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Paleoproterozoic Iron Oxide Apatite (IOA) and Iron Oxide-Copper-Gold (IOCG) mineralization in the East Arm Basin, Northwest Territories, Canada

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1 **Paleoproterozoic Iron Oxide Apatite (IOA) and Iron Oxide-Copper-Gold (IOCG)**
2 **mineralization in the East Arm Basin, Northwest Territories, Canada**

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Draft

Abstract

The Paleoproterozoic East Arm Basin of Canada hosts polymetallic vein, Iron Oxide-Apatite (IOA), and potential Iron Oxide-Copper-Gold (IOCG) mineral occurrences, mainly associated with a belt of ca. 1.87 Ga intermediate-composition sills termed the Compton intrusions. Advances in our knowledge of the East Arm Basin and of IOA and IOCG deposits within the broader context of iron oxide and alkali-calcic alteration systems enables a new regional analysis of this mineralization and facilitates comparison of these mineral occurrences and host rocks to the nearby Great Bear magmatic zone IOCG districts. The Compton intrusions and co-magmatic Pearson Formation volcanic rocks are comparable in age and composition to intrusive plus volcanic rocks of the Great Bear magmatic zone that host IOA-IOCG mineralization. Taking into account fault displacements, emplacement of Compton intrusions and Pearson Formation volcanic rocks are also consistent with the architecture of modern arcs, supporting a direct relationship with the Great Bear subduction zone. Trace element patterns of uraninite contained in IOA occurrences of the East Arm Basin are also similar to the patterns of uraninite from the Great Bear magmatic zone occurrences, consistent with both regions having experienced similar iron oxide and alkali-calcic alteration and mineralization. Our new results indicate that exploration for IOA, IOCG and affiliated deposits in the East Arm Basin should focus on delineating increased potassic-iron alteration types and fault/breccia zones associated with these systems through field mapping and application of geochemical, radiometric, magnetic and gravity surveys.

Keywords: *East Arm Basin, Great Bear magmatic zone, IOCG, IOA, iron oxide, uranium*

1. Introduction

The “East Arm Basin” (Kjarsgaard et al. 2013a) refers to a ~100 km by ~300 km area on the eastern extension of Great Slave Lake in the Northwest Territories of Canada (Fig. 1). This region has been withdrawn from mineral exploration since 1970 for a proposed national park (Wright et al. 2013). Following two federal Mineral and Energy Assessment Reviews (Roscoe et al. 1987; Wright et al. 2013), the park boundary that has been proposed by Parks Canada (Tait Communications and Consulting 2017) would open a significant portion of the withdrawn land to mineral exploration. However, our understanding of the geology and metallogeny of the region has not kept pace with modern advances in ore deposit studies, and in particular the mineral potential of the region for iron oxide-copper-gold (IOCG) deposits. These recent advances provided the impetus to re-examine the IOCG potential of the East Arm Basin.

The Paleoproterozoic East Arm Basin lies within the southern margin of the Archean Slave Craton, adjacent to the Taltson magmatic zone and Churchill Structural Province (Kjarsgaard et al. 2013a; Sheen et al. 2019; Fig 1). This basin has been significantly affected by the Great Slave Lake shear zone, a crustal-scale continental transform fault that offsets the Moho (Snyder and Kjarsgaard 2013), and the younger Paleoproterozoic McDonald fault. The sedimentary successions in the basin were punctuated by plutonic and volcanic magmatic episodes during sedimentation. As such, the geological settings and crustal architecture of the region has attributes of districts that host IOCG deposits (e.g., Drummond et al. 2006; Corriveau et al. 2010a).

Recent advances in our understanding of the genetic linkages between polymetallic vein, iron oxide-apatite (IOA), IOCG and affiliated deposits within regional-scale iron oxide and alkali-calcic alteration systems can be used to guide exploration in districts that have been historically overlooked for precious, base, strategic and nuclear metal potential. This is particularly relevant in Canada where most precious and base metal exploration (and production) is from magmatic mafic/ultramafic Ni-Cu-PGE deposits, e.g. Sudbury, Raglan, Thompson, and greenstone belt-hosted volcanogenic massive sulfide and lode gold deposits in Quebec, Ontario, Northwest Territories, and New Brunswick (Lydon 2007). Despite the Olympic Dam IOCG deposit hosting the world's largest recoverable uranium resource (OECD 2018), uranium exploration in Canada remains focused on the high-grade unconformity-related deposits of the Athabasca Basin.

This study examines linkages between key geological units from the East Arm Basin with rocks that host IOA-IOCG mineralization in the Great Bear magmatic zone, coupled with a comparison of uraninite chemistry from both districts. As the trace element chemistry of uraninite reflects conditions under which the mineral crystallized (e.g. Fryer and Taylor 1987; Pagel et al. 1987; Mercadier et al. 2011; Frimmel et al. 2014), these results provide insights on the conditions pertinent to uranium enrichment in the East Arm Basin occurrences. Our new data and interpretations reaffirm that both regions have similar geological origins (as first proposed by Hoffman et al. 1977) and experienced similar magmatic-hydrothermal conditions that resulted in formation of IOA, IOCG and affiliated mineralization.

2. Polymetallic vein, IOA, and IOCG deposits

Since discovery of the giant Olympic Dam deposit in Australia in the 1970's, the definition and classification of the IOCG deposit type has evolved, e.g. Hitzman et al. (1992), Gandhi and Bell (1996), Corriveau et al. (2010b), Groves et al. (2010), Williams (2010) and Slack et al. (2016), amongst others. Herein we adopt the broader iron oxide and alkali-(calcic) alteration deposit type umbrella proposed by Porter (2010) and revisited by Corriveau et al. (2016). This broader definition includes: IOCG deposits (magnetite-, magnetite-hematite- and hematite-group IOCG classes of Williams 2010); magnetite-rich, iron oxide-apatite (IOA) deposits (cf. Williams 2010), polymetallic albitite-hosted uranium (Montreuil et al. 2015; Potter et al. in press), iron and polymetallic potassic skarns (Yu et al. 2011; Ismail et al. 2014; Corriveau et al. 2016), uranium- and REE-rich iron-oxide mineralization (IOU; Hitzman and Valenta 2005; Groves et al. 2010; Skirrow et al. 2011), and epithermal-style mineralization in near surface environments (Mumin et al. 2010; Kreiner and Barton 2011).

These deposits document a wide range of mineralization styles (stratabound, discordant breccia zones, veins, replacements, disseminations, mantos, and skarns) with a variety of metal associations in a variety of host rocks, e.g. sedimentary, volcanic, intrusive and metamorphic rocks. As such, a wide range of mineralization types (e.g., polymetallic veins, IOA, IOCG) and anomalous metal contents in a single area may reflect an extensive iron oxide and alkali-calcic alteration system. Although ore grades are typically intermediate to low (Table 1), IOCG deposits can contain very large

tonnages of base (Fe, Cu, Pb, Zn, Ni, Co), precious (Au, Ag), strategic (Bi, Mo, V, and rare earth elements) and nuclear metals (U and Th) (Corriveau et al. 2018).

2.1 Iron oxide and alkali-calcic alteration

Through metasomatic dissolution-precipitation reactions, evolving fluids can intensely alter significant volumes of host rocks (cf. Putnis 2009; Putnis and Austrheim 2010), and in some cases chemically and texturally transform the country rocks to such degrees that protoliths are unrecognizable (Corriveau et al. 2010b, 2016; Montreuil et al. 2016a, b, c). These alteration systems evolve to generate mineral assemblages and bulk compositions (regardless of the host rocks) that form diagnostic “metasomatic facies” (Corriveau et al. 2010b; 2016; Fig. 2). These metasomatic rocks acquire distinctive geophysical (gravity, magnetic susceptibility, conductivity and radiometric) signatures that can be utilized in regional exploration programs (Hayward et al. 2013; Enkin et al. 2016).

The progressive nature of the metasomatic alteration and deposit types (Fig. 2), evolves from early, high temperature sodic alteration to high temperature calcic-iron alteration (IOA and skarn in carbonate-bearing hosts), high temperature potassic-iron alteration (magnetite-group IOCG) to low temperature potassic-iron alteration (hematite-group IOCG). Thrusting of deeper, high temperature sodic facies into shallower, lower temperature conditions can also form albitite-hosted uranium deposits (Montreuil et al. 2015; Corriveau et al. 2016, 2018; Potter et al. in press). The evolution of iron oxide and alkali-calcic alteration systems and their mineralization is well documented across the Great Bear magmatic zone, particularly in the Port Radium-Echo Bay, Camsell River,

Lou Lake and Fab Lake districts (Goad et al. 2000a; Mumin et al. 2007, 2010; Corriveau et al. 2010a, b, 2016; Potter et al. 2013a; Montreuil et al. 2013, 2015, 2016a, b, c).

3. The East Arm Basin geology and IOA-IOCG mineralization

3.1 Geology of the East Arm Basin

As proposed by Kjarsgaard et al. (2013a), the term “East Arm Basin” is used herein to encompass four groups of Paleoproterozoic sedimentary and volcanic rocks (Fig. 3). The supracrustal rocks in the East Arm Basin are subdivided into four unconformity-bound sequences (from oldest to youngest): 1) Union Island Group; 2) Wilson Island Group; 3) Great Slave Supergroup, and; 4) Et-Then Group. The revised stratigraphic position of the Union Island Group (Fig. 4) is supported by recent geochronology and geochemistry of mafic rocks that are distinct from other Paleoproterozoic volcanic and intrusive rocks in the East Arm Basin (Kjarsgaard et al. 2013a; Sheen et al. 2019). The structurally isolated exposures of the Wilson Island Group rocks along the southwestern margin of the basin are distinguished from other Paleoproterozoic sequences in the basin by the presence of greenschist-to-amphibolite facies mineral assemblages and greater penetrative fabric development (Johnson 1990), whereas Great Slave Supergroup rocks are sub-greenschist facies (Hoffman 1981). A rhyolite porphyry flow from the oldest formation within the Wilson Island Group was dated at 1928 ± 11 Ma, providing a maximum age for the group, while the cross-cutting 1895 ± 5 Ma Butte Island granodiorite intrusion defines the upper age limit (Bowring et al. 1984). The Great Slave Supergroup is composed of alternating fluvial and marine sedimentary rocks with evidence of former evaporites, intercalated with volcanic sequences (Hoffman 1968; Kjarsgaard et al. 2013a). Deposition of the

overlying and non-metamorphosed Et-Then Group sedimentary and volcanic rocks post-dates northwest thrusting of Wilson Island Group and Great Slave Supergroup rocks during formation of the East Arm fold-and-thrust belt (Hoffman 1968, 1988; Hoffman et al. 1977).

All the volcanic rocks in the Sosan and Kahochella groups are informally referred to as Seton formation rocks – not a strict time stratigraphic division within the Great Slave Supergroup (Badham 1978a; Kjarsgaard et al. 2013a). The Seton volcanic rocks are intercalated with sedimentary rocks of the Kluziai and Akaithcho River formations of the Sosan Group, as well as sedimentary rocks of the Gibraltar Formation of the Kahochella Group (Hoffman et al. 1977; Kjarsgaard et al. 2013a). The Seton formation volcanic rocks (tuffs, flows, intrusive breccia pipes) and associated hypabyssal rocks are predominantly bimodal consisting of alkaline basalt and alkali rhyolite (Kjarsgaard et al. 2013a). Exposures of Seton formation volcanic rocks on the southern and eastern margin of the East Arm Basin led Hoffman et al. (1977) to suggest that volcanism was concentrated along a rifted margin.

The lower Christie Bay Group (Stark, Tochatwi, Portage Inlet formations) has been shown by Hoffman (1968) and Stanworth and Badham (1984) to have pseudomorphs after anhydrite and gypsum, and collapse megabreccias with zones of drusy calcite and barite, interpreted to be related to the collapse of precursor evaporite units. This sequence, tens to hundreds of meters thick (Pope et al. 2000), likely developed during a transition from normal marine to evaporitic conditions (Pope and Grotzinger 2000). As

174 noted by Badham and Stanworth (1977), the East Arm Basin was within 30° of the
175 equator during deposition of the Great Slave Supergroup, creating ideal conditions for the
176 deposition of extensive evaporites in supratidal flats and sabkhas.

177

178 A belt of calc-alkaline laccoliths termed the Compton intrusions intrude carbonate
179 sequences of the upper Pethei Group and bulge discordantly upward into the lower
180 Christie Bay Group carbonates, sandstones and siltstones. In addition, several laccoliths
181 cut nappe boundaries, indicating they post-date folding and thrusting (Hoffman 1968,
182 1988; Hoffman et al. 1977; Bowring et al. 1984). The Compton intrusions were originally
183 dated by Bowring et al. (1984) at 1872 ± 8 Ma and 1861 ± 17 Ma for a mean age of 1865
184 ± 15 Ma; a recent re-analysis of material from Bowring et al. (1984) yielded an age of
185 1868.46 ± 0.76 Ma, as reported in Gong et al. (2018). Compositionally, the Compton
186 intrusions consist of hornblende-biotite diorite to biotite-quartz monzonite intrusions
187 (Gandhi and Prasad 1982; Kjarsgaard et al. 2013a), with increasingly differentiated units
188 intruding earlier phases (Badham 1978a). The tops of the Compton intrusions (and host
189 country rocks) are pervasively altered to a carbonate-sericite-chlorite-hematite
190 assemblage while the actual intrusive contacts consist of zones of igneous and
191 sedimentary rock fragments set in a red felsite matrix comprised of antiperthitic albite
192 and quartz (Badham 1978a). At some locations, the intrusions are thought to have
193 intruded along solution collapse megabreccia units filled with water and possibly brines,
194 resulting in explosion breccias up to 30 m thick, with pervasive alteration of the country
195 rocks and hydrothermal breccias and veins comprised of actinolite, apatite, magnetite and
196 uranium minerals (Badham 1981). Mineral assemblages containing actinolite, apatite and

magnetite are typical of the high temperature calcic-iron alteration facies whereas mineral assemblages with sericite and hematite are typical of the low temperature potassic-iron alteration facies in iron oxide and alkali-calcic alteration systems.

