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Targeted Geoscience Initiative 4: Increasing Deep Exploration Effectiveness

Preliminary geochemical signatures of uraninite from iron oxide-copper-gold (IOCG) systems of the Great Bear magmatic zone, Canada

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Geological Survey of Canada with Provincial and Territorial Collaboration

TGI 4 Ore Systems

Introduction

Although the Olympic Dam deposit contains the world's largest recoverable U resource, very little is known regarding the processes and timing of U enrichment in iron oxide-copper-gold (IOCG) systems. The Great Bear magmatic zone (GBMZ) in the Northwest Territories of Canada is an ideal natural laboratory to study U in iron oxide-alkali-altered (IOAA) systems. Reexamination of excellent glaciated 3D exposures of the weakly to un-deformed/metamorphosed IOAA systems has shown these systems to encompass not only IOCG deposits (magnetite, magnetite-hematite and hematite group IOCG deposits; *cf.* Williams, 2010), their alteration and breccia zones, but also the wide spectrum of affiliated deposits that form within such systems such as iron oxide-apatite (IOA or Kiruna-type) deposits (Williams et al., 2005; Potter et al., 2013a), iron oxide-uranium (IOU; Hitzman and Valenta, 2005; Skirrow et al., 2011), some skarns (Gandhi, 2003; Williams, 2010; Corriveau et al., 2011) as well as alkaline intrusion-hosted IOCG deposits (Groves et al., 2010). The GBMZ also hosts historic polymetallic U-bearing vein systems (e.g. Port Radium, Rayrock) attesting to the availability of U during formation of the mineral deposits (Kidd and Haycock, 1935; Lang et al., 1962).

The GBMZ is interpreted as an continental arc that is comprised of 1873 – 1865 Ma, predominantly intermediate to felsic suites of sub-volcanic, volcanic and volcaniclastic rocks intruded by several generations of felsic plutons from 1870 – 1855 Ma (Gandhi, 1988; Gandhi et al., 2001; Bennett and Rivers, 2006; Ootes et al., 2013; Hildebrand et al., 1987; Azar, 2007).

