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2018

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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 2018 field season, research scientists from the GEM program successfully carried out 18 research activities, 16 of which will produce an activity report and 14 of which included fieldwork. Activities applied a variety of geological, geochemical, and geophysical methods. 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.

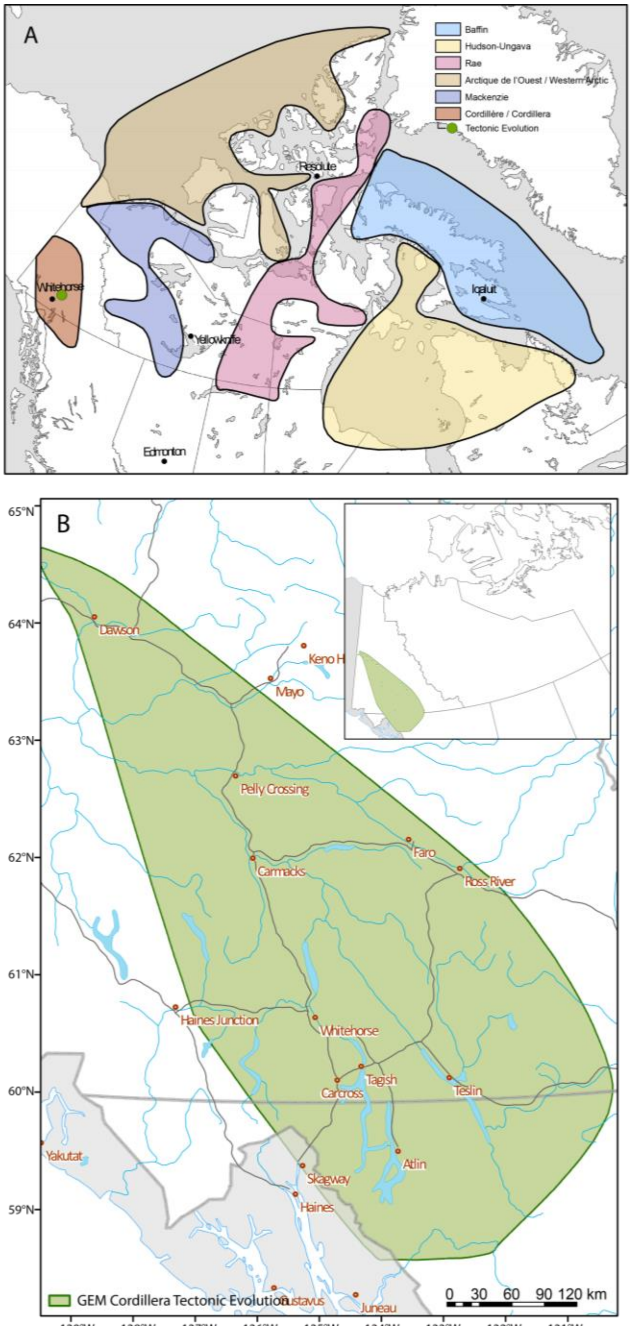

Figure 1. A. Overview map illustrating the footprint of the Cordillera project in northwest Canada. B. Footprint of the GEM Cordillera Yukon Tectonic Evolution activity.

Project Summary

In this research activity, we will attempt to determine the timing and direction of motion for faults, major breaks in the Earth's crust, that formed during the Jurassic to Paleogene periods (~200-20 million years ago) in the central portion of the Canadian Cordillera mountain belt. To do this, we will use three different methods: compare the temperature-time history of rock packages on either side of a fault, date fault-generated clay, and date fault-generated calcite fibres. The results will allow us to reconstruct the fault motion, and see the pre-fault geometry of the major rock assemblages in southern Yukon and northernmost British Columbia.

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 and pre-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 to middle Mesozoic, and host valuable mineral resources such as copper and gold. Since their accretion, they have been affected by a range of processes including the formation and inversion of overlap 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; Nelson et al,. 2013). The present distribution of these "Intermontane" terranes is governed not only by the geometry of accretion, but also by subsequent modification and/or displacement. For example, many of the currently mapped terrane boundaries such as the Nahlin, Teslin and Crag Lake faults likely formed after terrane amalgamation. Consequently, the timing of accretion, geometry of collision and relationships between them are still under investigation (e.g. Mihalynuk et al., 2017). 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; Kellett et al., 2018).

