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R.G. Berman[1], W.J. Davis[1], J.B. Whalen[1], M.W. McCurdy[1], J.A. Craven[1], B.J. Roberts[1], I. McMartin[1], J.A. Percival[1], R.H. Rainbird[1], A. Ielpi[2], R. Mitchell[3], M. Sanborn-Barrie[1], L. Nadeau[4], É. Girard[4], S. Carr[3], S.J. Pehrsson[1]

[1]Geological Survey of Canada, 601 Booth St., Ottawa, Ontario
[2]Canada-Nunavut Geoscience Office, Iqaluit, Nunavut
[3]Department of Earth Sciences, Carleton University, Ottawa, Ontario
[4]Ressources Naturelles Canada, 490 Rue de la Couronne, Québec, Quebec

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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 is providing 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 2015 fieldseason, the 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 GEM2 Chantrey-Thelon activity has initiated bedrock mapping and related surficial, geochemical and geophysical studies in and adjacent to the boundary region of two major parts of the Canadian shield in western Nunavut. The objective of this activity is to promote mineral exploration in this understudied area through improved understanding its geologic evolution, crustal structure, and potential exploration targets. This report summarizes laboratory results on samples collected during 2014 fieldwork in the Thelon tectonic zone and Montresor belt projects, as well as the results of 2015 fieldwork in the Elu basin project.

Introduction

A 550 km-long reconnaissance-scale geological transect across the western Rae craton and Thelon tectonic zone was successful in both revealing distinct geological domains with varied economic potential and confirming the broad impact of the ca. 2.35 Ga Arrowsmith orogeny (Berman et al., 2013, 2015b; Davis et al., 2014; McCurdy et al., 2013; McMartin et al., 2013). Following this transect, studies in the Bathurst Inlet - Chantrey Inlet region were initiated to understand the geological evolution, crustal architecture and mineral potential of three regions: (a) Thelon tectonic zone, (b) Montresor belt, and (c) Elu basin. This report includes a summary of 2015 activities for the first two regions as well as highlights of the Elu basin activities that are presented in more detail elsewhere (Ielpi et al., 2015).

Thelon tectonic zone project

Multidisciplinary geoscience studies are taking place within NTS map sheets 76I and 76H, which lie between and adjacent to two protected areas, the Queen Maud Migratory Bird and Thelon Wildlife sanctuaries (Figure 2). The first year of fieldwork (2014-15) involved bedrock and surficial mapping transects mostly in 76H, a magnetotelluric transect across both map sheets, and a stream geochemical survey in 76I (Berman et al., 2015a). A second year of fieldwork is scheduled for June-July, 2016. This report summarizes progress in key components of the project: bedrock geochronology and geochemistry, magnetotelluric data modelling, surficial geology, and a geochemical survey of stream waters and sediments.

Bedrock geology:

The Thelon tectonic zone (TTZ) comprises a series of pronounced, N- to NNE-striking magnetic anomalies that extend >500 km from the MacDonald fault to north of Queen Maud Gulf. The TTZ has been postulated to represent a ca. 2.0 Ga continental arc built on the western flank of the Rae craton and subsequently intensely deformed during ca. 1.97 Ga collision with, and subsequent indentation by the Slave craton (Hoffman, 1988). Alternative models propose that the TTZ formed in an intracontinental setting either after crustal thinning (Thompson et al., 1989) or within an interior mountain belt far removed from an active plate boundary (Chacko et al., 2000; Schultz et al., 2007). Distinguishing between these models is important for generating a comprehensive understanding of the economic potential of this region.

The project area is centred on the TTZ in the complex boundary zone between the easternmost Slave craton to the west, and the westernmost Rae craton in the east (Figure 2). Within the map area, the eastern Slave craton is dominated by metasedimentary and metavolcanic rocks of the Yellowknife Supergroup intruded by 2.61 – 2.58 Ga granitoids (Frith, 1982; Thompson et al., 1986). Metamorphic grade increases eastward toward the TTZ from lower- to upper-amphibolite facies during both Neoarchean and Paleoproterozoic (Thelon orogeny) events. This gradient culminates northeast of the Bathurst fault in 76I (Figure 2; region between S2 and S3), where the proportion of supracrustal rocks decreases and deeper crustal levels expose migmatitic granitoid gneisses interspersed with narrow metavolcanic belts and screens (Thompson et al., 1986).

In contrast to much of the mainland Rae craton which hosts voluminous ca. 2.6 Ga plutonic rocks (Hinchey et al., 2011 and references therein), the western Rae craton consists largely of Mesoarchean (ca. 3.2 – 2.9 Ga) upper amphibolite to granulite-facies plutonic rocks of the Queen Maud block (QMb; Figure 2; Tersmette, 2012; Davis et al., 2013; 2014). Mapping in 2014 suggests that orthopyroxene in relatively unstrained Mesoarchean tonalite formed during the ca. 2.35 Ga Arrowsmith orogeny whereas the western margin of the QMb was deformed at upper amphibolite facies during the ca. 2.0-1.9 Ga Thelon orogeny.

A 5-10 km wide belt of metaplutonic rocks, with a preliminary age of ca. 2.0 Ga (Davis et al., 2013), marks the western boundary of the QMb (Figure 2). This plutonic belt of gabbroic to granodioritic composition, is the easternmost of three pronounced, N- to NNE-striking aeromagnetic highs, all comprising Paleoproterozoic plutonic rocks. Whereas some gabbro and quartz diorite is weakly deformed, other granitoid rocks are well foliated, and the belt is wider in the south where it forms tight map-scale folds (Fig. 2). Fieldwork in 2014 revealed that in several locations, the eastern plutonic belt is spatially associated with magnetite-bearing diatexite (Berman et al., 2015a, c) which may have been derived from iron-rich metasedimentary rocks, including iron formation that could be the source of Au anomalies revealed in a stream water geochemical survey (McCurdy et al., 2013).