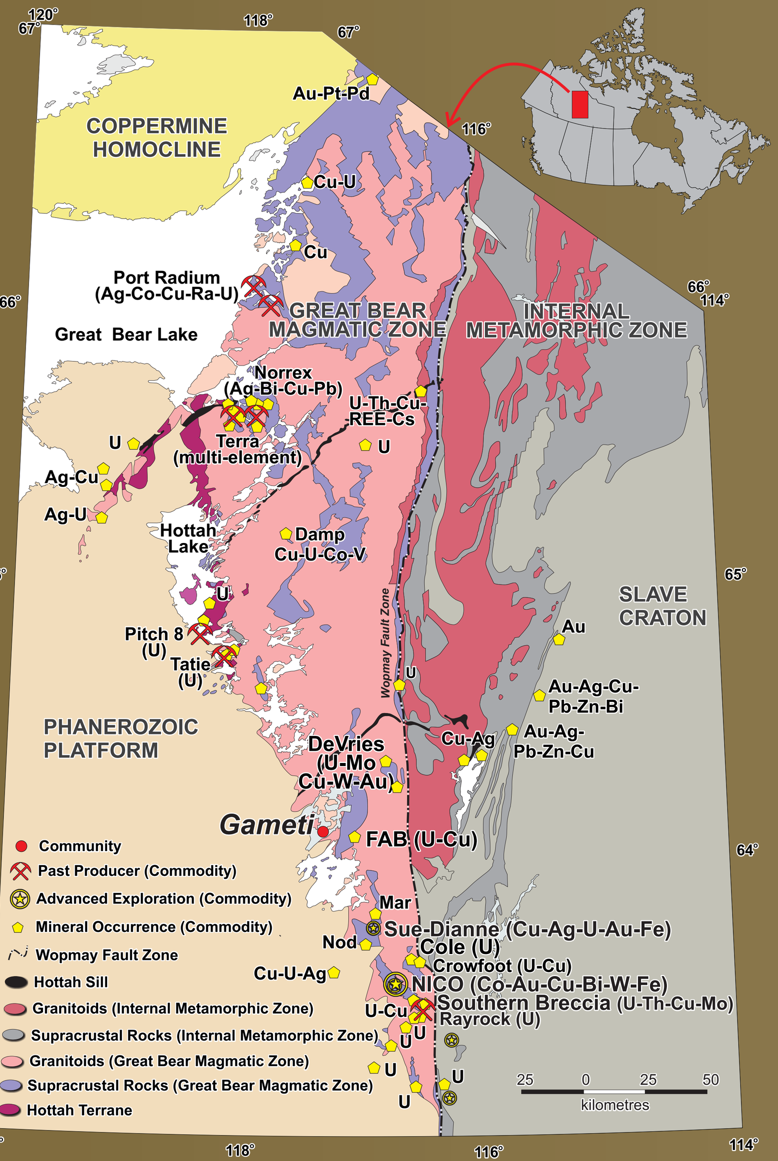


Figure 1. The GBMZ continental arc is situated on the western margin of the Wopmay orogen and developed on the composite Hottah terrane and overlying ca. 1.88 Ga Treasure Lake Group sedimentary basin following the short lived Calderian orogeny (Gandhi et al., 2001; Hildebrand et al., 2010).

IOAA Zoning Model

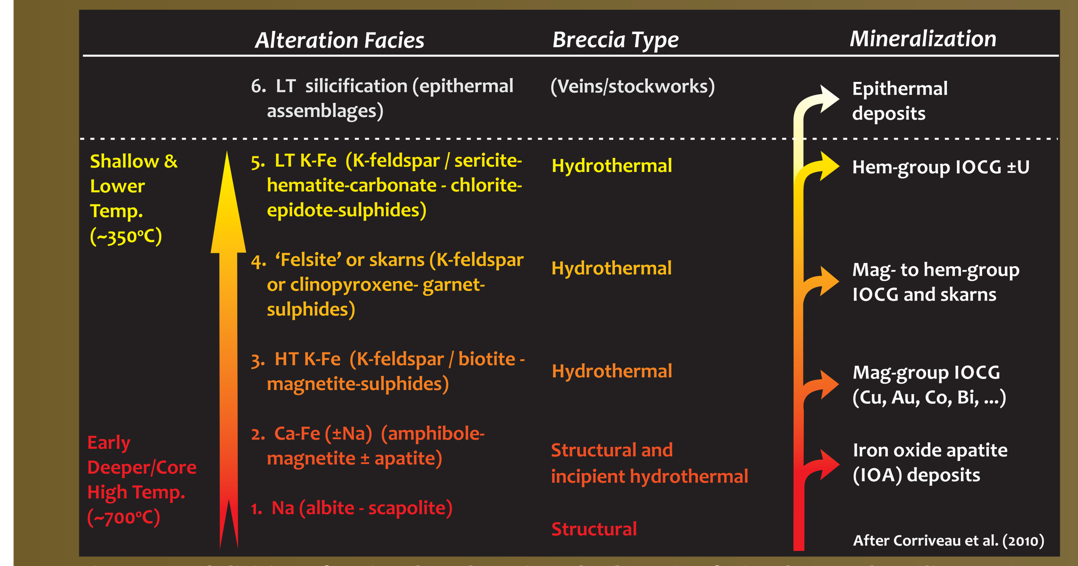


Figure 2. Subdivision of regional- to deposit-scale alteration facies that produce diagnostic lithological, mineralogical, chemical, and geophysical characteristics (Belperio et al., 2007; Benavides et al., 2008; Corriveau et al., 2010; Skirrow, 2010).

IOCG deposits are polymetallic hydrothermal mineral occurrences that contain economic Cu and Au concentrations, with abundant hydrothermal low-Ti iron-oxide (magnetite, hematite) gangue minerals or associated alteration, and sulphide-deficient ore consisting of native elements and low-sulphur base-metal sulphides and arsenides, such as chalcopyrite, bornite, chalcocite, pyrrhotite and arsenopyrite (Corriveau, 2007; Corriveau and Mumin, 2010). All IOCG deposits occur within broad-scale, chemically and mineralogically complex haloes of intensely altered rocks and breccias (Fig. 2).