Pearson Formation andesite and basaltic andesite flows occur in the mid-upper part of the Christie Bay Group, in a belt parallel to and north of the Murky Channel fault and Compton intrusions (Kjarsgaard et al. 2013a, b). These flows range in thickness from 1 to 20 m, have variable hematite staining and are interbedded with thin mudstone containing desiccation cracks and siltstone; indicative of subaerial deposition (Hofmann et al. 1977; Goff 1984). The Pearson Formation volcanic rocks exhibit trace element patterns remarkably similar to the Compton intrusions, which coupled with their stratigraphic position within the Christie Bay Group, led Kjarsgaard et al. (2013a) to propose that they are co-magmatic.

The Paleoproterozoic Et-Then Group, composed of conglomerates, basalts and sandstones, unconformably overlies the Christie Bay Group. Following a 600 m.y. hiatus in tectonic activity, mafic sills (also referred to as Fortress gabbro) and diabase dikes of the ca. 1271 Ma Mackenzie swarm (LeCheminant and Heaman 1989) intruded the rocks of the East Arm Basin (Hoffman 1981).

3.2 Regional structures

Located along the southern margin of the Archean Slave craton, the 1300 km long Great Slave Lake shear zone (GLSZ; Figs. 1, 3) is a corridor of granulite to lower

greenschist mylonitic rocks derived from magnetite-bearing granites and clinopyroxene tonalites. Previous research has interpreted the GLSZ to represent an older (ca. 1.97 Ga) crustal-scale continental transform structure that developed during the Paleoproterozoic by oblique collision and indentation of the southeast margin of Slave Province with the northwest margin of the Churchill Province (Badham 1978b; Hoffman 1987, 1988, 1989; Tirrul and Grotzinger 1990; Bowring and Grotzinger 1992; Hanmer et al. 1992; Tella et al. 2013). This long-lived fault zone was overprinted by brittle strike-slip displacements along the McDonald fault during the Paleoproterozoic, with post-1.86 Ga dextral movement of 70 to 125 km (Thomas et al. 1976; Hoffman et al. 1977; Hoffman 1981; Bowring et al. 1984).

3.3 Polymetallic vein, IOA and IOCG occurrences in the East Arm Basin

Table 2 and Figure 3 summarize the geological attributes and locations of mineralized occurrences and showings selected for this study in the East Arm Basin. This study excluded mineral occurrences that did not exhibit significant iron oxide or alkali-calcic alteration, such as certain five-element veins, copper-only veins, mafic base metals showings, etc. The data were extracted from Wright et al. (2013) and supplemented by industry, academic and government research compiled in the Northwest Territories Geological Survey Northern Minerals database (NORMIN 2011). Samples for this study were collected by J.A. Kerswill (reported in Potter et al. 2013b) and supplemented by S.S. Gandhi archives housed at the Geological Survey of Canada in Ottawa. Additional information on mineral occurrences from the East Arm Basin are presented in Badham

(1978a), Badham and Muda (1980), Gandhi (1983), Roscoe et al. (1987), Wright et al. (2013) and references therein.

The BBX (also known as Taltheilei Narrows, and Aristifats Lake) prospect (Fig. 3) has a pre-National Instrument 43-101 indicated resources of 5 000 short tons averaging 6.13 % Cu and 2.6 oz/t Ag (Argy and Siega 1971), with minor uranium concentrations superimposed on the copper-silver-iron mineralization. The mineralization is hosted in a strongly altered and brecciated mafic volcanic pipe that intrudes Sosan Group sedimentary rocks, with the age of mineralization dated at 1870 ± 15 Ma using Pb-Pb in galena (Blackadar 1981). The plug is one of several known Seton volcanic centres in the vicinity of Taltheilei Narrows that intruded Kluziai and Gibraltar formations of the Great Slave Supergroup. Fragments of mafic volcanic rocks, with lesser sedimentary and older granitic fragments, are set in a matrix of comminuted rock debris. The host volcanic rocks record prehnite-pumpellyite facies metamorphism, and propylitic, potassic, carbonate, silicic, hematite and chlorite alteration (Blackadar 1981). Geochemical assays (Potter et al. 2013b) confirm elevated Cu, Co, Ni, Ag and Au values within hydrothermally altered rocks containing anomalous K_2O and Fe_2O_3 contents (up to 9.68 and 8.07 wt. %, respectively) indicative of potassic-iron alteration (not simply potassic alteration).

At the Labelle (also known as GM, GMTN, and CC) showings (Fig. 3), IOA veins and breccia pipes occur within an elongate Compton intrusion and Stark Formation rocks hosting the intrusion. The showings contain variable uranium, arsenide, sulfarsenide,

265 sulfide, sulfosalts, and native metal contents (Badham 1978a). Badham and Muda (1980)
266 proposed a mineral paragenesis evolving from: 1) magnetite-apatite-actinolite; 2)
267 carbonate-allanite-uraninite-hematite (oxidation of magnetite); 3) quartz-arsenide-
268 sulfarsenide; and 4) supergene alteration. As noted by the authors, these paragenetic
269 assemblages closely resemble mineralization in the Port Radium-Echo Bay district of the
270 Great Bear magmatic zone (Fig. 1), where IOA mineralization has been intersected at
271 depth and IOCG mineralization occurs near the surface (Mumin et al. 2010; Somarin and
272 Mumin 2014; Corriveau et al. 2016). The Port Radium-Echo Bay district mineralization
273 is hosted within regional-scale iron oxide and alkali-calcic alteration with IOCG, IOA
274 and five-element vein attributes (Mumin et al. 2007, 2010). Notably, at Labelle the
275 oxidation of magnetite is associated with anomalous uranium concentrations. Thorpe
276 (1972) reported trench assays of 5.83% Ni, 6.97% U_3O_8 and 12.19% Ni, 2.62% Co, 0.2
277 oz/t Ag from the CC showings.

278

279 The Bell (or FF) showings (Fig. 3) are situated approximately 5 km northeast of the
280 Labelle showings and consist of similar IOA (actinolite-apatite) veins with anomalous
281 uranium concentrations, hosted in a Compton intrusion near the contact with the Stark
282 Formation. Thorpe (1972) reported an assay of 0.225% U_3O_8 from the northern showing
283 hosted in the Compton intrusion. Roughly 1 km south of these showings, anomalous
284 radioactivity is associated with additional IOA veins at the Carrie 2 showing (NORMIN
285 2011).

286

The REX (also known as Ridley, and Stevens) showings (Figs. 3, 5) are characterized by early sodic alteration (albite) and lenses of pegmatitic IOA veins that contain erratically distributed uraninite, chalcopyrite, pyrite and carbonate that are hosted within a fractured Compton intrusion (Badham 1978a; Jefferson 2013; this study). Structural measurements indicate strike-slip displacements were contemporaneous with vein formation (Jefferson 2013). The veins generally strike north (exposed for greater than 200 m, at widths up to 2 m) with a sub-vertical dip (Barnes 1952). At the REX showings, a Compton intrusion intrudes ferruginous mudstone and limestone of the Stark Formation (lower Christie Bay Group) and upper Pethei Group carbonate rocks, with up to 30 cm wide chill margins and less commonly, breccia zones. Badham (1978a) proposed that uraninite deposition was synchronous with partial oxidation of magnetite to hematite, reflecting interaction of the reduced magnetite-actinolite-apatite assemblage with oxidized uranium-bearing fluids.

The TEL and SHUM (also known as Chevron AB, Holy Moly, and MUSH) showings on Opener Island consist of thin hematite fractures, veinlets and hematite-cemented breccia zones with anomalous uranium, thorium and silver contents (Thorpe 1972). Mineralization occurs as isolated meter-scaled patches, but collectively they define an 8 by 0.8 km corridor within Hornby Channel Formation, Sosan Group rocks. Thorpe (1972) and Gandhi (1983) described the host rocks as arkosic quartzite near their northern contact with phyllite of the Union Island Group. Ore minerals identified from the SHUM showings include: specular hematite, pitchblende, pyrite, chalcopyrite, galena, clausthalite, glaucodot and skutterudite. Grab samples of vein material (Nichols 1968)

310 yielded grades up to 1.59 % U and up to 4.8 oz/t Ag, although from separate areas.
311 Nichols (1968) also reported stratabound enrichment in thorium (up to 0.33% Th) in the
312 host pebbly arkosic quartzite, which also has localized intense hematite alteration halos
313 up to 3 m wide in which precursor magnetite is oxidized to hematite (Gandhi 1983). The
314 showings are situated near faulted or unconformable contacts with Sosan and Union
315 Island groups and parallel the regional Preble Fault which outcrops near the southwestern
316 tip of Opener Island (Hoffman et al. 1977; Gandhi 1983).

317

318 The Iron Islands and Wilson Island (also known as Victory, Big Moose, and DOC)
319 showings exhibit characteristics similar to the aforementioned TEL and SHUM
320 showings. At Wilson Island, significant east-northeast trending specular hematite veins
321 contain minor gold and silver contents (trace to 0.11 oz/t Au; Lees 1975) in fractured
322 quartzite of the Wilson Island Group. At the Iron Islands showings, easterly striking
323 'beds' of specular hematite 0.3 to 10.5 m thick are observed within quartzite of the
324 Wilson Island Group (Brown 1950). Both showings are situated at the western margin of
325 the East Arm Basin, along strike of the Great Slave Lake shear zone and McDonald fault
326 system.

327

328 The UR showings (Fig. 3) were first discovered in the 1950's and described briefly by
329 McGlynn (1971). The six known showings occur along a deformation zone up to 40 m
330 wide over a strike length of approximately 2 km hosted within a Compton quartz diorite
331 intrusion, 30 m south of the northern intrusive contact with Stark Formation, Pethei
332 Group dolomite and shale. The mineralization consists of east-northeast trending, IOA

and quartz-carbonate veins and fracture-fillings with uraninite, chalcopyrite, hematite, and cobalt minerals.

4. Great Bear magmatic zone geology and IOA-IOCG mineralization

Located northwest of the East Arm Basin, on the western margin of the Slave craton (Fig. 1), the Great Bear magmatic zone is a north-south trending magmatic belt. Interpreted as an Andean-style continental magmatic arc, it developed at the western margin of the Wopmay orogen on the assembled Hottah terrane-Slave craton margin (Hildebrand et al. 2010a; Ootes et al. 2015, and references therein). The Hottah terrane is a 1.93–1.89 Ga volcanic arc that is interpreted to have developed south of the Slave craton, and subsequently translated northward along the proto-Wopmay fault zone to its current location at ca. 1.91–1.88 Ga (Davis et al. 2015; Ootes et al. 2015). Following translation, renewed subduction at ca. 1880 Ma drove onset of the ca. 1875–1850 Ma magmatism of predominantly intermediate to felsic suites of sub-volcanic, volcanic and volcanoclastic rocks (shoshonitic to high-K calc-alkaline series) of the Great Bear magmatic zone (Bowring 1984; Gandhi et al. 2001; Hildebrand et al. 2010b; Davis et al. 2015; Ootes et al. 2015; Montreuil et al. 2016a).

The main plutonic-volcanic sequences of the Great Bear magmatic zone form the McTavish Supergroup, which is subdivided into the LaBine, Dumas, Faber and Sloan groups (Gandhi et al. 2001; Hildebrand et al. 2010b; Ootes et al. 2015; Montreuil et al. 2016a). The LaBine, Dumas, and Faber groups are spatially and temporally associated with ca. 1.87 Ga subvolcanic intrusions, whereas the younger 1862 Ma Sloan Group is associated with granodioritic batholiths (Hildebrand et al. 2010b; Ootes et al. 2015;

357 Montreuil et al. 2016a). Syn- to post-tectonic syenogranites intruded the volcanic rocks at
358 1858–1850 Ma and form a large belt in the Great Bear magmatic zone (Bowring 1984;
359 Gandhi et al. 2001; Somarin and Mumin 2012; Jackson et al. 2013; Hayward and
360 Corriveau 2014). The 1.88 Ga Treasure Lake Group is a greenschist- to amphibolite-
361 facies platform-type metasedimentary sequence that was deposited, deformed and tilted,
362 before extrusion of the Faber Group volcanic sequence (Gandhi and van Breemen 2005;
363 Montreuil et al. 2016a). Importantly, the Treasure Lake and Faber groups and the ca.
364 1870 Ma syn-volcanic intrusions are the principal hosts of the IOA-IOCG mineralization
365 in the central-southern Great Bear magmatic zone, i.e. NICO and Sue Dianne deposits,
366 and numerous prospects such as the Southern Breccia, Brooke, Mar, Nod, Fab, Nori/RA
367 (Gandhi and Bell 1996; Goad et al. 2000a, b; Acosta-Gongora et al. 2015; Corriveau et
368 al. 2016; Montreuil et al. 2016a, b; Ootes et al. 2017). Many of the granitic phases and
369 syn-volcanic intrusions that host mineralization contain elevated uranium contents
370 relative to average continental crust, providing a fertile source of uranium for the ore
371 systems (Ootes et al. 2013). The timing of Great Bear magmatic zone IOA-IOCG
372 mineralization has been defined at several occurrences: (1) an albitized granitic intrusion,
373 an unaltered porphyritic dike and molybdenite Re-Os geochronology confine formation
374 of the NICO deposit and Southern Breccia to 1873–1868 Ma (Gandhi et al. 2001; Acosta-
375 Gongora et al. 2015; Montreuil et al. 2016b); (2) geochronology of unaltered porphyritic
376 monzonite dikes and weakly altered host rocks bracket hydrothermal alteration in the Fab
377 system to 1872–1865 Ma (Montreuil et al. 2016b, c); and (3) porphyritic dikes dated at
378 1866.4 ± 1.3 Ma and 1865.9 ± 0.9 Ma cut both the regional alteration and Cole Breccia,

thereby confining the alteration and Cole mineralization to older than 1866 Ma (Montreuil et al. 2016b).