The eastern plutonic belt forms the boundary of the Duggan Lake domain (Fig. 2), which has a dominant north-striking structural grain, similar to the western, deformed margin of the QMb. Recently acquired Nd isotopic data indicate widespread Mesoarchean model ages throughout the Duggan Lake domain and U-Pb zircon data (Davis et al., 2014; and reported below) confirm its Mesoarchean age. Evidence for ca. 2.35 Ga metamorphism in samples from the Duggan Lake domain and the western QMb (Davis et al., 2014) suggests they may have been contiguous at least until ca. 2.3 Ga. Ongoing studies are evaluating whether the Duggan Lake domain may have rifted off the QMb prior to the Thelon orogeny or may have been structurally emplaced.

The extent of Rae and Slave craton within the TTZ is not well established. The pronounced, magnetic low forming the west margin of the Duggan Lake domain (Figure 2) extends ~300 km northward to Queen Maud Gulf. Fieldwork in 2014 indicates that it comprises variably strained garnet-bearing leucogranite that potentially formed from melting of Rae margin sediments (Berman et al., 2015c). If correct, this would predict that a suture (S1 in Figure 2) demarcating the edge of the Rae craton lies ~60 km east of the Slave-Rae boundary based on the distribution of Yellowknife Group supracrustal rocks (S2, Figure 2; Thompson, 1992), and ~40 km east of a proposed Slave-Rae suture that corresponds to the western limit of recognized Paleoproterozoic plutonic rocks (S3, Figure 2; Culshaw, 1991; Hoffman and Hall, 1993). The upper amphibolite- to granulite-facies region between proposed suture locations S1 and S3 is marked by a pair of prominent magnetic highs that correspond to magnetite-bearing rocks (western and central plutonic belts, Figure 2). Both belts consist of ca. 2.01-1.99 Ga quartz diorite to monzogranite, with K-feldspar megacrystic granodiorite dominating the western belt. The occurrence of 2.03 Ga clinopyroxene quartz monzonite gneiss at one locality in the western belt (Davis et al., 2014) is consistent with an earlier study (van Breemen et al., 1987) documenting that ca. 1.99-1.98 Ga plutonic rocks intrude older, high-grade gneisses. The extent of older gneisses, which are well exposed at granulite facies along Ragged Lake (Thompson, 1992), is schematically represented on Figure 2 (Ragged Lake gneiss belt). Unravelling the history of this belt will be an important focus of ongoing studies aimed at understanding the overall tectonic evolution of the TTZ.

The pedigree of the crust between the western and central plutonic belts is presently unknown, but an isolated ca. 2.59 Ga age for gneissic monzogranite (Davis et al., 2014) suggests an affinity with the Archean Slave craton. This crustal domain, referred to here as the Ellice River supracrustal domain, also consists of a thin, <1 km wide ultramafic to mafic metavolcanic belt (Berman et al., 2015a,c) which is spatially associated with geochemical anomalies (e.g. Ag, Pb, Cu, Zn, Ni, U; McCurdy et al., 2013), and interstratified with well- foliated, lower amphibolite facies Paleoproterozoic psammitic rocks.

Geochronology:

Geochronological investigation focussed on establishing the age of supracrustal rocks within the Ellice River supracrustal domain, as well as ages of plutonism and metamorphism across a transect of NTS 76H. The data acquired consist of U-Pb zircon age determinations for sixteen plutonic rocks and a volcanic rock, U-Pb detrital zircon populations for two rocks, and U-Pb monazite ages from five metamorphic rocks.

Well foliated metadacite (Figure 3) forms an approximately 50 cm thick horizon interstratified with lower amphibolite-facies metapsammite in the Ellice River domain. Zircon grains, many with oscillatory zoning, form a single ca. 1.95 Ga age population interpreted as the age of volcanism. Foliated metapsammite varies from lower (staurolite-garnet) to upper amphibolite (migmatite) facies in the southern part of the Ellice River supracrustal domain. Several lower-grade samples yield detrital populations with prominent ca. 2.5, 2.3 Ga and 2.15 Ga age peaks (Figure 4). The youngest detrital age is ca. 2.05 Ga. Possible sources for the prominent ca. 2.5, 2.3 and 2.15 Ga detrital zircon populations are known from the QMb and southwestern Rae (Figures 1, 2), potentially linking this newly revealed Paleoproterozoic basin to sources associated with the western Rae margin. The tectonic setting of the volcanic rocks is the subject of ongoing work. Their age is coincident with the timing of <1.97 Ga foredeep sedimentation in the adjacent Kilihigok basin (Tirrul & Grotzinger, 1990), suggesting development of a syn to late-collision, extensional basin within the Thelon orogen.

Two new U-Pb zircon crystallization ages establish that plutonism in the western plutonic belt evolved from ca. 2.0 Ga quartz diorite to voluminous ca. 1.99 Ga Kfs-megacrystic granodiorite. In the adjacent central plutonic belt, strongly foliated quartz diorite is slightly younger (ca. 1.98 Ga), in agreement with a previous, poorly defined ca. 1.99 Ga upper-intercept age estimate for clinopyroxene-bearing granodiorite in this domain (van Breemen et al., 1987). For the Duggan Lake domain, two ca. 3.2-3.1 Ga age determinations for well-foliated charnockite and biotite monzogranite, as well as five Nd model age determinations greater than 3.1 Ga, demonstrate an equivalent age to the western QMb. Six samples of syn- to post-tectonic plutonic rocks from the central plutonic belt, Duggan Lake domain and western QMb yielded ages between ca. 1.94 Ga and ca. 1.89 Ga. Several of these samples are characterized by very high zirconium typical of A-type granitoids. One sample, which cuts orthopyroxene-bearing gneissic fabrics in the central plutonic belt, establishes a minimum age of 1.91 Ga for granulite-facies metamorphism at this locality. Comparison of a ca. 1.90 Ga age of garnet leucogranite from the main magnetic low (Figure 2) with previous data for this rock type (van Breemen et al., 1987; Davis et al., 2013) demonstrates the narrow time range of leucogranite formation across the area. This time coincides with that of high-grade metamorphism determined by monazite geochronology on five samples between the main magnetic low and the western QMb.

