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Abstract

Detailed mapping of the Fab Lake magnetite-group iron oxide-copper-gold (IOCG) system has defined an alteration footprint extending almost 10 by 5 km, with the long axis trending in a southeast-northwest direction. Within this area, field mapping identified seven alteration assemblages: 1) high temperature albite and albite + amphibole ± magnetite [HT Na and HT Na-Ca-Fe]; 2) amphibole + magnetite ± apatite and amphibole + magnetite + K-feldspar [HT Ca-Fe and HT Ca-Fe-K]; 3) high temperature K-feldspar + magnetite ± hematite [HT K-Fe]; 4) K-feldspar; 5) chlorite; 6) hematite; and 7) low temperature epidote + K-feldspar + quartz [LT Ca-Fe]. These alteration assemblages are expressed as incipient to pervasive alteration in the form of veins, hydrothermal breccias and replacement fronts in the host rocks exhibiting multiple crosscutting and overprinting relationships. All of the historic Fab U-Cu-Fe mineral showings occur within zones characterized by intense, texture-destructive alteration comprising multiple episodes of high temperature albite/albite + amphibole + magnetite (Na and Na-Ca-Fe) and amphibole + magnetite ± apatite/amphibole + magnetite + K-feldspar (Ca-Fe and Ca-Fe-K) overprinted by K-feldspar + magnetite ± biotite (K-Fe) assemblages.

The conceptual alteration to brecciation and mineralization model is key to understanding the alteration assemblages documented in the Fab IOCG system. These assemblages record the build-up of a magnetite-group IOCG system: early high-temperature Na/Na-Ca-Fe and Ca-Fe/Ca-Fe-K alteration, overprinted by high temperature K-Fe alterations and incipient to well-developed hydrothermal breccias. The alteration assemblages themselves and the zoning observed in outcrop provide true vectors towards mineralization, which based on the nature of the hydrothermal system, can be applied elsewhere in the Great Bear magmatic zone and other prospective terranes. As field observations indicate that lower-temperature K-Fe alteration associated with hematite-group IOCG systems is only weakly developed, the Fab Lake region is most prospective for magnetite-group types of IOCG mineralization.

Introduction

Building on a lengthy heritage of mineral exploration and production of vein-type uranium and silver deposits, the Great Bear magmatic zone (GBMZ) located in Northwest Territories is currently the most prospective terrane for IOCG deposits in Canada, with a high potential for undiscovered magnetite- and hematite-group iron oxide copper-gold (IOCG) deposits and IOCG-affiliated mineral systems (cf. Corriveau, 2007; 2011).

Under the Geomapping for Energy and Minerals (GEM) multiple metals/IOCG project, a field-based study of the Fab Lake occurrences was undertaken to build geoscience knowledge of the Great Bear magmatic zone (GBMZ) mineral occurrences and test hydrothermal alteration models developed and refined under the GEM project. With its excellent exposure, sub-greenschist regional metamorphism, known mineral occurrences and infrastructure, the GBMZ is an ideal district to examine IOCG and affiliated mineral systems. After two field seasons examining systems along the length of the belt, the Fab Lake system was selected for this study due to its restricted spatial extent, relatively uncomplicated nature, known mineral occurrences and ease of access via the community of Gamèti.

The field studies have culminated in the creation of an updated geological map and recognition of distinct alteration assemblages for the Fab Lake mineral occurrences. The alteration assemblages and the zoning observed in outcrop provide true vectors towards mineralization, which based on the intense nature of the hydrothermal system, can be applied elsewhere in the GBMZ and other prospective terranes. Furthermore, evolution of the hydrothermal system, as recorded in the evolution and overprinting of alteration assemblages, provides further insights into the nature of IOCG-related alteration and mineralization.

Iron oxide-copper-gold (IOCG) and affiliated mineral systems

IOCG deposits are polymetallic hydrothermal mineral occurrences that contain Cu and Au in economic concentrations, with abundant hydrothermal iron-oxide (magnetite, hematite) gangue minerals or associated alteration, and sulphide-deficient ore consisting of low-sulphur base-metal sulphides and arsenides, such as chalcopyrite, bornite, chalcocite, pyrrhotite, and arsenopyrite. IOCG deposits can be of any age, but many prospective terranes are Archean to Proterozoic. All IOCG deposits occur within broad-scale, chemically and mineralogically complex haloes of intensely altered rocks and breccias. The diagnostic regional- to deposit-scale alteration and metasomatic rock types are subdivided into Na; Fe-Ca (±Na); HT Fe-K; skarns; LT K-Fe; and/or quartz alteration types (Fig. 1; see also Corriveau et al., 2010a), which produce several lithological, mineralogical, chemical, and geophysical characteristics that can be useful in regional exploration (Belperio et al., 2007; Benavides et al., 2008; Corriveau et al., 2010a; McMartin et al., 2010; Skirrow, 2010).

Mineralization occurs within or close to characteristic alteration types and is commonly associated with large-scale breccias. The magnitude of brecciation is significantly more abundant and laterally more extensive in IOCG systems when compared to other types of ore systems (Groves et al., 2010; Jébrak, 2010). There are spatial relationships to major, crustal-scale fault zones (e.g. Drummond et al., 2006; Hayward and Skirrow, 2010) and commonly a temporal and spatial relationship with large-scale and voluminous magmatism. As a consequence of the tectono-magmatic control on ore genesis, IOCG deposits tend to occur in clusters that populate entire geological belts (e.g. Cloncurry district and Olympic Dam province in Australia; Williams et al. 2005; Hayward and Skirrow, 2010).

The evolution of the intense alteration types within IOCG systems leads to an extraordinary range of mineralization types and can create fertile corridors for a great variety of affiliated deposits. Hence, IOCG systems include not only magnetite-, magnetite-hematite- and hematite-group IOCG deposits (following the classification scheme of Williams, 2010) but also a wide spectrum of affiliated deposits, such as iron oxide-apatite (IOA) deposits, Na-metasomatic uranium deposits (also known as albitite-hosted uranium), some skarns (Gandhi, 2003; Williams, 2010; Corriveau et al., 2011), alkaline intrusion-hosted IOCG deposits (Groves and Vielreicher, 2001; Gandhi, 2003; Corriveau, 2007; Groves et al., 2010) and 'Merlin-type' Mo-Re deposits (Brown et al., 2010). An IOCG footprint can also include an entire IOCG-porphyry-epithermal continuum, as documented in the northern Great Bear magmatic zone (Mumin et al., 2007, 2010) and in the Andes (Tornos et al., 2010). Consequently, economic metals within IOCG systems include varied combinations of iron, base metals (Cu, Pb, Zn, and Ni), precious metals (Au, Ag, and platinum-group elements), strategic/specialty metals (Bi, Co, Mo, V, and rare earth elements), and nuclear metals (U and Th). Although ore grades are typically intermediate to low, the potential for very high tonnage and a wide range of commodities lower the economic risks of mining and make these deposits very attractive for mineral investments. Currently IOCG deposits are mined in Australia (Olympic Dam and Prominent Hill), South America (Brazil, Chile, and Peru), Europe (Sweden and Finland), and parts of Asia, including China and Russia, while alkaline intrusions that host IOCG-type deposits are known in China and South Africa (Williams et al., 2005; BHP Billiton, 2009; Groves et al., 2010).

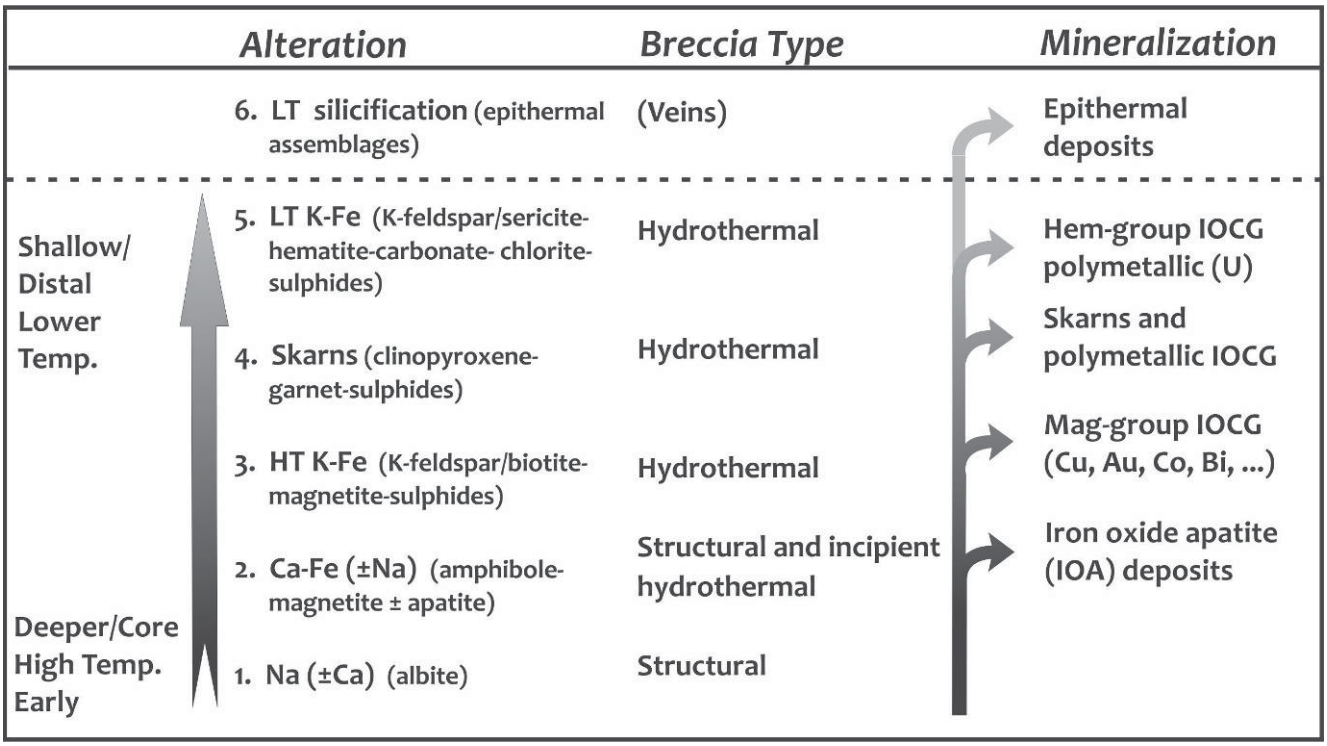

Figure 1: IOCG alteration zoning to ore model, modified from Corriveau et al., (2010b).

Regional Geology

The Fab Lake system is located in the south central GBMZ (Figs. 2 and 3) within a succession of undifferentiated calc-alkaline porphyries associated with the development of a Andean-type continental arc at the western margin of the Wopmay orogen between ca. 1.87-1.84 Ga (Fig. 2) (Azar 2007; Hildebrand et al. 2010). The porphyries represent the northernmost extension of the Faber Group of the McTavish Supergroup, the latter of which comprises all the volcanic sequences and hypabyssal intrusions within the GBMZ (Gandhi 1988; Gandhi et al. 2001). The Faber Group is the principal host of the IOCG deposits and prospects of the southern GBMZ (e.g. Sue Dianne, Brooke, Mar, Nod) and is subdivided into the Lou, Mazenod and Bea assemblages (Gandhi 1994; Goad et al. 2000; Camier 2002; Mumin et al. 2010). Gandhi et al. (2001) interpreted the Fab Lake porphyry complex as being a transitional sequence intercalated between the Mazenod and Lou assemblages and accordingly estimated its age to be around 1868 Ma, based on U-Pb age on zircon they obtained for the Mazenod assemblage near the Sue Dianne deposit. Details of the geological units mapped in the field are summarized in Table 1.

