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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 2015, GEM program successfully carried out 14 research activities that included geological, geochemical, and geophysical surveying. These activities were 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.

Project Summary

The Tehery-Wager Geoscience Mapping activity of the GEM-2 Rae project is being led by the Geological Survey of Canada (GSC) and the Canada-Nunavut Geoscience Office (CNGO) with participants from the Nunavut Arctic College and Canadian universities. The study area comprises all or parts of eight National Topographic System (NTS) map areas north of Chesterfield Inlet and south of Wager Bay in Nunavut (NTS 46D, E, 56A, B, C, F, G, and H). The focus is on targeted bedrock geology mapping (1:100 000 scale), surficial geology studies, surface and stream sediment sampling, and other thematic studies, which collectively will increase the level of geological knowledge in this frontier area to better evaluate its potential for a variety of commodities including diamonds and other gemstones, base and precious metals, industrial minerals, carving stone, and aggregates. This report presents some results from the 2015 bedrock mapping, which have allowed refinement of the spatial distribution of major rock units, documentation of their geological histories in relative time, and a preliminary evaluation of their economic potential. In addition, our work highlights the usefulness of acquiring portable X-Ray Fluorescence (pXRF) spectrometry analyses in the field, which have proven to be a powerful tool in support of mapping for differentiating disparate rock types and compositions.

Introduction

The Tehery-Wager area in south-central Nunavut (Fig. 1) is one of the least known and under-explored regions of the Rae craton. Until recently, significant geoscience knowledge gaps existed owing to limited or outdated mapping, and scant geochronological, isotopic, and geochemical information. During the final phase of the Geo-mapping for Energy and Minerals (GEM-1) program in 2012, reconnaissance studies and an aeromagnetic survey carried out under the Geo-mapping Frontiers project (Coyle and Kiss, 2012a-h; Day et al., 2013; Harris et al., 2013a-e; McMartin et al., 2013; Wodicka et al., in prep.)