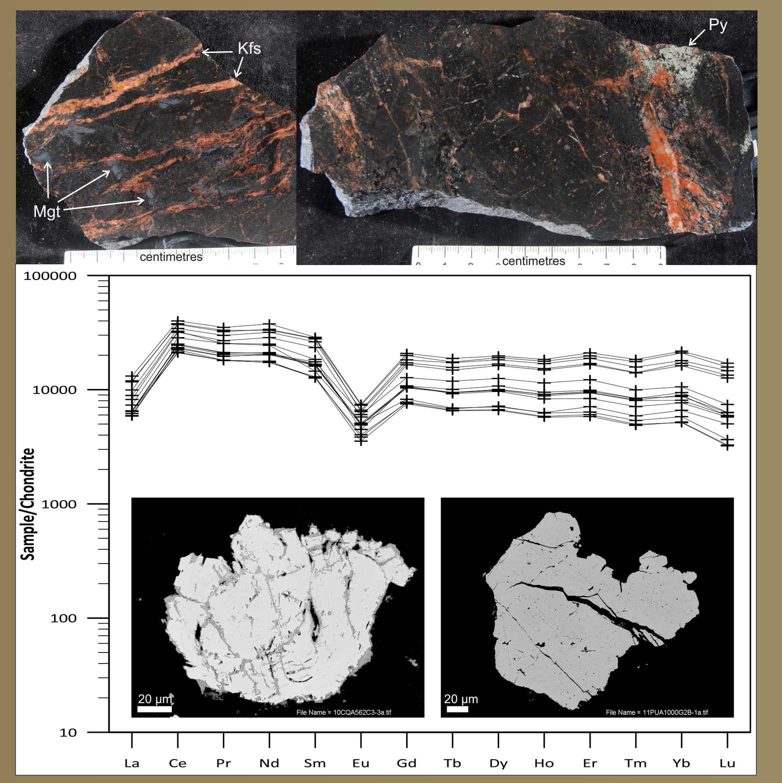
Geochemical signatures of uraninite in IOCG and affiliated systems from the GBMZ and East Arm

The Fab Lake magnetite-group IOCG system is located in the south central GBMZ (Fig. 1) within a succession of rhyolitic to andesitic shoshonitic rocks.

Alteration assemblages: Na, Na-Ca-Fe, Ca-Fe and Ca-Fe-K overprinted by HT K-Fe assemblages.

These give rise to magnetite-cemented hydrothermal crackle breccias developed in tension fractures, extensive amphibole + magnetite-bearing replacement fronts and K-feldspar + magnetite alteration zones.

Uraninite occurs as anhedral grains in magnetite+K-feldspar veins with chalcopyrite and pyrite.



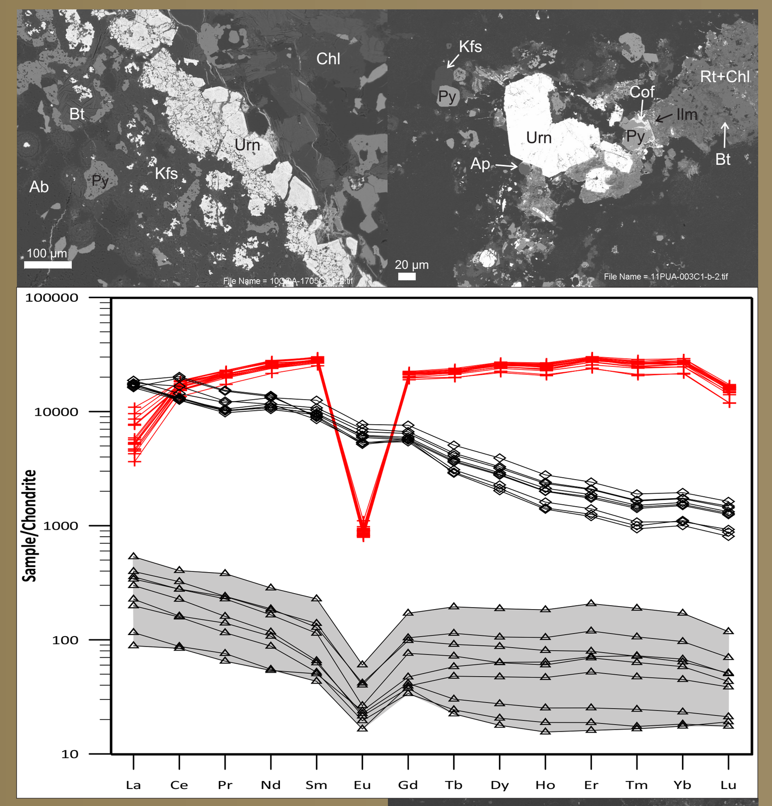
Top: Photographs of Ca-Fe and K-Fe altered, U-bearing samples from the Fab prospect. Middle: chondrite-normalized REE patterns of uraninite from the Fab IOCG prospect. Chondrite normalization values of McDonough & Sun (1995). Insets: Representative BSE-images of uraninite grains with variable coffinite alteration along the grain margins.