This research activity, carried out under the GEM Cordillera project, is focused on providing new and comprehensive data on the timing and kinematic history of the post-accretionary faults that have structurally reorganized the Intermontane geology of the Canadian Cordillera.

To achieve this goal, we are generating two novel and complementary data sets. The first involves applying and comparing two direct dating methods for fault-generated materials: K-Ar dating of fault gouge and U-Pb dating of calcite slickenfibres. In the second approach we will apply multiple low temperature thermochronometers (<400 °C) including Ar/Ar, U-Th/He and fission track dating to determine the thermal history of fault wall rocks, as well as the overall regional thermal history of the Intermontane region. These complementary approaches and datasets will allow us to reconstruct the post-accretionary thermal and structural history of the Intermontane region.

This activity is funded from 2017-2020 and is in collaboration with the Yukon Geological Survey, the British Columbia Geological Survey, industry and universities. In the first year of this activity, work focused on developing a seed thermochronological and fault dating dataset (Kellett et al., 2017) which was used to develop the sampling strategy for the field component of this project. The 2018 objectives are focused on strategic field sampling of and across key post-accretionary faults that displaced the Intermontane terranes. In particular, sampling is focused around the King Salmon and Nahlin thrust faults, the extensional Crag Lake fault, and the strike-slip Teslin and Big Creek faults (Fig. 2), with the potential long term goal of tracking the evolving kinematic response of the Intermontane region to continued outboard terrane accretion . The likelihood of