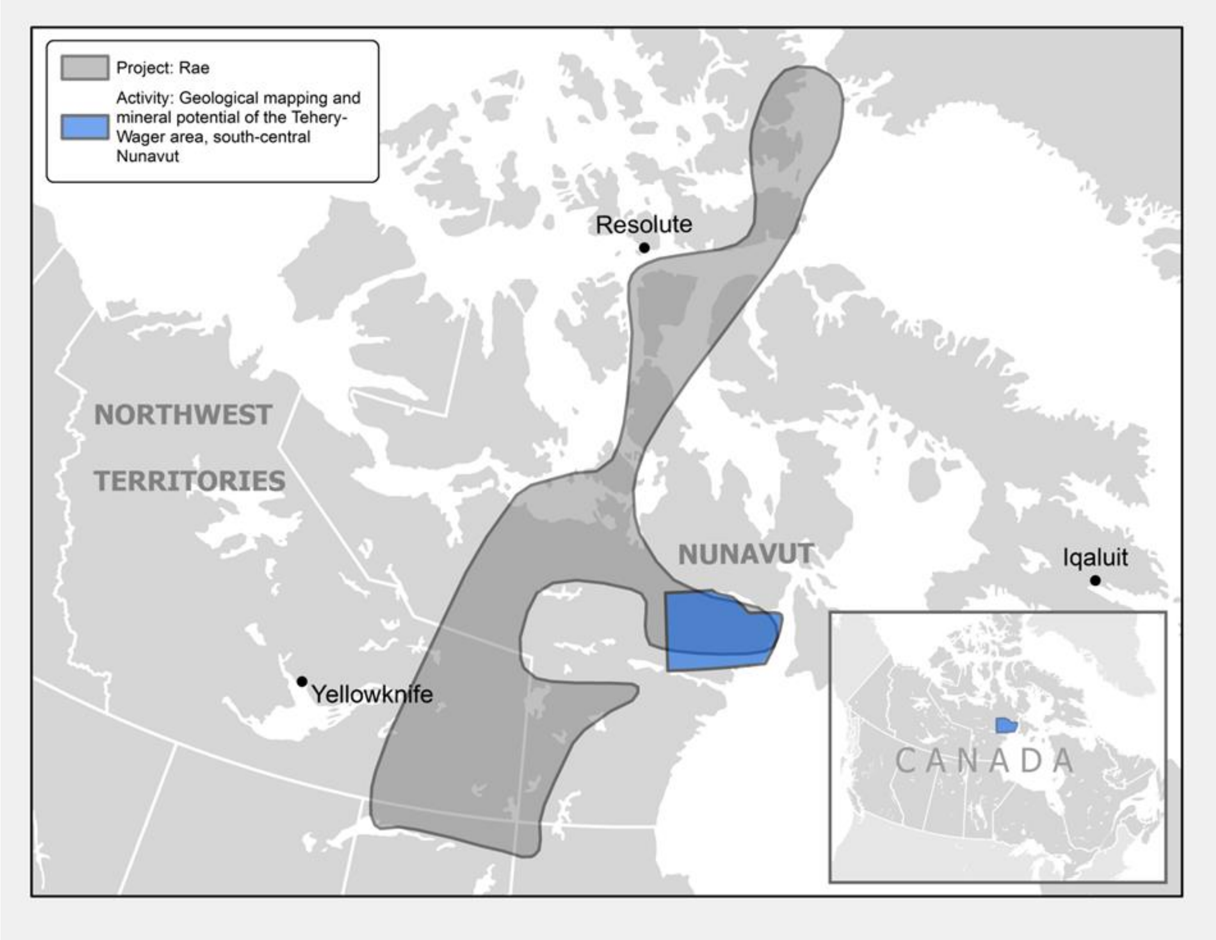

Figure 1. *Overview map of the GEM-2 Rae project in northern Canada. The footprint of the Tehery-Wager activity is represented by the blue polygon.*

revealed the presence of geochemically and temporally distinct suites of Archean and Paleoproterozoic plutonic rocks ranging in age from about 2.90 to 2.58 Ga and 1.92 to 1.82 Ga, confirmed the presence of folded supracrustal panels previously identified on the basis of remote predictive mapping, and identified economically prospective areas. Specifically, till and stream sediment samples showed anomalous concentrations of Ag, Cu, Bi, Au, and Co-Fe arsenide minerals within or near a folded supracrustal strand (Fig. 2) highlighting the potential for base- and precious-metal mineralization (McMartin et al., 2013; Day et al., 2013). In addition, McMartin et al. (2013; their Fig. 8) identified a regional Mg-rich olivine, SE-trending dispersal train in surface till south of the kimberlite field discovered by Peregrine Diamonds Ltd. (Fig. 2). Multiple kimberlite sources or olivine-rich crustal rocks were proposed as potential sources for the forsteritic olivine grains, which are locally coincident with mantle-derived indicator minerals (chromite, Cr-diospide, Cr-pyrope). Given the success of these pilot studies, a more comprehensive geoscience mapping project was deemed necessary by the GEM-2 program (Rae project) for the Tehery-Wager area (Fig. 1).

The 2015 targeted bedrock mapping program of the Tehery-Wager activity, coupled with planned geochronological, geochemical, isotopic, and structural/metamorphic analyses, will: 1) evaluate the nature of granitoid gneissic rocks and their contacts with supracrustal rocks; 2) document the stratigraphy of the main supracrustal belts and determine their age and tectonic/depositional environment; 3) determine the extent of the ca. 2.6 Ga Snow Island suite, as well as older Archean and younger Paleoproterozoic plutonic rocks; 4) evaluate the style of deformation, and degree and extent of metamorphism; and 5) increase our knowledge of the mineral and carving stone potential of the Tehery-Wager area. Over the course of this multi-year project, the following key scientific questions will be addressed: 1) are there major crustal boundaries within the Tehery-Wager area that separate distinct Archean crustal blocks?; 2) do known or unknown lithospheric-scale faults represent favourable environments for mineralization?; 3) are there linkages between supracrustal assemblages within the map area and cover sequences documented elsewhere in the Rae craton?; and 4) what were the conditions of peak metamorphism in the Tehery-Wager area, and how do they compare with adjacent high-pressure metamorphic complexes along the Snowbird Tectonic Zone? This report presents preliminary findings of the bedrock mapping sub-activity undertaken in the summer of 2015, whereas McMartin et al. (2015) summarize the results of surficial and stream sediment sub-activities. In addition, two upcoming CNGO Summary of Activities field reports discuss bedrock geology (Steenkamp et al., in press) and remote predictive mapping of surficial materials (Byatt et al., in press) in greater detail.

