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Contents

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 responsible land-use and 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 2017 field season, research scientists from the GEM program successfully carried out 27 research activities, 26 of which will produce an activity report and 12 of which included fieldwork. Each activity included 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 partners as the program advances.

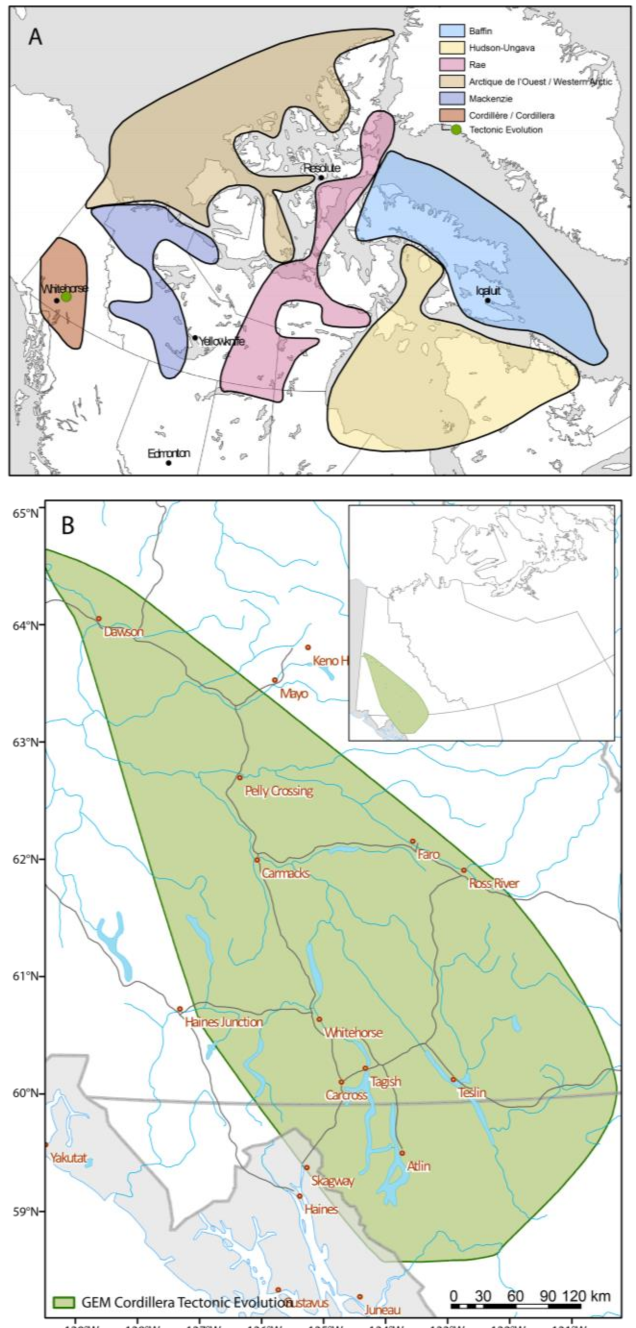

Figure 1. A. Overview map illustrating the footprint of the Cordillera project in northwest Canada. B. Footprint of the GEM Cordillera Yukon Tectonic Evolution activity.

Introduction

Terranes are fragments of the Earth's crust that share a common formation history and differ significantly from rock assemblages in adjacent terranes. In orogens such as the Canadian Cordillera that have formed by the progressive accretion of terranes, outboard terrane accretion and subsequent plate motions have commonly overprinted and/or reactivated the margins of inboard terranes, obscuring their original accretion relationships. Inboard Devonian to Jurassic terranes in the northern Canadian Cordillera (Yukon and northernmost British Columbia) were accreted to the western margin of Laurentia (North America) in the early Mesozoic, and host valuable mineral resources. Since their accretion, they have been affected by a range of processes including the formation and inversion of sedimentary basins, exhumation, formation of new igneous rocks and vertical and horizontal translation along the western margin of the North America continent.

The bedrock geology represented in the footprint of the GEM2 Cordillera project (Fig. 1, 2) records this complex and episodic history of mountain building within peri-Laurentian and exotic terranes, including the oceanic Cache Creek and Slide Mountain terranes, Stikinia/Quesnellia island arc terranes and Yukon-Tanana metamorphosed continental arc terrane (Fig. 2). The present distribution of these "Intermontane" terranes is governed not only by the geometry of accretion, but also by subsequent modification and/or displacement. Consequently, the timing of accretion, geometry of collision and relationships between them are still under investigation. The Whitehorse trough overlap sedimentary basin extends along Stikinia's eastern margin, is proximal to both the Yukon-Tanana and Cache Creek terranes, and also preserves a record of the progressive accretion, exhumation and erosion of these terranes (Fig. 2; Colpron et al., 2015).