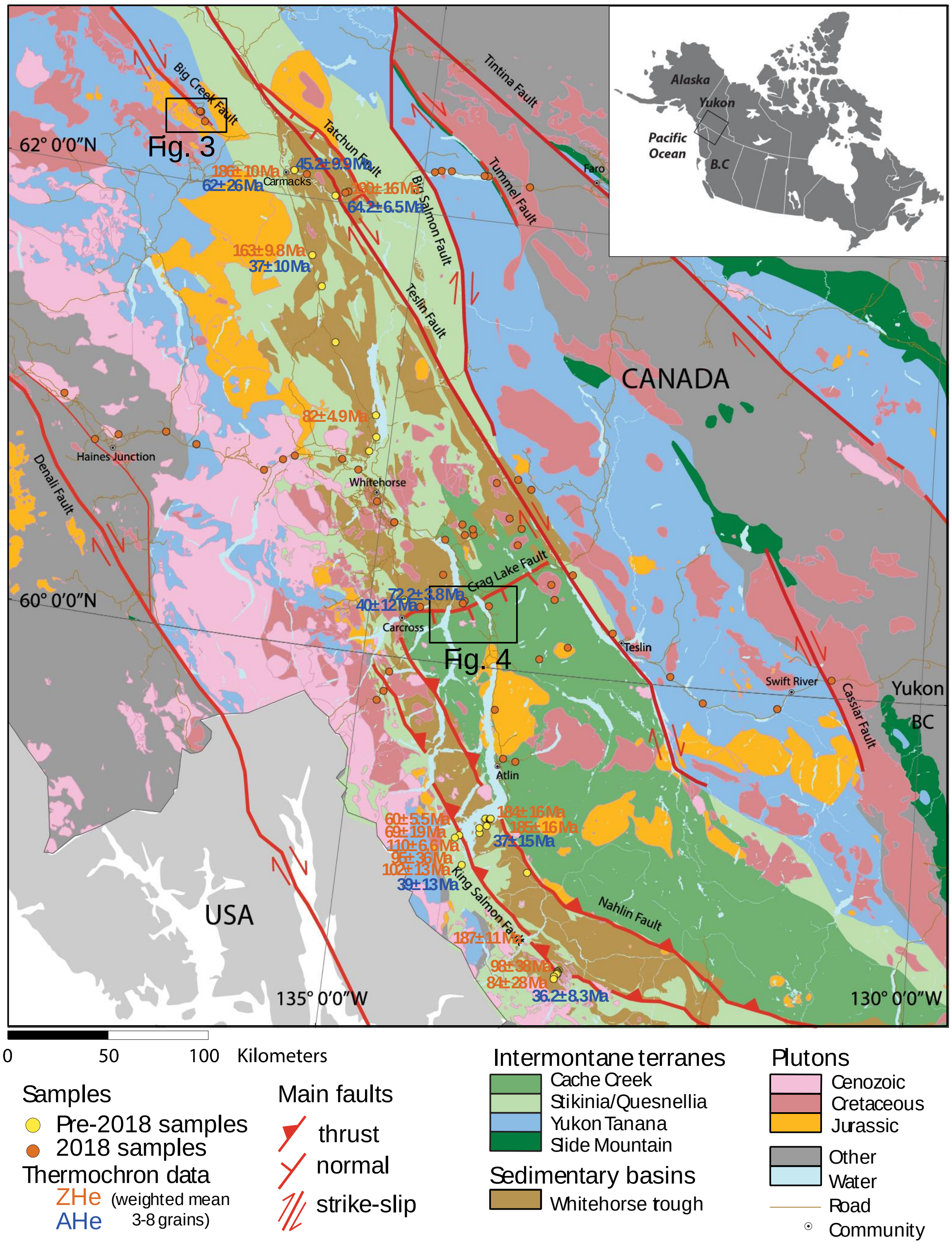

Figure 2. Terrane map of Intermontane terranes, Whitehorse trough, and Jurassic and younger plutons, southern Yukon and northern British Columbia. Map shows sample locations from 2018 and previous years, and U-Th/He age results to date. Maps are modified from Cui et al. (2017) and Colpron et al. (2016). Locations of Figures 3 and 4 are boxed.

success of the chosen methods depends on the rock types forming the fault walls, the amount of total displacement, particularly fault throw, and the post-fault history. Each fault under investigation is more or less favourable for each method depending on this considerations.

Two samples sets were collected during June-July 2018. The first set comprises a collection of fault materials for direct dating of brittle, post-accretionary faults, while the second is a large-scale regional sample set obtained for low temperature thermochronology analysis (Fig. 2). This report summarizes field sampling and observations relevant to both sample sets, as well as presents some preliminary analytical data from previously collected samples. However, the majority of the analytical work will be performed during the winter of 2018-2019 at various laboratories in Canada and internationally.

Field activities

Objective 1: Direct fault dating

Fault dating is a primary research target for the Yukon Tectonic Evolution 2017-2020 GEM research activity. However, there are few methods available for direct-dating of minerals formed during faulting. The K-Ar fault gouge dating method is being explored in this research activity (Kellett et al., 2017), which involves the separation, characterization and K-Ar dating of illite, a clay mineral found within fault gouge. However, interpreting the significance of fault gouge illite K-Ar ages can be challenging because of the potential for wall rock contamination, multiple illite growth events and thermal resetting (e.g. Torgersen et al., 2015). An exciting new technique has recently been developed to date calcite, a mineral that commonly crystallizes on fault surfaces during slip (Roberts et al., 2017). This method compliments the K-Ar method. Through funding from a UK-Canada Arctic research grant to C. Mottram, several samples of calcite slickenfibres were collected both at fault gouge sampling locations and at locations within or adjacent to other post-accretionary faults that are under investigation via regional thermochronology. This represents one of the first studies to apply these three independent methods to constraining the timing and kinematic history of brittle faults.

Fault gouge sampling

Eight fault gouge samples were collected from southern Yukon (Fig. 2), with particular focus on the Big Creek fault system, a Cretaceous NW-SE striking dextral fault network that hosts a suite of porphyry-style poly-metallic mineral deposits along its trend (Friend et al., 2018; Allen et al., 2013). Two to four kg samples of clay-rich gouge were collected from roadside outcrops, freshly scraped bedrock within placer operations, and from core recently drilled by Triumph Gold Corp along E to ESE-striking, steeply-dipping fault planes. Other gouge samples (Fig. 2) were collected in conjunction with calcite slickenfibres at the same outcrops adjacent to or within the Llewellyn, Nahlin and Crag Lake faults to provide and compare age data from these different fault-generated materials, as well as compare with wall rock thermal histories. The illite content of the clay-sized fraction (<2 μm) in each gouge sample will be determined using X-ray diffraction, followed by K-Ar dating of multiple size fractions of illite in suitable samples. This new dataset builds upon preliminary K-Ar age data for fault gouge collected from the Minto Cu-Au mine (Kellett et al., 2017).