5. Methods

Geochemical data were compiled from previous studies on the East Arm Basin (i.e., S.S. Gandhi and N. Prasad unpublished data; Olade and Morton 1972; Badham 1981; Blackadar 1981; Kjarsgaard et al. 2013a). Selected rock types of the Great Bear magmatic zone including porphyritic intrusions and volcanic rocks of the Faber Group and a 1.87 Ga intrusion of the Camsell River district (Hildebrand 1986; Hildebrand et al. 1987; Azar 2007; Corriveau et al. 2015; Ootes et al. 2015) were also compiled. The data were plotted in the discrimination plots of Thompson (1982), Pearce et al. (1984), Müller et al. (1992) and Montreuil et al. (2013). While most of the Pearson Formation volcanic rocks meet the Müller et al. (1992) compositional criteria for shoshonitic and potassic rocks (e.g., $K_2O > \sim 2.5$ wt.% and SiO_2 52–56 wt.%, $K_2O/Na_2O > 0.5$, etc.), most of the Compton intrusive data do not and are plotted as shaded symbols. Some of these include intermediate to felsic igneous rocks (i.e., numerous analyses of Compton intrusions and Balachey plutons) and volcanic rocks with higher SiO_2 and lower CaO plus MgO contents than suggested by Müller et al. (1992).

Thick (~ 200 μm) polished thin sections were examined using a Zeiss EVO 50 series Scanning Electron Microscope (SEM) equipped with a Backscattered Electron Detector at the Geological Survey of Canada (GSC) in Ottawa. The Oxford energy dispersive spectrometry (EDS) system includes the X-MAX 150 Silicon Drift Detector, the INCA

402 Energy 450 software and the latest AZtec microanalysis software. The SEM was
403 operating at 20 kV with a beam current of 400pA to 1nA. Once suitable grains were
404 located using a petrographic microscope and SEM, uraninite grains were analyzed with a
405 Cameca SX50 electron microprobe at the GSC and a JEOL 8230 electron microprobe at
406 the University of Ottawa. Operating conditions were 20 kV accelerating voltage and
407 10nA current, with 20 s on peak and 10 s off-peak counting times. A mixture of natural
408 and synthetic pure metal, simple oxides and simple compounds were used as standards.
409 Data were reduced with a ZAF matrix correction using Probe for Windows software
410 (Armstrong 1988) and Pouchou and Pichoir (1984) using JEOL software.

411

412 Trace element concentrations were analysed in-situ on polished thin sections at the
413 Geological Survey of Canada using a Photon-Machines Analyte.193 excimer laser
414 ablation system (LA-ICP-MS) ($\lambda = 193$ nm) with Helex ablation cell and an Agilent
415 7700x quadrupole ICP-MS. The laser was operated at 10 Hz, at 50% of 5 mJ for polished
416 sections 200 μm thick whereas standard polished thin sections (~ 30 μm thick) were
417 analysed at a lower frequency of 5 Hz to reduce the ablation rate. Helium gas was used to
418 transport ablated material from the ablation cell and was mixed with argon plasma (flow
419 rate of 1.05 mL/min) before entering the ICP-MS. Data acquisition cycles were 100 s in
420 length, including ~ 40 s of background signal monitoring prior to ablation. Standards
421 were analysed using a 52 μm spot size (NIST 610), whereas samples were ablated with a
422 26 μm diameter spot size. Element concentrations were determined using the GLITTER
423 program (version 4.4.3, Macquarie Research Ltd), with data acquisition adjusted to
424 exclude data from inclusions and/or ablation of surrounding minerals. In addition to

standards, runs were bracketed by analyses of GSE-1G plus BCR2 and normalized to uranium contents determined by EMPA, following methods outlined in Jackson (2008). Trace element concentrations were also verified through analysis of well-characterized uraninite from the Mistamisk occurrence, Quebec (e.g., Kish and Cuney 1981; Bonhoure et al. 2007; Mercadier et al. 2011; Lach et al. 2013).

6. Results

6.1 East Arm whole rock geochemistry

In terms of geochemical discrimination plots (Fig. 6), the Pearson Formation volcanic rocks and Compton intrusions plot within the volcanic arc field of Pearce et al. (1984) and the continental arc fields of Müller et al. (1992). The volcanic and plutonic rocks are shoshonitic in nature (Fig. 6e) with suprasubduction-zone geochemical signatures, including negative primitive mantle normalized Ta, Nb, P, and Ti anomalies. However, as noted by Ootes et al. (2017) and shown in Figure 6, Great Bear magmatic zone rocks of similar age plot in the same fields and were suggested to reflect more complex sources, such as derivation of primary melts from a mantle wedge contaminated by subducting pelagic sediments indicated by similar Nb/La values to global subducting sediment composition and flux (GLOSS; Fig. 6f). Conversely, or in addition to, the presence of duplexed crust or crust imbricated with upper lithospheric mantle observed across the Slave-Taltson-Churchill teleseismic transect (Snyder and Kjarsgaard 2013) may explain the subduction-related signature observed in the co-magmatic Compton intrusive and Pearson Formation volcanic rocks (Kjarsgaard et al. 2013a).

6.2 REE in uraninite

Uraninite from the REX occurrence occurs in steeply-dipping, north-trending coarse-grained, magnetite, apatite, actinolite $\pm$ calcite veins, spatially associated with magnetite and actinolite. The uraninite grains are REE-rich, with Σ REE values from 6.4–9.4 wt. % and thorium values between 0.25–0.5 wt. % Th (Table 3). Chondrite-normalized REE patterns of the uraninite grains produce slightly light REE-rich profiles with strong negative europium anomalies (Fig. 7). These profiles and trace element concentrations are consistent with uraninite patterns measured from IOA and magnetite-group IOCG occurrences in the Great Bear magmatic zone that occur within the same mineral assemblages (Fig. 7b-c; Potter et al. 2014). The patterns are also similar to magmatic (i.e., pegmatite-hosted) uranium mineralization reported in Mercadier et al. (2011) and Frimmel et al. (2014). Slight variations in the uraninite patterns from Fab and Cole Lake can be explained by the presence of co-precipitated monazite at Cole Lake and greater degrees of low temperature alteration (hematite-bearing potassic-iron and low temperature calcic-iron) at Fab Lake. As shown by Martz et al. (2017) low temperature alteration of primary uraninite can cause enrichment in HREE coupled with depletion of LREE in chondrite-normalized plots.

7. Discussion

7.1 East Arm Basin linkages with the Great Bear magmatic zone arc volcanism

The presence of subsidence and nappe tectonics plus the Compton calc-alkaline intrusions led Hoffman (1987) to propose that basin formation may have been related to subduction of a re-entrant oceanic lithosphere south of the Slave province, equivalent to the slab above which the Great Bear magmatic zone was generated. Gandhi and Prasad

(1982) proposed that compositional data including a west to east differentiation trend along the Compton intrusions, and the presence of mafic cognate inclusions indicate that the intrusions represent products of differentiation from mafic magmas at depth. Alternatively they could record injection and mixing of mafic and more evolved differentiates within magma chambers. Structural and sedimentological observations led Hoffman (1981) to state that the overall distribution of the intrusions is not related to major strike-slip faults such as the northeast-trending McDonald fault as strike-slip faulting occurred during deposition of the Et-Then Group which unconformably overlies the intrusions (Figs. 4). However, as noted by Kjarsgaard et al. (2013a) the Compton intrusions and Pearson Formation volcanic rocks occur parallel to two major structures: the margin of the Archean Slave craton, and the Great Lake shear zone and associated splays (Fig. 3). Furthermore, the older Union Island Group volcanic and sedimentary rocks are rift related (Sheen et al. 2019), with the long axis of this rift parallel to these two major structures. The older Wilson Island Group in the southern part of the East Arm Basin, a thick platformal sequence deposited on thinned sialic crust, also indicate the presence of weakened lithosphere. Therefore, the underlying geology and tectonic history support that this linear corridor adjacent to and along the southeastern margin of the Slave craton was a conduit for Compton-Pearson magmas generated at depth that intruded the Paleoproterozoic volcano-sedimentary sequence.

The linear, belt-like nature of the Compton intrusions and Pearson Formation volcanic rocks, as well as their “arc-like” geochemistry and age suggests a direct relationship with the eastward dipping Great Bear magmatic zone subduction zone. However, Kjarsgaard et al. (2013a) suggested this to be problematic as the Compton and Pearson belts lie

almost perpendicular to the Great Bear subduction zone. However, there are modern analogs in arc volcanism where magmatism occurred perpendicular or oblique to the trench axis. In the New Britain Island arc, a chain of volcanoes extends for 60 km perpendicular to the main volcanic front (Woodhead et al. 1988). Davies et al. (1987) originally proposed that flexure in the subducting plate may have given rise to this orientation, while Woodhead et al. (1988) proposed that a high plate convergence rate may have disturbed the normal dynamics of slab dehydration and melting. More recently, Pacey et al. (2013) documented linear chains of volcanoes that extend 10–100 km at ca. 60° angle to the Sunda Arc in Indonesia and proposed that the volcanism exploited extensional or strike-slip faults.

The linear belts of Compton intrusions and Pearson volcanic rocks currently lie 50–250 km from the inferred margin of the Great Bear magmatic zone at a ~50° angle. From sampling of the Pearson Formation volcanic rocks, Gong et al. (2018) proposed that small blocks in the fold belt experienced significant (~60°) vertical-axis rotations during large dextral displacements along the McDonald Fault system. Block rotation is a mechanism for conjugate transcurrent faults to accommodate slip (Freund 1970, 1974), such as the McDonald Fault system in the East Arm Basin that has post-1.86 Ga displacements of 70–125 km (Thomas et al. 1976; Hoffman et al. 1977; Hoffman 1981; Bowring et al. 1984). Accounting for possible widening of the angle between the McDonald and Bathurst fault systems (Fig. 1) due to far-field stresses (Mitchell et al. 2010), and post-1.86 Ga displacement along the fault, intrusion of the Compton belt granitoids would have been 0–125 km at ~60° from the Great Bear arc front, consistent with observations from the Sunda Arc in Indonesia (Pacey et al. 2013).

7.2 IOCG potential of the East Arm Basin

The East Arm Basin contains all the criteria outlined by Skirrow (2010) to define the most prospective terranes for major hematite-group IOCG±U deposits: (i) high-level intermediate to felsic intrusions with elevated uranium contents (*Compton intrusions*); (ii) crustal-scale structural pathways for magmas and fluids (*Union Island Group rift, Great Slave Lake shear zone, Murky Channel Fault; Fig. 1*); (iii) pre-IOA and IOCG, oxidized sedimentary basins commonly containing evidence for evaporites (*gypsum, halite and anhydrite casts, lower Christie Bay Group, Great Slave Supergroup; Fig. 4*); (iv) mafic extrusive magmatism (*Pearson Formation*); (v) a syn- to post-compressional tectonic regime (*fold-and-thrust belt, post-thrust magmatism and graben sedimentation*), (vi) district- to deposit-scale magnetite-rich alteration characterized by high temperature calcic-iron metasomatism, ‘rare’ metal anomalies (Th, REE) and generally minor Cu-Au-Fe mineralization (*IOA and numerous polymetallic and Cu ± Au mineral occurrences*); (vii) evidence of upper crustal magnetite-forming hydrothermal regimes interacting with oxidized surface-derived fluids in extensional or transtensional settings (*oxidation of magnetite and precipitation of uranium minerals in IOA showings*); (viii) hydrological settings in which large volumes of oxidized waters were mobilized through uranium-rich host rocks to sites associated with magnetite formation, allowing fluid mixing (*hematite staining in Pearson Formation volcanic rocks*); and (ix) deposit-scale hydrothermal alteration zones containing combinations of hematite, chlorite, sericite, carbonate, pyrite, gold, chalcopyrite, bornite, chalcocite, barite and various REE and phosphate minerals (*various mineral occurrences and alteration along margins of Compton intrusions*). The

541 altered margins of Compton intrusions with igneous and sedimentary rock fragments set
542 in a red felsite matrix comprised of antiperthitic albite and quartz (Badham 1978a) also
543 exhibit characteristics in common with the Southern Breccia occurrence of the Great Bear
544 magmatic zone that is linked with formation of the NICO deposit (Montreuil et al. 2015;
545 Potter et al. in press).

546
547 The Compton intrusions contain elevated uranium concentrations which may account
548 for the numerous uranium showings documented in the region through leaching and
549 transport of hexavalent uranium in oxidized fluids (Gandhi and Prasad 1982). Whole-
550 rock geochemistry of the Compton intrusions (Gandhi and Prasad 1982; Kjarsgaard et al.
551 2013a) indicates that the laccoliths are metaluminous to peraluminous in character, which
552 makes them highly fertile sources for scavenging uranium and/or secondary uranium
553 enrichment (Cuney 2010). The TEL and SHUM occurrences of the East Arm also share
554 key characteristics with IOU mineralization outlined by Skirrow et al. (2011) and
555 described by Mernagh and Mieozitis (2008) for the Mount Painter system in southern
556 Australian.

557
558 In the Great Bear magmatic zone, geological relationships and geochronology
559 constrain formation of the IOA-IOCG deposits to a 5 m.y. window linked to eruption of
560 ca. 1.87 Ga magmas under largely sub-aerial conditions while co-genetic sub-volcanic
561 intrusions were emplaced at the base of the volcanic piles (Montreuil et al. 2016a; Ootes
562 et al. 2017). At ca. 1.87 Ga, the East Arm Basin experienced similar magmatic activity,
563 with eruption of subaerial Pearson Formation volcanic rocks (Hofmann et al. 1977; Goff

1984; Kjarsgaard et al. 2013a) and emplacement of the co-genetic Compton intrusions into fluid-saturated sedimentary sequences. Following emplacement of the Compton intrusions, magmatism waned in the East Arm while extensive calc-alkaline volcanism and intrusion of co-genetic plutons continued in the Great Bear magmatic zone until ca. 1855 Ma. However, the 1866–1855 Ma phase of magmatism in the Great Bear magmatic zone postdates IOA-IOCG mineralization in the district (Ootes et al. 2017).