Terrane formation and accretion of the Intermontane terranes involved relatively high to medium temperature (>400 °C) crustal processes (e.g. magmatism, medium- to high-grade metamorphism), and regional U-Pb and Ar-Ar geochronological studies have been invaluable in reconstructing their formation during Devonian to Triassic, including the formation of significant mineral deposits. However, the bedrock of this region has been displaced significantly since the Early Jurassic. The upper crustal processes that modified these mineral-endowed terranes are poorly understood, yet are critical for controlling the setting of formation, and subsequent translation of base metal mineralization.

This research activity is designed to address this gap in knowledge by focusing on the upper crustal processes that occurred from the Early Jurassic, during and post-accretion of the Intermontane terranes, including formation of sedimentary basins, differential exhumation, fluid events and

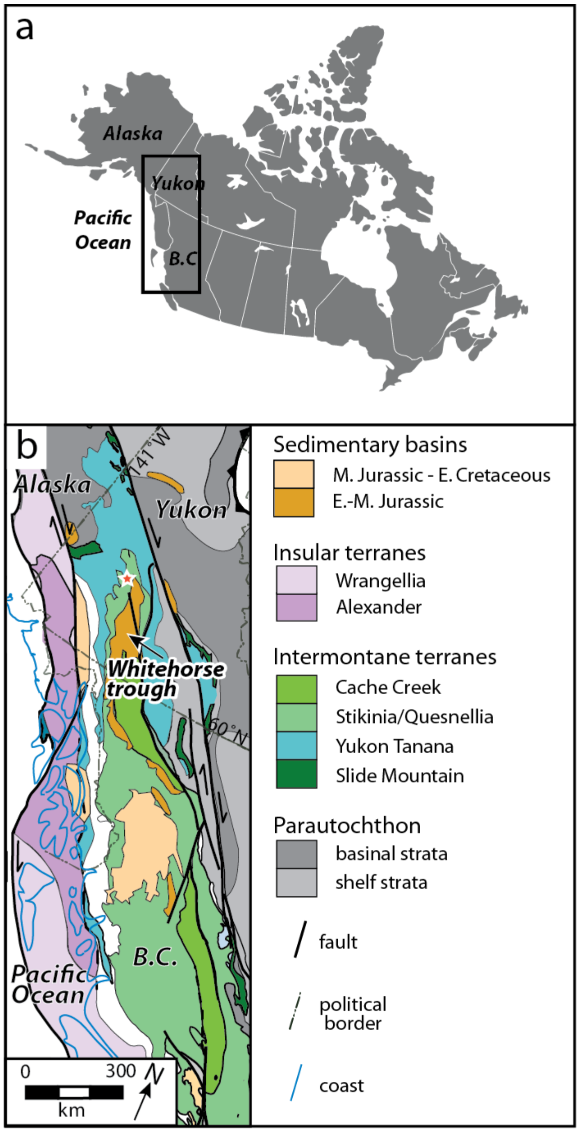

Figure 2. Terrane map of the northern Cordillera, modified from Colpron et al. (2015) Star – Minto Cu-Ag-Au deposit.

translation of terranes along faults. To achieve this goal, we are applying low temperature (<400 °C) thermochronology methods including Ar/Ar, K/Ar, U-Th/He and fission track dating. This work will provide new and key constraints on the possible styles of mineralization for different crustal blocks through time, as much of the mineralization is depth dependent.

This activity is funded from 2017-2020. Geological Survey of Canada (GSC) geoscientists are collaborating with Yukon Geological Survey, industry and universities on samples from western and southern Yukon and northern British Columbia to investigate the temperature-time (T-t) history of rocks within the Intermontane terranes. The 2017 objectives are focused on analysis of existing GEM Cordillera samples, in order to guide strategic field sampling in 2018. Two main sample sets were analyzed, both from within the bedrock mapping footprints of the Crustal Blocks (see reports by Ryan et al., 2015, 2016), Porphyry Transitions (Zagorevski et al., 2015a, 2016a), and Cache Creek (Zagorevski et al., 2015b, 2016b) activities within the overall GEM-2 Cordillera project.

The first set comprises sedimentary rocks from the Laberge Group of Whitehorse trough, and adjacent basement rocks of Stikinia and Yukon-Tanana terranes (Fig. 2, 3). We performed U-Pb detrital zircon, Ar/Ar detrital muscovite, U-Th/He zircon and U-Th/He apatite age analyses. The objective of this work is to determine the source regions, extent of burial, and exhumation history of the Laberge Group, particularly focusing on basin-wide trends, and differential burial and exhumation across major faults.