The Fab Lake porphyry complex is bordered by Great Bear batholiths to the north and east, while the western and southern margins are defined by the Faber Lake rapakivi granite (*cf* Jackson 2008). Within the porphyry complex, numerous porphyritic monzonite dykes and coarse-grained granitic bodies intrude the Fab Lake porphyries and post-date hydrothermal alteration.

Alteration assemblages associated with the development of the Fab Lake system and its historic U-Cu-Fe showings are observed within exposed sections of the distinctive and homogeneous porphyritic dacite intrusion (Figs. 2 and 3). Mineralization within the Fab Lake system occurs primarily along the eastern shoreline of Fab Lake, within magnetite-cemented hydrothermal crackle breccias developed in tension fractures or within extensive amphibole + magnetite-bearing replacement fronts and K-feldspar + magnetite alteration zones (Figs. 3 and 4). Gandhi (1988) was the first to note similarities between these systems and those of the Sue Dianne deposit, laying the groundwork for recognition of an IOCG district in the GBMZ. Chalcopyrite is the main Cu-bearing mineral, U is mostly hosted in fine-grained pitchblende and accessories minerals include apatite and fluorite (Gandhi 1988). A summary of the showings observed in the present study are listed in Table 2.

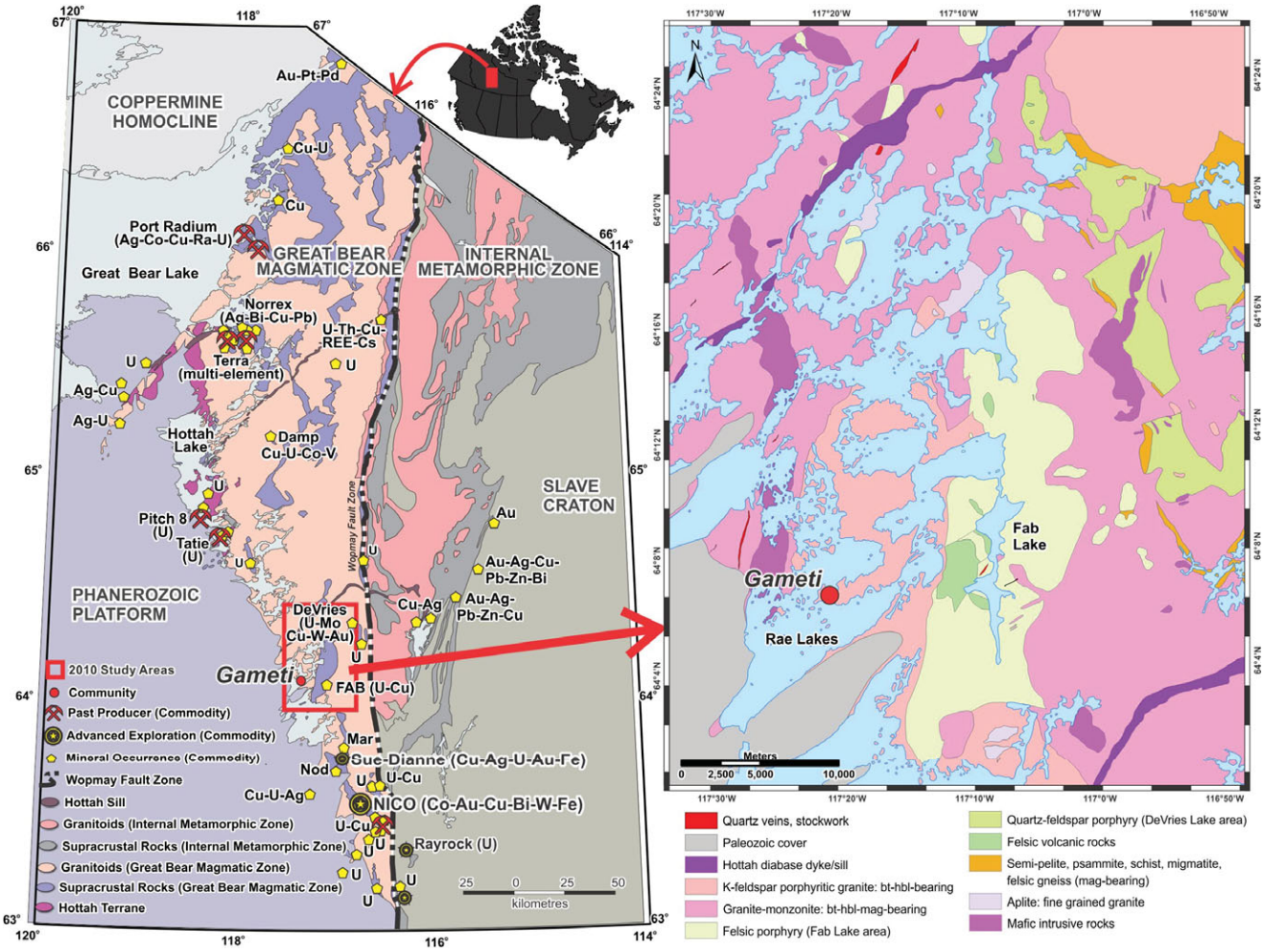

Figure 2: Location and regional geology of the Fab Lake region. Great Bear magmatic zone geology and mineral occurrences after Corriveau (2007), geology of the Fab region from Jackson (2008).

Table 1: Geological units of Fab Lake identified during field studies.

Map Unit	Intrusion Suite	Group	Lithology
Quartz veins			Giant quartz veins and stockworks; related to brittle faults (mainly NE trending)
Rapakivi granite	Great Bear intrusions	Faber Lake rapakivi granite suite (1856 +2/-3 Ma[3])	Very coarse- to coarse-grained K-feldspar phenocrysts with alternating overgrowths of albite and K-feldspar set in a medium- to coarse-grained groundmass composed primarily of quartz, K-feldspar, plagioclase and trace amphibole and biotite
Fab Lake granite	Great Bear intrusions	Fab Lake granite pluton (1858.2 ± 6.1 Ma[1,2])	Coarse-grained, phaneritic granite composed of quartz, K-feldspar and plagioclase. Hornblende is the main mafic mineral with lesser quantities of biotite
Undivided granite	Great Bear intrusions		Medium- to coarse-grained, leucocratic to mesocratic rocks, granitic to monzonitic in composition with accessory biotite±hornblende±magnetite. Equigranular to seriate textured with weakly developed K-feldspar or plagioclase-phyric zones[4]
Andesite dyke	Fab Lake porphyries	Faber Group (McTavish Supergroup)	A circa 200 metres wide unit in sharp contact with the porphyritic dacite. Massive and homogenous to flow-banded unit with fine-grained, sparsely disseminated plagioclase and pyroxene phenocrysts with accessory magnetite, apatite, zircon and quartz[5]
Porphyritic dacite	Fab Lake porphyritic dacite (1868.5 ± 2.2 Ma[1,2])	Faber Group (McTavish Supergroup)	Fine- to medium-grained euhedral plagioclase phenocrysts set in a fine-grained to aphanitic groundmass of quartz and altered feldspar. Groundmass phases include chlorite, amphibole, pyroxene, iron-oxides and titanite. Occasional K-feldspar and quartz phenocrysts.
Undivided porphyries	Fab Lake porphyries	Faber Group (McTavish Supergroup)	Fine- to medium-grained, feldspar porphyries: one-feldspar porphyritic intrusions with rhyolitic to andesitic compositions, one-feldspar porphyritic intrusions containing trace quartz phenocrysts with rhyolitic compositions and two-feldspar porphyries with dacitic to rhyolitic compositions
Porphyritic monzonite	Fab Lake porphyries	Faber Group (McTavish Supergroup)	Phaneritic porphyritic monzonite to monzodiorite, with localized zones with aphanitic groundmass. Plagioclase and K-feldspar are the main phenocrysts and occur in a proportion of 3:1 to 2:1. Plagioclase phenocrysts are coarser grained than the K-feldspar phenocrysts. Matrix is replaced by amphibole+magnetite±apatite clots disseminated throughout the unit, which results in a high magnetic susceptibility.

References: 1- Jackson and Tosdal (unpublished); 2- this study; 3- Gandhi et al., (2001); 4- Jackson (2008); and 5- Gandhi (1988).

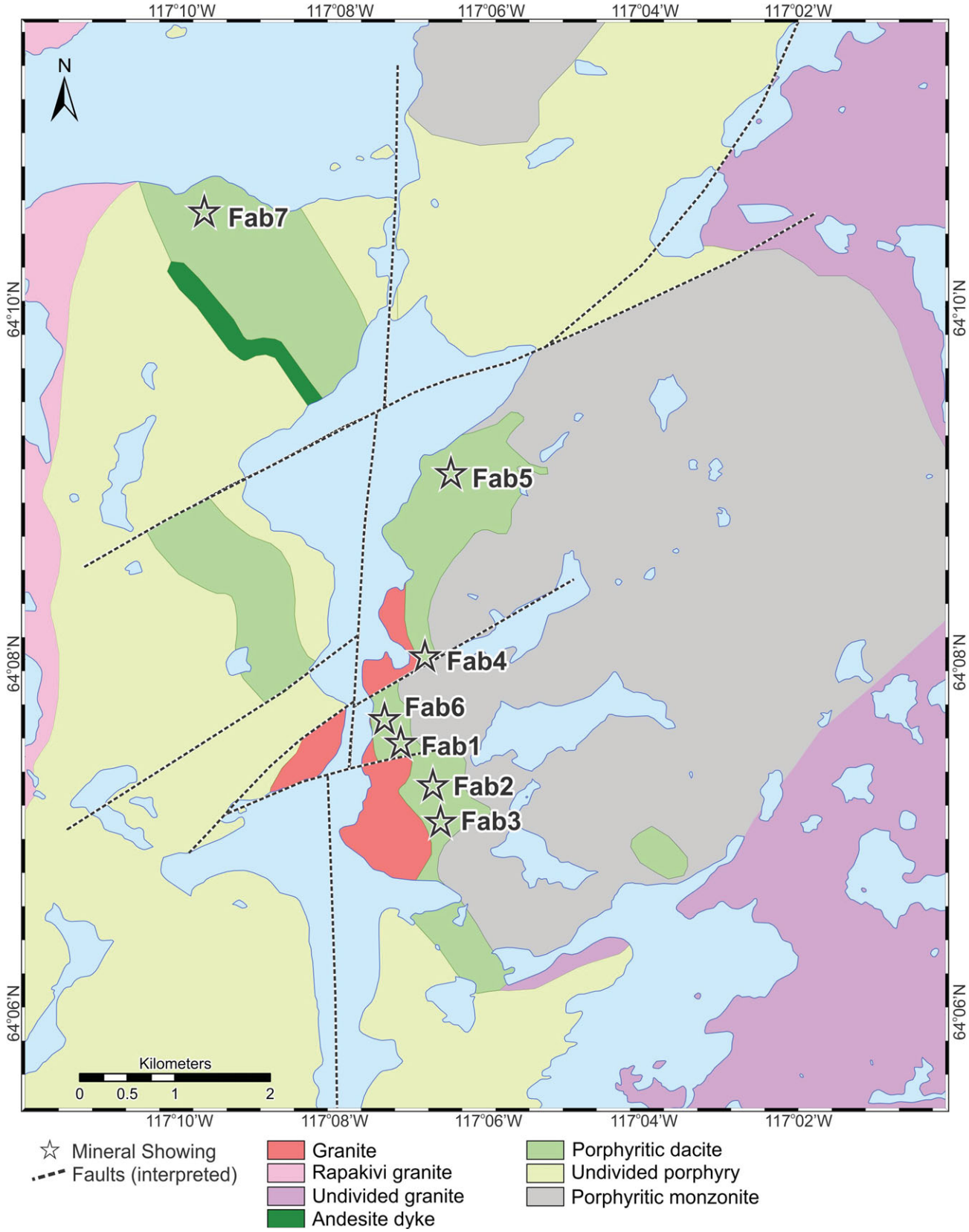

Figure 3: Updated geological map and mineral showings/anomalies of the Fab Lake region examined in this study, building on previous mapping in the region by Gandhi (1988) and Jackson (2008).