Methodology

The 2015 bedrock mapping program, the first of two planned field seasons, involved fieldwork between June 30th and August 3rd in the eastern part of the Tehery-Wager project area (all or parts of NTS sheets 46D, E and 56A, B, G; Fig. 2). The work was based out of a temporary camp situated on the Lorillard River and was supported by a Bell 206L3 helicopter. Mapping was undertaken primarily by 6–10 km foot traverses, but also included strategic helicopter stops to remote sites or within areas heavily covered by surficial sediments. Field sites and traverses were primarily chosen based on previous mapping, good bedrock exposure, and aeromagnetic anomalies.

Geological field observations, including rock types, mineral assemblages, and structural measurements, were taken at over 630 stations and recorded on air photos and small, handheld and tablet computers (Getac instruments) equipped with the Ganfeld system (Shimamura et al., 2008), along with station coordinates, sample and photo records, and magnetic susceptibility measurements. All gathered data were then downloaded on a daily basis to the master GIS geodatabase by the project data manager. A total of 470 samples were collected from representative lithologies for various purposes, including petrography, lithogeochemistry, assay geochemistry, geochronology (U-Pb), thermochronology, isotope geochemistry (Sm-Nd and Lu-Hf), and microstructural and metamorphic analysis. In addition, portable X-Ray Fluorescence (pXRF) spectrometry analyses were acquired at camp on a small subset of mafic to intermediate samples (discussed briefly below).