The second sample set comprises fault gouge collected from faults that cut the Minto Cu-Ag-Au deposit (Fig. 2). We performed X-ray diffraction and K-Ar age analysis on the clay-sized fractions of the fault gouge. Our objective is to directly constrain the age of post-accretionary upper crustal faults that cut the Intermontane terranes.

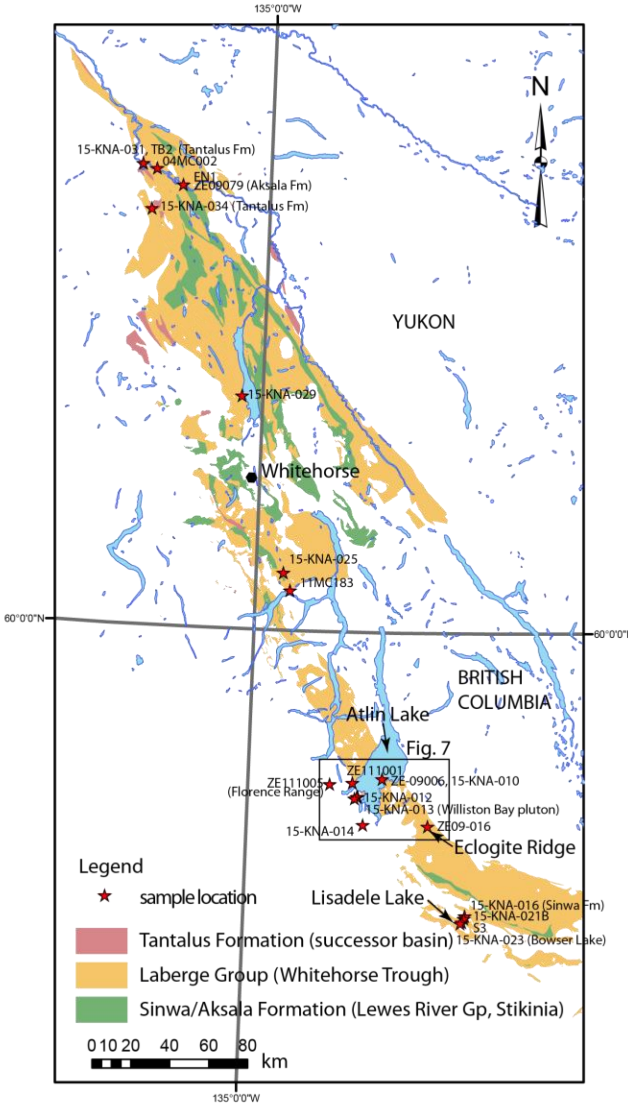

Figure 3: Map showing the extent of the Laberge Group, Whitehorse trough, with underlying Sinwa/Aksala Fm of Stikinia, and overlying Tantalus Fm. Locations of thermochronology samples described in this report are shown. Samples are Laberge Group unless otherwise indicated.

Methodology

Objective 1: Whitehorse trough and related samples

U-Pb detrital zircon geochronology

Detrital zircon was extracted from ten wacke, sandstone and conglomerate samples of the Lower to Middle Jurassic Laberge Group, underlying Aksala/Sinwa Formation siliciclastic sedimentary rocks, and overlying Bowser Lake and Tantalus formations, spanning both the N-S extent, and stratigraphic range of the trough. Zircon were embedded in epoxy, polished to mid-section and analyzed for U and Pb isotopes using a sensitive high resolution ion microprobe (SHRIMP) housed at the GSC in Ottawa.

Ar/Ar detrital muscovite geochronology

Detrital muscovite occurs rarely in the Laberge Group. Grains were separated from a metamorphic cobble collected from the Lisadele Lake area. Detrital muscovite were also extracted from sandstone in the overlying Upper Jurassic to Cretaceous Tantalus Formation. The mineral separates were irradiated, and then single grains were step heated under ultra-high vacuum and analyzed on a multicollector noble gas mass spectrometer housed at the GSC in Ottawa.

U-Th/He zircon (ZHe) thermochronology

Zircon was separated from eight sedimentary, metamorphic and igneous rocks sampled from the study region. Four to eight pristine grains were selected from each, measured, and then degassed to release He. He isotopes were measured in a noble gas mass spectrometer housed at Dalhousie University in Halifax. Grains were then digested, and U, Th and Sm were measured from solution in an inductively-coupled plasma mass spectrometer housed at the University of Colorado, Boulder.

A subset of six of the samples that were subjected to detrital zircon U-Pb analysis were selected for double dating (an individual grain is analyzed to determine first its U-Pb crystallization age and then its U-Th/He cooling age). Half grains previously dated using the SHRIMP for U-Pb age were plucked from the epoxy grain mount and analyzed in the same way as described above to determine their U-Th/He ages.

