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Geological framework of ancient oceanic crust in northwestern British Columbia and southwestern Yukon GEM 2 Cordillera

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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 of 2014, GEM's new research program has been launched with 14 field 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 Cache Creek terrane comprises an imbricated stack of carbonate, chert, basalt, gabbro and ultramafic rocks that are exposed from southern British Columbia to southern Yukon. Its components have been variably interpreted to represent fragments of accreted seamounts, ophiolites and rifted arc complexes. Some of these are associated with Tethyan fauna-bearing limestone that is exotic to Laurentia (e.g., Monger 1977a; Monger and Ross 1971). The apparent entrapment of exotic Tethyan fauna between the less exotic Stikinia and Quesnellia terranes has guided the development of the tectonic models for the evolution of the northern Cordillera far beyond the boundaries of the Cache Creek terrane itself (e.g., Mihalynuk et al. 1994 and references therein). Although the individual tectonostratigraphic units are locally well known, their regional distribution remains poorly constrained. This precludes detailed tectonic reconstructions of the Cache Creek terrane that are necessary to understand the distribution and significance of mineral deposits within Cache Creek and adjacent terranes.

The *Geological framework of ancient oceanic crust in northwestern British Columbia and southwestern Yukon* activity aims to develop an updated regional geologic framework for the Cache Creek terrane in southern Yukon and northern British Columbia (Fig. 1). This framework will address the origin of individual tectono-stratigraphic units and their mineral

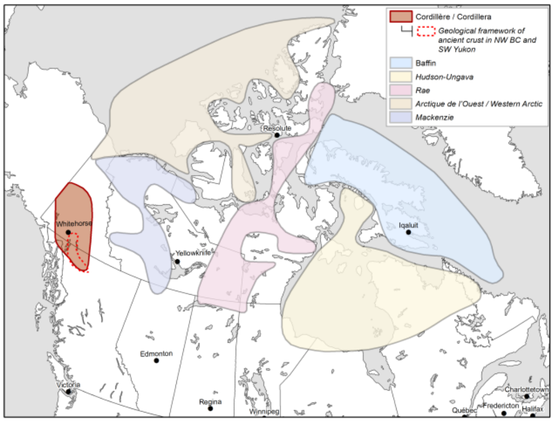

Figure 1: Geomapping for Energy and Minerals Project areas

potential, the history of associated sedimentary basins, and the accretionary history that brought the various tectono-stratigraphic units together. The proposed project area contains superb large-scale exposures that provide ample opportunities to study the larger tectonic processes that occur during formation of oceanic terranes and associated syn- and epigenetic mineral deposits.

Geological background

The Cache Creek terrane is recognized to be a composite terrane along its entire length (Fig. 2). In the Cry Lake and Dease Lake areas (NTS 104I, J), the northern Cache Creek terrane is divided into two major units: the Cache Creek Complex and the Kutcho Assemblage (Fig. 2; Gabrielse 1998). The Cache Creek Complex is separated from the Kutcho assemblage by the Nahlin Fault. The Kutcho assemblage occurs to the south of the Nahlin Fault and is interpreted as an Early to Middle Triassic rifted arc complex (e.g., Childe and Thompson 1997; Gabrielse 1998; Schiarizza 2011) that hosts volcanogenic massive sulphide potential. The Kutcho assemblage comprises felsic to mafic volcanic and hypabyssal rocks and associated epiclastic sediments. These rocks are unconformably overlain and structurally imbricated with the Jurassic Inklin Formation above the King Salmon Fault. Correlatives of these rocks occur to the northwest in the Nakina (English et al. 2010; Mihalynuk et al. 2002) and Marsh Lake areas (Bickerton 2013). Similar rocks also occur to the north of Kutcho fault in the Cry Lake area, but have provisionally assigned to Quesnellia (uPT unit of Gabrielse 1998).

The Cache Creek Complex occurs above the Nahlin Fault and comprises large slabs of variably serpentinized ultramafic rocks (alpine peridotites; Fig. 2) that are structurally juxtaposed with mafic volcanic, mafic hypabyssal and sedimentary rocks including limestone, ribbon chert and fine-grained silicilastic rocks all ranging in age from Carboniferous to Jurassic. During initial studies of the mafic-ultramafic rocks, they have been interpreted as an ophiolite (i.e. spreading centre; e.g., Terry 1977) and/or a seamount (i.e. ocean island/plateau with carbonate atoll; e.g., Monger 1977b) that were in part coeval with and overlain with deep water basin strata characterized by chert and fine-grained silicilastic rocks. Subsequent workers followed these interpretations (e.g., Ash 1994; English et al. 2010; Gabrielse 1998; Mihalynuk et al. 1994); however, a consistent tectono-stratigraphy has not been developed across the northern Cache Creek terrane. As such, the relationship between the seamount and ophiolite components remains enigmatic, as does their relationship to the abundant mantle tectonites and rare crustal cumulates.