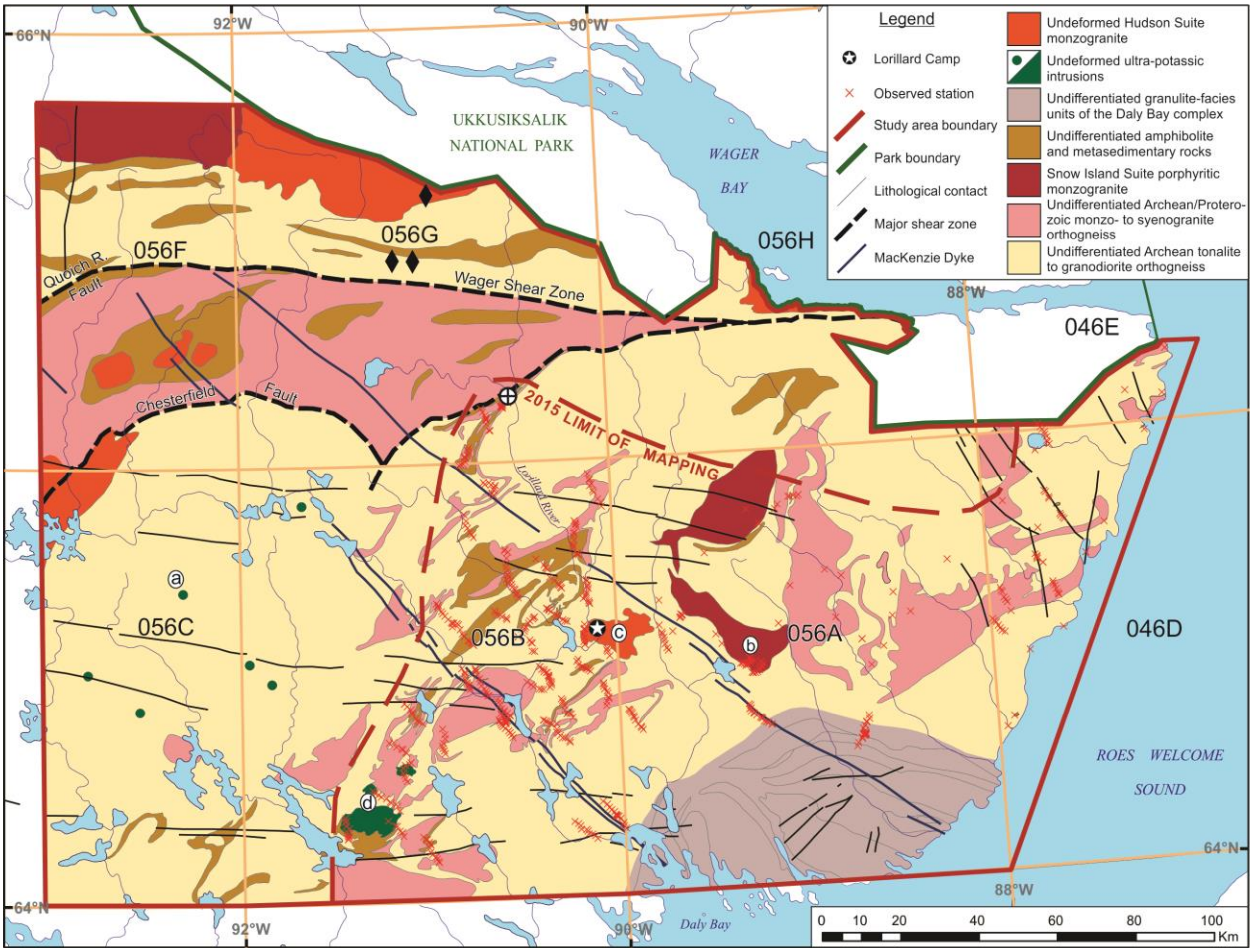

Figure 2. *Simplified geological map of the Tehery-Wager area (modified from Wodicka et al., in prep., Steenkamp et al., in press, and references therein) showing the location of 2015 stations, Lorillard camp, known kimberlite bodies from Peregrine Diamonds Ltd. (black diamonds), and anomalous concentrations of Ag, Cu, Bi, Au in surface till (circled black cross). Letters are locations discussed in the text.*

Results

The main results from our 2015 bedrock mapping include the following:

1) Archean plutonic rocks and nature of basement-cover contact: Our field work across the study area confirmed the predominance of pervasively deformed Archean gneissic rocks, which range in composition from mainly tonalite (Fig. 3a) to granodiorite. Similar rocks within the Tehery-Wager area have been dated previously at ca. 2705-2700 Ma (van Breemen et al. 2007). In many places, exposures of granitoid gneiss are structurally intercalated with ultramafic to intermediate bands (metapyroxenite, metagabbro, amphibolite, metadiorite), some of which may represent transposed dykes. Isolated inclusions or pods (tens of centimetres to metres; Fig. 3b) of similar mafic to intermediate composition may be the oldest rocks in the field area. Amphibolite and mafic orthogneiss samples from both geological settings (pods versus bands in gneissic rocks), together with compositionally similar bands within metasedimentary panels (discussed below), were targeted for pXRF analysis in order to constrain possible protoliths and investigate potential geochemical differences between mafic rocks from the various geological settings (Steenkamp et al., in press). Initial results allowed distinction of metasomatized versus least-altered samples, the latter of which can be broadly classified into relatively primitive, depleted mantle-like, basalt to more geochemically evolved basaltic and andesitic compositions.