U-Th/He apatite (AHe) thermochonology

Apatite was separated from 10 sedimentary rocks sampled from the study region. Five pristine grains were selected from each, measured, and then degassed to release He into a noble gas mass spectrometer housed at Dalhousie University. Grains were then digested, and U, Th and Sm were measured from solution in an inductively-coupled plasma mass spectrometer housed at the University of Colorado, Boulder.

Objective 2: Fault gouge, Minto deposit

Clay separation and X-ray diffraction

Four samples of fault gouge were collected from drill core at the Minto deposit in southern Yukon. The clay-sized (≤2 µm) fraction was separated from the gouge by suspension and centrifuging. Mineralogy of the clay-sized fraction was determined by X-ray diffraction using a powder diffractometer, applied to air-dried, ethylene glycol and heat-treated aliquots at the GSC in Ottawa.

K-Ar geochronology

K-content of the clay-sized fraction was determined by atomic absorption, and ^{40}Ar was extracted by fusing samples in a furnace, spiking with ^{38}Ar and then analyzed using a noble gas mass spectrometer, both instruments housed at Kyoto University, Kyoto, Japan.

Results

Objective 1: Whitehorse trough

Source regions

The Whitehorse trough extends ~700 km along a NW-SE trend, with a maximum across-strike width of about 100 km, and comprises Early to Middle Jurassic clastic sedimentary and volcaniclastic rocks of the Laberge Group. Previous detrital zircon studies have demonstrated that Laberge Group sedimentary rocks are dominated by proximal Triassic to Jurassic volcanic, sedimentary and plutonic sources derived from Stikinia or Quesnellia (Shirmohammad et al., 2011; Colpron et al., 2015). Detailed ammonite biostratigraphy indicates that the youngest detrital zircons are a reasonable proxy for the time of deposition (Shirmohammad et al., 2011). The Eclogite Ridge member of the Laberge Group is a notable ~300 m thick horizon of Early

Jurassic conglomerate and sandstone that contains abundant eclogite, amphibolite, granulite, and mica schist clasts, as well as detrital garnet, olivine, pyroxene and spinel grains. Detailed investigations of the Eclogite Ridge member detritus have delineated ultra-high pressure and high pressure metamorphic sources (Canil et al., 2004, 2006), and recent work under the GEM 2 Cordillera – Characterization of volcanic and intrusive rocks across the British Columbia-Yukon border activity (Zagorevski et al., 2016a) has indicated a likely latest Triassic age for eclogite-facies metamorphism.

Detrital zircon age distributions for the Laberge Group samples (Fig. 4) are dominated by Late Triassic to Early Jurassic grains, with few late Paleozoic and rare Proterozoic grains (not shown). The Aksala/Sinwa Formation samples lack Jurassic grains, consistent with their interpreted Late Triassic to earliest Jurassic depositional age (e.g. English et al., 2005; Hutchison, 2017). Similarly, the Bowser Lake and Tantalus Formation samples yielded abundant Late Jurassic and Cretaceous grains, respectively, consistent with their depositional ages (Shirmohammad et al., 2011; Colpron et al,. 2015). A metamorphic rock from the Florence Range of Yukon-Tanana terrane (Fig. 4E) shows a much older detrital zircon age distribution dominated by Mesoproterozoic grains, with abundant Paleoproterozoic grains and few Archean

