event recorded by the RRT may represent collision an arc-related terrane of unknown origin and the distal Laurentian margin, prior to the main onset of Yukon-Tanana terrane arc activity known to have been active from ca. 363-345 Ma (cf. Piercey et al., 2006), and indeed prior to subduction initiation anywhere along the western margin of North America (Laurentia).

**Figure 5:** Photo of mafic tectonite component of the Rapid River tectonite, characterized by heterogeneous amphibolite, that we interpret to have a fragmental volcanic to volcaniclastic protolith.

**Figure 6:** Mylonitic layers interpreted as highly strained tonalite within the Rapid River tectonite.

## Dawson Area Reconnaissance

Nine days of reconnaissance work in the southwest Dawson map area included stops along the Top of the World Highway and associated access roads, as well as helicopter spot checks. The quality of existing geological mapping on the regional Yukon geology compilation was evaluated, and compared with the new aeromagnetic survey of the Dawson area released in August 2014 (Kiss and Coyle, 2014a, b, c, d, e, f, g, h). Preliminary evaluation of the new geophysical data suggests that it provides exceptional detail of many geological features that were vague or invisible in the previous regional-scale data. The new geophysical data resolve many geological structures in this area, which will be a key benefit to explorers interested in targeting structurally-controlled gold mineralization. In terms of the comparability of the geophysical data with existing geological maps, there is good agreement in the vicinity of road networks, where previous mapping was presumably focussed. In more remote areas, however, improvement can be made with follow-up mapping, and this will be considered for future years of the GEM program. J.K. Mortensen is currently compiling in digital format the unpublished mapping that he undertook in the 1980's in that region (J.K. Mortensen, pers. comm., 2014).

## Nisling River - Aishihik Lake Area Reconnaissance

Three days of helicopter spot checks were done in the Nisling River and Aishihik Lake area (Fig. 2) to evaluate the quality of the existing reconnaissance mapping by Tempelman-Kluit (1974), and consider if the area should be re-mapped to modern standards. Our reconnaissance spot checking of the regional geology indicates that the area would strongly benefit from modern-style remapping, utilizing the advances made in the understanding of Yukon-Tanana terrane and related rocks over the last 15 years. It is clear that major crustal breaks transect the area. A primary question that needs to be further explored is if structures controlled exhumation of the Long Lake suite. Did the reactivation of such structures control the distribution of younger suites of rocks (e.g. the ca. 75 Ma Casino Suite)?

The area of interest lies mainly west of the Aishihik batholith, and thus partly coincides with that covered by a new initiative by the Yukon Geological Survey (Patrick Sack and Maurice Colpron) to characterise in detail the Aishihik batholith, determine its place within the regional understanding of the Jurassic plutonic suites in Yukon, and to characterise the porphyry potential of these suites compared to similar-aged bodies that host the Triassic-Jurassic porphyry deposits of British Columbia. The work also supports the Porphyry Transitions activity under the GEM2 – Cordillera Project that seeks to improve understanding of the setting and porphyry potential of the Late Triassic to Early Jurassic Stikine – Quesnel suite through northern British Columbia and southern and western Yukon (Zagorevski et al., 2014b). Initial assessment of the tectonomagmatic setting and porphyry prospectivity of major lithological units of the Aishihik batholith and wider Yukon Early Jurassic plutonic rocks was conducted under GEM-1 (Chapman et al., *in prep.*). Further zircon U-Pb dating of samples from the Chapman et al. (in prep) study shows that the batholith can be subdivided into several phases of slightly different age ranging between ca. 186 Ma and ca. 181 Ma (N. Joyce, unpublished data, 2014) and form part of the Long Lake suite.

## Indian River Formation

The Indian River Formation is a middle-Cretaceous aged coarse clastic sedimentary sequence described in Lowey (1984) and (Lowey and Hills, 1988). It provides an opportunity to better understand the middle Cretaceous paleoenvironment and tectonic setting of the northern Cordillera. Outcrops of Indian River Formation were visited in the valley of Indian River in the southern Klondike region, including the type locality along McKinnon Creek (Lowey, 1984), in the vicinity of Henderson Dome, and at Last Chance Creek (a tributary to Hunker Creek). Additional outcrops correlated with the Indian River Formation were also studied along Top of the World Highway west of Dawson City, and in the valley of 60 Mile River. This rock unit is generally poorly exposed in most localities, and consists mostly of isolated exposures with limited stratigraphic section. Outcrops were studied to assess environment of deposition, and a total of 24 paleontological samples were collected in an effort to improve age assessment.

In the Henderson Dome area, restricted exposures are found beneath volcanic strata of the Carmacks Group and consist of rusty sandstone, locally with pebble conglomerate, and locally siliceous siltstone. Sedimentary structures suggest the strata were deposited in localized non-marine environments. Along Indian River, thicker sections of Indian River Formation are known (e.g. Lowey and Hills, 1988) from work along exploration roads in mid-1980s; however, much of the exposure has subsequently been overgrown with dense vegetation. An unsuccessful attempt was made to locate core drilled along McKinnon Creek in 1970s and 1980s and stored on site, as described in Lowey and Hills (1988) and Bond and Chapman (2007), in order to resample for paleontology. The exposure of Indian River Formation described by Bond and Chapman (2007) along Diversion Creek no longer exists as it has been processed for placer gravels. Similarly, an attempt was made to find the westernmost known exposure of Indian River Formation in the Indian River valley, described by Bond and Chapman (2007) at Boulder Mining pit, but this outcrop is now overgrown and no longer accessible. The final exposure described by Bond and Chapman (2007), found along the north side of Indian River near Arkenstall's camp, was visited and fine-grained strata was sampled for paleontology.

Exposures of Indian River Formation along Top of the World Highway are in similar stratigraphic setting to those in the Henderson Dome area, found as thin accumulations underlying volcanic strata of the Carmacks Group. These exposures were also studied to assess depositional environment, and sampled to improve paleontological age control. Finally, in the 60 Mile River area, thicker sections of conglomerate, sandstone, siltstone, and mudstone were studied to assess sedimentary environment and paleontological age.

## Next steps

The Rapid River tectonite is a little-understood regional scale shear zone. Our geochronology analyses on rocks within and cross-cutting the tectonite should shed the timing and nature of this shear zone and improve our understanding of the early structural relationship between Yukon-Tanana terrane and the ancient margin of North America.

Petrological and geochronological investigation of samples from the mafic-ultramafic complexes of the Slide Mountain and associated parts of the Yukon-Tanana terranes in Yukon and northern BC will better elucidate the genesis and setting of these tectonically important rock packages, which in turn will impose more rigid constraints on the timing, nature and complexities of the tectonic evolution of these terranes.

Decisions about the location of future mapping initiatives based on this year's reconnaissance mapping will be greatly assisted by preliminary results of follow up laboratory analysis and consultations between with the GSC and the Yukon Geological Survey.

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

## Acknowledgments

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