Bedrock geochemistry:

Whole rock geochemical data have been obtained for 85 bedrock samples. The samples fall into distinct K_2O groups, although not without some overlap, particularly at higher SiO_2 contents (Figure 5). All but two of the Mesoarchean samples (zircon crystallization age or Nd model age) fall in the low K_2O group, thus enabling recognition of other likely Mesoarchean rocks. On a Nb-Y tectonic discriminant diagram (Figure 6), a distinct group of 1.92-1.89 Ga, high Zr samples plot in the “within plate” field, consistent with their A-type nature. Other Proterozoic samples (known from zircon ages or inferred from Nd model ages or high-K_2O contents) plot in the arc or slab failure fields (Figure 6). Within the western plutonic belt, there is a hint of a progression from arc-type at 2.03 Ga to slab failure-type at 1.99-1.98 Ga, but more data are needed from older gneisses to test this possibility. Work is ongoing to further constrain the tectonic setting of 2.03 – 1.89 Ga plutonism in the area.

Magnetotelluric transect:

Electrical strike directions have different orientations in the crust and mantle, requiring 3-D modelling to derive lithospheric-scale cross sections. One such section from a preliminary 3-D model along the southern transect shows a complex boundary zone possibly imaging different lithospheric blocks between the Slave and Rae cratons (Figure 7). The shallow conductor underlying the Ellice River supracrustal domain may image a sulphide-rich source (volcanic belt, thrust fault?) of metal-rich anomalies in stream sediment geochemical data. The resistive crustal column separating conductors beneath Mesoarchean crustal blocks may reflect rifting of the western Rae prior to Thelon orogenesis. Modelling is ongoing to place limits on the thickness of conductors and orientation of boundaries between them.

Stream sediment geochemistry:

A regional stream sediment, heavy mineral and water geochemical survey was carried out in 2014 in the northern part of NTS map 76I, adjoining the area in 76H and southern 76I where a similar survey was completed in 2012. A GSC open file report (McCurdy et al., in press) consisting of field observations and analytical data from 92 sites for 65 elements in stream silts by a partial method of analysis (aqua regia digestion), 35 elements in stream silts by a total method (Instrumental Neutron Activation) and 62 elements in waters is currently being reviewed for publication. Mineralogical data derived from 36 heavy mineral concentrate samples are included with this report. Two highlights include:

Ni-Cu-PGE potential: The potential for Ni-Cu-PGE mineralization within or adjacent to watersheds draining the survey area is indicated from the distribution of (mostly) visually identified chalcopyrite grains (0.25-2.0 mm) in the <2.0 mm heavy mineral concentrate fraction of bulk sediment samples from the 2014 survey area (northern NTS 76I) in combination with the patterns of concentrations of several elements in stream silt (Ag, Ni, Cu ± Co, Sb, Zn, Pt) and locations downstream and/or down-ice of rock units mapped as metavolcanic or mafic-ultramafic metavolcanic (Figure 8). Additional potential Ni-Cu-PGE indicator minerals (Averill, 2009) identified in samples from this survey include hercynite, ruby corundum, chromite and low-Cr diopside (McCurdy et al., in press). Two areas are suggested for followup work in 2016 (Figure 8).

U-Th-REE potential: Thorianite-uraninite series mineral grains (0.25-2.0 mm) were identified in nine of the <2.0 mm heavy mineral concentrate fraction of bulk stream sediment samples (Figure 9). Concentrations of both uranium and REEs are elevated in stream silt samples adjacent to, downstream and/or down-ice from mineral grain locations and may be associated with contact zones between granitoid units and metavolcanic units (Figure 9). Minerals commonly found in pegmatites and present in samples include red rutile and topaz.

Till geochemistry:

The field database and analytical results from a targeted till sampling survey completed in 2014 over NTS 76H and 76I was released as a GSC Open File report (McMartin and Berman, 2015). This survey covered parts of the Thelon tectonic zone and adjacent Slave craton. Targeted surface till samples were collected at GEM-1 till and stream sediment geochemical anomalies (McCurdy et al., 2013; McMartin et al., 2013), and along two 80-km long transects across various paleoglaciological domains, including within and outside the Dubawnt ice stream footprint and across two splays of the MacAlpine Moraine System. Samples were analyzed for matrix geochemistry, gold grain counts, indicator minerals, and pebble lithology. An overview of the bedrock and Quaternary geology of the study area is also provided in this report. Future work includes the interpretation of till provenance and the implications for mineral exploration and economic potential.

Montresor belt project

Field work in 2014 (Percival et al. 2015a) identified three major lithotectonic units in the Montresor River region (Figure 1). From structurally highest to lowest these are: 1) low-grade metasedimentary rocks of the upper Montresor group, exposed in the Montresor syncline; 2) a structural footwall complex made up of imbricate panels of granodiorite gneiss and quartz arenite-dolostone-pelite units of the lower Montresor group; and 3) Archean (ca. 2.59 Ga) granodiorite and gneissic derivatives. The Paleoproterozoic Rae cover sequence has been subdivided into 4 sedimentary (S) units (Rainbird et al. 2010), abbreviated as S1, 2, 3 and 4 (Pehrsson et al. 2013). Field and aeromagnetic correlations were made between the lower Montresor metasedimentary rocks and the regional S1 and S2 units, and between upper Montresor sandstone- siltstone and the regional S3 unit.