Calcite slickenfibre sampling

Seventeen calcite slickenfibre samples were collected from several of the same locations as the aforementioned fault gouge samples. Sampling focused primarily on two structures, the Big Creek Fault (Fig. 3) and the Crag Lake Fault (Fig. 4). Structural measurements were taken to record the orientation of fault planes, fracture and joint surfaces and kinematics of slickenfibres and slickensides. Orientation measurements of faults, fracture surfaces and slickenfibres at the Big Creek Fault are generally consistent with NW-SE trending strike-slip system. Along the Crag Lake normal fault, samples 23-25 are consistent with NE-SW trending fault and fracture surfaces where slickenfibres record two senses of motion: strike-slip, and normal/thrust-sense shear. Sample location 71 has predominantly NW-SE trending fault surfaces that record several different orientations of slickenfibres.

Objective 2: Thermochronology of faulted blocks, Intermontane terranes

Fault motions perturb the geothermal gradient, and in doing so condition the thermal history of fault wall rocks. Hence, the thermal histories of structurally-controlled rock samples can be used to determine constraints on timing and kinematics of brittle faults (e.g. Coutand et al., 2014). To do so, we will conduct multi-thermochronology, and inverse thermal modeling on our large-scale regional sample set (Fig. 2). The results will be used to reconstruct the “post-accretionary” deformation response of the Canadian Cordillera interior to ongoing outboard collisions.

Fifty bedrock samples were collected along four transects across the Intermontane region of southern Yukon - northern British Columbia, approximately perpendicular to the strike of faults mapped as key structures of the Intermontane terranes: the west-verging thrusts King Salmon fault (KSF), Nahlin fault (NF); the extensional Crag Lake fault (CLF); and strike slip Teslin fault (TF), Big Creek fault (BCF), Llewellyn fault (LF) and Cassiar fault (CF) (Fig. 2).