Table 2: Summary of Fab lake mineral showings and the maximum assay values recorded in outcrop (spectrometer) and hand sample.

Showing	Coordinates Easting	Northing	Brief outcrop description	Spectrometer assays (ppm)	Geochemical assays (ppm)	Station ID (this study)	Gandhi (1988)
Fab1	494107	7110983	Porphyritic (feldspar) dacite with incipient amphibole+magnetite (HT Ca-Fe) alteration, texture-destructive magnetite+biotite fronts (HT K-Fe), K-spar veinlets with magnetite selvages (HT K-Fe) and epidote veinlets (LT Ca-Fe). U and sulphide mineralization associated with K-Fe (HT) veinlets.	448 eTh; 3811 eU	90.2 Th; 960 U; 1140 P; 6910 F; 13.05% Fe;	10CQA-562 11PUA-031 11PUA-032 11PUA-1000	A-2
Fab2	494484	7110528	Porphyritic (feldspar) dacite with incipient amphibole+magnetite (HT Ca-Fe alteration, texture-destructive magnetite+biotite fronts and K-spar veinlets with magnetite selvages (HT K-Fe). U and sulphide mineralization associated with K-Fe (HT) veinlets.	66 eTh; 444 eU	36.8 Th; 315 U; 1850 F; 1230 P; 655 Cu; 14.05% Fe	10CQA-566	A-3
Fab3	494607	7110198	Albite+amphibole+magnetite (HT Ca-Fe-Na) altered feldspar porphyry with K-feldspar+magnetite (HT K-Fe) veinlets. U and trace sulphide mineralization present	61 Th; 474 eU	42.6 Th; 227 U; 1850 F; 1220 P; 5.44% Fe	10CQA-572	A-4
Fab4	494450	7111881	Porphyritic (feldspar) dacite with incipient amphibole+magnetite (HT Ca-Fe) alteration, texture-destructive magnetite+biotite fronts and crackle breccias (HT K-Fe), K-spar veinlets with magnetite selvages (HT K-Fe) and epidote veinlets (LT Ca-Fe).	626 eTh; 86 eU		11PUA-053	A-5
Fab5	494957	7113803	Na (HT) altered porphyritic dacite with incipient amphibole+magnetite (HT Ca-Fe) and amphibole+magnetite +K-feldspar (HT Ca-Fe-K) breccias. Trace U and sulphide minerals in breccia matrix.	50 eTh; 331 eU	42.6 Th; 460 U; 1080 P; 9.8% Fe	10CQA-187	A-6
Fab6	494037	7111307	Porphyritic (feldspar) dacite with incipient amphibole+magnetite (HT Ca-Fe) alteration, texture-destructive magnetite+biotite fronts (HT K-Fe) and K-spar veinlets with magnetite selvages (HT K-Fe). U and sulphide mineralization associated with K-spar veinlets.	416 eTh; 3596 eU	95.7 Th; 3010 U; 5170 F; >10000 P; 13.4% Fe	10CQA-579	na
Fab7	492170	7116702	Porphyritic (feldspar) dacite with incipient amphibole+magnetite (HT Ca-Fe) alteration, amphibole+magnetite+apatite (HT Ca-Fe-P) veins and crackle breccias, chlorite alteration and epidote veinlets (LT Ca-Fe). Minor Th enrichment associated with Ca-Fe-P veins.	473 eTh; 45 eU		11PUA-1017	na

Note: coordinates are in UTM, NAD83, Zone 11N. Alteration types correspond with assemblages listed in Figure 1. Geochemical analyses performed at ALS Vancouver, using an agate pulverization, four acid digestion and ICP-MS and ICP-AES techniques (package ME-MS61U). Fluorine analyses done by fusion-S.I.E. technique (package F-ELE81a). Duplicates, blind standards and international reference materials were analyzed to confirm reproducibility of the results.

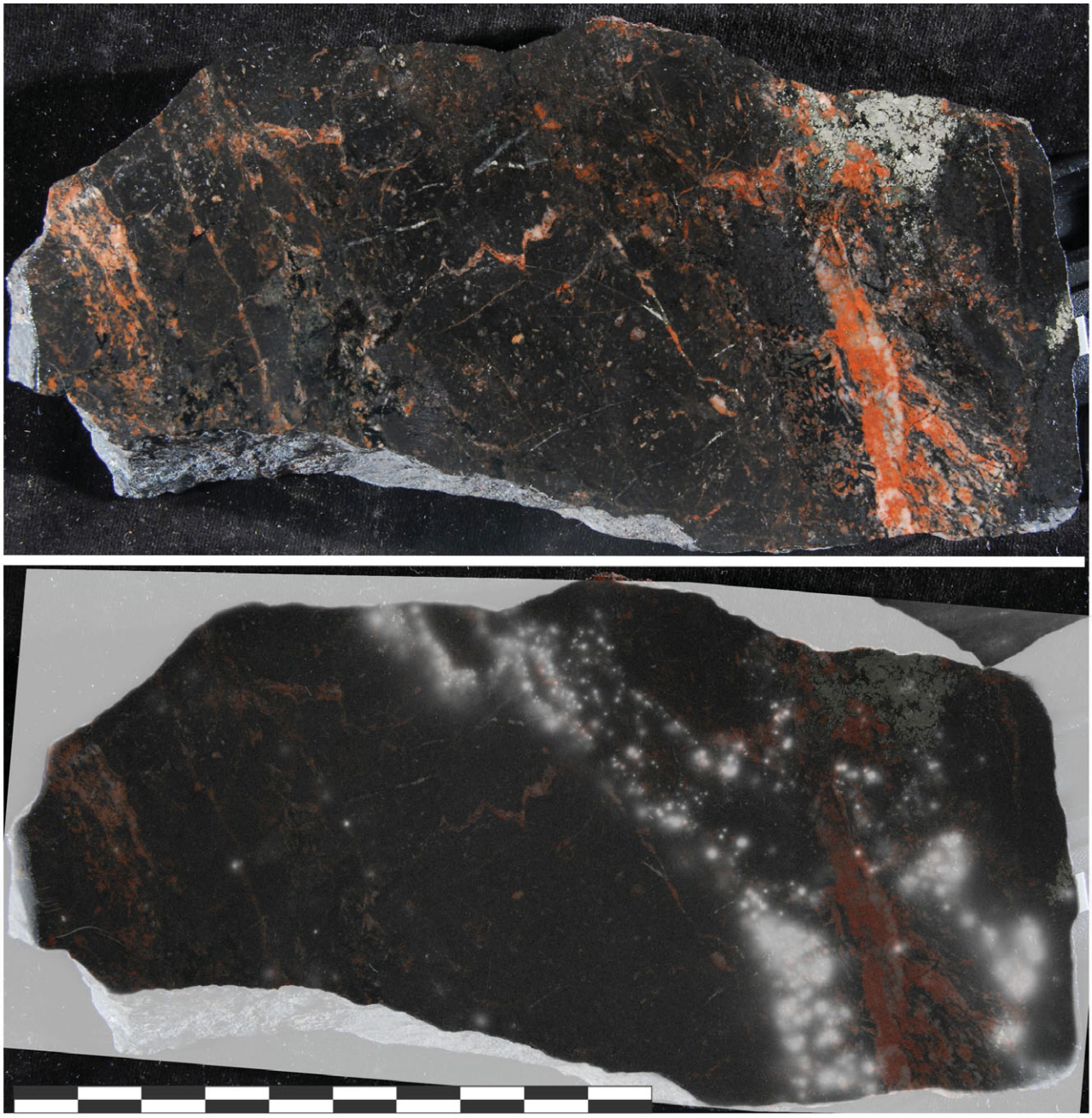

Figure 4: Representative sample from U-Cu-Fe mineralized occurrence (Fab1; sample 11PUA-1000H2). (A) Polished slab highlighting late K-Fe (HT) veinlets and sulphide (pyrite) mineralization in an intensely amphibole-magnetite (HT) altered porphyritic dacite. (B) Autoradiograph superimposed on slab image, illustrating presence of U-minerals (white spots) in magnetite-rich K-Fe vein selvages.

Alteration mapping protocol

Each alteration type, style, mineral paragenesis and timing relationships with the other alteration types and porphyries were systematically documented, sampled and photographed during field studies. In order to detect cryptic levels of incipient alteration, %K, *e*Th (ppm) and *e*U (ppm) were measured with a portable gamma-ray spectrometer (Radiation Solutions Inc. RS-230 spectrometer equipped with a bismuth germanate detector) and volumetric magnetic susceptibility were measured with a portable magnetic susceptibility meter (ZH instruments SM-30, Terraplus KT-10 and Terraplus KT-9) . The prefix "*e*" (i.e. *e*Th or *e*U) denotes that U and Th concentrations were determined indirectly from those of their daughter products (Bi^{214} and Tl^{208} respectively), assumed to be in equilibrium with their parent isotopes. The spatial and temporal distributions of the various hydrothermal alteration signatures in the Fab system were then established based on the alteration mapping results, allowing the timing and spatial relationships between alteration and mineralization in the Fab system to be better understood. Subsequent laboratory examination involving petrographic and scanning electron microscopy and K-feldspar staining was applied to confirm key field observations.