Other significant mappable units of Archean plutonic rocks include gneissic to migmatitic biotite ± magnetite ± muscovite monzogranite to syenogranite, that also occur as transposed, centimetre- to metre-scale veins and dykes in the tonalite to granodiorite gneissic rocks, and variably foliated K-feldspar porphyritic monzogranite. The latter has been dated at ca. 2585 Ma in one locality within the Tehery-Wager area (locality A on Fig. 2; van Breemen et al., 2007). The composition and U-Pb age data of these K-feldspar porphyritic monzogranite bodies suggest that they form part of the ca. 2.6 Ga Snow Island Suite (e.g., Peterson et al., 2015 and references therein). A large folded complex of amphibole+biotite-bearing porphyritic monzogranite in central-west 56A (locality B on Fig. 2) may also form part of this suite. It locally displays magma mingling textures with gabbroic to dioritic rocks. Along the base of the complex, the monzogranite is highly strained and occurs as garnet-bearing augen gneiss with spectacular porphyroclastic textures (Fig. 3c), consistent with a tectonic contact between this plutonic complex and adjacent Archean gneissic rocks. The geometry and significance of this contact awaits further study.

Contact relationships between the Archean gneissic rocks and supracrustal units described below are complex. Exposed contacts are generally tectonic and characterized by strong co-planar fabrics (Fig. 3d), suggesting some degree of reworking. Many of the mapped supracrustal panels are also typically interleaved with metre-thick layers of K-feldspar porphyritic monzogranite, which shows both igneous and tectonic contacts with the host metasedimentary rocks. Narrow, isolated (tectonic?) rafts of metasedimentary rocks also occur with Archean gneiss in the absence of K-feldspar porphyritic monzogranite. Structural analysis, U-Pb geochronology, and more fieldwork are required to better understand the nature of the basal contact and distribution of lithological units.

2) Supracrustal rocks: In map sheets 56B and G, over 20 traverses were conducted across folded panels which, on the basis of previous field and remote predictive mapping, were interpreted to comprise primarily supracrustal rocks of possible Archean and/or Paleoproterozoic age (e.g., Panagapko et al., 2003; Wodicka et al., in prep.; Fig. 2). With few exceptions, supracrustal rocks were present in all panels and were represented by variable proportions of quartzite, psammite, semipelite to pelite, garnetite, iron formation, amphibolite, mafic gneiss, calc-silicate, and rare marble. Ultramafic bodies (pyroxenite, peridotite) are common and occur primarily as boudinaged sills. Preliminary pXRF results indicate that amphibolite and mafic gneiss bands yield relatively depleted incompatible element concentrations (K-Sr-Rb) that may reflect variable element mobility, or point to a systematic geochemical difference compared to Archean gneiss-hosted mafic and intermediate pods and bands (Steenkamp et al., in press). Whether the metasedimentary-hosted mafic rocks represent volcanic flows will be the focus of ongoing study. Although a consistent stratigraphy could not be determined, the presence of distinctive, bright green, skarn-like bodies (Fig. 3e) in all mapped supracrustal panels suggests that the rocks form part of a single supracrustal sequence that is repeated by thrusting and/or folding. The local presence of marble