The East Arm Basin showings define areas with IOA-IOCG mineralization such as the Rex, Labelle, UR and Bell showings (Figs. 3 and 5). Using the Montreuil et al. (2013) IOCG alteration discrimination plot, combined with chemical bar codes representing the molar proportions of dominant cations for each alteration facies (Corriveau et al. 2017; Fig. 8a, c), the alteration related to development of the systems is recorded in rocks sampled throughout the East Arm Basin. These altered samples typically have chemical bar codes comprised of less than three dominant cations in Figure 8. Least-altered igneous rocks, clastic sedimentary rocks and common metamorphic rocks fall within the field of least-altered rocks and have chemical bar codes with fairly equal cationic proportions in their chemical bar codes (i.e., three to five dominant cations except for rhyolite as shown in Fig. 8b; cf. Corriveau et al. 2018). Altered rocks overprinted by lower temperature alteration may fall in the least altered field, but have only one to three dominant cations in the bar codes. Another distinctive feature of late, low temperature alteration is a high proportion of magnesium with respect to the other cations induced by chlorite or carbonate alteration. This is well illustrated in the East Arm samples by the magnesium-rich bar codes in Figure 8c.

587 Certain geological units, such as the Seton formation volcanic rocks, exhibit more
588 intense alteration such as sodic, calcic-iron and more importantly, potassic-iron alteration
589 (Fig. 8a). The alteration is reaffirmed through comparison of the Seton formation
590 chemical bar codes to published compositions of unaltered reference rocks (Fig. 8b).
591 Regionally, the Seton volcanic rocks are chemically alkaline (Olade and Morton 1972;
592 Kjarsgaard et al. 2013a). Olade (1975) suggested they were subjected to sodic
593 metasomatism; sodic and potassic alteration were also noted in samples collected by
594 Kjarsgaard et al. (2013a). In addition, sodic alteration of Seton formation subvolcanic
595 granophyres (Olade and Morton 1972) and porphyries (Hoffman et al. 1977) with albite
596 (albitized) phenocrysts has been documented. Potassic-iron altered Seton formation rocks
597 host mineralization at the BBX showings (Fig. 3), where the host lithology (intrusive
598 volcanic breccia pipe), brecciation, and alteration (iron-oxide, albitization and chlorite
599 with concentric zones of sericite-carbonate-sulfide) are consistent with IOCG-related
600 mineralization described in the Port Radium-Echo Bay district by Mumin et al. (2010).
601 Furthermore, the age of mineralization at BBX is 1870 ± 15 Ma (Blackadar 1981),
602 identical to the age of IOA-IOCG mineralization in the Great Bear magmatic zone and
603 Compton intrusions. A string of $\text{Cu} \pm \text{Ag} \pm \text{Au}$ occurrences in quartz-carbonate veins and
604 shear zones within the surrounding Sosan Group quartzite (e.g. Bay, Woosie and McLeod
605 showings), are also consistent with the presence of quartz-carbonate veins peripheral to
606 IOA-IOCG showings in the Great Bear magmatic zone (Acosta-Góngora et al. 2015;
607 Corriveau et al. 2016).
608

The Compton intrusions exhibit significant sodic enrichment, which is reflected in samples that deviate from the calc-alkaline reference (Fig. 8b) and which plot within the sodic and high temperature calcic-iron domain of the IOCG discrimination plot (Fig. 8a, c). Gandhi and Prasad (1982) ascribed this enrichment to late sodic metasomatism during crystallization, but it could also reflect albitization related to the early development of an iron oxide and alkali-calcic alteration system. Within the intrusions, sodium contents reach as high as 8.50 wt. % Na_2O , clearly well above the average monzonite value of 3.73 % Na_2O presented by Lemaitre (1976). In the IOCG discrimination plot (Fig. 8a), several Compton intrusion samples plot within the sodic and sodic-calcic-iron domains, and exhibit molar proportions dominated by sodium and/or calcium (Fig. 8c). The sodium content manifests as increased albite within the intrusive bodies. Importantly, in the altered Compton intrusions, hornblende and biotite occur as medium-grained aggregates with magnetite, apatite and zircon. This mineralogy and texture was also observed at the Balachey and Rainy Lake plutons and the Fab Lake IOCG prospect in the Great Bear magmatic zone, where monzonite plutons with disseminated magnetite-amphibole-biotite-apatite aggregations represent local alteration of the host rocks and are spatially associated with IOA-IOCG mineralization (Hildebrand 1986; Potter et al. 2013b). Within the Rainy Lake intrusion, border monzonite phases hosting IOA veins and the central monzonite phase also exhibit elevated sodium contents of 6.01 and 7.38 wt. % Na_2O , respectively.

The trace element patterns of uraninite from the IOA veins (Fig. 7) in the East Arm are similar to patterns of uraninite from the Great Bear magmatic zone, reaffirming that

632 uraninite formed under similar conditions and fluid chemistry. As proposed by Potter et
633 al. (2014), the trace element patterns of uraninite in the IOA veins (Fig. 7) are inferred to
634 reflect precipitation from high temperature fluid(s) ($>350^{\circ}\text{C}$) and are very similar to
635 intrusive or magmatic (pegmatitic) uraninite patterns as reported by Mercardier et al.
636 (2011). The moderate to high thorium contents in uraninite from occurrences in the East
637 Arm (Table 3) and Great Bear magmatic zone also mirror magmatic-derived
638 compositions (Cuney 2010), ranging from 0.25 to 12.9 wt.% Th (Potter et al. 2014). The
639 negative europium anomalies are interpreted to reflect scavenging of metals during
640 reduced sodic alteration and subsequent precipitation from fluids that evolved and
641 equilibrated through progressive sodic (albite), calcic-iron (amphibole + magnetite) and
642 ultimately potassic-iron (K-feldspar/biotite + Fe-oxides) alteration.

643
644 Weak, cryptic and distal expressions of these alteration systems are difficult to detect
645 and even moderate to strong degrees of alteration may preserve igneous or sedimentary
646 textures. For example, in the Great Bear magmatic zone, a hematite “ironstone” occurs
647 structurally above the Mag Hill IOA prospect (Mumin et al. 2010) but preserved relicts of
648 the porphyritic andesite textures and incremental destruction of the relicts to massive
649 hematite support a metasomatic origin (Corriveau et al. 2010a, b). In addition, regular
650 examples of stratabound magnetite alteration of albitized metasilstone occur within and
651 south of the NICO deposit (Corriveau et al. 2016, 2018). As such, historical iron
652 formations (e.g. TEL and SHUM showings) and specular hematite occurrences (e.g. Iron
653 Islands and Wilson Island showings) should be examined in detail for potassic-iron

and/or high temperature calcic-iron alteration as they may represent products of these metasomatic systems.

8. Concluding remarks and exploration guidelines for the East Arm Basin

The structural architecture, regional geology and geochronology of key geological units clearly link the East Arm to the Great Bear magmatic zone at ca. 1.87 Ga and support the hypothesis that the East Arm Basin is highly prospective for undiscovered IOCG and affiliated mineralization. For most of the East Arm occurrences discussed in this study, sodic metasomatism and early amphibole-magnetite-apatite (IOA) $\pm$ uraninite veins are overprinted by K-feldspar, carbonate, hematite, sericite, and sulfides. These relationships are interpreted as early sodic plus high temperature calcic-iron alteration superimposed by potentially fertile, lower temperature potassic-iron alteration that formed during the same period (ca. 1.87 Ga) as IOA-IOCG mineralization in the Great Bear magmatic zone (Figs. 2 and 8). As noted by Corriveau et al. (2010b), following discovery of alteration zones consisting of either: albitite or albite/amphibole, magnetite-amphibole-apatite (IOA), or potassium-feldspar with iron oxide (magnetite or hematite), exploration should focus on increased potassium-iron alteration (potassium-feldspar, biotite or sericite and magnetite or hematite) coupled with brecciation. As such, exploration efforts in the East Arm Basin should focus on delineating zones with intense potassic-iron alteration in Seton formation volcanic rocks peripheral to fault zones and Compton intrusions - Pearson Formation volcanic rocks and then expanded to follow the entire iron oxide and alkali-calcic system through field mapping and application of geochemical, radiometric, magnetic and gravity surveys. Geophysical data can be

processed to highlight dense and magnetic anomalies characteristic of IOCG systems (e.g. Hayward et al. 2013), while the transition from magnetite to hematite, in association with potassic alteration and sulfide-bearing mineralization, can produce the most sought after geophysical expression in IOCG exploration: coincident, or slightly laterally or vertically offset, positive gravity and magnetic anomalies (Nisbet et al. 2000).

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6. References

- Acosta-Góngora, P., Gleeson, S.A., Samson, I.M., Corriveau, L., Ootes, L., Taylor, B.E., Creaser, R.A., and Muehlenbachs, K. 2015. Genesis of the Paleoproterozoic NICO iron oxide–cobalt–gold–bismuth deposit, Northwest Territories, Canada: evidence from isotope geochemistry and fluid inclusions. *Precambrian Research*, **268**: 168–193.
- Argy, G.H., and Siega, L.J. 1971. Report of regional geology and property history on BBX mineral claims, Aristifats Lake area. Northwest Territories Geoscience Office, Assessment report # 0196633 [online], available from www.nwtgeoscience.ca/

- 703 Armstrong, J.T. 1988. Quantitative analysis of silicate and oxide materials: comparison
704 of Monte Carlo, ZAF, and $\psi(\rho z)$ procedures. *Microbeam Analysis*, pp. 239–246.
- 705 Azar, B. 2007. The lithogeochemistry of volcanic and subvolcanic rocks of the Fab Lake
706 area, Great Bear magmatic zone, Northwest Territories, Canada. M.Sc. thesis,
707 University of Toronto, Toronto, Canada.
- 708 Badham, J.P.N. 1978a. Magnetite-apatite-amphibole-uranium and silver-arsenide
709 mineralization in lower Proterozoic igneous rocks, East Arm, Great Slave Lake,
710 Canada. *Economic Geology*, **73**: 1474–1491.
- 711 Badham, J.P.N. 1978b. The early history and tectonic significance of the East Arm
712 graben, Great Slave Lake, Canada. *Tectonophysics*, **45**: 201–215.
- 713 Badham, J.P.N. 1981. Petrochemistry of late Aphebian (-1.8 Ga) calc-alkaline diorites
714 from the East Arm of Great Slave Lake, N.W.T., Canada. *Canadian Journal of Earth
715 Sciences*, **18**: 1018–1028.
- 716 Badham, J.P.N., and Muda, M.M.Z. 1980. Mineralogy and paragenesis of hydrothermal
717 mineralizations in the East Arm of Great Slave Lake. *Economic Geology*, **75**: 1220–
718 1238.
- 719 Badham, J.P.N., and Stanworth, C.W. 1977. Evaporites from the lower Proterozoic of the
720 East Arm, Great Slave Lake. *Nature*, **268**: 516–517.
- 721 Barnes, F.Q. 1952. McLean Bay map-area, District of Mackenzie, Northwest Territories.
722 Geological Survey of Canada, Paper 52-5.
- 723 BHP 2018. BHP annual report 2018. BHP Billiton Limited [online] available from
724 www.bhp.com [accessed 6 November 2018]
- 725 Blackadar, D.W. 1981. The Artistifats diatreme: a Proterozoic copper-lead-cobalt-nickel-
726 silver deposit, Northwest Territories. M.Sc. thesis, University of Alberta, Calgary,
727 Canada.
- 728 Bonhoure, J., Kister, P., Cuney, M., and Deloule, E. 2007. Methodology for rare earth
729 element determinations of uranium oxides by ion microprobe. *Geostandards and
730 Geoanalytical Research*, **31**: 209–225.
- 731 Bowring, S.A., and Grotzinger, J.P. 1992. Implications of new chronostratigraphy for
732 tectonic evolution of Wopmay orogen, northwest Canadian Shield. *American Journal
733 of Science*, **292**: 1–20.
- 734 Bowring, S.A., Van Schmus, W.R., and Hoffman, P.F. 1984. U-Pb zircon ages from
735 Athapuscow aulacogen, East Arm of Great Slave Lake, N.W.T., Canada. *Canadian
736 Journal of Earth Sciences*, **21**: 1315–1324.

- 737 Brown, I.C. 1950. Fort Resolution N.W.T. - Preliminary map and notes. Geological
738 Survey of Canada, Paper 50–28.
- 739 Burgess, H., Gowans, R.M., Hennessey, B.T., Lattanzi, C.R., and Puritch, E. 2014.
740 Technical report on the feasibility study for the NICO gold–cobalt–bismuth–copper
741 deposit, Northwest Territories, Canada. Fortune Minerals Ltd., NI 43-101 Technical
742 Report No. 1335, Available at www.sedar.com
- 743 Corriveau, L., and Mumin, A.H. 2010. Exploring for iron oxide-copper-gold (Ag-Bi-Co-
744 U) deposits: case examples, classification and exploration vectors. *In* Exploring for
745 iron oxide-copper-gold (Ag-Bi-Co-U) deposits, examples from Canada and global
746 analogues. Edited by L. Corriveau and A.H. Mumin. Geological Association of
747 Canada, Short Course Notes 20, pp. 1–13.
- 748 Corriveau, L., Setterfield, T., and Mumin, A.H. 2010a. IOCG environments in Canada:
749 characteristics and geological vectors to ore. *In* Hydrothermal iron oxide copper-gold
750 and related deposits: a global perspective, volume 4 - advances in the understanding
751 of IOCG deposits. Edited by T.M. Porter. Porter Geoscience Consultancy Publishing,
752 Adelaide, pp. 311–343.
- 753 Corriveau, L., Williams, P., and Mumin, A.H. 2010b. Alteration vectors to IOCG
754 mineralization from unchartered terranes to deposits. *In* Exploring for iron oxide-
755 copper-gold (Ag-Bi-Co-U) deposits, examples from Canada and global analogues.
756 Edited by L. Corriveau and A.H. Mumin. Geological Association of Canada, Short
757 Course Notes 20, pp. 89–110.
- 758 Corriveau, L., Mumin, A.H., and Montreuil, J.-F. 2011. The Great Bear magmatic zone:
759 the IOCG spectrum and related deposit types. *In* Proceedings of the 11th biennial
760 meeting Society for Geology Applied to Mineral Deposits, Antofagasta, Chile, pp.
761 524–526.
- 762 Corriveau, L., Lauzière, K., Montreuil, J.-F., Potter, E.G., Hanes, R., and Prémont, S.
763 2015. Dataset of new lithogeochemical analysis in the Great Bear magmatic zone,
764 Northwest Territories, Canada. Geological Survey of Canada, Open File 7643.
- 765 Corriveau, L., Montreuil, J.-F., and Potter, E.G. 2016. Alteration facies linkages among
766 iron oxide-copper-gold, iron oxide-apatite, and affiliated deposits in the Great Bear
767 magmatic zone, Northwest Territories, Canada. *Economic Geology*, **111**: 2045–2072.
- 768 Corriveau, L., Potter, E.G., Acosta-Góngora, P., Blein, O., Montreuil, J.-F., De Toni,
769 A.F., Day, W., Slack, J.F., Ayuso, R.A., and Hanes, R. 2017. Petrological mapping
770 and chemical discrimination of alteration facies as vectors to IOA, IOCG, and
771 affiliated deposits within Laurentia and beyond. *In* Proceedings of the 14th biennial
772 Society of Geology Applied for Mineral Deposits meeting, Québec City, Canada, pp.
773 851–855.