No radiometric ages were previously available for the Montresor region. Frisch (2000) had correlated the upper Montresor group with the Amer group 50 km to the south and interpreted the lower

Montresor units as part of the Archean basement. New geochronology supports correlation of both the upper and lower Montresor groups with Paleoproterozoic sedimentary units of the Rae cover sequence and adds precision to the regional temporal framework. Detrital zircons from a quartz arenite panel in the structural footwall yielded U-Pb SHRIMP ages ranging between 2.8 and 2.19 Ga (B. Davis, pers. comm. 2015). Together with the 2.05 Ga U-Pb zircon TIMS age for a gabbro sill (Percival et al. 2015a, in press) that is intrusive into this panel, the depositional age for the lower Montresor is bracketed between 2.19 Ga and 2.05 Ga. U-Pb SHRIMP ages on detrital zircons from a sandstone unit in the upper Montresor are as young as 1.938 Ga (B. Davis, pers. comm. 2015), revealing a >110 m.y. time gap between deposition of the lower and upper sequences. Attempts to date altered igneous rocks within the southwestern Montresor breccia zone (Percival et al. 2015a, in press) were unsuccessful. Exposed over a strike length of at least 4 km, the non-magnetic breccia zone has been modeled as a continuous, 500-m thick stratabound layer folded within the Montresor syncline (Tschirhart et al., in press). One of seven grab samples of breccia returned anomalous values of copper, gold and silver.

Metamorphic studies (C. Dziawa, Carleton University) have confirmed a contrast in metamorphic grade between mid-amphibolite facies in the structural footwall complex, and mid-to upper greenschist facies in the upper Montresor units. Metamorphic monazites yield U-Pb SHRIMP ages of ca. 1.861-1.844 Ma for amphibolite-facies (Berman et al. 2015b), and ca. 1.847 Ga for upper greenschist-facies (B. Davis, pers. comm. 2015). These results are consistent with the interpretation (Percival et al. 2015a, in press) that the two lithotectonic units underwent Trans-Hudsonian deformation and metamorphism at different structural levels and were juxtaposed along a low-angle extensional detachment after ca. 1.84 Ga.

Elu basin project

The Elu Basin Geoscience Project is co-led by the Canada-Nunavut Geoscience Office and the Geological Survey of Canada, and aims to collect information on the stratigraphy, sedimentology, and economic potential of the Elu Basin and northeastern margin of the adjacent Kilohigok Basin (Figure 1; Ielpi and Rainbird, 2015a). The study area encompasses Elu Inlet, Tariyunnuaq (*Melville Sound*) and northeastern Kiluhiqtuk (*Bathurst Inlet*)

In 2015, we focused on the stratigraphy and gamma-ray spectrometry of the northeastern margin of the Kilohigok Basin, which is represented by the ca. 1.9 Ga Burnside River Formation, a sandstone-dominated fluvial unit that nonconformably overlies granitoid and greenstone-belt rocks of the Archean Slave Province. At the contact, a well-developed paleo-saprolite derived from the granitoid protoliths demonstrate potential for unconformity-related uranium mineralization, while poorly developed alteration profiles derived from greenstone-belt rocks are overall less prospective. The overlying Burnside River Formation is mainly composed of laterally continuous sandstone sheets, representing large foreset bars, channel bodies, and eolian dunes. Radioactivity measurements from the Burnside River Formation indicate background levels of uranium; local coarse-grained bodies contained within basement paleovalleys host nominally higher uranium concentrations. Above-background levels of radioactivity were also recorded at higher stratigraphic levels, notably in proximity to intrabasin-fill surfaces of the unconformity.

Future work

Following fieldwork scheduled for June-July, 2016 in the Thelon tectonic zone, bedrock maps will be published for map sheets 76H and I. A bedrock map of the Montresor belt is in press (Percival et al., in press) and a thematic map of the Elu basin is being prepared. Open file and journal publications are in progress, and will continue to release results and interpretations of the multidisciplinary datasets acquired over the course of this activity.

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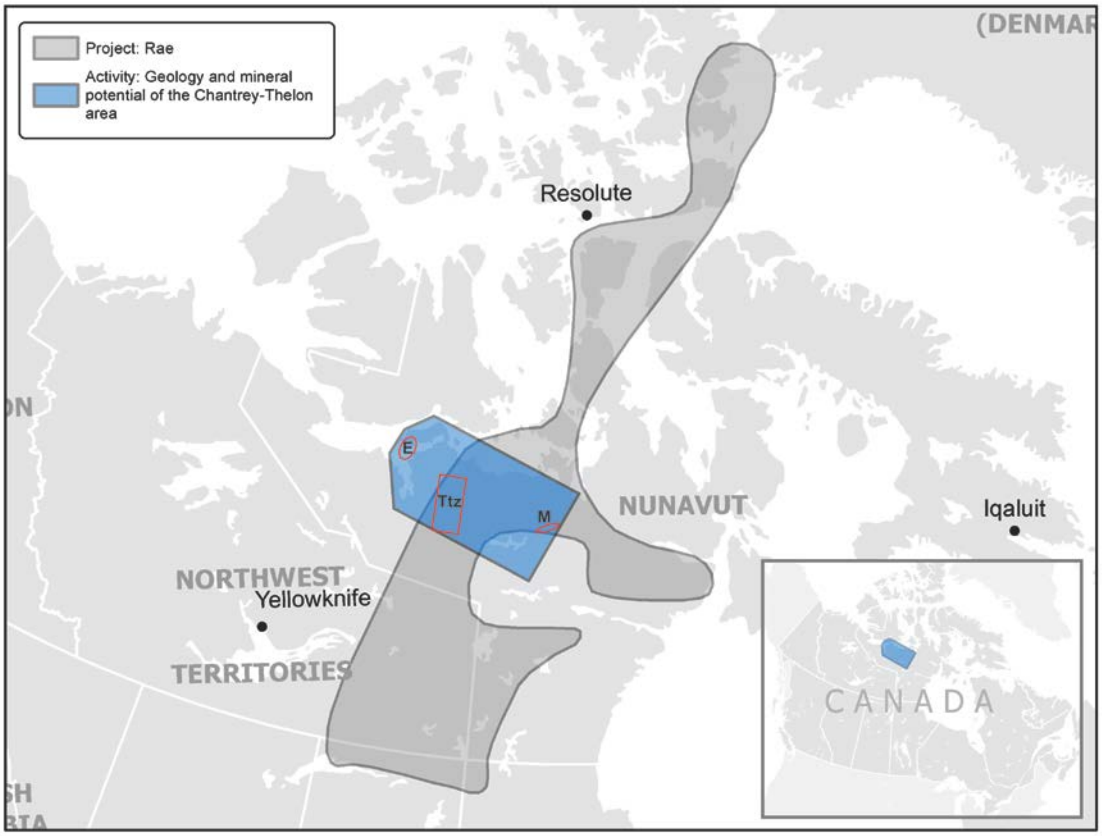