Hydrothermal alteration types in the Fab Lake IOCG system

Na (HT) and Na-Ca-Fe (HT)

High temperature Na alteration occurs as: 1) incipient to pervasive albitization of the host rocks; 2) albite selvages on amphibole ± magnetite veins; 3) albite veins with and without amphibole ± magnetite selvages; and 4) texture-destructive amphibole + albite + magnetite replacements. The pervasive, texture destructive albite replacement occurs as spatially restricted alteration fronts whereas early incipient albite alteration occurs throughout the eastern portion of the system (Fig. 5A). Recognition of this early incipient albite alteration in the feldspar porphyries is difficult as it is overprinted in most cases by amphibole + magnetite ± K-feldspar assemblages (a variant of the Ca-Fe (HT) alteration type described below). In the vicinity of the main Fab showings, the albite veins with amphibole selvages are associated with a pervasive albite replacement that was observed to overprint and crosscut some amphibole ± magnetite ± K-feldspar veins (Fig. 5B). Texture-destructive amphibole-albite-magnetite replacement forms variegated pegmatitic alteration zones in the feldspar porphyries (e.g. station CQA-06-0435). These zones grade into intense, massive and coarse-grained amphibole-magnetite alteration, several metres in width and are crosscut by albitized porphyry. Locally the pegmatitic replacement zones resemble the pegmatitic albite-bearing amphibole-magnetite alteration associated with iron-oxide apatite mineralization in the Port Radium-Echo Bay district (Corriveau et al. 2010a, b; Mumin et al. 2010). Field observations suggest at least three albitization episodes: 1) incipient to well-developed albitization overprinted by an early K alteration; 2) albite + amphibole + magnetite veining and replacement; and 3) late pervasive albitization/veining observed at the Fab Lake showings, which overprints earlier K-Fe and Ca-Fe alteration.

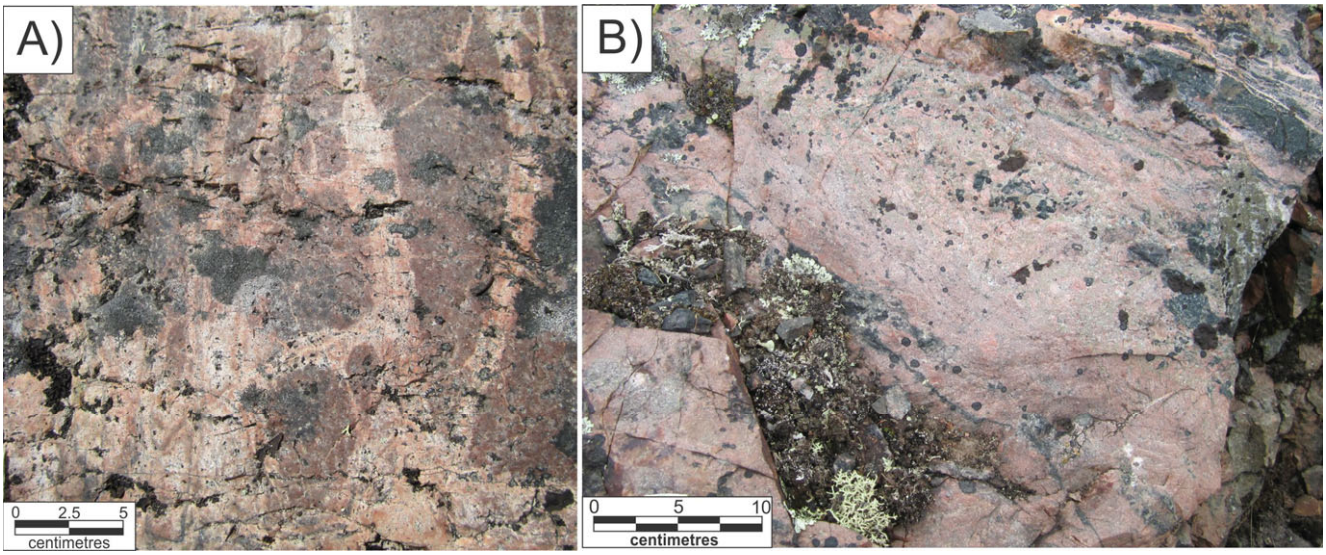

Figure 5: incipient (A) to pervasive (B) Na alteration (albitization) of porphyritic dacite. Field stations 11PUA-057 (A) and 11PUA-032 (B).

HT Ca-Fe

High temperature Ca-Fe alteration types, distributed throughout the entire Fab system except for its western margins, are subdivided in three categories based on their mineral assemblages: 1) amphibole and magnetite ± amphibole alteration types (herein referred to as Ca-Fe alteration), 2) amphibole + apatite and amphibole + magnetite + apatite alteration types (herein referred to as Ca-Fe-P alteration) and 3) amphibole ± magnetite veins with K-feldspar ± magnetite selvages (herein referred to as Ca-Fe-K alteration). Ca-Fe-K alteration is prominent within the Fab Lake hydrothermal system, forming veins, composite veins, replacement veining, hydrothermal crackle breccias and stockworks (Fig. 6).

Metre-scale Ca-Fe alteration zones are the result of a combination of veins and intense replacements that record distinct pulses of Ca-Fe and Ca-Fe-P alteration types. Magnetite (Ca-Fe alteration stage) and apatite-rich alteration are commonly hosted within these massive amphibole veins and were emplaced as distinctive veins within the cores of the large Ca-Fe veins and replacements. Late magnetite veins also locally crosscut the massive Ca-Fe veins at sharp angles. Some of these polyphase Ca-Fe alteration zones are locally Th-enriched (i.e. > 100 ppm Th). In its early stage, Ca-Fe alteration occurs as a sporadic and pervasive but fairly cryptic amphibole ± magnetite replacement of the porphyritic dacite groundmass. A small to moderate increase in the magnetic susceptibility combined with a small decrease of the K concentration usually accompanies these Ca-Fe replacement zones, which have been mapped out with a magnetic susceptibility meter and a gamma-ray spectrometer. These incipient Ca-Fe replacements are usually indicative of intense Ca-Fe and Ca-Fe-K alteration nearby and occur in the outer margins of the central parts of the system.

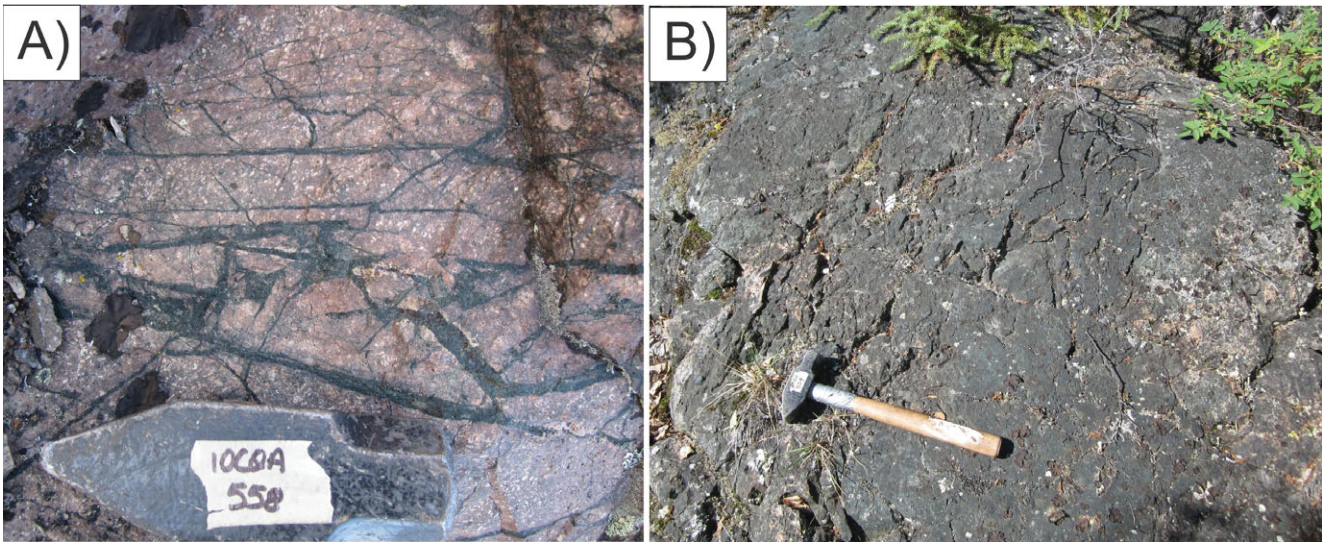

Figure 6: A) Ca-Fe-K crackle brecciation of porphyritic dacite, with minor K-feldspar alteration restricted to the host rocks. B) Metre-scale veining/whole rock replacements of porphyritic dacite by Ca-Fe-P veins. The length of the hammer head and handle are 12 and 30 cm, respectively. Field stations 10CQA-0558 and 10CQA-0559.

Ca-Fe-K alteration is manifested by amphibole+magnetite veins with selvages rich in K-feldspar. The width of the K-feldspar selvages for centimetre-scale veins is in the order of a few centimetres, whereas selvages for metre-scale veins can extend up to ten metres into the host rocks. K-feldspar alteration is typically fine grained and texture destructive next to the vein and imparts a dark grey pink to red pink color to the rock (Fig. 7A). Occasionally, the K-feldspar selvages are bright pink, similar in colour and texture to albitization developed under Na-Ca-Fe alteration (Fig. 7B). The systematic use of the portable gamma-ray spectrometer in the field was key in the identification of these K-feldspar alteration types. Near the historical mineral occurrences, intense Ca-Fe-K alteration/veining created crackle breccia zones.

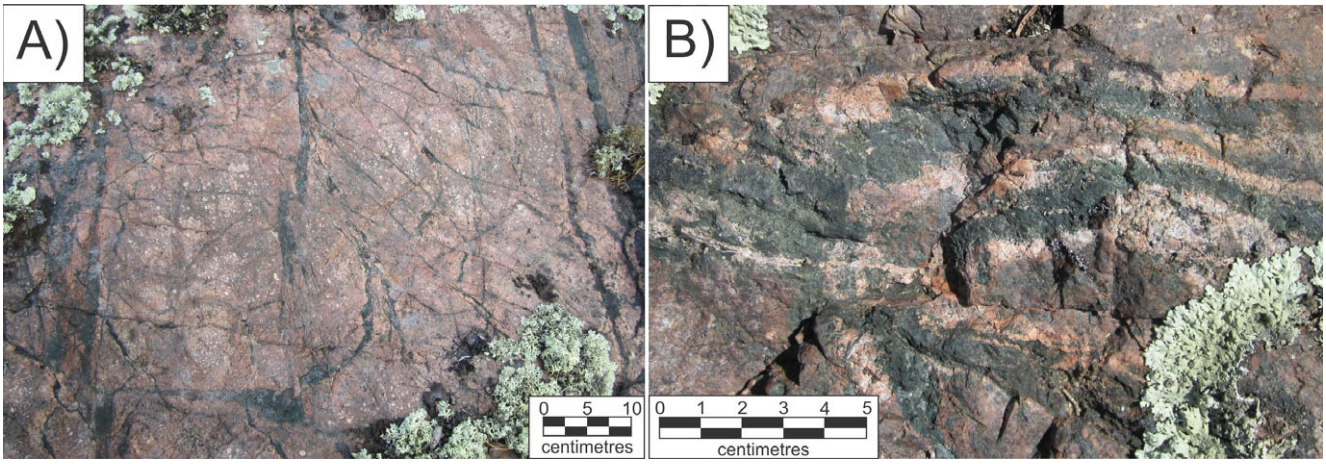

Figure 7: Ca-Fe-K veining/brecciation with K-feldspar alteration of the porphyry (left) and fine-grained K-feldspar (right) selvages developed in porphyritic dacite. Field stations 11PUA-0534 (A) and 11PUA-0085 (B).