The Southern Breccia is a 3 km long corridor of U-rich polymetallic showings developed within the albitite zone of the Lou IOAA system. The Lou IOAA system also hosts the co-genetic NICO magnetite-group IOCG deposit (Montreuil et al., accepted).

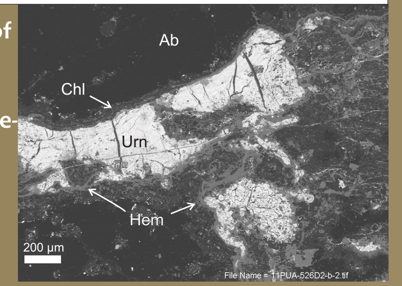
Alteration: Na (albite), Ca-Fe (amphibole + magnetite), K-Fe (K-feldspar/biotite + magnetite/ilmenite), K±Fe (K-feldspar + biotite) and Mg-Fe (hematite + chlorite).

Uraninite, brannerite and coffinite occur within magnetite-bearing K-Fe alteration with ± pyrite ± chalcopyrite ± molybdenite ± bismuthinite ± galena in magnetite + ilmenite + K-feldspar ± biotite-cemented breccias developed in albitite.

Late, northeast-trending brittle faults remobilized U into earthy hematite+chlorite+K-feldspar veins.



Top: Representative BSE-images of uraninite grains from primary U mineralization in the Southern Breccia corridor. Middle: Chondrite-normalized REE patterns of primary (red) and secondary (black) uraninite compared to the whole-rock values (grey). Right: representative BSE-image of secondary uraninite.



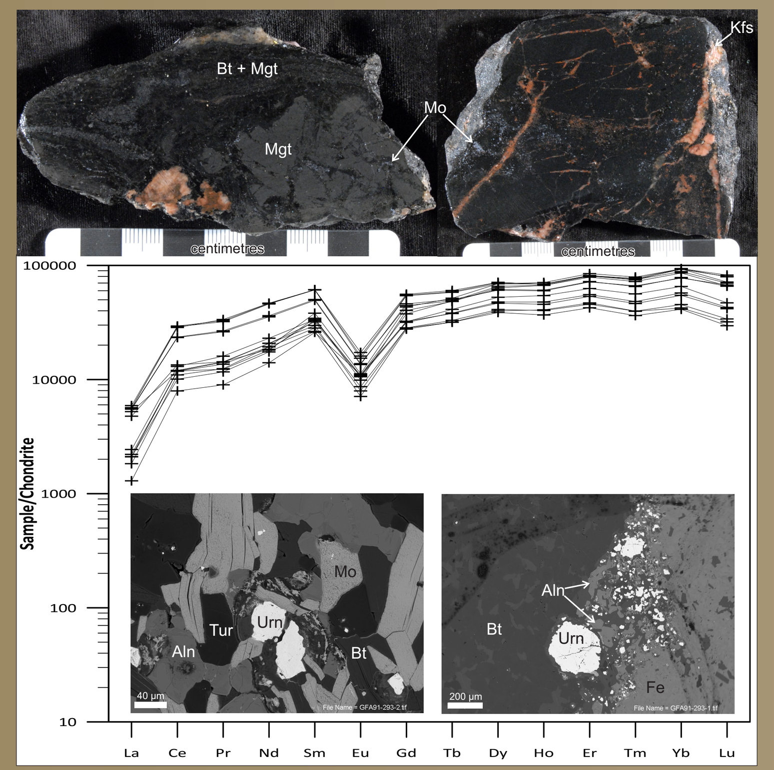
Ab=albite, Ap=apatite, Bt= biotite, Chl=chlorite, Cof=coffinite, Hem=hemaite, Kfs=K-feldspar, Ilm=ilmenite, Py=pyrite, Urn=uraninite.