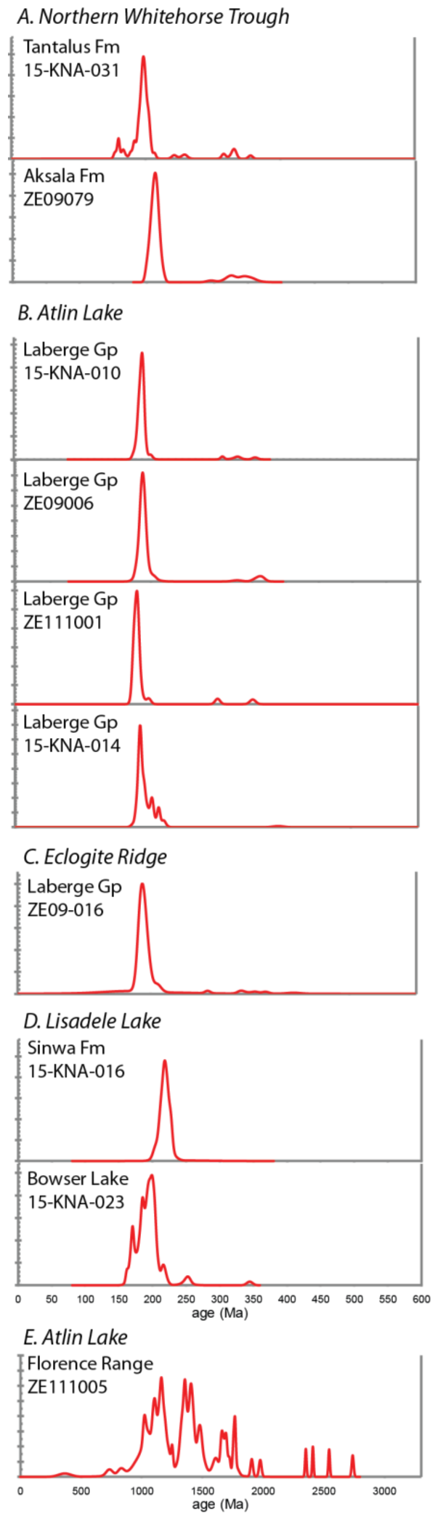

Figure 4. Detrital zircon probability plots (intended to be representative, no selection based on discordance. A-D are 206/238 ages for sedimentary rocks. E are 207/206 ages from the metamorphic Florence Range, west of the Llewellyn fault. Y-axis is relative probability. Note the different x-axis for E. Sample locations are shown in Figure 3.

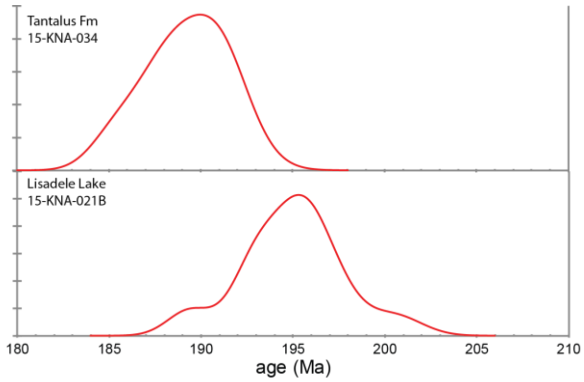

Figure 5. Detrital mica probability plots. Ages are based on interpretation of single grain step heat experiments. Y-axis is relative probability. N=11 for 15-KNA-034 and n=12 for 15-KNA-021B.

grains. The youngest concordant grains are Neoproterozoic.

The detrital muscovite age distributions (Fig. 5) indicate Early Jurassic cooling ages, with the Laberge Group boulder from Lisadele Lake yielding older, ca. 195 Ma cooling and the Tantalus Formation sandstone from the Klondike highway yielding slightly younger, ca. 190 Ma cooling ages.

In general, detrital zircon and muscovite populations are consistent with a dominantly Stikinia or Quesnellia volcanic source such as the Lewes River Group and Jurassic successor volcanic rocks, with a local, brief influx of medium to high grade metamorphic rocks with Early Jurassic cooling ages, of probable Yukon-Tanana terrane origin (Currie and Parrish, 1993; Dusel-Bacon et al., 2002; Berman et al., 2007; Joyce et al., 2015).

Extent of burial

The nominal closure temperature for He in apatite is 60-70 °C, while that for zircon is 180-190 °C. However, closure temperatures for He diffusion in zircon and apatite are dependent on a number of factors including but not limited to the cooling rate, the degree of radiation damage in the grain, and time spent in the partial He retention temperature window (see Farley and Stockli, 2002, Guenther et al., 2013 and Reiners et al., 2005 for comprehensive reviews). Note that the data presented here will be subjected to a full analysis during the timeline of the GEM2 program – their presentation in this report is intended to document progress and initial findings, and are at a preliminary stage. Following that caveat, results from the ZHe (Fig. 6) and AHe (Fig. 7) analysis show some general trends along the length of the Whitehorse trough.

In sedimentary basins, detrital minerals may yield cooling ages that represent cooling of the source terrane (as in the case of the detrital muscovite ages presented above), or post-depositional ages that represent heating during basin evolution, depending on whether the basin experienced sufficient heating to reset each particular thermochronometer. In comparing the ages from Figures 6 and 7, it is apparent that all parts of the basin, as well as the overlying Tantalus Formation have experienced post-depositional heating above the apatite He closure temperature. In contrast, only some regions of the Whitehorse trough and adjacent units have experience reheating above the zircon He closure temperature. These include one sample from the western shore of Lake Laberge, and several samples from the southern portion of the trough, in British Columbia. This trend is shown in detail for the Atlin Lake area (Fig. 8). Samples east of the King Salmon thrust show ZHe ages that overlap with zircon U-Pb ages (confirmed by double dating of several grains). In contrast, samples west of the King Salmon thrust, including analyses from the Lisadele Lake area along strike to the SE, have all been reset, yielding Cretaceous or younger ZHe ages. Since the detrital muscovite from Lisadele Lake have not been reset (nominal closure temperature for Ar in muscovite is 400 °C), this pattern indicates that the Whitehorse trough east of the King Salmon thrust remained below 180-190 °C throughout its evolution, while the portion of the trough that sits west of the thrust was heated to between 190-400 °C sometime after deposition.