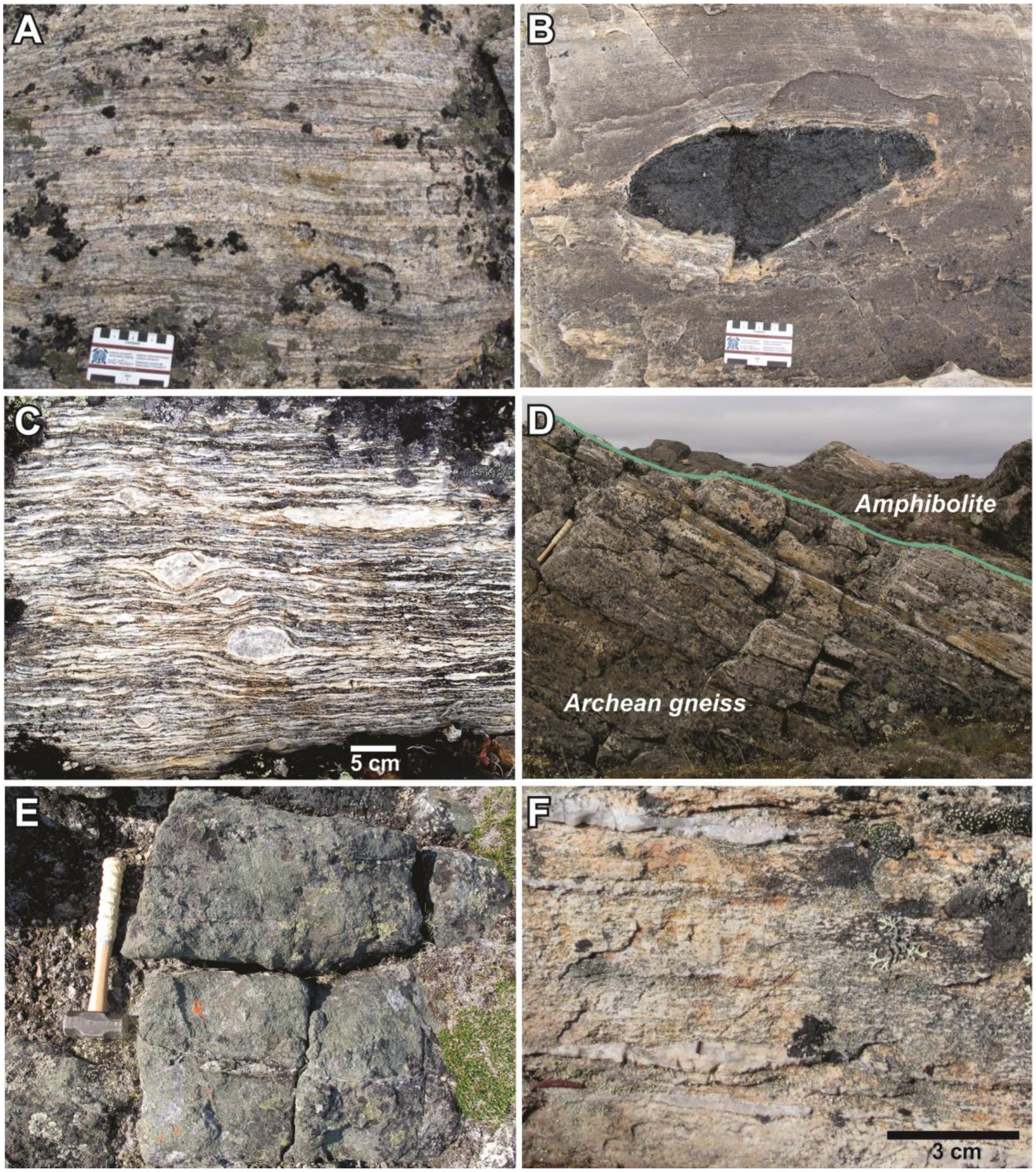

Figure 3. *Field photographs from the Tehery-Wager area. A) Well-deformed tonalite gneiss with transposed, cm-thick monzogranite veins. B) Pyroxenite pod in monzogranite gneiss. C) Porphyroclastic texture developed in K-feldspar porphyritic monzogranite (now augen gneiss) along the base of a potential Snow Island suite body. D) Strong co-planar fabric developed in Archean gneissic rocks structurally below garnet-bearing amphibolite. E) Example of a green, diopside-rich skarn-like body observed in all mapped supracrustal belts in 56B and G. F) Buff-weathering metasandstone with thin, foliation-parallel quartz layers of possible primary origin from the low-grade supracrustal assemblage along the "outer shear zone" of the Daly Bay Complex.*

suggests that the sequence is Paleoproterozoic in age, a hypothesis that remains to be tested by U-Pb geochronology.

Our limited mapping within the Daly Bay Complex area yielded unexpected preliminary results. Rocks included in the "outer shear zone" were previously described as primarily strongly deformed, layered biotite and hornblende gneiss with local quartzite and marble along its western edge (Gordon, 1988). However, where crossed, the *eastern* part of the outer shear zone comprises highly-strained, low-grade metasedimentary rocks including quartzite, metasandstone with thin quartz-rich layers (Fig. 3f), and metasiltstone. These ductilely deformed rocks are juxtaposed against a fault breccia, likely related to the brittle, greenschist facies cataclastic zones described by Gordon (1988). Such low-grade metasedimentary rocks are in striking contrast to the high-grade paragneiss occurring within and outside of the Daly Bay Complex.