Goals and objectives

Presence of both ophiolitic (ridge) and seamount/plateau components in the Cache Creek complex suggests that these represent distinct tectonic panels, because these environments rarely occur together in modern settings, with the exception of Iceland. To pursue this hypothesis, several areas and transects were identified to (i) characterize ultramafic and associated rocks and to determine their tectonic affinity, (ii) characterize and

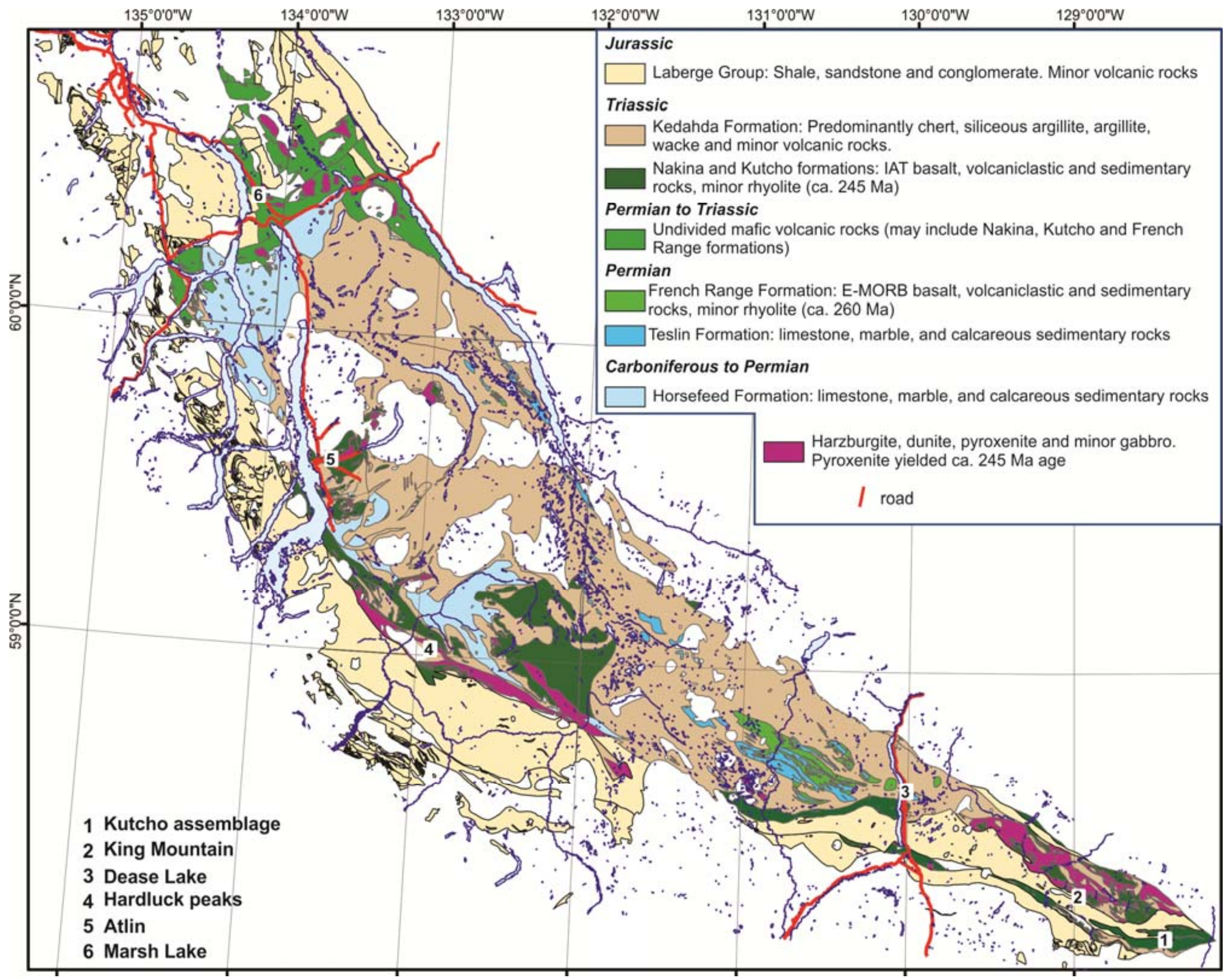

Figure 2: Simplified geology of the northern Cache Creek terrane showing the distribution of various tectono-stratigraphic units.