Ca-Fe-P alteration types are characterized by macroscopic apatite crystals set in a coarse-grained amphibole and magnetite groundmass (Fig. 8). These apatite-rich alteration types are not evenly distributed in the Fab hydrothermal system and were mostly observed in its northern part, on both sides of Fab Lake. They commonly occur as centimetre- to metre-scale veins and replacement zones,

generally devoid of K-feldspar selvages. Some of the apatite-bearing veins are enriched in Th compared to the host porphyry but there is no conclusive evidence of a relationship between apatite and the Th-rich Ca-Fe alteration of the Fab Lake system. A large zone of Ca-Fe-P alteration is located on the eastern margin of the Fab Lake system, within the porphyritic monzonite. In this zone, disseminated amphibole + magnetite ± apatite clots replace fine-grained groundmass material.

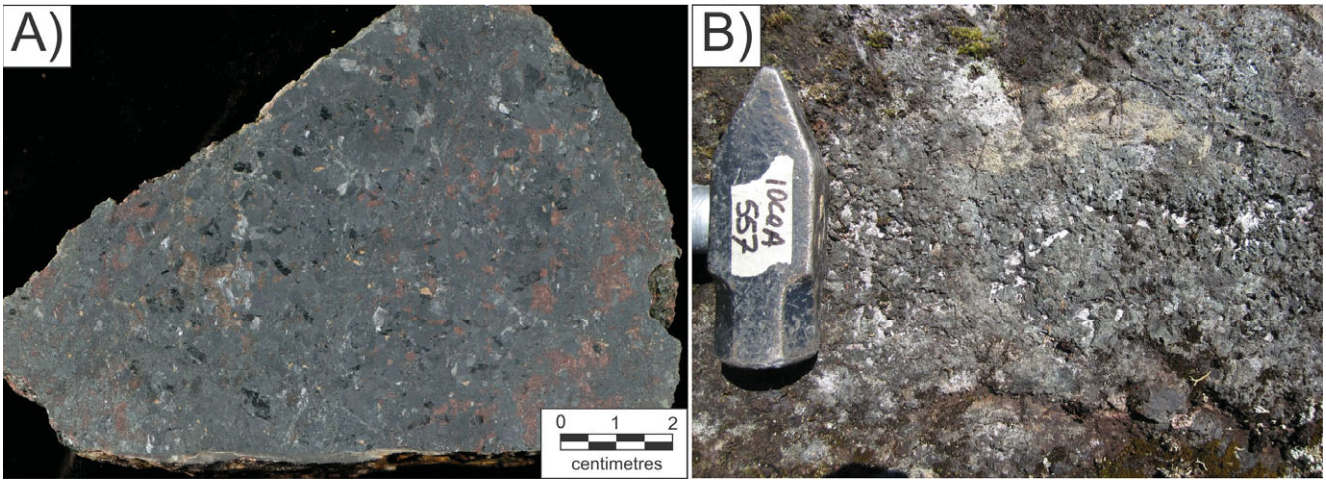

Figure 8: Polished sample and field photograph of Ca-Fe-P veins. Left: bright red apatite interstitial to actinolite (amphibole), magnetite and trace pyrite. Right: Apatite crystals (off-white) preferentially weathered in an exposed Ca-Fe-P altered outcrop. The head of the hammer is 12 cm long. Sample 11PUA-086B4 and field station 10CQA-557.

HT K-Fe and LT K-Fe

High temperature (HT) K-Fe alteration is divided into three assemblages and alteration styles: 1) pervasive K-feldspar + magnetite/hematite replacement; 2) K-feldspar + magnetite/hematite + biotite alteration fronts and replacement zones; and 3) K-feldspar veins with magnetite selvages. In the Fab system, most of the K-Fe alteration is of the high temperature, K-feldspar + magnetite variety (HT K-Fe). Localized zones with lower temperature K-Fe alteration consisting of K-feldspar + hematite are weakly developed at the present exposure and are denoted as K-Fe (LT) on the map.

K-feldspar + magnetite/hematite alteration that is unrelated to amphibole vein emplacement mostly occurs as pervasive K-feldspar + magnetite/hematite replacement (Fig. 9). It is spatially constrained to the vicinity of the mineral showings, but in many cases discrimination from the K-Fe alteration related to the large Ca-Fe-K veins or in the crackle breccia zones (previous section) is impossible. This alteration is texture-preserving in its incipient to moderate stages but becomes texture-destructive in its well developed stages. It imparts a bright pink to reddish pink color to the rock.

Figure 9**:** K-Fe (K-feldspar + hematite: K-Fe [LT]) alteration of the porphyritic dacite producing bright red colouration. Late quartz veinlets are also present. Field station 09CQA-0434.

K-feldspar + magnetite/hematite + biotite alteration fronts and replacement zones (Fig. 10A) characterize most of Fab mineralized zones. These K-Fe alteration fronts have anomalous uranium contents and host most of the chalcopyrite and pyrite-bearing veins that were observed in the system (Acosta et al. 2011; this work). Zones of intense K-feldspar alteration ingress are associated with breccias containing amphibole, magnetite and chalcopyrite (outcrop CQA-06-0392; Corriveau et al. 2010b). Sulphide-bearing veins themselves locally brecciate the K-Fe alteration zones (Acosta et al. 2011). K-Fe alteration fronts can also form magnetite-cemented hydrothermal breccias along their margins. The magnetite-rich matrices of these breccias are fine-grained, overprint the Ca-Fe alteration types described in the previous section and are crosscut by K-feldspar veins with and without magnetite selvages. The alteration fronts can be continuous over tens of metres and may completely destroy the textures of the porphyritic dacite host. The presence of magnetite-cemented breccias is clear indicators of proximity to the Fab Lake mineralized zones.

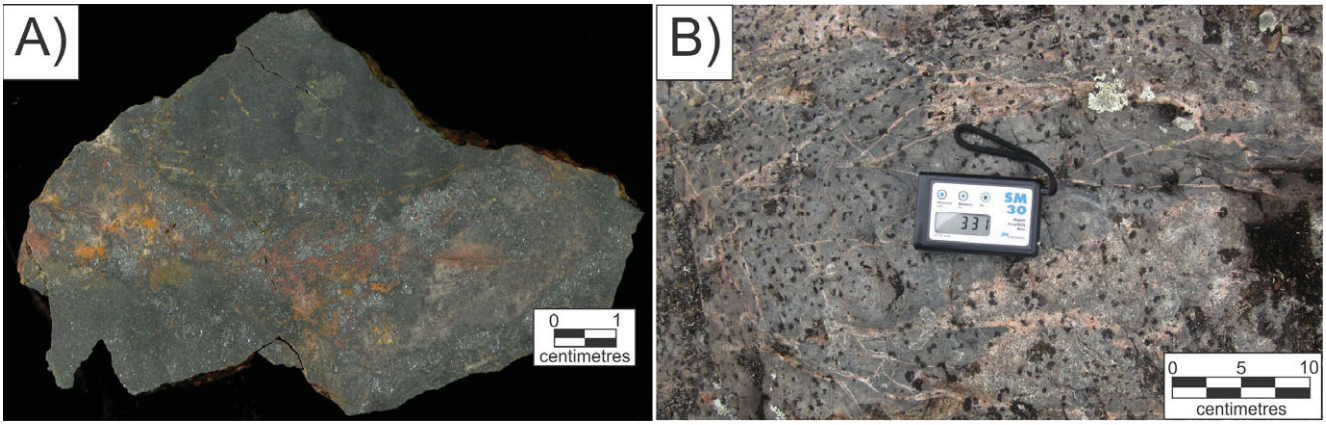

Figure 10: A) Specular hematite veining cross-cutting Ca-Fe-P veining. B) Pervasive Ca-Fe (magnetite-rich) replacement front in porphyritic dacite, cross-cut by K-Fe veinlets with magnetite selvages. The black spots in (B) are lichen. Sample 11PUA-0086B6 and field station 10CQA-0562.

Near the main Fab showings, K-feldspar veinlets with and without magnetite selvages crosscut the Ca-Fe and Ca-Fe-Na alteration described in the previous section. The veins are centimetre-wide and frequently have magnetite selvages that extend a few centimetres into the host rocks (Fig. 11). The veins are bright pink in colour and when present, the magnetite-rich selvages are metallic grey. K-feldspar is medium to fine grained and magnetite is very fine grained. The veins are well developed in the vicinity of the main Fab showings and in the outcropping of the porphyritic dacite east of the main Fab Lake showings. In zones where they reached their highest intensity, they form vein stockworks several metres in width. Anomalous uranium concentrations are locally associated with these chalcopyrite- and pyrite-bearing veins.

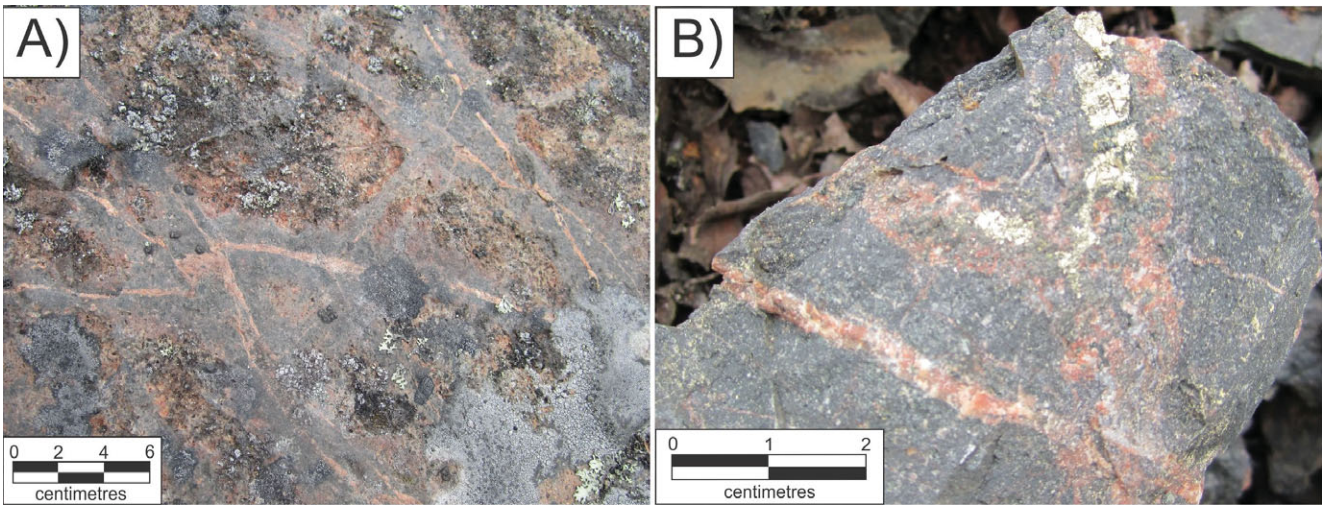

Figure 11: A) K-feldspar veinlets with well-developed magnetite selvages cross-cutting a Ca-Fe altered porphyritic dacite. B) Detailed view of pyrite+chalcopyrite-bearing K-feldspar veinlet (with no magnetite) in Ca-Fe altered porphyritic dacite. Field stations 11PUA-0031 and 11PUA-1000.