Exhumation history

This preliminary Ar/Ar, ZHe and AHe dataset will be used to construct temperature-time forward models for different defined exhumation domains for the study region. For example, the thermal history for rocks on either side of the King Salmon thrust will be modeled and

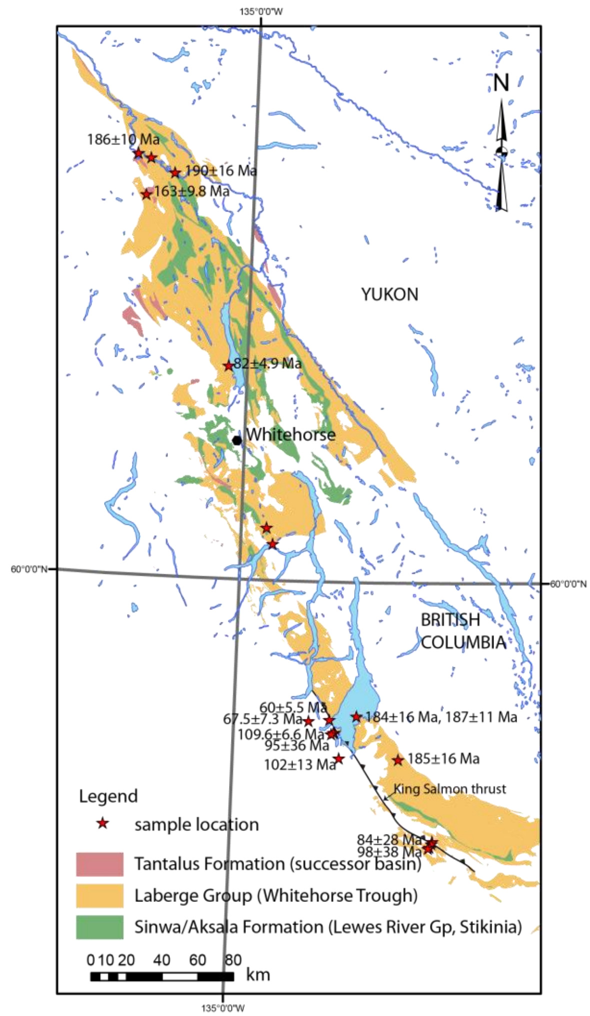

Figure 6. ZHe ages obtained from select samples. Reported ages are weighted means of multiple single grain analyses. For sample lithology, see Fig. 2.

contrasted. Though the ZHe ages indicate a different thermal history during the Jurassic and Cretaceous, AHe analysis yielded similar Eocene ages on either side of the King Salmon thrust, suggesting a possible common late exhumation history through 60-70 °C. These thermal models will form the basis for an analysis of the timing and displacement of post-accretionary structures within the Intermontane region.

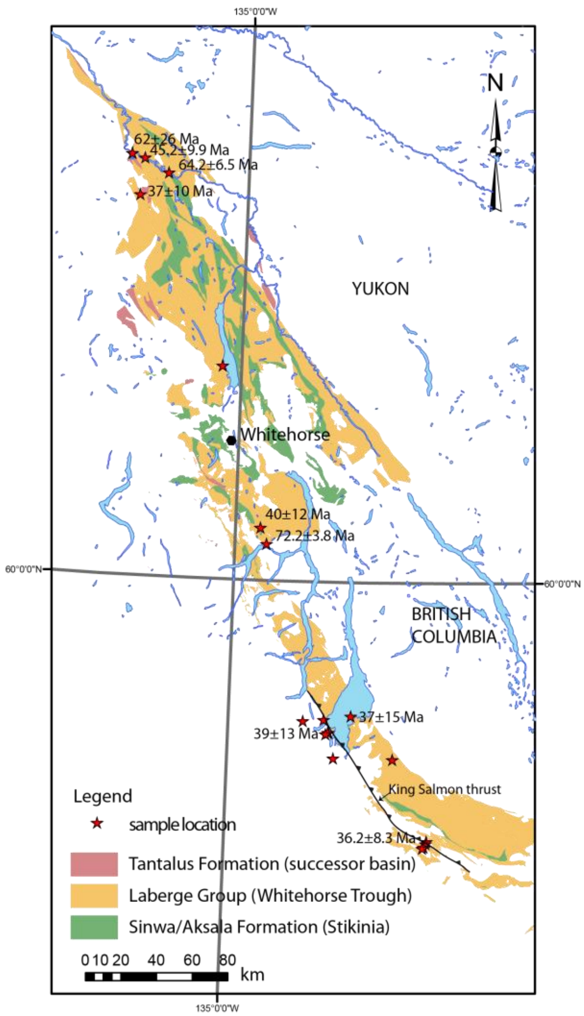

Figure 7. AHe ages obtained from select samples. Reported ages are weighted means of multiple single grain analyses. For sample lithology, see Fig. 3.