determine the tectonic setting of lower crustal gabbro/norite; (iii) examine volcanic rocks; and (iv) examine the relationship of the ultramafic rocks to the crustal packages. These were in part selected based on previous mapping, accessibility and relevance to testing an intra-oceanic core complex model.

Preliminary results

Ultramafic rocks

Variably serpentinized ultramafic rocks are present throughout the northern Cache Creek terrane, although the largest exposures occur in the hanging wall of the Nahlin Fault. These ultramafic rocks were examined and sampled at several localities including King Mountain, Dease Lake, Hardluck Peaks, Atlin and Marsh Lake (Fig. 2). Where the primary mineralogy and textures are preserved, mantle harzburgite tectonite is dominant, with about 25-35% of mm to cm sized porphyroclastic orthopyroxene with neoblastic tails. Minor holly-leaf chromite is common. Rare orthopyroxenite interlayers are generally 1-3 cm wide and are typically very sparsely distributed, but may form reticulated swarms and swell to decimeter scales. Some orthopyroxenites are boudinaged into the dominant harzburgite foliation. Dunite dykes are minor but common (Fig. 3A). Some dunite replaces harzburgite and orthopyroxenite.

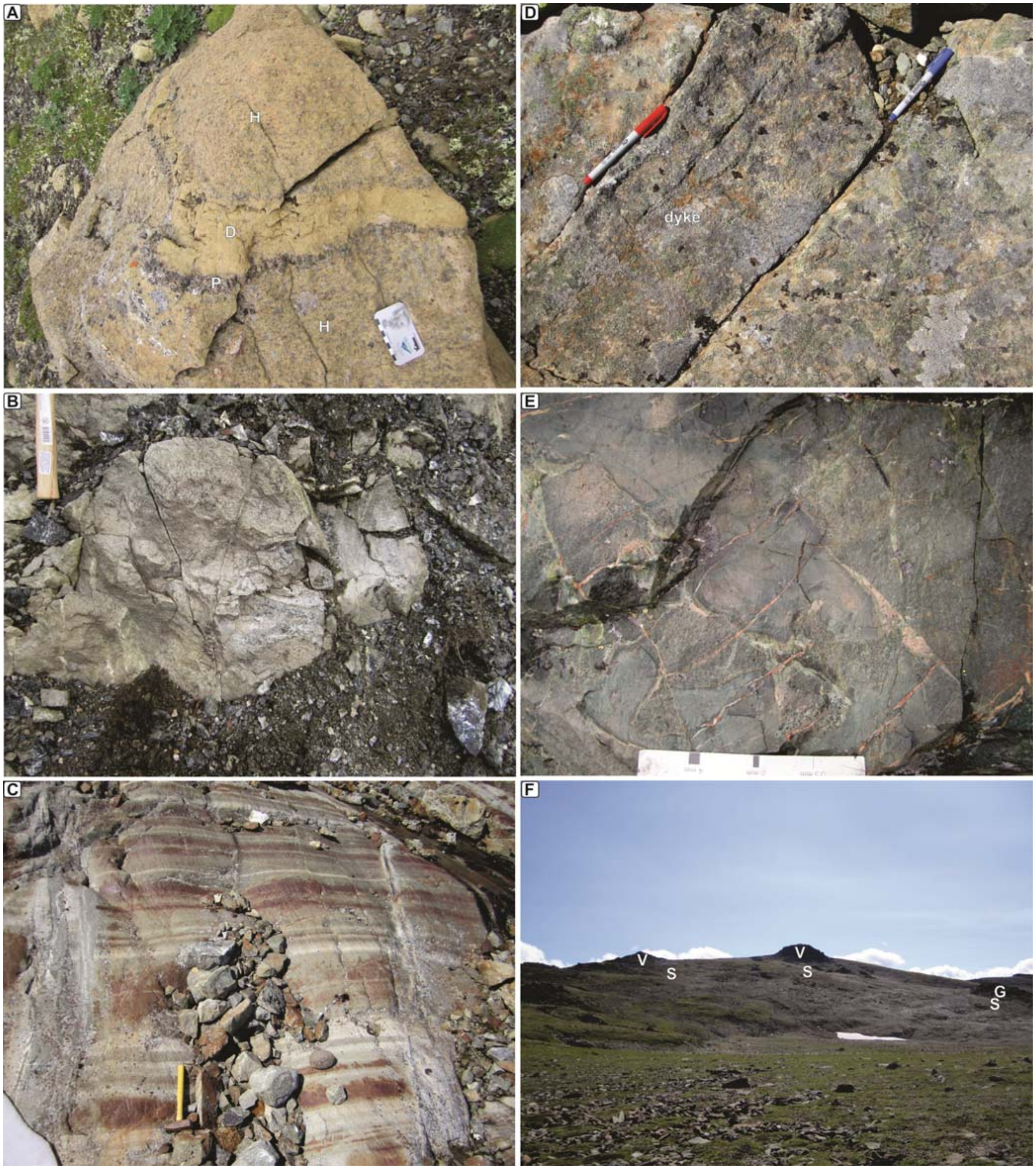

Figure 3 Representative photographs of the northern Cache Creek terrane. A. Harzburgite (H) with a dunite (D) dyke rimmed by orthopyroxenite (P), Hardluck Peaks area. B. Roddingitized gabbro in serpentizined harzburgite, Dease Lake area. C. Layered norite with sulphide-rich zones cut by gabbro, diorite and trondhjemite dykes, King Mountain. Hornblendite is locally developed. D. Basaltic dyke cuts fine-grained gabbro, north of King Mountain. Pens outline the margins of the dyke. Swarms of basaltic to gabbroic dykes form a sheeted dyke complex in this area. E. Hypabyssal basalt-gabbro breccia, Hardluck Peaksarea. F. Typical crust-mantle relationships in the Atlin area. Serpentinized mantle hosts gabbroic dykes (G). Resistant knockers of volcanic/hypabyssal rocks (V) lie above highly strained, recessively weathering, serpentinized peridotite (S).

Gabbroic dykes