3) Paleoproterozoic plutonic rocks: Our bedrock mapping provided further insight into the distribution and occurrence of Paleoproterozoic plutonic rocks in the Tehery-Wager area. Late, largely undeformed and equigranular monzogranite with rafts of older gneissic rocks were observed in many localities. The monzogranite occurs mostly as centimetre- to metre-scale dykes and thick sill complexes, whereas large intrusions (locality C on Fig. 2) are uncommon. The field occurrence and composition suggest that these rocks belong to the Hudson suite (Peterson et al., 2002; van Breemen et al., 2005).

Exposures of ultrapotassic rocks, ranging in composition from phlogopite clinopyroxenite to biotite-pyroxene syenite and showing magma mingling textures, are more extensive than previously known, especially in the southern part of map sheet 56B (locality D on Fig. 2). These rocks occur primarily as coarse-grained intrusions and rarely as dykes. The field occurrences of these ultrapotassic rocks contrast markedly with those of the compositionally similar and potentially correlative ultrapotassic suite of dykes (Martell Syenite) elsewhere in the Rae and Hearne cratons (Peterson et al., 2002).

The distribution and style of the Hudson suite monzogranite and the ultrapotassic rocks suggest that the Tehery-Wager area exposes a much deeper crustal level compared to nearly all other exposures of these rocks elsewhere in the western Churchill Province. Namely, source magmas were likely proximal and, in the case of the Hudson monzogranite, migrated only a short vertical distance in dyke swarms before being emplaced laterally in sheets along density or structural discontinuities.

4) Deformation and metamorphic episodes: Our field work allowed first-order constraints to be placed on the nature and relative timing of the main deformation and metamorphic episodes. Lithological units throughout the mapped area are generally characterized by the development of a pervasive, shallowly- to steeply-dipping, dominantly SW-trending compositional foliation, referred to as S_{main} in the field. High-strain L-S fabrics oriented parallel to S_{main} were observed in several locations in NTS sheet 56B. They range in thickness from a few metres to tens of metres, and are best developed in Archean gneissic rocks. The extent and significance of these high-strain fabrics await further study. Shallowly- to moderately NE-SW-plunging mineral or stretching lineations (L_{main}) are also common, especially in relatively high-strain domains. The geometry of the dominant, doubly-plunging, stretching lineation is consistent with shallowly- to moderately-plunging NE-SW-trending fold hinges that define the main regional map pattern (Fig. 2). Rare, refolded recumbent folds, which occur within the hinge zones of the broad, shallowly-plunging, NE-SW-trending folds (broadly axial planar to S_{main}), point to an early deformation event(s) that is obscured by later reworking during the main phase of deformation. One exposure of refolded, mylonitized granitoid gneiss further documents local preservation of relatively early deformation fabrics during a complex, poly-deformational history. Late, upright, NW-SE-trending folds generated doubly-plunging map patterns most evident in map sheet 56B (Fig. 2).

Metamorphic assemblages in supracrustal rocks suggest upper amphibolite to possibly granulite facies conditions during the development of the pervasive S_{main} foliation. In metasedimentary strata, this fabric is defined by the orientation of the assemblage biotite-sillimanite-muscovite-melt. Garnet is typically surrounded by these aligned minerals. Mafic lithologies, including amphibolite, are generally characterized by hornblende-garnet-clinopyroxene±biotite assemblages with the local presence of orthopyroxene. The latter lithologies were targeted to constrain maximum pressures and temperatures attained during peak metamorphism. The presence of plagioclase±biotite rims around garnet in both semipelite-pelite and mafic lithologies suggests retrograde metamorphism (decompression), but the timing of this event with respect to the main deformation episodes is currently unknown.