K-only

K-only alteration unrelated to either the Ca-Fe-K or the K-Fe alteration occurs as cryptic, yet pervasive K-feldspar replacements in the porphyritic dacite, porphyritic monzonite, the amphibole-

magnetite-rich porphyritic monzonite, the undifferentiated porphyries and the granitic intrusion postdating the Fab Lake alteration and mineralization (Fig. 12). As the felsic intrusions of the GBMZ are well known to be associated with extensive K alteration halos (Hildebrand et al. 1987; Gandhi et al. 2001), most of the K replacements may be related to orthomagmatic alteration. Furthermore, discrimination of K-only alteration from Ca-Fe-K alteration or K-Fe alteration is difficult. K replacements are usually texture-preserving in their incipient to moderate stages to texture-destructive in their well developed stages and impart a bright-pink to reddish-pink color to the rock.

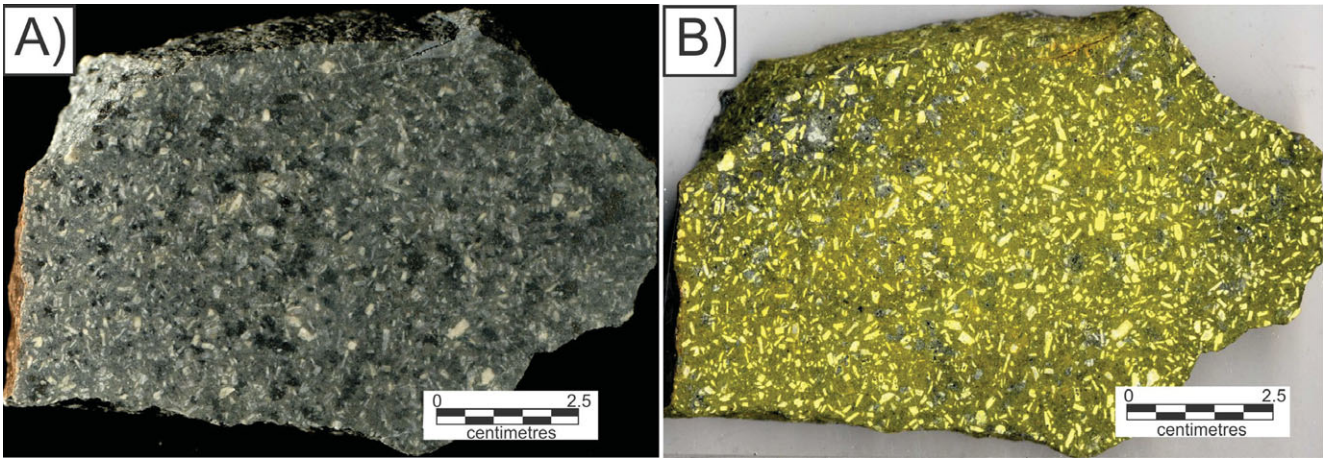

Figure 12: Polished sample illustrating the cryptic, pervasive K-feldspar alteration of the HT Ca-Fe-P altered porphyritic monzonite located on the eastern margin of the Fab lake system. In (B) cobalt nitrate staining was used to highlight the pervasive K alteration, as shown in yellow. Sample 11PUA-068.

Epidote±K-feldpsar+quartz+chlorite [LT Ca-Fe]

Epidote-bearing alteration types form a regional alteration aureole of the Fab hydrothermal system. Styles include: 1) pervasive replacements; and 2) vein networks (Figure 13). The intensity and variety of these alteration types decrease southward. Epidote is accompanied by a wide variety of minerals, commonly including microcrystalline K-feldspar, quartz, and minerals in their more oxidized, forms, and is not always the predominant mineral. Field evidence of their presence is increasing K concentration, increasing rock hardness or visible quartz associated with epidote, and a strong decrease in rock magnetic susceptibility. Locally chlorite is also present and replaces older amphibole veins. Epidote-bearing alteration usually occurs as a network of epidote veins associated with bright red to whitish grey replacement fronts that are texture-preserving to texture-destructive where very intense. Partial replacement of the rock by these alteration fronts can locally lead to altered rocks with textures that can be confused with fragmental volcanic rock textures. However continuity between the feldspar phenocrysts in the pseudo-fragments, feldspar phenocrysts in the pseudo-matrix and the transitional pseudo-fragments to pseudo-matrix preclude a volcaniclastic origin for these rocks. Epidote-bearing alteration overprints the Ca-Fe, K-Fe and some of the K-feldspar alteration types.

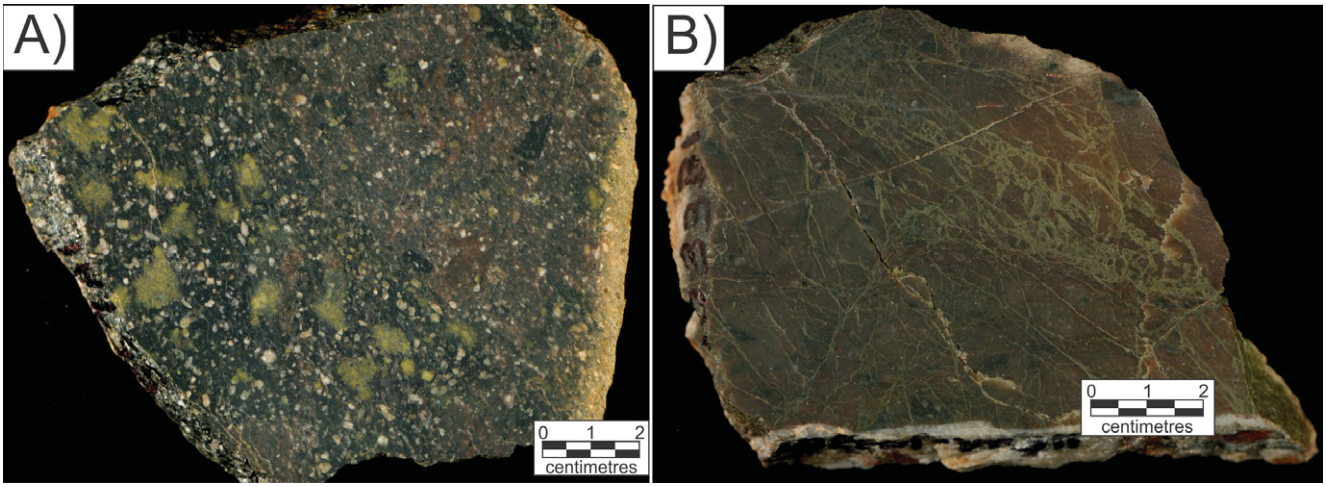

Figure 13: LT Ca-Fe alteration producing pervasive epidote replacements (left) and veinlets (right). Samples 11PUA-0557 and PUA-1033.

Chlorite alteration

Chlorite alteration occurs as pervasive replacements and veinlets (Fig. 14). The first variety is associated with the main Fab showings, where it forms sporadic and texture-destructive replacement zones characterized by chlorite overprinting earlier Ca-Fe and K-Fe alteration types. Chlorite is fine grained, accompanied by minor pyrite and chalcopyrite, and has a dark green color. Some of the amphibole formed during the Ca-Fe alteration event may also be slightly chloritized. The second variety of chlorite alteration occurs as veinlets and selective replacements and can be locally associated with hematite alteration of the rock. It was mainly observed outside the porphyritic dacite intrusion in the northern parts of the undifferentiated porphyries. Chlorite replacements are fine-grained and texture preserving to texture destroying. These chlorite replacement zones are usually crosscut and overprinted by epidote-bearing alteration. Chlorite in the veinlets is commonly associated with epidote and relates to the preferential replacement of amphibole veins observed outside the porphyritic dacite.

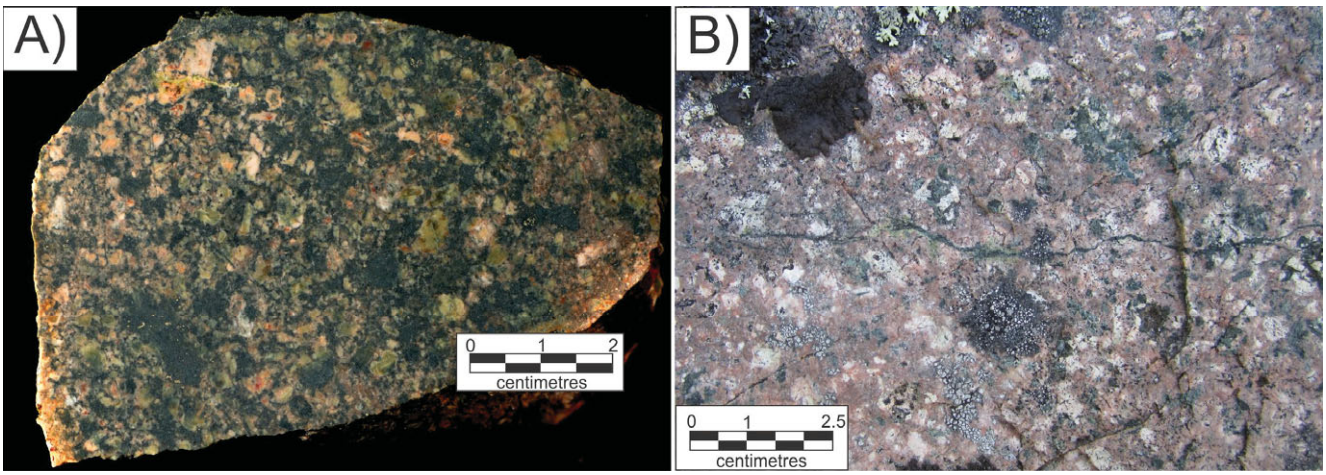

Figure 14: (A) Pervasive chlorite alteration and (B) chlorite veinlets (with trace epidote); both within porphyritic monzonite also exhibiting extensive sausseritization of the feldspar phenocrysts. Sample 11PUA-0050A1 and field station 11PUA-0054.

Specular hematite-bearing alteration types

Three different specular hematite alteration types were observed in the Fab hydrothermal system: 1) specular hematite veinlets or replacements; 2) specular hematite veinlets with K-feldspar±quartz selvages; and 3) as specular hematite selvages of quartz veins (Fig. 15). In the central parts of the Fab hydrothermal system located in the porphyritic dacite, hematite alteration of any kind is uncommon (Gandhi 1988; this work). Where observed, specular hematite forms tiny and fine-grained veinlets that crosscut the main Ca-Fe and Ca-Fe-K alteration events, and can form very localized and fine-grained replacements spatially associated with the Cu-U mineralization in the main Fab showings (Acosta et al. 2011; this work). Some of the Ca-Fe veins are also locally overprinted by earthy hematite alteration. Specular hematite veinlets were also observed in the granite intrusion at the contact with the porphyritic dacite, and crosscut epidote alteration.