Variably serpentinized ultramafic rocks are commonly dissected by fine to medium-grained gabbroic dyke swarms. Dykes range from centimeter to decameter scales. In extensively serpentinized hosts, these dykes are commonly strongly altered to rodingite (Fig. 3B) and boudinaged. Some of the larger dykes show coarsening of grain size towards their centers indicating chilling against previously cooled mantle. Some gabbroic bodies are emplaced at the transition between serpentinized mantle and upper crustal lithologies. These gabbros are strongly vari-textured, and range from fine to coarse-grained on centimetre scale. Some mantle sections appear to completely lack gabbroic dykes. Their absence may be due to either a difference in tectono-magmatic history or to depth of derivation of the various mantle sections. Since feldspar-bearing assemblages are restricted to the immediate vicinity of the Moho, presence of gabbroic dykes may indicate shallower and/or exhumed mantle.

Layered gabbro

Crustal cumulate rocks are rare in the northern Cache Creek terrane. Gabrielse (1998) identified a section of layered gabbro partially covered by alpine glacier in the cirque of King Mountain. This small alpine glacier has since retreated exposing >400 m of continuous ourcrop of layered (generally 30-50 cm thick), foliated to granular-textured gabbronorite > gabbro > norite (Fig. 3C). Approximately 350 m of the cumulate section was mapped and sampled in detail as part of M.Sc. thesis research by A-S. Corriveau (INRS).

The entire cumulate pile acquired a fabric at the late-cumulus stage as indicated by layer parallel foliation, isoclinal folding and boudinage. The apparent lack of systematic magmatic evolution and lack of olivine suggest a near-steady state magmatic system that produced cumulates en-route between a lower crustal reservoir and a high-level hypabyssal and volcanic system. Hornblende-rich veins occur locally and are commonly tightly to isoclinally folded and/or boudinaged. In some localities, hornblende veins are boudinaged into swarms of small (cm-scale) augen, yielding a spectacular hybrid flaser hornblende gabbro. This late stage plastic transposition of hydrothermal vein assemblages into the dominant gabbroic fabric implies that the rocks were very close to the brittle-ductile transition. Prominent late hydrothermal/trondhjemitic vein systems occur as breccia corridors about 10 m wide, where host rocks are replaced by hornblende-rich assemblages. Widespread, but less penetrative, brecciation also occurs between these corridors, with fractures being lined by thin hornblende selvages and veinlets. Wider veins show development of black hornblende + plagioclase + quartz, and grade into small trondhjemitic dykes and veins.