- 774 Corriveau, L., Potter, E.G., Montreuil, J.-F., Blein, O., Ehrig, K., and De Toni, A. 2018.
775 Iron-oxide and alkali-calcic alteration ore systems and their polymetallic IOA, IOCG,
776 skarn, albitite-hosted U±Au±Co, and affiliated deposits: a short course series. Part 2:
777 overview of deposit types, distribution, ages, settings, alteration facies, and ore
778 deposit models. Geological Survey of Canada, Scientific Presentation 81,
779 doi:10.4095/306560.
- 780 Couture, J.F., Cole, G., Zhang, B., Nilsson, J., Dance, A., Scott, C., and Vidal, M.I. 2017.
781 Technical report for the Candelaria copper mining complex, Atacama Province,
782 Region III, Chile [online]. Available from www.lundinmining.com [accessed 6
783 November 2018].
- 784 Cuney, M. 2010. Evolution of uranium fractionation processes through time: driving the
785 secular variation of uranium deposits. *Economic Geology*, **105**: 553–569.
- 786 Davies, H.L., Honza, E., Tiffin, D.L., Lock, J., Okuda, Y., Keene J.B., Murakami, F., and
787 Kisimoto, K. 1987. Regional setting and structure of the Western Solomon Sea. *Geo-*
788 *Marine Letters*, **7**: 153–160.
- 789 Davis, W.J., Ootes, L., Newton, L., Jackson, V., and Stern, R.A. 2015. Characterization
790 of the Paleoproterozoic Hottah terrane, WopmayOrogen using multi-isotopic (U-Pb,
791 Hf and O) detrital zircon analyses: an evaluation of linkages to northwest Laurentian
792 Paleoproterozoic domains. *Precambrian Research*, **269**: 296–310.
- 793 Drummond, B., Lyons, P., Goleby, B., and Jones, J. 2006. Constraining models of the
794 tectonic setting of the giant Olympic Dam iron oxide–copper–gold deposit, South
795 Australia, using deep seismic reflection data. *Tectonophysics*, **420**: 91–103.
- 796 Edelbro, C., Sjöberg, J., Malmgren, L., and Dahnér-Lindqvist, C. 2012. Prediction and
797 follow-up of failure and fallouts in footwall drifts in the Kiirunavaara mine. *Canadian*
798 *Geotechnical Journal*, **49**: 546–559.
- 799 Enkin, R., Corriveau, L., and Hayward, N. 2016. Metasomatic alteration control of
800 petrophysical properties in the Great Bear magmatic zone (Northwest Territories,
801 Canada). *Economic Geology*, **111**: 2073–2085.
- 802 Freund, R. 1970. Rotation of strike-slip faults in Sistan, southeast Iran. *Journal of*
803 *Geology*, **78**: 188–200.
- 804 Freund, R. 1974. Kinematics of transform and transcurrent faults. *Tectonophysics*, **21**:
805 93–134.
- 806 Frimmel, H.E., Schedel, S., and Brätz, H. 2014. Uraninite chemistry as forensic tool for
807 provenance analysis. *Applied Geochemistry*, **48**: 104–121.

- 808 Fryer, B.J., and Taylor, R.P. 1987. Rare earth elements distributions in uraninites:
809 implications for ore genesis. *Chemical Geology*, **63**: 101–108.
- 810 Gale, A., Dalton, C.A., Langmuir, C.H., Su, Y., and Schilling, J-G. 2003. The mean
811 composition of ocean ridge basalts. *Geochemistry, Geophysics, Geosystems*, **14**:
812 489–518.
- 813 Gandhi, S.S. 1983. Origin of pitchblende veins in the Union Island area, Great Slave
814 Lake, Northwest Territories. Geological Survey of Canada, Paper 83-1B, pp. 317–
815 326.
- 816 Gandhi, S.S., and Bell, R.T. 1996. Kiruna/Olympic Dam iron–copper–uranium–gold. *In*
817 *Geology of Canadian mineral deposit types*. Edited by O.R. Eckstrand, W.D. Sinclair
818 and R.I. Thorpe. Geological Survey of Canada, *Geology of Canada* 8, pp. 513–522.
- 819 Gandhi, S.S., and Prasad, N. 1982. Comparative petrochemistry of two cogenetic
820 monzonitic laccoliths and genesis of associated uraniferous actinolite-apatite-
821 magnetite veins, East Arm of Great Slave Lake, District of Mackenzie. *In* *Uranium in*
822 *granites*. Edited by Y.T. Maurice. Geological Survey of Canada Paper 81-23, pp. 81–
823 90.
- 824 Gandhi, S.S., and van Breemen, O. 2005. U-Pb geochronology of detrital zircons from
825 the Treasure Lake Group—new evidence for Paleoproterozoic collisional tectonics in
826 the southern Hottah terrane, northwestern Canadian Shield. *Canadian Journal of Earth*
827 *Sciences*, **42**: 833–845.
- 828 Gandhi, S.S., Prasad, N., and Charbonneau, B.W. 1996. Geological and geophysical
829 signatures of a large polymetallic exploration target at Lou Lake, southern Great Bear
830 magmatic zone, Northwest Territories. Geological Survey of Canada, Paper 1996-E,
831 pp. 147–158.
- 832 Gandhi, S.S., Mortensen, J.K., Prasad, N., and van Breemen, O. 2001. Magmatic
833 evolution of the southern Great Bear continental arc, northwestern Canadian Shield:
834 geochronological constraints. *Canadian Journal of Earth Sciences*, **38**: 767–785.
- 835 Gandhi, S.S., Kerswill, J.A., and Lemkow, D. 2013. Potential for vein-hosted copper
836 mineralization in the area of the proposed Thaidene Nene national park, East Arm of
837 Great Slave Lake. *In* *Mineral and energy resource assessment for the proposed*
838 *Thaidene Nene national park reserve in the area of the East Arm of Great Slave Lake,*
839 *Northwest Territories*. Edited by D.F. Wright, E.J. Ambrose, D. Lemkow and G.F.
840 Bonham-Carter. Geological Survey of Canada, Open File 7196, pp. 437–461.
- 841 Goad, R.E., Mumin, A.H., Duke, N.A., Neale, K.L., and Mulligan, D.L. 2000a. Geology
842 of the Proterozoic iron oxide-hosted NICO cobalt-gold-bismuth and Sue-Dianne
843 copper-silver deposits, southern Great Bear Magmatic Zone, Northwest Territories,
844 Canada. *In* *Hydrothermal iron oxide copper-gold and related deposits: a global*

- 845 perspective, volume 1. Edited by T.M. Porter. Porter Geoscience Consultancy
846 Publishing, Adelaide, pp. 249–267.
- 847 Goad, R.E., Mumin, A.H., Duke, N.A., Neale, K.L., Mulligan, D.L., and Camier, W.J.
848 2000b. The NICO and Sue-Dianne Proterozoic, iron oxide-hosted, polymetallic
849 deposits, Northwest Territories: application of the Olympic Dam model in
850 exploration. *Exploration and Mining Geology*, **9**: 123–140.
- 851 Goff, S.P. 1984. The magmatic and metamorphic history of the East Arm, Great Slave
852 Lake, N.W.T. Ph.D. thesis, University of Alberta, Edmonton, Canada.
- 853 Gong, Z., XinXin, X., Evans, D.A.D., Hoffman, P.F., Mitchell, R.N., and Bleeker, W.
854 2018. Paleomagnetism and rock magnetism of the ca. 1.87 Ga Pearson Formation,
855 Northwest Territories, Canada: a test of vertical-axis rotation within the Great Slave
856 basin. *Precambrian Research*, **305**: 295–309.
- 857 Gorton, M.P., and Schandl, E.S. 2000. From continents to island arcs: a geochemical
858 index of tectonic setting for arc-related and within-plate felsic to intermediate
859 volcanic rocks. *The Canadian Mineralogist*, **38**: 1065–1073.
- 860 Groves, D.I., Bierlein, F.P., Meinert, L.D., and Hitzman, M.W. 2010. Iron oxide copper-
861 gold (IOCG) deposits through Earth history: implications for origin, lithospheric
862 setting, and distinction from other epigenetic iron oxide deposits. *Economic Geology*,
863 **105**: 641–654.
- 864 Hanmer, S., Bowring, S.A., van Breemen, O., and Parrish, R. 1992. Great Slave Lake
865 shear zone, NW Canada: mylonitic record of Early Proterozoic continental
866 convergence, collision and indentation. *Journal of Structural Geology*, **14**: 757–773.
- 867 Hayward, N., and Corriveau, L. 2014. Fault reconstructions using aeromagnetic data in
868 the Great Bear magmatic zone, Northwest Territories, Canada. *Canadian Journal of*
869 *Earth Sciences*, **51**: 1–16.
- 870 Hayward, N., Corriveau, L., Craven J.A., and Enkin, R.J. 2016. Geophysical signature of
871 the NICO Au-Co-Bi-Cu deposit and its iron oxide-alkali alteration system, Northwest
872 Territories, Canada. *Economic Geology*, **111**: 2087–2109.
- 873 Hayward, N., Enkin, R., Corriveau, L., Montreuil, J-F., and Kerswill, J. 2013. The
874 application of rapid potential field methods for the targeting of IOCG mineralisation
875 based on physical property data, Great Bear magmatic zone, Canada. *Journal of*
876 *Applied Geophysics*, **94**: 42–58.
- 877 Hennessey, B.T., and Puritch, E. 2008. A technical report on a mineral resource estimate
878 for the Sue-Dianne deposit, Mazenod Lake area, Northwest Territories, Canada.
879 Fortune Minerals Limited, Technical Report.

- 880 Hildebrand, R.S. 1986. Kiruna-type deposits: their origin and relationship to intermediate
881 subvolcanic plutons in the Great Bear magmatic zone, northwest Canada. *Economic*
882 *Geology*, **81**: 640–659.
- 883 Hildebrand, R.S., and Bowring, S.A. 1984. Continental intra-arc depressions: a
884 nonextensional model for their origin, with a Proterozoic example from Wopmay
885 orogen. *Geology*, **12**: 73–77.
- 886 Hildebrand, R.S., Hoffman, P.F., and Bowring, S.A. 1987. Tectono-magmatic evolution
887 of the 1.9 Ga Great Bear magmatic zone, Wopmay Orogen, Northwestern Canada.
888 *Journal of Volcanology and Geothermal Research*, **32**: 99–118.
- 889 Hildebrand, R.S., Hoffman, P.F., and Bowring, S.A. 2010a. The Calderian orogeny in
890 Wopmay orogen (1.9 Ga), northwestern Canadian Shield. *Geological Society of*
891 *America Bulletin*, **122**: 794–814.
- 892 Hildebrand, R.S., Hoffman, P.F., Housh, T., and Bowring, S.A. 2010b. The nature of
893 volcano-plutonic relations and shapes of epizonal plutons of continental arcs as
894 revealed in the Great Bear magmatic zone, northwestern Canada. *Geosphere*, **6**: 812–
895 839.
- 896 Hitzman, M.W., and Valenta, R.K. 2005. Uranium in iron oxide-copper-gold (IOCG)
897 systems. *Economic Geology*, **100**: 1657–1661.
- 898 Hitzman, M.W., Oreskes, N., and Einaudi, M.T. 1992. Geological characteristics and
899 tectonic setting of Proterozoic iron oxide (Cu-U-Au-LREE) deposits. *Precambrian*
900 *Research*, **58**: 241–287.
- 901 Hoffman, P.F. 1968. Stratigraphy of the Lower Proterozoic (Aphebian), Great Slave
902 Supergroup, East Arm of Great Slave Lake, District of Mackenzie. Geological Survey
903 of Canada, Paper 68-42.
- 904 Hoffman, P.F. 1981. Autopsy of Athapuscow aulacogen: a failed arm affected by three
905 collisions. *In* Proterozoic basins in Canada. Edited by F.H.A. Campbell. Geological
906 Survey of Canada, Paper 81-10, pp. 97–102.
- 907 Hoffman, P.F. 1987. Continental transform tectonics: Great Slave Lake shear zone (ca.
908 1.9 Ga), northwest Canada. *Geology*, **15**: 785–788.
- 909 Hoffman, P.F. 1988. Geology and tectonics, East Arm of Great Slave Lake, Northwest
910 Territories. Geological Survey of Canada “A” Series Map 1628A.
- 911 Hoffman, P.F. 1989. Precambrian geology and tectonic history of North America. *In* The
912 geology of North America – an overview. Edited by A.W. Bally and A.R. Palmer.
913 Geological Society of America, volume A, pp. 447–512.