Specular hematite veinlets with K-feldspar± quartz selvages were observed in diverse locations in the northern and central parts of the undifferentiated porphyries. Specular hematite is fine grained and K-feldspar and quartz in the selvages are very fine grained. The timing relationship between the specular hematite veinlets with K-feldspar±quartz selvages and the Ca-Fe, K-Fe and Na alteration types remains uncertain as these alteration types occur within different sectors of the Fab hydrothermal system. However it has been established that specular hematite veinlets with K-feldspar ± quartz selvages are overprinted by epidote alteration and are crosscut by the quartz veins with the specular hematite selvages.

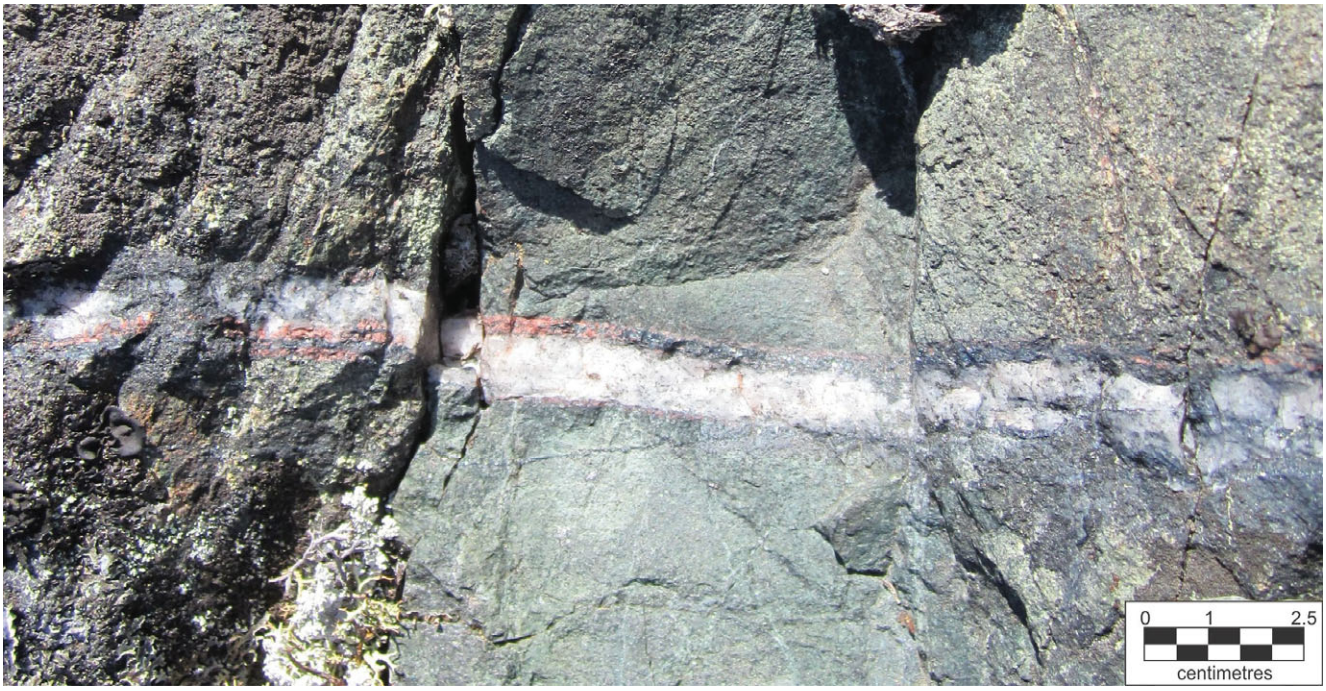

Figure 15: Quartz veinlet with specular hematite and K-feldspar selvages cross-cutting LT Ca-Fe altered feldspar porphyry. Field station 11PUA-0618.

Alteration map

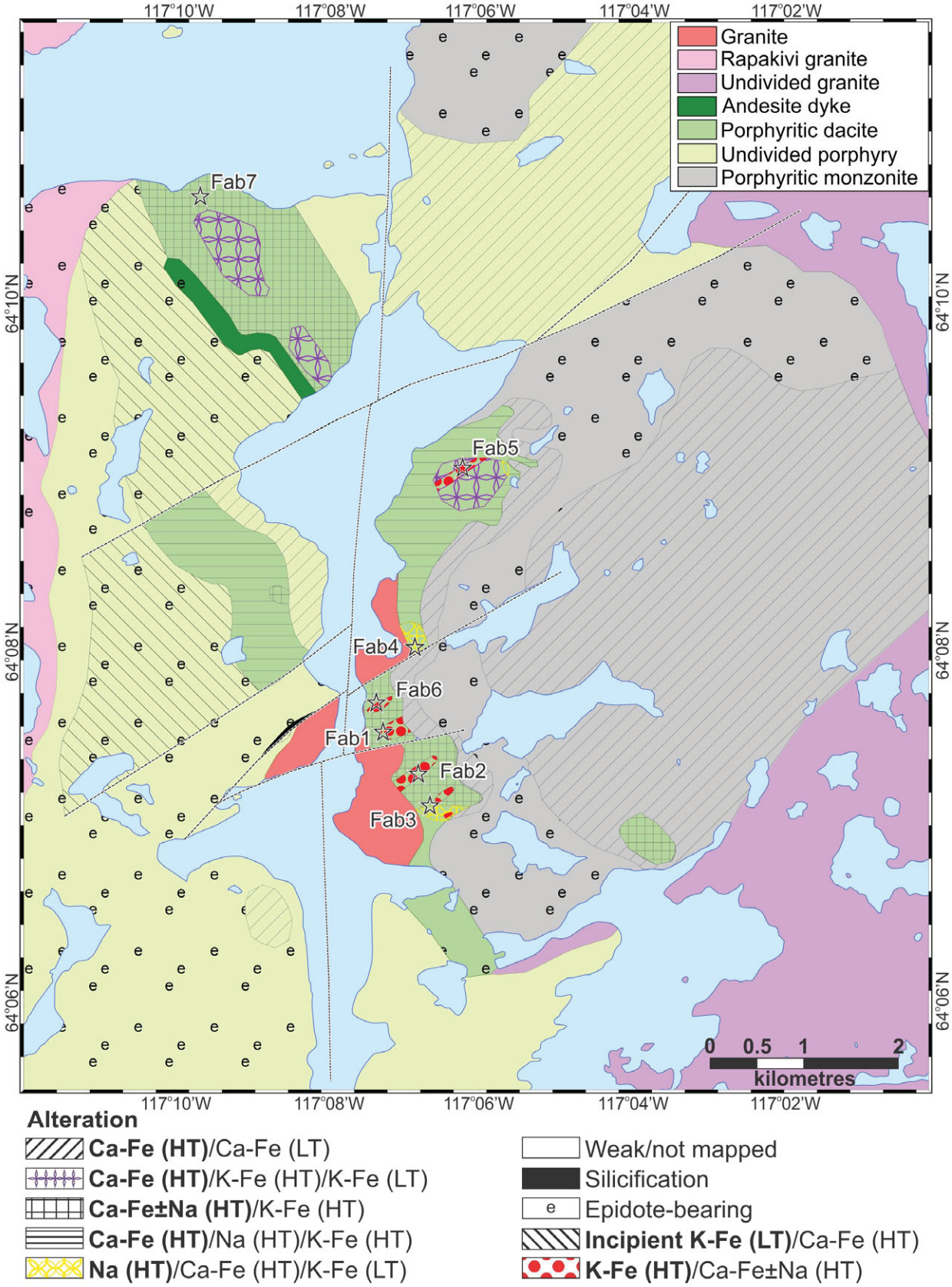

Figure 16: Hydrothermal alteration of the Fab Lake region. See Appendix A for a full detail map.

Fab Alteration assemblages and implications for exploration

At Fab Lake, the alteration assemblages observed in the field clearly record the build-up of a magnetite-group IOCG system. The zoning of the alteration assemblages aligns with the alteration zoning to ore model of Corriveau et al. (2010b), with an early high temperature Na alteration overprinted by successive Ca-Fe and K-Fe alteration events. Multiple episodes of each alteration assemblage record re-setting of the hydrothermal system, presumably linked to magmatism in the region. More importantly, the alteration assemblages observed at Fab Lake record the evolution of an iron oxide-apatite (IOA) system into a magnetite-group IOCG system. This is clearly evident at the historic U-Cu-Fe showings, where of early Na, Na-Ca-Fe, Ca-Fe and Ca-Fe-K alteration events are overprinted by K-Fe (HT) fronts and veinlets (Fig. 16). Localized and weakly developed hematite + K-feldspar + carbonate + chlorite and sulphide mineralization suggests that at the present exposure, the system may have not fully evolved into hematite-group IOCG type mineralization.

Acknowledgments

This is a contribution of the IOCG/Multiple Metals Great Bear Region and Northern Uranium for Canada projects of the Geomapping for Energy and Minerals program (Geological Survey of Canada, NRCan) conducted in partnership with the Northwest Territories Geoscience Office and the Community Government of Gamèti. Field research was permitted under the Aurora Research Institute Scientific Research licenses 14548, 14649, GSC land use permit W2010J0004 granted by the Wek'èezhìi Land and Water Board (WLWB) in accordance with the Mackenzie Valley Resource Management Act, and NWT archaeological sites database agreement # DR2009-335 and # DR2010-390. The authors would like to acknowledge the significant logistical support provided by Fortune Minerals Limited to study the entire southern Great Bear magmatic zone and the collaborative partnership with the community of Gamèti. The authors would also like to acknowledge all those who helped us during fieldwork in the Fab Lake area: Dolphus Apple, Alfred Arrowmaker, Crystal Arrowmaker, L.-P. Gélinas, Cindy Gon, Freda Gon, Vincent Martel and Edward Williah. Lesley Chorlton and Jean-Sébastien Comeau provided essential database management, GIS and cartographic assistance. Finally, the authors would like to acknowledge the Natural Sciences and Engineering Research Council that provided funding for the PhD studies of JFM and a constructive review by Leslie Chorlton.

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Geological Survey of Canada Open File 7339

Appendix A: Geology and Hydrothermal Alteration of the Fab Lake Region, Northwest Territories

Potter, E.G., Montreuil, J-F., Corriveau, L. and DeToni, A.

Scale 1:7,500

kilometres

0 0.5 1 2

Abstract

Detailed mapping of the Fab Lake magnetite-group iron oxide-copper-gold (IOCG) system has defined an alteration footprint extending almost 10 by 5 km, with the long axis trending in a southeast-northwest direction. Within this area, field mapping identified seven alteration assemblages: 1) high temperature albite and albite+amphibole±magnetite [HT Na and HT Na-Ca-Fe]; 2) amphibole +magnetite±apatite and amphibole+magnetite+K-feldspar [HT Ca-Fe and HT Ca-Fe-K]; 3) high temperature K-feldspar+magnetite±hematite [HT K-Fe]; 4) K-feldspar; 5) chlorite; 6) hematite; and 7) low temperature epidote+K-feldspar+quartz [LT Ca-Fe]. These alteration assemblages are expressed as incipient to pervasive alteration in the form of veins, hydrothermal breccias and replacement fronts in the host rocks exhibiting multiple crosscutting and overprinting relationships. All of the historic Fab U-Cu-Fe mineral showings occur within zones characterized by intense, texture-destructive alteration comprising multiple episodes of high temperature albite/albite+amphibole+magnetite (Na and Na-Ca-Fe) and amphibole+magnetite±apatite/amphibole+magnetite-K-feldspar (Ca-Fe and Ca-Fe-K) overprinted by K-feldspar+magnetite±biotite (K-Fe) assemblages.