Non-magnetic sulphide-stained layers, some discontinuous, are ubiquitous and locally prominent in the layered sequence (Fig. 3C). They occur at 1-2 m intervals in and among the more common gabbroic rocks. A few discordant examples were also seen. These rocks contain trace amounts (2-10%) of Fe-sulphide. These layers may represent discrete sulphide-saturation events, consistent with a magma that was perched near sulphide saturation. Since S-rich cumulate rocks represent the putative reservoir of metals for VHMS mineralization, more detailed study of these would have implications for the S-systematics of the mantle-crust system.

Hypabyssal and volcanic rocks

Fine-grained mafic rocks occur throughout the northern Cache Creek terrane. There have been generally mapped as volcanic rocks, even though extrusive textures are very sparsely observed. In the Cry Lake area, Gabrielse (1998) mapped several large klippe of “volcanic rocks intruded by diorite” which lie structurally above variably serpentinized mantle. Examination of these rocks in several localities revealed medium to fine-grained gabbro intruded by swarms of fine-grained gabbro to vesicular basaltic dykes (Fig. 3D, E). Several outcrops revealed poly-stage emplacement of sub-parallel sheeted dykes. This is also apparent in some cliff faces, where these rocks acquire blocky bedded/sheeted appearance suggestive of organized spreading. White trondhjemite dykes locally intrude the sheeted dyke complex. Marble rarely occurs as screens between sheeted dykes, suggesting proximity to the volcano-sedimentary facies.The character of the sheeted dyke complex changes laterally from basaltic dyke dominated to predominantly gabbroic suggesting that these rocks lie near transition between isotropic gabbro and sheeted dyke zone.

Crust-mantle relationships

Crust and mantle lithologies are commonly imbricated and cut by late faults, making the identification of the primary relationships difficult. In many localities, upper crustal lithologies (i.e. hypabyssal, volcanic and sedimentary rocks) lie structurally above mantle rocks with no intervening lower or middle crust rocks (Fig. 3F). This relationship commonly occurs across the entire northern Cache Creek terrane from Cry Lake to Teslin area. The structural stacking and missing crustal components indicate that the contact is a detachment that has been subsequently reworked during Cordilleran orogenesis. The contact is typically marked by scaly serpentinite and or talc schist derived from dunite and harzburgite. Locally, peridotite mylonites are preserved at this contact. These are characterised by boudins of pyroxenite and chromitite in a mylonitic olivine rich (?) matrix. The lack of post-deformational annealing of the matrix suggests that these rocks were rapidly cooled following deformation.

Conclusions

Reconnaissance mapping and sampling was conducted across the northern Cache Creek terrane to facilitate identification of various crustal components. Preliminary work indicates that mantle, lower crust, hypabyssal, and volcano-sedimentary components of an ophiolite are structurally dismembered but preserved in the Cache Creek Complex. The relationships between the components are consistent with an intra-oceanic core complex model (Zagorevski 2013). Subsequent work will focus on constraining the nature and timing of magmatism and sedimentation in the Cache Creek Complex. This will be done through geochronology, paleontology (compilation and new), petrography, whole-rock and mineral chemistry on the mantle, lower crust, hypabyssal, and volcanic samples. Inversion modelling of dunite and orthopyroxenite chemistry will be carried out to yield compositions of melts in the mantle. The results of this inversion will be used to test the homogeneity of the mantle characteristics and to compare mantle peridotites to crustal lithologies in the Cache Creek Complex. Chemistry will also be compared to results of model melt compositions derived from inversion modelling of ultramafic rocks (see previous) and other cumulate, hypabyssal and volcanic facies. The timing of magmatism will be constrained by Ar-Ar dating of magmatic hornblende bearing lithologies at King Mountain, and by U-Pb dating of suitable lithologies such as pegmatite, trondhjemite, and evolved diorite. Dykes, including rodingites, will also be investigated to determine their potential for isotopic dating. These data will then be used to test the homogeneity of the Cache Creek Complex and to identify target mapping areas for following years.

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