5) Economic considerations: More detailed work was undertaken in the supracrustal strand that showed anomalous concentrations of base and precious metals (Ag, Cu, Bi, Au; Day et al., 2013; McMartin et al., 2013; Fig. 2) in order to provide a better understanding of the geological setting. In addition, new gossanous horizons were identified within supracrustal rocks in a few other localities, including within iron formation in south-central NTS 56B, and in the low-grade metasiltstone within the outer shear zone of the Daly Bay Complex (southern 56A). These sites will be investigated for their base- and precious-metal prospectivity through whole-rock assay, till, and/or stream sediment geochemistry.

Mafic-ultramafic layers in the supracrustal panels may represent favorable lithostratigraphic settings for Ni–Cu–platinum-group element mineralization. No new serpentinized ultramafic rocks were found outside of the previously known carving stone deposits in the Daly Bay area (Beauregard and Ell, 2012). Finally, further investigations into the antiquity of Archean crust in the study area and the composition of key units will be carried out in support of ongoing surficial and stream sediment surveys to better characterize the diamond potential of the Tehery-Wager area outside the currently known kimberlite field (Fig. 2).

Conclusions

Highlights of our 2015 targeted bedrock mapping in the eastern portion of the Tehery-Wager area include: 1) further characterization of the nature of Archean felsic to intermediate gneissic rocks and enclosed or intercalated mafic-intermediate units that can be subdivided into relatively primitive basaltic to more evolved compositions; 2) better control on the distribution and potential parentage of supracrustal rocks; 3) identification of a previously unrecognized low-grade metasedimentary sequence within the Daly Bay Complex; 4) improved understanding of the distribution and occurrence of Paleoproterozoic plutonic rocks and their significance for constraining the present level of exposure of this map area; and 5) first-order constraints on the nature and relative timing of the main deformation and metamorphic episodes. Our results also highlight the usefulness of field-acquired pXRF data as a powerful chemostratigraphic tool in support of bedrock mapping. The new field observations, combined with the acquisition of new datasets, will permit an improved understanding of the magmatic, depositional, and tectonometamorphic evolution of the Tehery-Wager area that is paramount toward a better understanding of its economic potential.

Future work/next steps

Laboratory work planned for the Fall/Winter 2015/2016 includes lithogeochemistry, U-Pb geochronology, petrography, and isotope geochemistry (Sm-Nd and/or Lu-Hf) of key lithological units to further establish the age and composition of major Archean and Paleoproterozoic plutonic units, constrain the location of potential major crustal boundaries, and determine the provenance of the supracrustal rocks. The data will also be used to establish or refine potential correlations with major plutonic suites and supracrustal sequences elsewhere in the Rae craton. Combined with the field observations and structural analysis, the new data will form the basis for the production of new bedrock maps for the area.

Holly Steenkamp is initiating a Ph.D. thesis under the supervision of Dr. Carl Guilmette at Université Laval. She will be studying the supracrustal rocks of the Tehery-Wager area, documenting their depositional setting, the pressure-temperature-time paths of metamorphism, and mineral potential using various techniques, including litho- and assay geochemistry, petrography, multi-equilibria thermobarometry, and U-Pb and Lu-Hf dating of key metamorphic minerals.

Jeremy Beales is undertaking a B.Sc. thesis at University of Victoria to constrain the petrogenesis of amphibolite and mafic orthogneiss pods through a combination of field-acquired pXRF data, conventional lithogeochemistry, and petrography. Billy Garrison is investigating the low-grade metasedimentary rocks within the outer shear zone of the Daly Bay Complex as part of a B.Sc. thesis at Dalhousie University, with a focus on their structural and metamorphic history, stratigraphy and parentage, and mineral potential.

Planning and engagement activities are underway in preparation for a five-week mapping campaign in the summer of 2016. Fieldwork will be primarily focused in the western part of the Tehery-Wager area and will include bedrock mapping and surficial and stream sediment surveys.

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