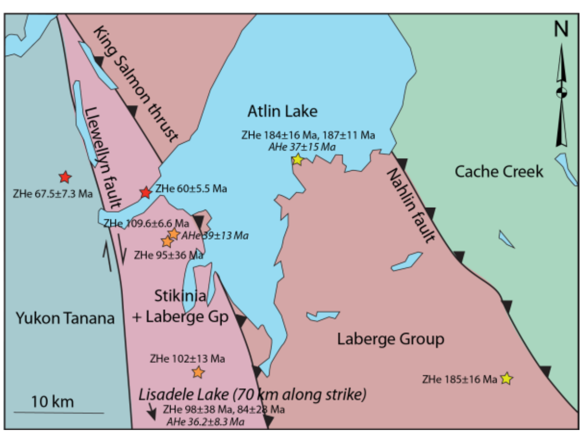

Figure 8. Geological map of Atlin Lake area showing terranes and major structures (iMapBC bedrock database and. ZHe and AHe weighted mean age results. Yellow stars - detrital ZHe ages, orange stars - Cretaceous ZHe cooling ages, and red stars - latest Cretaceous to Paleocene ZHe cooling ages.

Objective 2: Brittle faults, Minto deposit

The two faults sampled at the Minto Cu-Ag-Au deposit, DEF and “2-118”, are small offset, WNW-striking reverse faults that cut through the Early Jurassic Minto suite granodiorite host rock, and postdate and offset the main stratiform ore horizons of the Minto deposit. The faults tilt Late Jurassic to Cretaceous sedimentary units, and have created a pathway for meteoric fluid infiltration and oxidation of sulphide minerals and host rocks (Tafti and Mortensen, 2003).

Within these faults, the clay portion of the gouge is dominated by kaolinite and smectite, with a significant component of illite and illite-mixed layer clays. K-Ar dating of the <2 µm fraction yielded Late Cretaceous ages, with the youngest fraction yielding 76.6 ± 1.6 Ma.

The wall rock of the sampled faults is granodiorite of Early Jurassic (198-197 Ma) age (Hood, 2012), and only local alteration veins contain muscovite, with Ar/Ar age of 182 Ma (Tafti and Mortensen, 2003). Thus there is no plausible source for detrital clay-sized muscovite in the gouge, and the illite fraction should represent authigenic fault-generated clay only. This supports a preliminary interpretation that the brittle faults formed during latest Cretaceous.

Next steps

The goal of this research activity is to identify and characterize upper crustal processes that occurred from the late Jurassic, during and post-accretion of the Intermontane terranes, including formation of sedimentary basins, exhumation of crustal blocks, fluid events and translation of terranes. The preliminary results presented here demonstrate the potential of our two approaches – regional thermochronology and direct dating of fault materials – for achieving the goals of this activity.

Future work focused on thermochronology will involve expanding ZHe and AHe regional coverage to span the E-W extent of the NW-SE striking Intermontane terranes, as well as the addition of zircon fission track and apatite fission track analyses, which will provide significantly improved constraints on rock cooling paths. Sampling will be conducted during the summer of 2018, and will also make use of the extensive sample and mineral separate archive of the GEM Cordillera project. This work will be complemented where appropriate with detrital zircon and mica geochronology. Data will be synthesized into temperature-time models.

To evaluate the regional extent and geometries of Late Cretaceous brittle faulting in the Minto region, we will expand our fault gouge sample set, to be collected in summer 2018. Clay identification and K-Ar dating of the fault gouge materials will be conducted, and an evaluation of clay size fraction vs. age will be performed.

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References

Berman, R.G., Ryan, J.J., Gordey, S.P., and Villeneuve, M., 2007, Permian to Cretaceous polymetamorphic evolution of the Stewart River region, Yukon-Tanana terrane, Yukon, Canada: P-T evolution linked with in situ SHRIMP monazite geochronology: Journal of Metamorphic Geology, v. 25, p. 803–827, doi:10.1111/j.1525-1314.2007.00729.x.

Canil, D., Mihalynuk, M. G., & Charnell, C. (2004). Heavy Mineral Sampling and Provenance Studies for Potentially Diamond-Bearing Source Rocks in the Jurassic Laberge Group, Atlin-Nakina Area (NTS 104N), Northwestern British Columbia. Geological Fieldwork, British Columbia Geological Survey, 83-92.