Figure 1. Location map showing region of Chantrey-Thelon activity. Project area abbreviations: E = Elu basin; M = Montresor belt; Ttz = Thelon tectonic zone

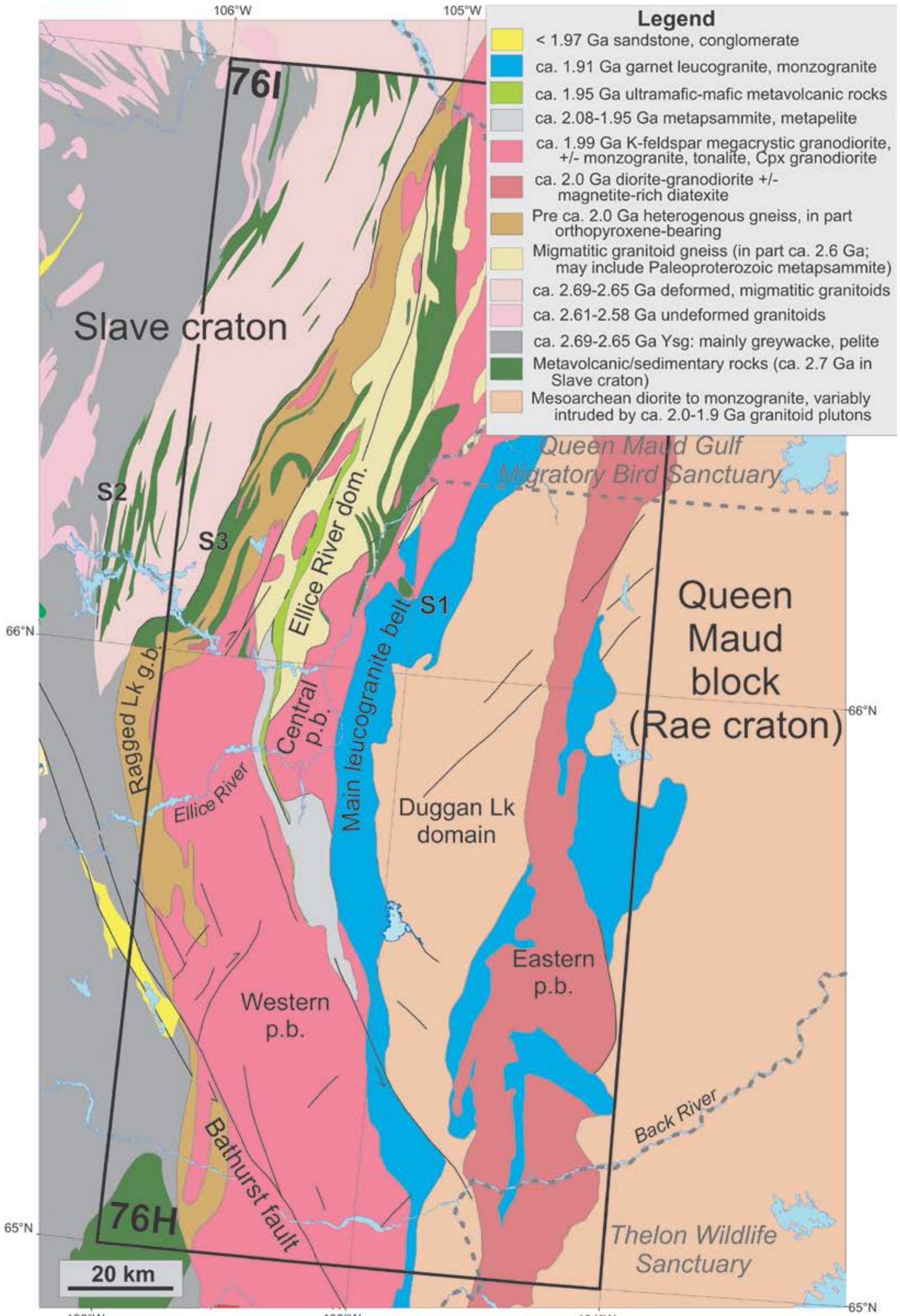

Figure 2: Simplified geologic map of the Thelon tectonic zone in NTS map sheets 76H and 76I, based on interpretation of aeromagnetic data integrated with previous work (Thompson et al., 1986; Frith, 1981), 2014 mapping observations, and geochronology and geochemistry acquired in 2015. Solid curves = faults, shear zones; dotted curves = form lines; RL = Ragged Lake; p.b. = plutonic belt; g.b. = gneiss belt; S1, S2, and S3 are alternative suture locations.