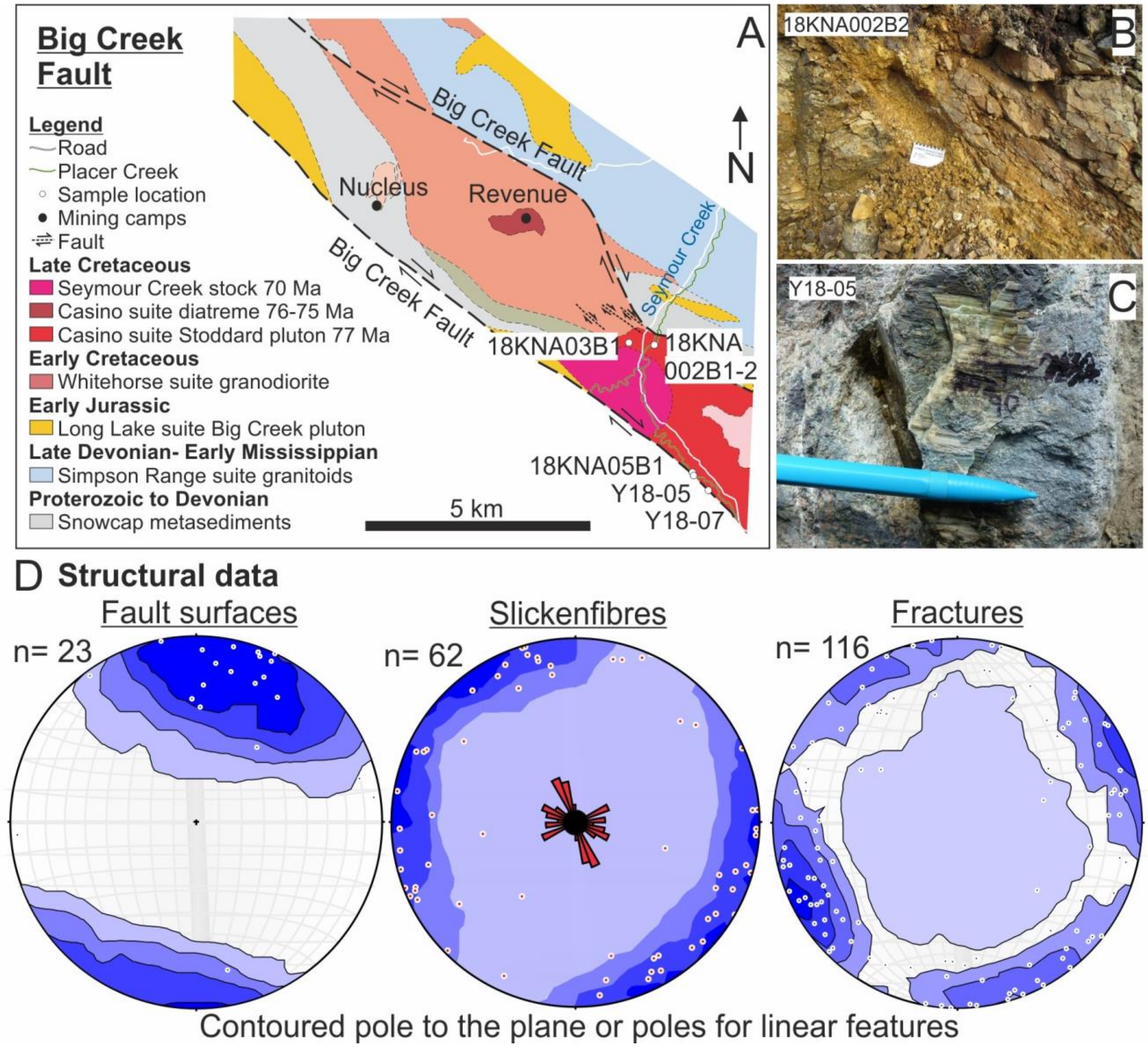

Figure 3: Sampling locations and structural data from the Big Creek fault. A. Geological map (adapted from Friend et al., 2017) with sample locations, B. Field photograph of fault gouge, C. Field photograph of calcite slickenfibres, D. Stereonet of contoured pole to the plane (i) fault surfaces (trend striking WNW-ESE), (ii) slickenfibre lineations (trend trending NW-SE) and iii. Fractures (mostly trend striking NW-SE with NE-SW conjugate).