Colpron, M., Crowley, J.L., Gehrels, G., Long, D.G.F., Murphy, D.C., Beranek, L., and Bickerton, L., 2015, Birth of the northern Cordilleran orogen, as recorded by detrital zircons in Jurassic synorogenic strata and regional exhumation in Yukon: Lithosphere, v. 7, p. 541-562.

Currie, L., and Parrish, R.R., 1993, Jurassic accretion of Nisling terrane along the western margin of Stikinia, Coast Mountains, northwestern British Columbia: Geology, v. 21, p. 235-238.

Dusel-Bacon, C., Lanphere, M.A., Sharp, W.D., Layer, P.W., and Hanson, V.L., 2002, Mesozoic thermal history and timing of structural events for the Yukon-Tanana Upland, east-central Alaska: $^{40}Ar/^{39}Ar$ data from metamorphic and plutonic rocks: Canadian Journal of Earth Sciences, v. 39, p. 1013–105.

English, J.M., Johannson, G.G., Johnston, S.T., Mihalynuk, M.G., Fowler, M., and Wight, K.L., 2005. Structure, stratigraphy and petroleum resource potential of the Central Whitehorse Trough, Northern Canadian Cordillera. Bulletin of Canadian Petroleum Geology, 53, 2, 130-153.

Farley, K.A. and Stockli, D.F., 2002. (U-Th)/He Dating of Phosphates: Apatite, Monazite, and Xenotime. Reviews in Mineralogy and Geochemistry, 48, 559-577.

Guenther, W.R., Reiners, P.W., Ketcham, R.A., Nasdala, W., and Giester, G., 2013. Helium diffusion in natural zircon: radiation damage, anisotropy, and the interpretation of zircon (U-Th)/He thermochronology. American Journal of Science, 313, 145-198.

Hood, S., 2012. Mid-crustal Cu-Au Mineralisation during Episodic Pluton Emplacement, Hydrothermal Fluid Flow, and Ductile Deformation at the Minto Deposit, YT, Canada. Unpublished MSc thesis, University of British Columbia, 220 p.

Hutchison, M.P., Whitehorse Trough: past, present and future petroleum research – with a focus on reservoir characterization of the northern Laberge Group. Yukon Geoloigcal Survey, Open File 2017-2, 48 p.

Joyce, N., Ryan, J.J., Colpron, M., Hart, C.J.R., and Murphy, D.C., 2015, A compilation of $^{40}Ar/^{39}Ar$ age determinations from igneous and metamorphic rocks, and mineral occurrences from central and southeast Yukon: Geological Survey of Canada, Open File 7924, doi:10.4095/297446.

Reiners, P.W., 2005. Zircon (U-Th)/He Thermochronometry. Reviews in Mineralogy and Geochemistry, 58, 151-179.

Ryan, J.J., Parsons, A. J. Israel, S.A., Haggart, J.W., Joyce, N.L. and Kellett, D.A., 2016. 2016 Report of activities for Ancient Faults and Their Controls on Mineralization in Northern British Columbia and Southern Yukon: GEM2 Cordillera Project; Geological Survey of Canada, Open File 8139, 19 p. doi:10.4095/299193.

Shirmohammad, F., Smith, P.L., Anderson, R.G., and McNicoll, V., 2011, The Jurassic succession at Lisadele Lake (Tulsequah map area, British Columbia, Canada) and its bearing on the tectonic evolution of the Stikine terrane: Volumina Jurassica, v. IX, p. 43-60.

Tafti, R., and Mortensen, J.K., 2003. Early Jurassic porphyry (?) copper (-gold) deposits at Minto and Williams Creek, Carmacks Copper Belt, western Yukon. *In:* Yukon Exploration and Geology 2003, D.S. Emond and L.L. Lewis (eds), Yukon Geological Survey, p. 289-303.

Zagorevski, A., Mihalynuk, M.G., Milidragovic, D., Joyce, N., Kovacs, N., Allan, M., and Kellett, D., 2016a. Characterization of volcanic and intrusive rocks across the British Columbia Yukon border, GEM 2 Cordillera; Geological Survey of Canada, Open File 8141, 13 p. doi:10.4095/299198.

Zagorevski, A., Mihalynuk, M.G., McGoldrick, S., Bedard, J.H., Golding, M., Joyce, N., Lawley, C. Canil, D., Corriveau, A-S., Bogatu, A., Tremblay, A., 2016b. Geological framework of ancient oceanic crust in northwestern British Columbia and southwestern Yukon, GEM 2 Cordillera; Geological Survey of Canada, Open File 8140, 13 p. doi:10.4095/299196.