Figure 3: Well-foliated, ca. 1.95 Ga metadacite in the Ellice River supracrustal domain

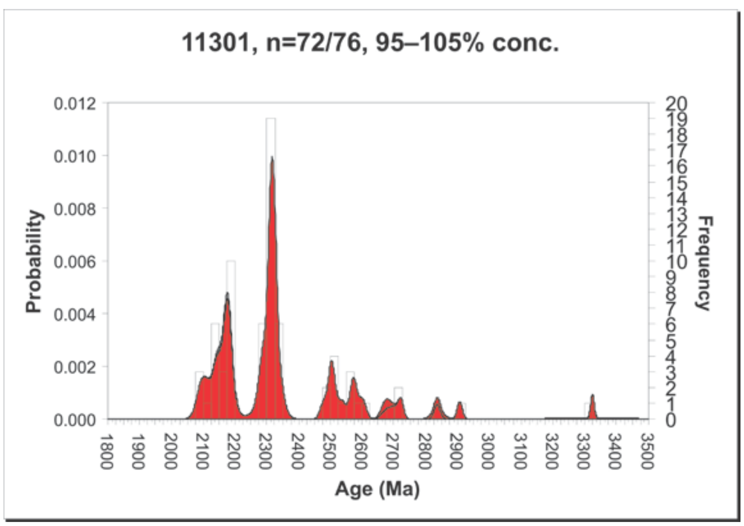

Figure 4: Detrital zircon population in metapsammite sample from the Ellice River supracrustal domain

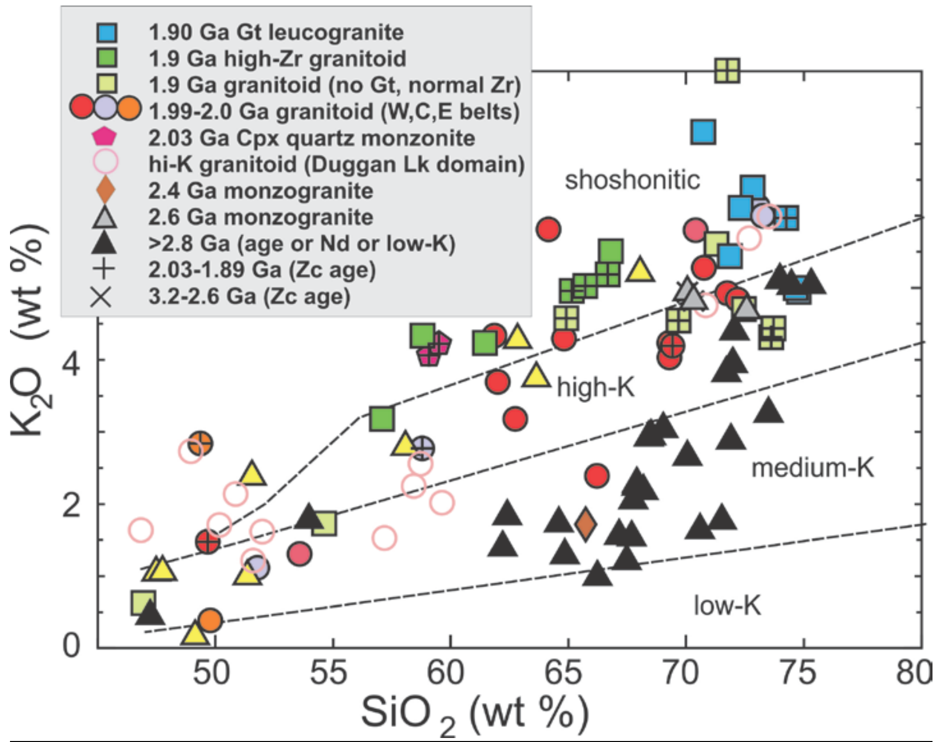

Figure 5: K2O-SiO2 plot showing the lower K2O contents of most Mesoarchean samples (known or inferred). Plot subdivisions from Le Maitre (1989) and shoshonite field from Peccerillo and Taylor (1976).

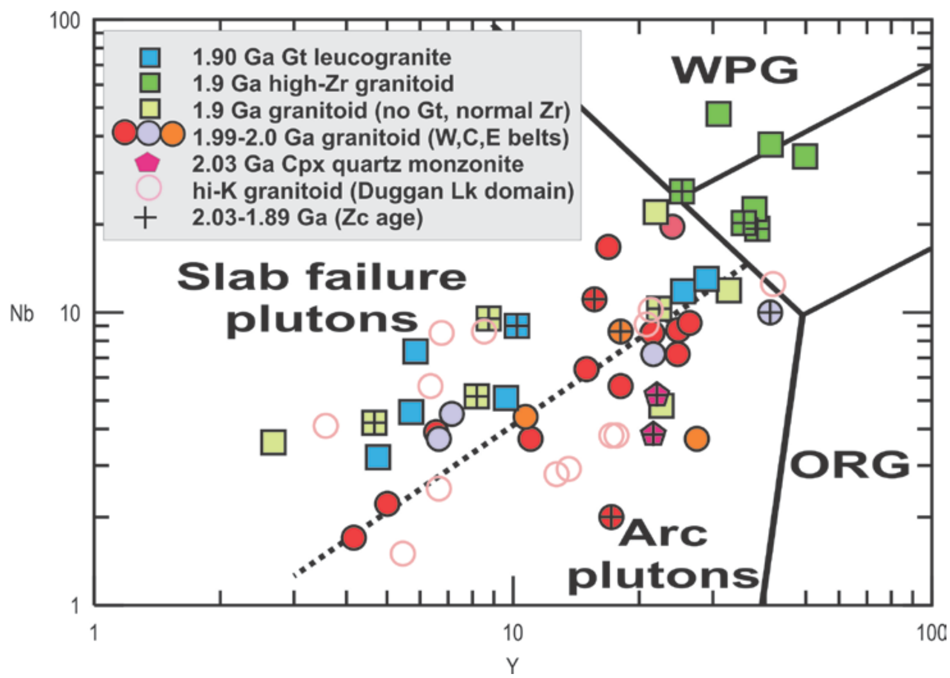

Figure 6: Modified tectonic discriminant diagram from Pearce et al. (1984) showing "within plate" (anorogenic) character of high-Zr suite, and arc – slab failure character of other ca. 2.03-1.89 Ga plutonic rocks. The fields for arc plutons and slab-failure derived plutons are based on geochemical data from western and eastern segments of the Peninsular Ranges batholith, respectively, as documented in Hildebrand and Whalen (2012).