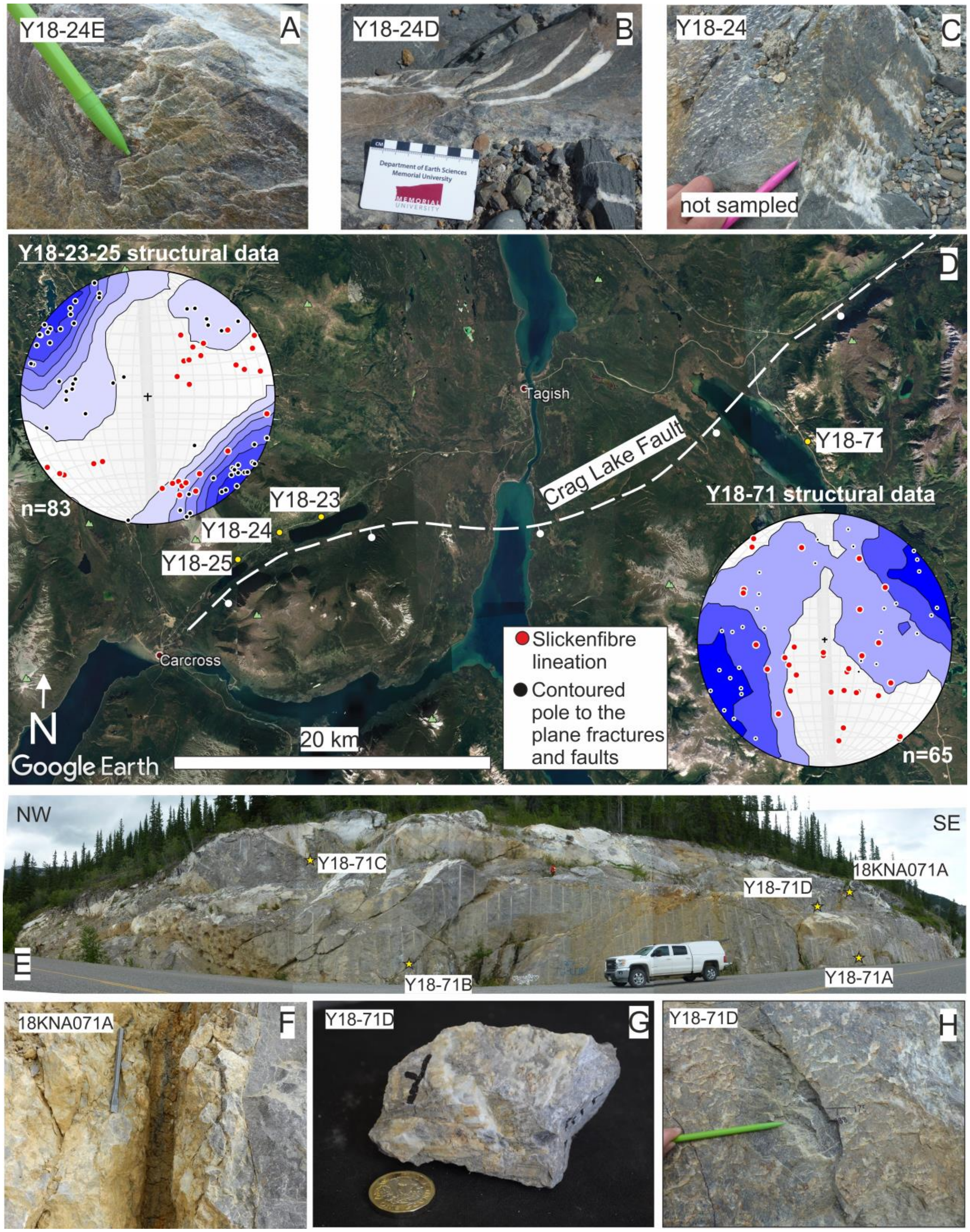

Figure 4: Sampling locations and structural data from the Crag Lake Fault. A-C. Field photograph of calcite slickenfibres and tension gashes from locality 24. D. Google Earth map of area (with approximate location of the Crag Lake Fault based on Colpron et al., 2016) with sample locations. Stereonet of contoured pole to the plane and slickenfibre lineations E. Locality 71 outcrop photo. F-H Photographs from locality 71. F. fault gouge sampling location, G, H slickenfibres.

Some of the samples collected in 2015 and 2018 are sedimentary rocks, and to accurately model the thermal history of these samples using detrital apatite and zircon, we require constraints on the depositional age of the sediment (see Kellett et al., 2017 for details). Consequently, we dated detrital zircon from an additional three samples from the Whitehorse trough using the U-Pb method (Fig. 2). Zircon were embedded in epoxy, polished to midsection and analyzed for U and Pb isotopes using a sensitive high resolution ion microprobe (SHRIMP) housed at the GSC in Ottawa.

Preliminary results

Objective 2: Thermochronology of faulted blocks, Intermontane terranes

Thermochronological samples collected during summer 2018 and earlier will undergo apatite and zircon U-Th/He and fission track analysis during winter 2018/2019. New detrital zircon U-Pb results from Whitehorse trough Laberge Group samples 15-KNA-005, 15-KNA-030 and 15-KNA-035C, collected in 2015, are shown in a cumulative age distribution plot in Figure 5: the weighted mean age of the three youngest dated zircon grains in each sample are 177 ± 1.6 Ma, 183 ± 1.7 Ma, and 190 ± 1.8 Ma, respectively (^{204}Pb corrected $^{206}Pb/^{238}U$ ages reported at 1σ), and correspond to the maximum deposition age for these sample locations.

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 to North America, including formation of sedimentary basins, exhumation of crustal blocks, fluid events and translation of terranes. The next step will be to complete the analytical component of this activity during 2018/2019.

Acknowledgments

We would like to thank Triumph Gold Corp for hosting our field crew at Revenue camp and providing us access to their core and databases. Critical discussion with Maurice Colpron, Craig Hart, Fionnuala Devine and Alex Zagorevski improved our sampling strategy. Thanks to Capital Helicopters and Discovery Helicopters for safe and efficient transport in the field. This report benefitted from critical review by Jim Ryan. Funding from Natural Environment Research Council's Arctic Office is gratefully acknowledged.