The Nori occurrences at DeVries Lake (Fig.1) occur within foliated and altered metasiltstones in the Central GBMZ.

Alteration: stratabound to discordant HT K-Fe (biotite + K-feldspar + magnetite).

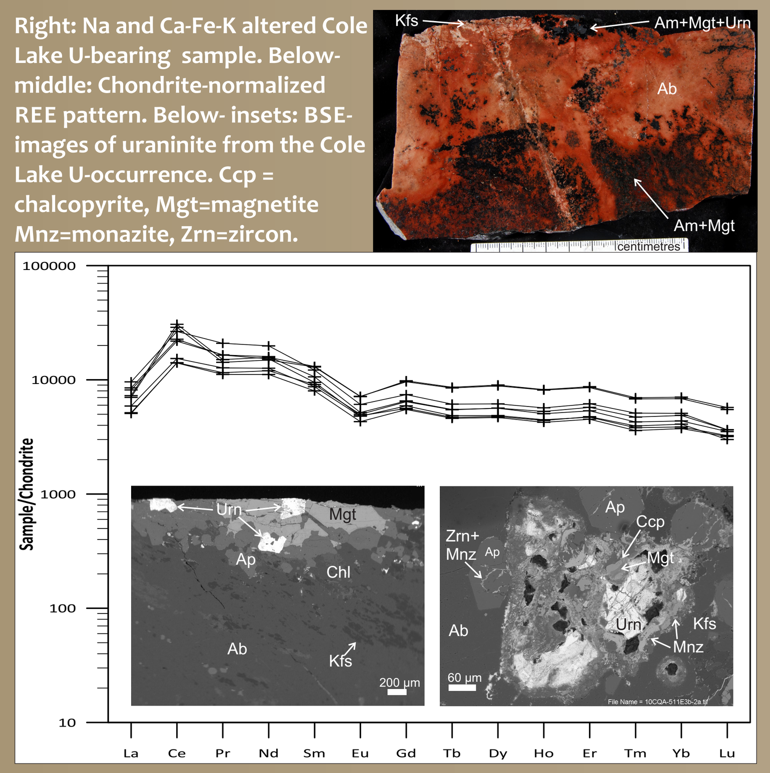
Uraninite occurs within biotite + magnetite veins with K-feldspar, tourmaline, molybdenite, allanite-Ce, pyrite and chalcopyrite (Gandhi, 1993; Ootes et al., 2010; Acosta-Góngora et al. 2011).

Mild LREE depletion may relate to co-precipitation of allanite-Ce.



Top: Photographs of U-bearing, magnetite-rich and K-feldspar veined samples from the Nori prospect. Middle: chondrite-normalized REE patterns of uraninite, chondrite normalization values of McDonough & Sun (1995). Insets: Representative BSE-images of uraninite (Urn) grains with allanite (Aln), biotite (Bt), tourmaline (Tur), molybdenite (Mo) and magnetite (Fe).

Right: Na and Ca-Fe-K altered Cole Lake U-bearing sample. Below-middle: Chondrite-normalized REE pattern. Below- insets: BSE-images of uraninite from the Cole Lake U-occurrence. Ccp = chalcopyrite, Mgt=magnetite Mnz=monazite, Zrn=zircon.