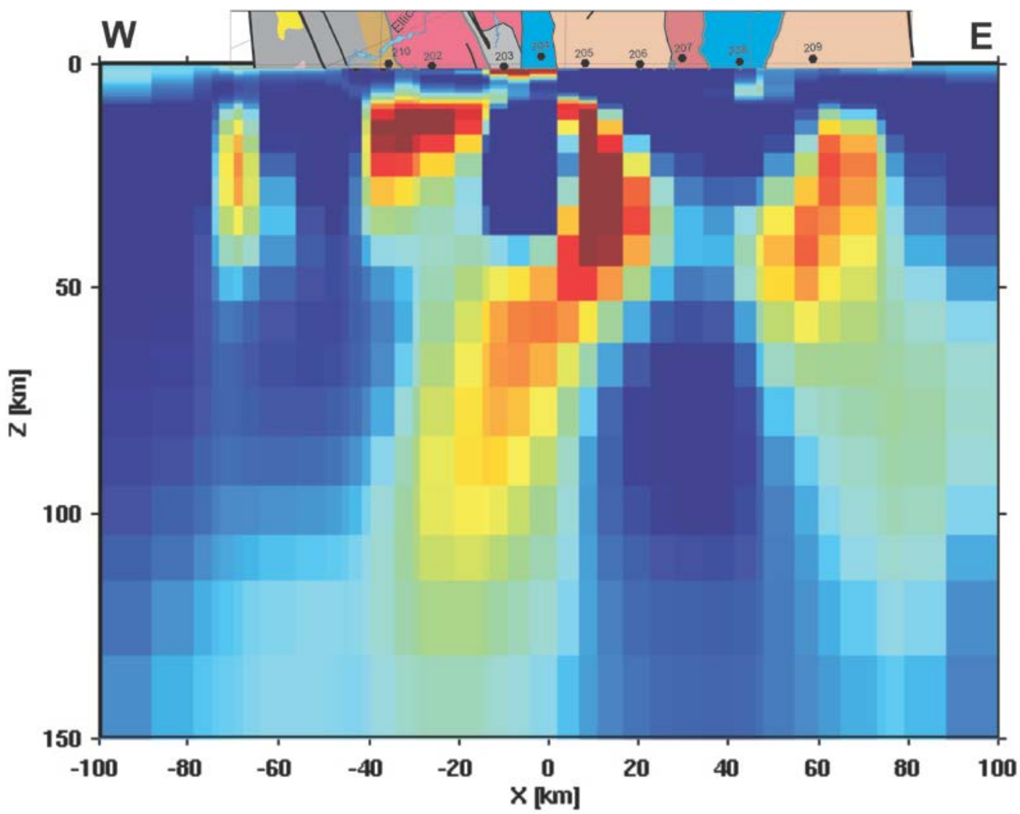

Figure 7: West-east cross section through preliminary 3-D magnetotelluric model across NTS map sheet 76H. Top strip shows geological map units (Fig. 2) and MT stations.