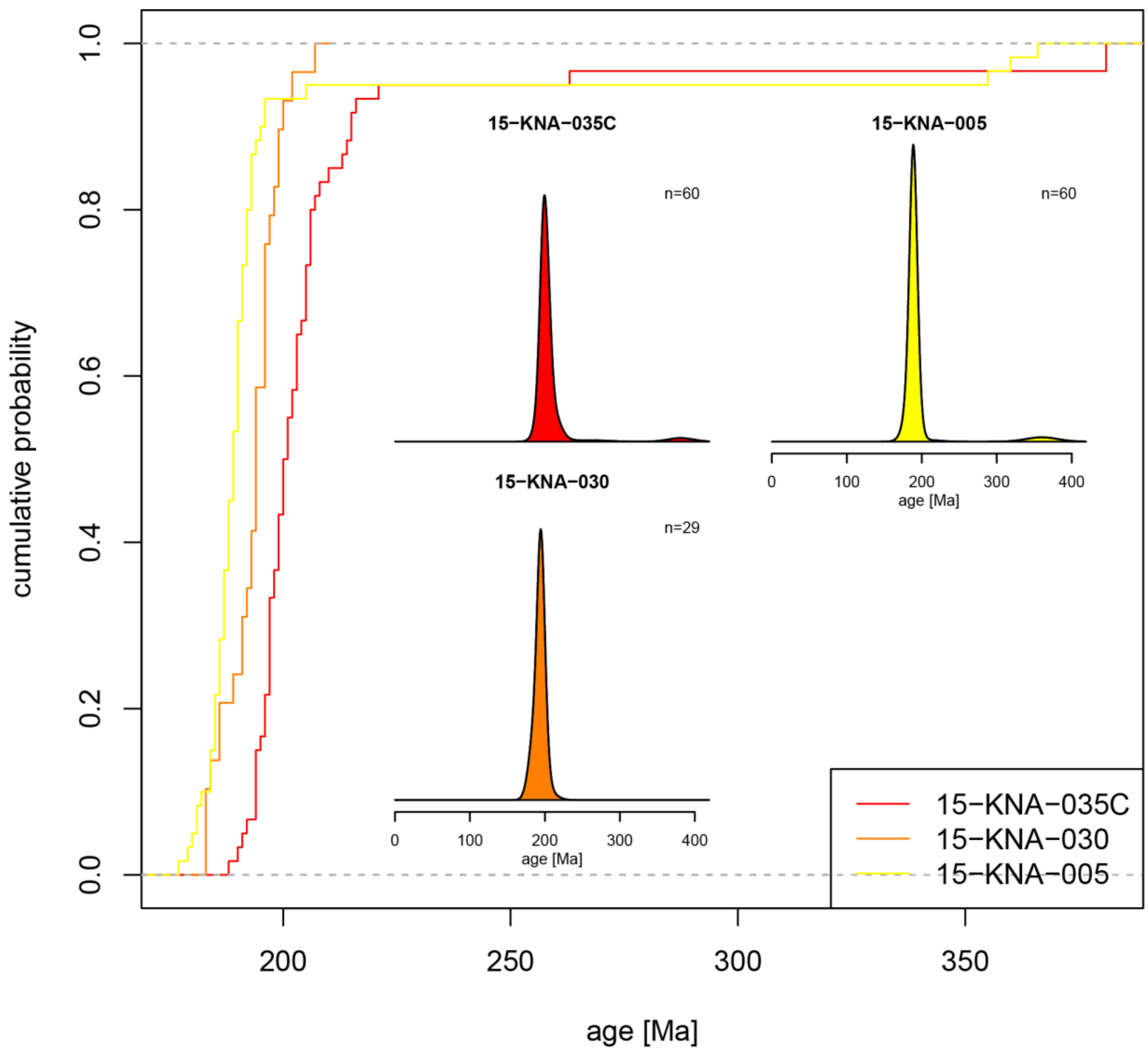

Figure 5: Cumulative age distribution plot for 15-KNA-035C, 15-KNA-030 and 15-KNA-005, with inset kernel density estimation plots. Plots constructed using IsoplotR (Vermeesch, 2018). For all other U-Pb detrital zircon and Ar/Ar detrital muscovite data for this activity, see Kellett et al. (2017).

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