- 914 Hoffman, P.F., and Hall, L. 1993. Geology, Slave craton and environs, district of
915 Mackenzie, Northwest Territories. Geological Survey of Canada, Open File 2559.
- 916 Hoffman, P.F., Bell, I.R., Hildebrand, R.S., and Thorstad, L. 1977. Geology of the
917 Athapuscow aulacogen, East Arm of Great Slave Lake, District of MacKenzie.
918 Geological Survey of Canada, Paper 77-1A, pp. 117–129.
- 919 Hoffman, P.F., Bowring, S.A., Buchwaldt, R., and Hildebrand, R.S. 2011. Birthdate for
920 the Coronation paleocean: age of initial rifting in Wopmay orogen, Canada. *Canadian*
921 *Journal of Earth Sciences*, **48**: 281–293.
- 922 Ismail, R., Ciobanu, C.L., Cook, N.J., Giles, D., Schmidt-Mumm, A., and Wade, B. 2014.
923 Rare earths and other trace elements in minerals from skarn assemblages, Hillside
924 iron oxide–copper–gold deposit, Yorke Peninsula, South Australia. *Lithos*, **184–187**:
925 456–477.
- 926 Jackson, S.E. 2008. Calibration strategies for elemental analysis by LA-ICP-MS. *In* *Laser*
927 *ablation-ICP-mass spectrometry in the Earth sciences: current practices and*
928 *outstanding issues*. Edited by P. Sylvester. Mineralogical Association of Canada,
929 Short Course Series 40, pp. 169–188.
- 930 Jackson, V.A., van Breeman, O., Ootes, L., Bleeker, W., Bennett, V., Davis, W.J.,
931 Ketchum, J.W.F., and Smar, L. 2013. U–Pb zircon ages and field relationships of
932 Archean basement and Proterozoic intrusions, south-central Wopmay Orogen, NWT:
933 implications for tectonic assignments. *Canadian Journal of Earth Sciences*, **50**: 979–
934 1003.
- 935 Jefferson, C.W. 2013. Uranium potential and levels of radioactivity in the proposed
936 national park area, Thaidene Nene MERA Phase II report. *In* *Mineral and energy*
937 *resource assessment for the proposed Thaidene Nene national park reserve in the area*
938 *of the East Arm of Great Slave Lake, Northwest Territories*. Edited by D.F. Wright,
939 E.J. Ambrose, D. Lemkow and G.F. Bonham-Carter. Geological Survey of Canada,
940 Open File 7196, pp. 363–375.
- 941 Johnson, B.J. 1990. Stratigraphy and structure of the Early Proterozoic Wilson Island
942 Group, East Arm thrust-fold belt, N.W.T. *Canadian Journal of Earth Sciences*, **27**:
943 552–569.
- 944 Keleman, P.B., Hanghøj, K., and Greene, A.R. 2014. One view of the geochemistry of
945 subduction-related magmatic arcs, with an emphasis on primitive andesite and lower
946 crust. *In* *Treatise on geochemistry, second edition, volume 4, The Crust*. Edited by
947 R.L. Rudnick, H.D. Holland and K.K. Turekian. Elsevier, Amsterdam, pp. 749–806.
- 948 Kemp, A.J., and Hawkesworth, C.J. 2005. Granitic perspectives on the generation and
949 secular evolution of the continental crust. *In* *Treatise on geochemistry, volume 3, The*

- 950 Crust. Edited by R.L. Rudnick, H.D. Holland and K.K. Turekian. Elsevier,
951 Amsterdam, pp. 349–410.
- 952 Kjarsgaard, B.A., Pearson, D.G., DuFrane, A., and Heaman, L. 2013a. Proterozoic
953 geology of the East Arm Basin with emphasis on Paleoproterozoic magmatic rocks,
954 Thaidene Nene MERA study area. *In* Mineral and energy resource assessment for the
955 proposed Thaidene Nene national park reserve in the area of the East Arm of Great
956 Slave Lake, Northwest Territories. Edited by D.F. Wright, E.J. Ambrose, D. Lemkow
957 and G.F. Bonham-Carter. Geological Survey of Canada, Open File 7196, pp. 77–117.
- 958 Kjarsgaard, B.A., Tella, S., and Lemkow, D. 2013b. Bedrock geology of the proposed
959 Thaidene Nene national park reserve in the area of the East Arm of Great Slave Lake,
960 Northwest Territories. *In* Mineral and energy resource assessment for the proposed
961 Thaidene Nene national park reserve in the area of the East Arm of Great Slave Lake,
962 Northwest Territories. Edited by D.F. Wright, E.J. Ambrose, D. Lemkow and G.F.
963 Bonham-Carter. Geological Survey of Canada, Open File 7196, scale 1:500,000.
- 964 Kish, L., and Cuney, M. 1981. Uraninite-albite veins from the Mistamisk Valley of the
965 Labrador Trough, Quebec. *Mineralogical Magazine*, **44**: 471–483.
- 966 Kreiner, D.C., and Barton, M.D. 2011. District-scale view of the upper levels of iron-
967 oxide (-Cu-Au) ('IOCG') vein systems, Copiapó, Chile. *In* Proceedings of the 11th
968 biennial meeting Society of Geology Applied to Mineral Deposits 2013, Antofagasta,
969 Chile, pp. 497–499.
- 970 Lach, P., Mercadier, J., Dubessy, J., Boiron, M-C., and Cuney, M. 2013. In situ
971 quantitative measurement of rare earth elements in uranium oxides by laser ablation-
972 inductively coupled plasma-mass spectrometry. *Geostandards and Geoanalytical*
973 *Research*, **37**: 277–296.
- 974 LeCheminant, A.N., and Heaman, L.M. 1989. Mackenzie igneous events, Canada:
975 middle Proterozoic hotspot magmatism associated with ocean opening. *Earth and*
976 *Planetary Science Letters*, **96**: 38–48.
- 977 Lees, R. 1975. Trench locations DOC claims. Northwest Territories Geoscience Office,
978 Assessment report #015062 [online], available from www.nwtgeoscience.ca.
- 979 LeMaitre, R.W. 1976. The chemical variability of some common igneous rocks. *Journal*
980 *of Petrology*, **17**: 589–637.
- 981 Li, W., Audétat, A., and Zhang, J. 2015. The role of evaporites in the formation of
982 magnetite–apatite deposits along the Middle and Lower Yangtze River, China:
983 evidence from LA-ICP-MS analysis of fluid inclusions. *Ore Geology Reviews*, **67**:
984 264–278.

- 985 Lydon, J.W. 2007. An overview of the economic and geological contexts of Canada's
986 major mineral deposits. *In* Mineral deposits of Canada. Edited by W.D. Goodfellow.
987 Geological Association of Canada, Mineral Deposits Division Special Publication 5,
988 pp. 3–48.
- 989 Marschall, H.R., and Schumacher, J.C. 2012. Arc magmas sourced from mélange diapirs
990 in subduction zones. *Nature Geoscience*, **5**: 862–867.
- 991 Martz, P., Mercadier, J., Cathelineau, M., Perret, J., Quirt, D., Doney, A., and Ledru, P.
992 2017. Multiple mineralizing events at the Cigar Lake deposit: an integrated study of
993 uranium oxide dating and geochemistry. *In* Proceedings of the 14th biennial meeting
994 of the Society of Geology Applied to Mineral Deposits, Québec, pp. 755–758.
- 995 McDonough, W.F., and Sun, S.-S. 1995. The composition of the Earth. *Chemical*
996 *Geology*, **120**: 223–253.
- 997 McGlynn, J.C. 1971. Metallic mineral industry, district of Mackenzie, Northwest
998 Territories. Geological Survey of Canada, Paper 70-17, pp. 128–129.
- 999 Mercadier, J., Cuney, M., Lach, P., Boiron, M.-C., Bonhoure, J., Richard, A., Leisen, M.,
1000 and Kister, P. 2011. Origin of uranium deposits revealed by their rare element
1001 signature. *Terra Nova*, **23**: 264–269.
- 1002 Mernagh, T.P., and Miezeitis, Y. 2008. A review of the geochemical processes controlling
1003 the distribution of thorium in the Earth's crust and Australia's thorium resources.
1004 *Geoscience Australia, Record* 2008/05.
- 1005 Migdisov, A.A., Boukhalfa, H., Timofeev, A., Runde, W., Roback, R., and Williams-
1006 Jones, A.E. 2018. A spectroscopic study of uranyl speciation in chloride-bearing
1007 solutions at temperatures up to 250°C. *Geochimica et Cosmochimica Acta*, **222**: 130–
1008 145.
- 1009 Mitchell, R.N., Hoffman, P.F., and Evans, D.A.D. 2010. Coronation loop resurrected:
1010 oscillatory apparent polar wander of Orosirian (2.05–1.8 Ga) paleomagnetic poles
1011 from Slave craton. *Precambrian Research*, **179**: 121–134.
- 1012 Montreuil, J.-F., Corriveau, L., and Grunsky, E.C. 2013. Compositional data analysis of
1013 hydrothermal alteration in IOCG systems, Great Bear magmatic zone, Canada: to
1014 each alteration type its own geochemical signature. *Geochemistry: Exploration,*
1015 *Environment, Analysis*, **13**: 229–247.
- 1016 Montreuil, J.-F., Corriveau, L., and Potter, E.G. 2015. Formation of albitite-hosted
1017 uranium within IOCG systems: the Southern Breccia, Great Bear magmatic zone,
1018 Northwest Territories, Canada. *Mineralium Deposita*, **50**: 293–325.

- 1019 Montreuil, J.-F., Corriveau, L., and Davis, W. 2016a. Tectonomagmatic evolution of the
1020 southern Great Bear magmatic zone (Northwest Territories, Canada) – Implications
1021 on the genesis of iron oxide alkali-altered hydrothermal systems. *Economic Geology*,
1022 **111**: 2111–2138.
- 1023 Montreuil, J.-F., Corriveau, L., Potter, E.G., and De Toni, A.F. 2016b. On the relation
1024 between alteration facies and metal endowment of iron oxide–alkali-altered systems,
1025 southern Great Bear magmatic zone (Canada). *Economic Geology*, **111**: 2139–2168.
- 1026 Montreuil, J.-F., Potter, E.G., Corriveau, L., and Davis, W.J. 2016c. Element mobility
1027 patterns in magnetite-group IOCG systems: the Fab system, Northwest Territories,
1028 Canada. *Ore Geology Reviews*, **72**: 562–584.
- 1029 Müller, D., Rock, M.M.S., and Groves, D.I. 1992. Geochemical discrimination between
1030 shoshonitic and potassic rocks in different tectonic settings: a pilot study. *Mineralogy
1031 and Petrology*, **46**: 259–289.
- 1032 Mumin, A.H., Corriveau, L., Somarin, A.K., and Ootes, L. 2007. Iron oxide copper-gold-
1033 type polymetallic mineralization in the Contact Lake Belt, Great Bear Magmatic
1034 Zone, Northwest Territories, Canada. *Exploration and Mining Geology*, **16**: 187–208.
- 1035 Mumin, A.H., Somarin, A.K., Jones, B., Corriveau, L., Ootes, L., and Camier, J. 2010.
1036 The IOCG-porphyry-epithermal continuum in the Great Bear magmatic zone,
1037 northwest Territories, Canada. *In Exploring for iron oxide-copper-gold (Ag-Bi-Co-U)
1038 deposits, examples from Canada and global analogues*. Edited by L. Corriveau and
1039 A.H. Mumin. Geological Association of Canada, Short Course Notes 20, pp. 59–78.
- 1040 Nichols, R.F. 1968. Report on a geological and radiometric survey of the Tel claims, East
1041 Arm, Great Slave Lake. Northwest Territories Geoscience Office, Assessment Report
1042 018779.
- 1043 Nisbet, B., Cooke, J., Richards, M., and Williams, C. 2000. Exploration for iron oxide
1044 copper gold deposits in Zambia and Sweden; comparison with the Australian
1045 experience. *In Hydrothermal iron oxide copper-gold and related deposits: a global
1046 perspective, volume 1*. Edited by T.M. Porter. Porter Geoscience Consultancy
1047 Publishing, Adelaide, pp. 297–308.
- 1048 NORMIN 2011. The Northern minerals database. Northwest Territories Geoscience
1049 Office, Yellowknife, NT [online], www.nwtgeoscience.ca/normin.
- 1050 Nyström, J.O., and Henriquez, F. 1994. Magmatic features of iron ores of the Kiruna-type
1051 in Chile and Sweden: ore textures and magnetite geochemistry. *Economic Geology*,
1052 **89**: 820–839.
- 1053 OECD 2018. Uranium, resources, production and demand. Joint report of the Nuclear
1054 Energy Agency and the International Atomic Energy Agency, NEA No. 7413.

- 1055 Olade, M.A.D. 1975. Trace-element and isotopic data and their bearing on the genesis of
1056 Precambrian spilites from the Athapuscow aulacogen, Great Slave Lake, Canada.
1057 Geological Magazine, **112**: 283–293.
- 1058 Olade, M.A.D., and Morton, R.D. 1972. Observations on the Proterozoic Seton
1059 formation, East Arm of Great Slave Lake, Northwest Territories. Canadian Journal of
1060 Earth Sciences, **9**: 1110–1123.
- 1061 Ootes, L., Harris, J., Mumin, A.H., Jackson, V.A., Azar, B., and Corriveau, L. 2013.
1062 Uranium-enriched bedrock in the central Wopmay orogen: implications for uranium
1063 mineralization. Exploration and Mining Geology, **21**: 85–103.
- 1064 Ootes, L., Davis, W.J., Jackson, V.A., and van Breemen, O. 2015. Chronostratigraphy of
1065 the Hottah terrane and Great Bear magmatic zone of Wopmay orogen, Canada, and
1066 exploration of a terrane translation model. Canadian Journal of Earth Sciences, **52**:
1067 1062–1092.
- 1068 Ootes, L., Snyder, D., Davis, W.J., Acosta-Góngora, P., Corriveau, L., Mumin, A.H.,
1069 Gleeson, S.A., Samson, I., Montreuil, J.-F., Potter, E.G., and Jackson, V.A. 2017. A
1070 Paleoproterozoic Andean-type iron oxide copper-gold environment, the Great Bear
1071 magmatic zone, Northwest Canada. Ore Geology Reviews, **81**: 123–139.
- 1072 Pacey, A., Macpherson, C.G., and McCaffrey, K.J.W. 2013. Linear volcanic segments in
1073 the central Sunda Arc, Indonesia, identified using Hough Transform analysis:
1074 implications for arc lithosphere control upon volcano distribution. Earth and
1075 Planetary Science Letters, **369**: 24–33.
- 1076 Pagel, M., Pinte, G., and Rotach-Toulhoat, N. 1987. The rare earth elements in natural
1077 uranium oxides. Monograph Series on Mineral Deposits, **27**: 81–85.
- 1078 Pearce, J.A., Harris, N.B.W., and Tindle, A.G. 1984. Trace element determination
1079 diagrams for the tectonic interpretation of granitic rocks. Journal of Petrology, **25**:
1080 956–983.
- 1081 Plank, T., and Langmuir, C.H. 1998. The chemical composition of subducting sediment
1082 and its consequences for the crust and mantle. Chemical Geology, **145**: 325–394.
- 1083 Pope, M.C., and Grotzinger, J.P. 2000. Controls on fabric development and morphology
1084 of tufas and stromatolites, uppermost Pethei Group (1.8 Ga), Great Slave Lake,
1085 Northwest Canada. In Carbonate sedimentation and diagenesis in the evolving
1086 Precambrian world. Edited by J.P. Grotzinger and N.P. James. SEPM Special
1087 Publication **67**: 103–121.
- 1088 Pope, M.C., Grotzinger, J.P., and Schreiber, B.C. 2000. Evaporitic subtidal stromatolites
1089 produced by in situ precipitation textures, facies associations, and temporal
1090 significance. Journal of Sedimentology Research, **70**: 1139–1151.