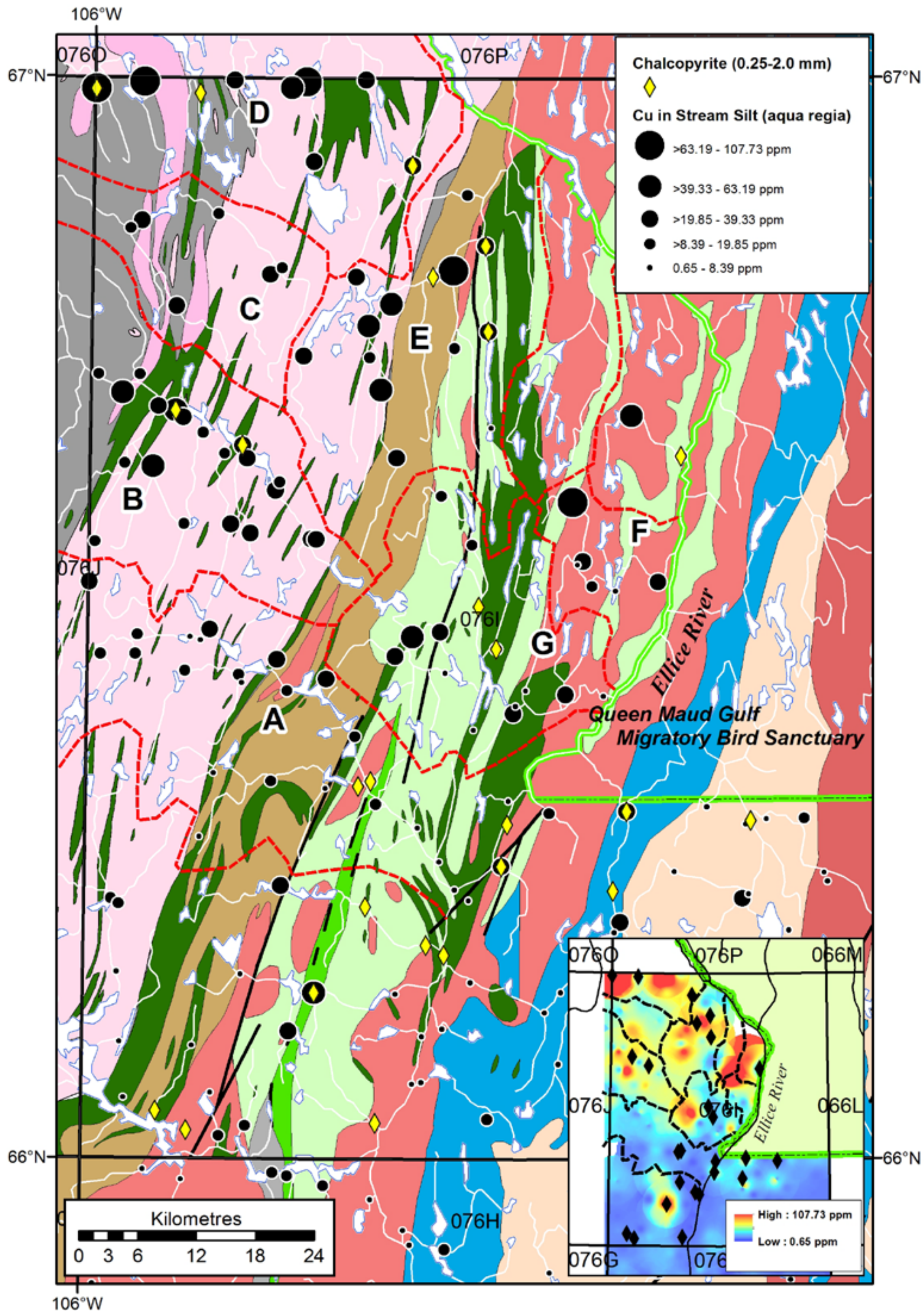

Figure 8. Sample locations at which chalcopyrite grains (yellow diamonds) were identified are shown with proportional spots representing relative Cu concentrations in stream silt samples. The inset map shows relative concentrations of Cu, contoured using an Inverse Distance Weighting (IDW) algorithm, with chalcopyrite (black circles) grain locations. Red dashed lines outline drainage basins labelled with letters A-G. Basins B and D are suggested for follow-up work.

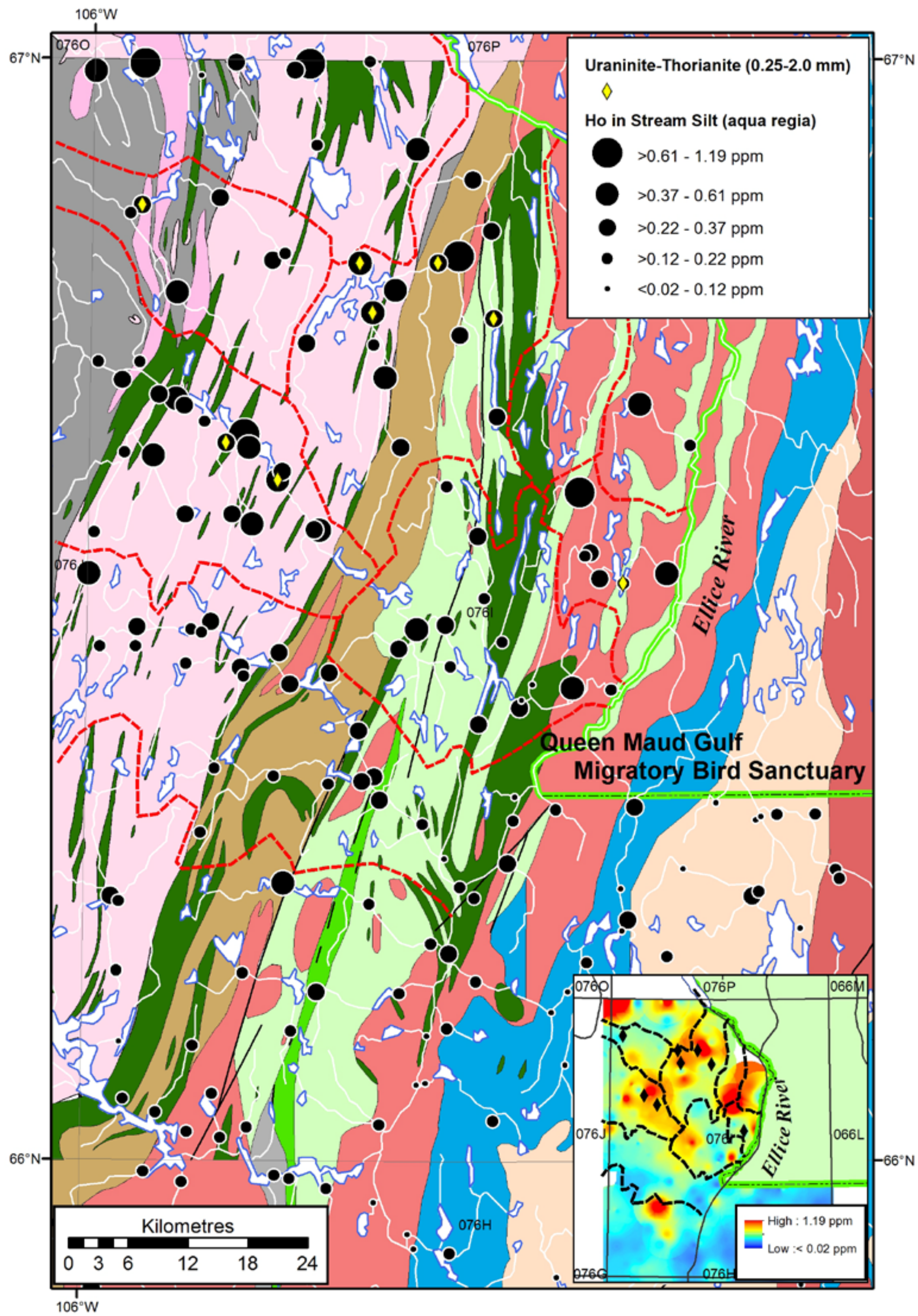

Figure 9. Geochemical survey results with proportional spots representing relative concentrations of Ho, a heavy rare earth element, in stream silt samples and yellow diamonds showing locations at which uraninite-thorianite series grains were identified. The inset map shows relative concentrations of Ho, contoured using an Inverse Distance Weighting (IDW) algorithm, with uraninite-thorianite (black circles) grain locations.