The conceptual alteration to brecciation and mineralization model is key to understanding the alteration assemblages documented in the Fab IOCG system. These assemblages record the build-up of a magnetite-group IOCG system: early high-temperature Na/Na-Ca-Fe and Ca-Fe/Ca-Fe-K alteration, overprinted by high temperature K-Fe alterations and incipient to well-developed hydrothermal breccias. The alteration assemblages themselves and the zoning observed in outcrop provide true vectors towards mineralization, which based on the nature of the hydrothermal system, can be applied elsewhere in the GBmz and other prospective terranes. As field observations indicate that lower-temperature K-Fe alteration associated with hematite-group IOCG systems is only weakly developed, the Fab Lake region is most prospective for magnetite-group types of IOCG mineralization.

Alteration nomenclature

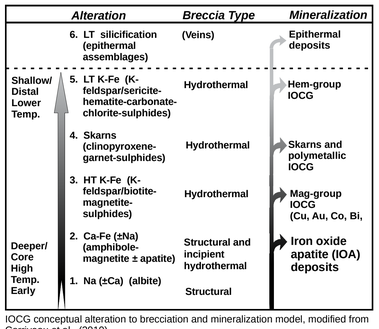
Na (HT) and Na-Ca-Fe (HT)
Na alteration occurs as: 1) incipient to pervasive albitization of the host rocks; 2) albite selvages on amphibole±magnetite veins; 3) albite veins with and without amphibole±magnetite selvages; and 4) texture-destructive amphibole+albite+magnetite replacements.

Ca-Fe (HT)
Observed as: 1) amphibole and magnetite±amphibole alteration types (herein referred to as Ca-Fe alteration), 2) amphibole+apatite and amphibole+magnetite+apatite alteration types (herein referred to as Ca-Fe-P alteration) and 3) amphibole±magnetite veins with K-feldspar±magnetite selvages (herein referred to as Ca-Fe-K alteration). Ca-Fe-K is a prominent hydrothermal alteration within the Fab hydrothermal system, expressed as veins, composite veins, replacement veining, hydrothermal crackle breccias and stockworks

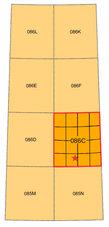
K-Fe (HT)
K-Fe alteration is divided into three assemblages: 1) pervasive K-feldspar+magnetite/hematite impregnation; 2) K-feldspar+magnetite/hematite+biotite alteration fronts and replacement zones; and 3) K-feldspar veins with magnetite selvages.

K-Fe (LT)
Specular hematite veinlets with K-feldspar± quartz selvages overprinted by epidote alteration and are crosscut by the quartz veins with the specular hematite selvages.

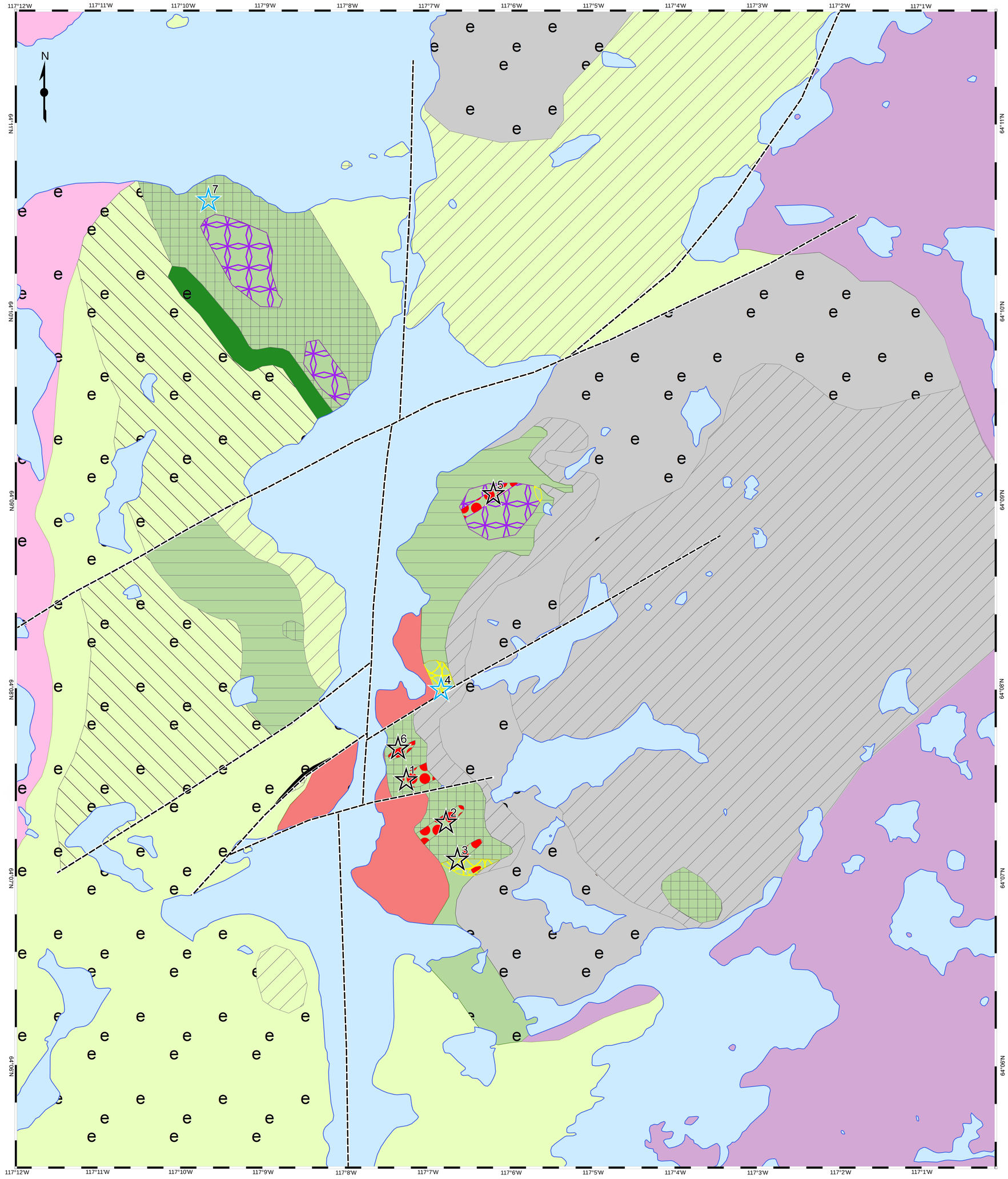
Ca-Fe (LT): epidote±K-feldpsar+quartz+chlorite
Epidote-bearing alteration types form the regional alteration aureole of the Fab hydrothermal system. The intensity and variety of these alteration types decrease southward. They occur as pervasive replacements and vein networks in varying proportions of epidote, microcrystalline K-feldspar, quartz and pervasive oxidation fronts.



IOCG conceptual alteration to brecciation and mineralization model, modified from Corriveau et al., (2010).



National Topographic System reference
Geodetic Reference System 1980
Approximate magnetic declination 2013: 19°52'E



Legend

Geological Units

- **Granite**: Coarse-grained, phaneritic granite composed of quartz, K-feldspar and plagioclase. Hornblende is the main mafic mineral with lesser quantities of biotite.
- **Rapakivi granite**: Very coarse- to coarse-grained K-feldspar phenocrysts with alternating overgrowths of albite and K-feldspar set in a medium- to coarse-grained groundmass composed primarily of quartz, K-feldspar, plagioclase and trace amphibole and biotite.
- **Undivided granite**: Medium- to coarse-grained, leucocratic to mesocratic rocks ranging in composition from granitic to monzonitic with accessory biotite±hornblende±magnetite. Equigranular to seriate textured with weakly developed K-feldspar or plagioclase-phyric zones.
- **Andesite Dyke**: A circa 200 metres wide unit in sharp contact with the dacitic feldspar porphyry. Massive and homogenous to flow-banded unit with fine-grained, sparsely disseminated plagioclase and pyroxene phenocrysts with accessory magnetite, apatite, zircon and quartz.
- **Porphyritic dacite**: Fine- to medium-grained euhedral plagioclase phenocrysts set in a fine-grained to aphanitic groundmass of quartz and altered feldspar. Groundmass phases include chlorite, amphibole, pyroxene, iron-oxides and titanite. Occasional K-feldspar and quartz.
- **Undivided porphyries**: Fine- to medium-grained, feldspar porphyries: one-feldspar porphyritic intrusions with rhyolitic to andesitic compositions, one-feldspar porphyritic intrusions containing trace quartz phenocrysts with rhyolitic compositions and two-feldspar porphyries with dacitic to rhyolitic compositions.
- **Porphyritic monzonite**: Phaneritic porphyritic monzonite to monzodiorite, with localized zones with aphanitic groundmass. Plagioclase and K-feldspar are the main phenocrysts and occur in a proportion of 3:1 to 2:1. Plagioclase phenocrysts are coarser grained than the K-feldspar phenocrysts. This intrusion has a bright pink to orange pink color on weathered surfaces.

Faults (interpreted)

Alteration

- Weak/Not mapped
- Silicification
- Ca-Fe (LT)/epidote
- Incipient K-Fe (LT)/Ca-Fe (HT)
- K-Fe (HT)/Ca-Fe±Na (HT)
- Ca-Fe (HT)/K-Fe (HT)/K-Fe (LT)
- Ca-Fe (HT)/Ca-Fe (LT)
- Ca-Fe±Na (HT)/K-Fe (HT)
- Ca-Fe (HT)/Na (HT)/K-Fe (HT)
- Na (HT)/Ca-Fe (HT)/K-Fe (HT)

Mineral showings/anomalies

- 1 Fab Lake U-Cu-Fe showings (Fab1)
- 2 Fab Lake U-Cu-Fe showings (Fab2)
- 3 Fab Lake U-Cu-Fe showings (Fab3)
- 4 Fab Lake Th-U-Fe Anomaly (Fab4)
- 5 Fab Lake U-Cu-Fe showings (Fab5)
- 6 Fab Lake U-Cu-Fe showings (Fab6)
- 7 Fab Lake Th-U-Fe Anomaly (Fab7)

Geology modified after

Gandhi, S.S., 1988. Volcano-plutonic settings of Cu-bearing magnetite veins of FAB claims, southern Great Bear magmatic zone, Northwest Territories; in Current Research, Part C, Geological Survey of Canada, Paper 88-1C, p. 177-187.

Jackson, V.A. 2008. Preliminary geologic map of part of the southern Wopmay Orogen (parts of NTS 86B and 86C; 2007 updates), Descriptive notes to accompany 1:100 000 scale map; Northwest Territories Geoscience Office, Open Report 2008-007, 51p.

References

Corriveau, L., Williams, P., and Mumin, A.H., 2010. Alteration vectors to IOCG mineralization from unchartered terranes to deposits, In Exploring for Iron Oxide-Copper-Gold (Ag-Bi-Co-U) Deposits: Canada and Global Analogues, (eds.) L. Corriveau and A.H. Mumin; Geological Association of Canada, Short Course Notes 20, p. 89-110.

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