- 1091 Porter, T.M. (Ed.) 2010. Hydrothermal iron oxide copper-gold and related deposits: a
1092 global perspective - advances in the understanding of IOCG deposits, volumes 3 and
1093 4. Porter Geoscience Consultancy Publishing, Adelaide, Australia.
- 1094 Potter, E.G., Corriveau, L., and Kerswill, J.A. 2013b. Potential for iron oxide-copper-
1095 gold and affiliated deposits in the proposed national park region of the East Arm of
1096 Great Slave Lake, Northwest Territories: insights from the Great Bear magmatic zone
1097 and global analogs *In* Mineral and energy resource assessment for the proposed
1098 Thaidene Nene national park reserve in the area of the East Arm of Great Slave Lake,
1099 Northwest Territories. Edited by D.F. Wright, E.J. Ambrose, D. Lemkow and G.F.
1100 Bonham-Carter. Geological Survey of Canada, Open File 7196, pp. 477–493.
- 1101 Potter, E.G., Montreuil, J.-F., Corriveau, L., and DeToni, A. 2013a. Geology and
1102 hydrothermal alteration of the Fab Lake region, Northwest Territories. Geological
1103 Survey of Canada, Open File 7339.
- 1104 Potter, E.G., Corriveau, L., Montreuil, J.-F., Yang, Z., and Comeau, J.-S. 2014.
1105 Geochemical signatures of uraninite from iron oxide-copper-gold (IOCG) systems of
1106 the Great Bear magmatic zone, Canada. Geological Survey of Canada, Open File
1107 7545.
- 1108 Potter, E.G., Montreuil, J.-F., Corriveau, L., and Davis, W.J. *in press*. The Southern
1109 Breccia metasomatic uranium system of the Great Bear magmatic zone, Canada: iron
1110 oxide-copper-gold (IOCG) and albitite-hosted uranium linkages. *In* Mineral deposits:
1111 origins and exploration. Edited by S. Decree and L. Robb, Geophysical Monograph
1112 242, First Edition, American Geophysical Union, pp. 109–130.
- 1113 Pouchou, L., and Pichoir, F. 1984. A new model for quantitative X-Ray microanalysis.
1114 *Recherche Aérospatiale*, **3**:167–192.
- 1115 Putnis, A. 2009. Mineral replacement reactions. Mineralogical Society of America,
1116 *Reviews in Mineralogy and Geochemistry*, **70**: 87–124.
- 1117 Putnis, A., and Austrheim, H. 2010. Fluid-induced processes: metasomatism and
1118 metamorphism. *Geofluids*, **10**: 254–269.
- 1119 Roscoe, S.M., Gandhi, S.S., Charbonneau, B.W., Maurice, Y.T., and Gibb, R.A. 1987.
1120 Mineral resource assessment of the area in the East Arm (Great Slave Lake) and
1121 Artillery Lake region, N.W.T., proposed as a national park. Geological Survey of
1122 Canada, Open File 1434.
- 1123 Rudnick, R.L., and Gao, S. 2014. Composition of the Continental Crust. *In* Treatise on
1124 geochemistry, second edition, volume 4, the crust. Edited by R.L. Rudnick, H.D.
1125 Holland and K.K. Turekian. Elsevier, Amsterdam, pp. 1–64.

- 1126 Sheen, A.I., Heaman, L.M., Kjarsgaard, B.A., Ootes, L., Pearson, D.G., and Creaser,
1127 R.A. 2019. Athapuscow aulacogen revisited: geochronology and geochemistry of the
1128 2046 Ma Union Island Group mafic magmatism, East Arm of Great Slave Lake,
1129 Northwest Territories, Canada. *Precambrian Research*, **321**: 85–102.
- 1130 Shives, R.B.K., Charbonneau, B.W., and Ford, K.L. 2000. The detection of potassic
1131 alteration by gamma-ray spectrometry – recognition of alteration related to
1132 mineralization. *Geophysics*, **65**: 2001–2011.
- 1133 Skirrow, R.G. 2010. “Hematite-group” IOCG U ore systems: tectonic settings,
1134 hydrothermal characteristics and Cu-Au and U mineralizing processes. *In* Exploring
1135 for iron oxide-copper-gold (Ag-Bi-Co-U) deposits, examples from Canada and global
1136 analogues. Edited by L. Corriveau and A.H. Mumin. Geological Association of
1137 Canada, Short Course Notes 20, pp. 39–58.
- 1138 Skirrow, R.G., Huston, D.L., Fraser, G.L., Cross, A., and Jaireth, S. 2011. Summary and
1139 conclusion: uranium mineralisation timing in five Australian deposits. *In* Uranium
1140 mineralisation events in Australia: geochronology of the Nolans Bore, Oasis, Kintyre,
1141 Mt Gee-Armchair and Maureen uranium deposits. Edited by R.G. Skirrow.
1142 Geoscience Australia Record 2011/12, GeoCat # 71639, pp. 68–77.
- 1143 Slack, J., Corriveau, L., and Hitzman, M. 2016. A special issue devoted to Proterozoic
1144 iron oxide-apatite ($\pm$ REE) and iron oxide-copper-gold and affiliated deposits of
1145 Southeast Missouri, USA, and the Great Bear magmatic zone, Northwest Territories,
1146 Canada. *Economic Geology*, **111**: 1803–1814.
- 1147 Somarin, A.K., and Mumin, A.H. 2012. The Paleoproterozoic high heat production
1148 Richardson granite, Great Bear magmatic zone, Northwest Territories, Canada:
1149 source of U for Port Radium? *Resources Geology*, **62**: 227–242.
- 1150 Somarin, A.K., and Mumin, A.H. 2014. P–T-composition and evolution of paleofluids in
1151 the Paleoproterozoic Mag Hill IOCG hydrothermal system, Contact Lake belt,
1152 Northwest Territories, Canada. *Mineralium Deposita*, **49**: 199–215.
- 1153 Snyder, D.B., and Kjarsgaard, B.A. 2103. Mantle roots of major Precambrian shear zones
1154 inferred from structure of the Great Slave Lake shear zone. *Lithosphere*, **5**: 539–546.
- 1155 Stanworth, C.W., and Badham, J.P.N. 1984. Lower Proterozoic red beds, evaporites and
1156 secondary sedimentary uranium deposits from the East Arm, Great Slave Lake,
1157 Canada. *Journal of the Geological Society of London*, **141**: 235–242.
- 1158 Tait Communications and Consulting 2017. Proposed Thaidene Nënë national park
1159 reserve: consultation and engagement report [online]. Available from
1160 www.pc.gc.ca/en/pn-np/cnnp-cnnp/thaidene-nene/nouvelles-news [accessed on 13
1161 February 2018]

- 1162 Tella, S., Kjarsgaard, B.A., and Lemkow, D. 2013. Bedrock geology of the Churchill
1163 Province and Taltson and Thelon magmatic-tectonic zones, Thaidene Nene MERA
1164 study area. *In* Mineral and energy resource assessment for the proposed Thaidene
1165 Nene national park reserve in the area of the East Arm of Great Slave Lake,
1166 Northwest Territories. Edited by D.F. Wright, E.J. Ambrose, D. Lemkow and G.F.
1167 Bonham-Carter. Geological Survey of Canada, Open File 7196, pp. 27–45.
- 1168 Thomas, M.D., Gibb, R.A., and Quince, J.R. 1976. New evidence from offset
1169 aeromagnetic anomalies for transcurrent faulting associated with the Bathurst and
1170 McDonald faults, Northwest Territories. *Canadian Journal of Earth Sciences*, **13**:
1171 1244–1250.
- 1172 Thompson, R.N. 1982. Magmatism of the British Tertiary volcanic province. *Scottish*
1173 *Journal of Geology*, **18**: 49–107.
- 1174 Thorpe, R.I. 1972. Mineral exploration and mining activities, mainland Northwest
1175 Territories, 1966 to 1968. Geological Survey of Canada, Paper 70-70.
- 1176 Timofeev, A., Migdisov, A.A., Williams-Jones, A.E., Roback, R., Nelson, A.T., and Xu,
1177 H. 2018. Uranium transport in acidic brines under reducing conditions. *Nature*
1178 *Communications* 9, Article number 1469. DOI: 10.1038/s41467-018-03564-7
- 1179 Tirrul, R., and Grotzinger, J.P. 1990. Early Proterozoic collisional orogeny along the
1180 northern Thelon tectonic zone, Northwest Territories, Canada: evidence from the
1181 foreland. *Tectonics*, **9**: 1015–1036.
- 1182 van Breemen, O., Kjarsgaard, B.A., Tella, S., Lemkow, D., and Aspler, L.B. 2013. U-Pb
1183 detrital geochronology of clastic sedimentary rocks of the Paleoproterozoic Nonacho
1184 and East Arm basins, East Arm MERA study area. *In* Mineral and energy resource
1185 assessment for the proposed Thaidene Nene national park reserve in the area of the
1186 East Arm of Great Slave Lake, Northwest Territories. Edited by D.F. Wright, E.J.
1187 Ambrose, D. Lemkow and G.F. Bonham-Carter. Geological Survey of Canada, Open
1188 File 7196, pp. 119–136.
- 1189 Wheeler, J.O., Hoffmann, P.F., Card, K.D., Davidson, A., Sanford, B.V., Okulitch, A.V.,
1190 and Roest, W.R. 1996. Geological map of Canada. Geological Survey of Canada,
1191 Map 1860A, scale 1:5,000,000.
- 1192 Williams, P.J. 2010. Classifying IOCG deposits. *In* Exploring for iron oxide-copper-gold
1193 (Ag-Bi-Co-U) deposits, examples from Canada and global analogues. Edited by L.
1194 Corriveau and A.H. Mumin. Geological Association of Canada, Short Course Notes
1195 20, pp. 13–22.
- 1196 Woodhead, J.D., Eggins, S.M., and Johnson, R.W. 1998. Magma genesis in the New
1197 Britain island arc: further insights into melting and mass transfer processes. *Journal of*
1198 *Petrology*, **39**: 1641–1668.

- 1199 Wright, D.F., Kerswill, J.A., Kjarsgaard, B.A., Gandhi, S.S., Jefferson, C.W., Lydon,
1200 J.W., Potter, E.G., Bretzlaff, R.E., and Bonham-Carter, G.F. 2013. Modelling mineral
1201 potential for the Thaidene Nene study area, East Arm of Great Slave Lake, Northwest
1202 Territories, using GIS-based analytical methods. *In* Mineral and energy resource
1203 assessment for the proposed Thaidene Nene national park reserve in the area of the
1204 East Arm of Great Slave Lake, Northwest Territories. Edited by D.F. Wright, E.J.
1205 Ambrose, D. Lemkow and G.F. Bonham-Carter. Geological Survey of Canada, Open
1206 File 7196, pp. 553–646.
- 1207 Yu, J., Chen, Y., Mao, J., Pirajno, F., and Duan, C. 2011. Review of geology, alteration
1208 and origin of iron oxide–apatite deposits in the Cretaceous Ningwu basin, Lower
1209 Yangtze River Valley, eastern China: implications for ore genesis and geodynamic
1210 setting. *Ore Geology Reviews*, **43**: 170–181.
1211

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Figure Captions

Figure 1. Location of the East Arm Basin. Monzonitic intrusions of the Great Bear magmatic zone and East Arm Basin are shown in red (e.g. Balachey intrusion) while metasedimentary and volcanic rocks are shown in green. Key deposits, historical mines and showings are indicated by yellow stars. HT=Hottah Terrane, TMTZ=Taltson magmatic-tectonic zone, GLSZ=Great Slave Lake shear zone, TTZ=Taltson-Thelon orogenic belt. Geology after Wheeler et al. (1996) and Hoffman and Hall (1993).

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Figure 4. Stratigraphic column of the volcano-sedimentary rocks of the East Arm Basin, including evidence for the presence of evaporites from Hoffman (1968) and Badham and Stanworth (1977). Maximum depositional ages (detrital zircon ages) are shown for the Hornby Channel, Murky and Preble formations and a lahar from the Seton volcanic rocks. Stratigraphy after Kjarsgaard et al. (2013a) and references therein. Geochronology references: a- Kjarsgaard et al. (2013a); b- Bowring et al. (1984); c- van Breemen et al. (2013); d – Sheen et al. (2019), e – Gong et al. (2018).

Figure 5. Photographs (a, b, d) and backscatter electron image (c) of magnetite-apatite-amphibole vein hosted within a sodic-altered Compton monzonite intrusion at the REX showings. (a) Coarse-grained, acicular amphibole and magnetite. (b) Amphibole (black) and magnetite (grey) vein containing altered Compton clasts. (c) Vein material in detail illustrating the association of uraninite (Urn) with magnetite (Mag) and euhedral apatite (Ap). Cal=calcite, Amp=amphibole. (d) Detail of the rose-coloured apatite ± carbonate surrounded by actinolite (Amp) and magnetite (Mag).

Figure 6. (a-e) Tectonic discrimination plots of ca. 1.87 Ga rocks from the East Arm and Great Bear magmatic zone (GBMZ), all of which host IOA-IOCG mineralization. (f) Similarity of Nb/La values to global subducting sediment composition and flux (GLOSS of Plank and Langmuir 1998). ACM=Active continental margin; CALC=calc-alkaline; CAP=continental arc; IOP=initial oceanic arc; LOP=late oceanic arc; ORG=oceanic ridge granite; PAP=post-collisional arc; SHO=shoshonite; syn-COLG=syn-collisional granite; THOL=Tholeiite; VAG=volcanic arc granite; WIP=within plate; and WPG=within plate granite. Plots (a, b) after Pearce et al. (1984); (c-e) after Müller et al. (1992) using ACM of from Gorton and Schandl (2000); and (f) after Marschall and Schumacher (2012). Note (d and e) include intrusive phases with compositions outside the parameters suggested by Müller et al., (1992). Data from Kjarsgaard et al. (2013a), Ootes et al. (2017) and Azar (2007).

Figure 7. Chondrite-normalized REE patterns of uraninite from (a) Rex showing, East Arm Basin, (b) Fab IOA-IOCG system, Great Bear magmatic zone, (c) Cole Lake showing, Great Bear magmatic zone, and (d) various uranium deposit types. Insets: representative backscatter electron images of uraninite grains analyzed in this study. Intrusive, Mistamisk, Zambia and Cigar Lake patterns from Mercadier et al. (2011), Fab and Cole Lake from Potter et al. (2014) and Key Lake from this study. All data normalized to McDonough and Sun (1995).

Figure 8. East Arm Basin geochemical data plotted in the Montreuil et al. (2013) IOCG alteration discrimination plot. (a) All data highlighting Na and Ca-Fe-K alteration of the felsic Compton intrusions and Na, Na-Ca-Fe to K-Fe and K alteration of mafic and felsic Seton formation volcanic rocks. (b) Chemical bar codes (molar proportions) of global reference rock types, also plotted in (a). (c) Chemical bar codes of samples from the East Arm, which record significant Na, Ca-Fe and K-Fe alteration in Compton and Seton formation rocks. Data from S.S. Gandhi and N. Prasad (unpublished data), Olade and Morton (1972), Badham (1972), Blackadar (1981), Kjarsgaard et al. (2013a). Reference rock types from: 1 - Keleman et al. (2014); 2 - Gale et al. (2003); 3 to 6 - Keleman et al. (2014); 7 - Rudnick and Gao (2014); 8 & 10 - Kemp and Hawkesworth (2005); 9 - Rudnick and Gao (2014); 11 & 12 - Pearce et al. (1984).

Table 1. Global type examples of IOCG and Canadian IOCG deposits with known resources.

Deposit Type	Deposit	Country	Resources
<i>Type Localities</i>			
Hematite-group IOCG	Olympic Dam	Australia	10,100 Mt @ 0.78% Cu, 0.25kg/t U ₃ O ₈ , 0.33 g/t Au, 1.00 g/t Ag ¹ (<i>measured, indicated and inferred resources</i>)
Magnetite-group IOCG	Candelaria	Chile	501 Mt @ 0.54% Cu, 0.13 g/t Au, 2.06 g/t Ag ² (<i>measured and indicated resources</i>)
Iron oxide-apatite (IOA)	Kiruna	Sweden	2,000 Mt@ 60–68% Fe ^{3,4}
<i>Canadian Examples</i>			
Magnetite-group IOCG	NICO	Canada	33.077 Mt @ 1.03 g/t Au, 0.11% Co, 0.14% Bi and 0.04% Cu ⁵ (<i>proven and probable mineral reserves</i>)
Magnetite-hematite IOCG	Sue Dianne	Canada	8.4 Mt @ 0.80% Cu, 0.07 g/t Au and 3.2 g/t Ag ⁶ (<i>indicated resources</i>)

Data sources: 1- BHP (2018); 2- Couture et al. (2017); 3- Nyström and Henriquez (1994); 4- Edelbro et al. (2012); 5- Burgess et al. (2014); and 6- Hennessey and Puritch (2008). Note: Olympic Dam resources *do not include* additional 508 Mt of proven and probable reserves at 1.99 % Cu, 0.58 kg.t U₃O₈, 0.72 g/t Au and 4 g/t Ag (BHP, 2018).

Table 2: Localities in the East Arm Basin exhibiting iron oxide-alkali-calcic alteration.

Occurrence/Showing Name(s)	Latitude	Longitude	Host Lithology	Mineral Assemblage	Morphology
BBX; Taltheilei Narrows; Aristifats	62.5812	-111.5587	Seton volcanic rocks	cna-cpy-py-hem-ur	brecciated volcanic plug
Bell; FF	62.3093	-111.198	Compton Intrusive & Christie Bay Gp	amp-ap-mag-ur	veins
Carrie 2	62.3022	-111.185	Compton Intrusive	amp-mag-ap-cc-ur-th-	veins
Labelle Peninsula West	62.2792	-111.3049	Compton Intrusive	amp-mag-ap-ur-cpy	fracture coatings
Labelle Zone 1 (north)	62.2859	-111.2879	Compton Intrusive	amp-mag-ap-ur-cna-cpy	shear veins
Labelle Zone 1 (south)	62.2851	-111.2892	Compton Intrusive	am-mag-ap-ur-cna	shear veins & breccias
Labelle Zone 2; GMTN; GM	62.2828	-111.2848	Compton Intrusive	hem-brn-cpy-ur	stringers & fractures
Labelle Zone 3; GMTN; GM	62.283	-111.2819	Compton Intrusive	amp-mag-ap-py-cpy-ur-cna	stringers & fractures
Iron Islands	61.6594	-113.4092	Wilson Island Gp	hem (specular)	veins?
Rex 'A' Vein; Ridley	62.4483	-110.2988	Compton Intrusive	amp-mag-ap-ur	veins
Rex 'B' Vein; Ridley	62.4484	-110.305	Compton Intrusive	amp-mag-ap-ur	veins
Rex 'C' Vein; Ridley	62.4474	-110.3088	Compton Intrusive	amp-mag-ap-ur	veins
Rex 'D' Vein; Ridley	62.4464	-110.3198	Compton Intrusive	amp-mag-ap-ur	veins
Rex 'E' Vein; Ridley	62.4461	-110.3206	Compton Intrusive	amp-mag-ap-ur	fracture coatings
Rex 'F' Zone; Ridley	62.4437	-110.3248	Compton Intrusive	amp-mag-ap-ur	veins
SHUM 2; Chevron	62.0106	-111.7269	Union Island Gp & Hornby Channel Fm	hem-ag-ur-th-cpy-py	veins, fractures & breccia
Stevens Vein; Ridley	62.4484	-110.3257	Compton Intrusive	amp-mag-ap-ur-fl	veins
TEL; SHUM; MUSH	61.9747	-111.8022	Union Island Gp & Hornby Channel Fm	hem-ag-ur-th-cpy-py	veins, fractures & breccia
UR 2	62.4045	-110.9605	Compton Intrusive	amp-mag-ap-ur-hem-cpy-cna	veins
UR 8	62.4074	-110.9357	Compton Intrusive	amp-mag-ap-ur-cpy	shear veins
Wilson Island; Victory; Big Moose	61.7953	-113.1844	Wilson Island Gp	hem-au-ag	veins

Notes: Data from NORMIN (2011), Wright et al. (2013) and references therein. Mineral abbreviations: ag=native silver; amp=amphibole; ap=apatite; au=gold; brn=bornite; cna=cobalt nickel arsenides; cc=calcite; cpy=chalcopyrite; fl=fluorite; hem=hematite; mag=magnetite; py=pyrite; th=thorium; ur=uraninite.

Table 3. Trace element concentrations of uraninite from the Rex occurrence.

Element (ppm)	Rex-1	Rex-2	Rex-3	Rex-4	Rex-5	Rex-6	Rex-7
Mg	1.58E+01	2.52E+01	3.44E+01	1.33E+01	2.70E+01	9.38E+01	3.48E+02
Al	2.54E+01	2.43E+01	5.11E+01	2.75E+01	3.74E+01	3.89E+01	4.52E+01
Si	1.33E+03	1.61E+03	3.70E+03	1.07E+03	2.11E+03	2.13E+03	3.20E+03
Ca	1.54E+04	1.67E+04	1.93E+04	1.39E+04	1.74E+04	1.75E+04	2.50E+04
Ti	9.3E+00	4.1E+00	5.9E+00	8.2E+00	2.69E+01	5.20E+01	5.2E+00
V	1.45E+01	1.00E+01	2.84E+01	1.74E+01	2.21E+01	1.34E+01	1.35E+01
Mn	3.87E+02	4.71E+02	8.47E+02	2.82E+02	5.46E+02	4.56E+02	9.66E+02
Fe	3.10E+03	4.00E+03	5.49E+03	2.40E+03	3.82E+03	5.68E+03	7.54E+03
Co	2.3E+00	4.4E+00	3.2E+00	4.9E+00	2.3E+00	2.4E+00	2.5E+00
Sr	7.18E+01	7.66E+01	8.01E+01	4.52E+01	6.79E+01	9.84E+01	1.12E+02
Y	1.01E+04	8.78E+03	8.59E+03	9.80E+03	1.26E+04	1.24E+04	1.12E+04
Zr	1.45E+01	1.00E+01	1.29E+01	7.5E+00	6.1E+00	9.5E+00	1.40E+01
Nb	5.7E+00	4.0E+00	1.9E+00	2.9E+00	1.98E+01	5.55E+01	1.12E+01
Ba	6.23E+01	4.62E+01	2.49E+02	4.88E+01	1.87E+02	1.40E+02	1.84E+02
La	2.74E+03	2.74E+03	2.55E+03	2.92E+03	3.38E+03	4.15E+03	2.70E+03
Ce	2.88E+04	2.82E+04	2.66E+04	3.04E+04	3.45E+04	3.89E+04	2.81E+04
Pr	4.24E+03	4.08E+03	3.88E+03	4.38E+03	5.07E+03	5.64E+03	4.32E+03
Nd	2.08E+04	1.94E+04	1.85E+04	2.10E+04	2.49E+04	2.68E+04	2.14E+04
Sm	4.56E+03	4.08E+03	3.86E+03	4.50E+03	5.47E+03	5.56E+03	4.96E+03
Eu	2.40E+02	2.31E+02	2.38E+02	2.54E+02	3.02E+02	3.13E+02	2.79E+02
Gd	2.95E+03	2.57E+03	2.43E+03	2.90E+03	3.47E+03	3.53E+03	3.20E+03
Tb	4.44E+02	3.80E+02	3.70E+02	4.34E+02	5.38E+02	5.40E+02	4.94E+02
Dy	2.89E+03	2.48E+03	2.44E+03	2.78E+03	3.60E+03	3.48E+03	3.24E+03
Ho	5.57E+02	4.76E+02	4.70E+02	5.29E+02	6.78E+02	6.69E+02	6.16E+02
Er	1.72E+03	1.48E+03	1.47E+03	1.63E+03	2.16E+03	2.09E+03	1.91E+03
Tm	2.36E+02	2.02E+02	1.96E+02	2.23E+02	2.96E+02	2.94E+02	2.59E+02
Yb	1.68E+03	1.47E+03	1.38E+03	1.58E+03	2.07E+03	2.13E+03	1.81E+03
Lu	1.87E+02	1.65E+02	1.56E+02	1.75E+02	2.33E+02	2.44E+02	1.99E+02
Hf	2.2E-01	1.7E-01	1.7E-01	2.1E-01	2.4E-01	2.7E-01	2.4E-01
Ta	7.3E-01	5.9E-01	2.3E-01	3.6E-01	2.6E+00	7.3E+00	1.3E+00
Bi	6.9E+00	4.7E+00	3.9E+00	8.3E+00	9.2E+00	6.0E+00	3.3E+00
Th	5.38E+03	5.45E+03	3.45E+03	2.75E+03	2.51E+03	4.35E+03	5.27E+03
Σ REE (wt. %)	7.20	6.80	6.45	7.37	8.66	9.43	7.35
LREE	5.66	5.44	5.15	5.87	6.78	7.54	5.66
MREE	1.16	1.02	0.98	1.14	1.41	1.41	1.28
HREE	0.38	0.33	0.32	0.36	0.48	0.48	0.42
Σ LREE/ Σ HREE	14.8	16.4	16.1	16.3	14.3	15.9	13.5

Fig. 1. Location of the East Arm Basin. Monzonitic intrusions of the Great Bear magmatic zone and East Arm Basin are shown in red (e.g. Balachey intrusion) while metasedimentary and volcanic rocks are shown in green. Key deposits, historical mines and showings are indicated by yellow stars. HT=Hottah Terrane, TMTZ=Taltson magmatic-tectonic zone, GLSZ=Great Slave Lake shear zone, TTZ=Taltson-Thelon orogenic belt. Geology after Wheeler et al. (1996) and Hoffman and Hall (1993).

203x176mm (300 x 300 DPI)

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203x115mm (300 x 300 DPI)

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266x188mm (300 x 300 DPI)

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203x158mm (300 x 300 DPI)

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203x166mm (300 x 300 DPI)

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165x256mm (300 x 300 DPI)

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203x199mm (300 x 300 DPI)

Fig. 8. East Arm Basin geochemical data plotted in the Montreuil et al. (2013) IOCG alteration discrimination plot. (a) All data highlighting Na and Ca-Fe-K alteration of the felsic Compton intrusions and Na, Na-Ca-Fe to K-Fe and K alteration of mafic and felsic Seton formation volcanic rocks. (b) Chemical bar codes (molar proportions) of global reference rock types, also plotted in (a). (c) Chemical bar codes of samples from the East Arm, which record significant Na, Ca-Fe and K-Fe alteration in Compton and Seton formation rocks.

Data from S.S. Gandhi and N. Prasad (unpublished data), Olade and Morton (1972), Badham (1972), Blackadar (1981), Kjarsgaard et al. (2013a). Reference rock types from: 1 - Kelemen et al. (2014); 2 - Gale et al. (2003); 3 to 6 - Kelemen et al. (2014); 7 - Rudnick and Gao (2014); 8 & 10 - Kemp and Hawkesworth (2005); 9 - Rudnick and Gao (2014); 11 & 12 - Pearce et al. (1984).

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