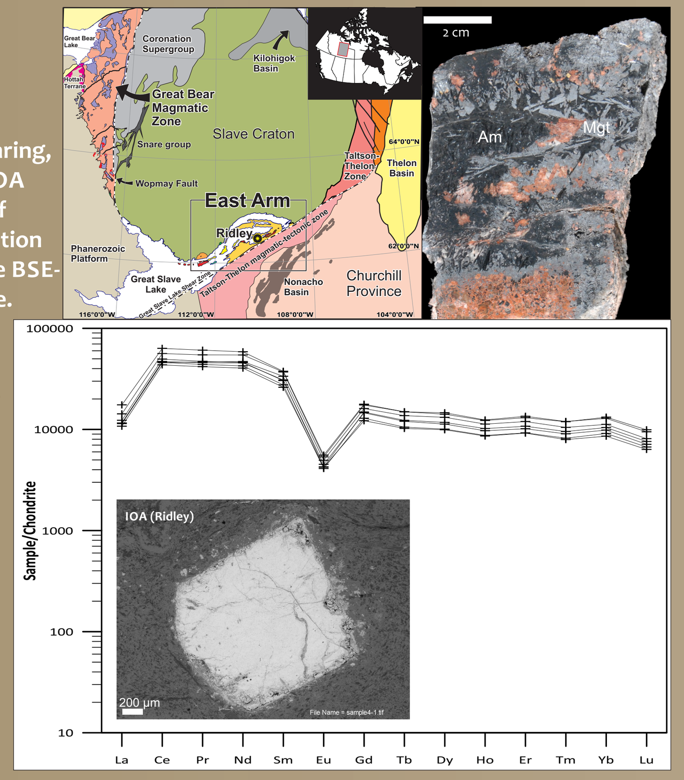


The Cole Lake U showing is located 16 km to the northeast of NICO (Fig.1; Cole U) in an intensely Na-altered, brecciated volcanic host.

Alteration assemblage: Na overprinted by Ca-Fe±K (amphibole + magnetite + K-feldspar) veining that transitions into HT K-Fe (magnetite + K-feldspar) assemblages.

Uraninite occurs in magnetite, K-feldspar, amphibole and apatite veins with trace chlorite, zircon, monazite, chalcopyrite, titanite and rutile.

Right: Location of the East Arm and photograph of U-bearing, amphibole+magnetite+K-feldspar vein from the Ridley IOA prospect. Bottom: chondrite-normalized REE patterns of uraninite from the Ridley prospect. Chondrite normalization values of McDonough & Sun (1995). Inset: Representative BSE-image of uraninite grain hosted within magnetite+biotite.

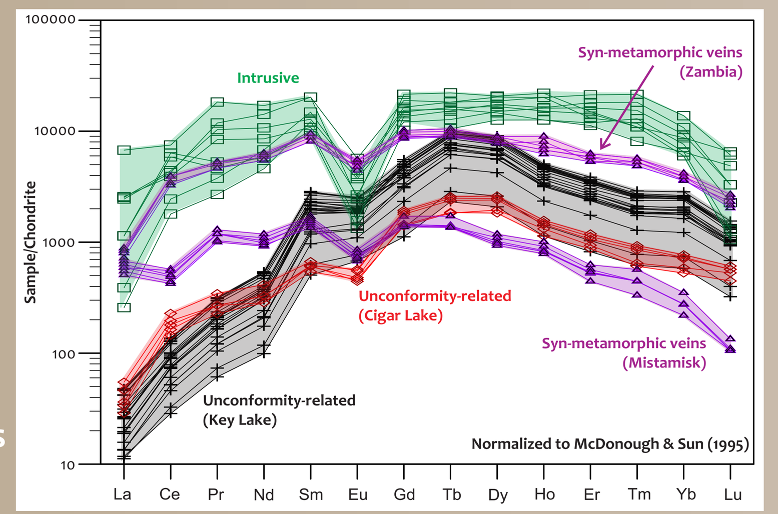


The Ridley iron oxide-apatite (IOA or Kiruna-type) veins are located in the East Arm of Great Slave Lake.

The prospects are characterized by lenses of pegmatitic actinolite + magnetite + apatite ± K-feldspar veins with erratically distributed uraninite, chalcopyrite, pyrite and carbonate hosted within a fractured and variably Na-altered quartz monzonite laccolith that intrudes sedimentary rocks of the East Arm Basin (Badham, 1978; Jefferson 2013; Potter et al., 2013b).

Comparative Analyses

As presented by Fryer and Taylor (1987), Pagel et al. (1987), Maas and McCulloch (1990), Hidaka et al., (1992), Fayek and Kyser (1997), Hidaka and Gauthier-Lafaye (2001), Cuney (2010) and Mercadier et al. (2011), chondrite-normalized REE patterns of uraninite are distinctive for deposit types, reflecting conditions under which they form (combinations of fluid chemistry, temperature, source materials, etc.). Recent technological advances permitting in-situ analysis (SIMS and LA-ICP-MS methods) have faciliatated analysis of least-altered grains with greater accuracy and precision. Uraninite from IOCG and affiliated systems are most similar in REE signature to 'intrusive' related U deposits, where the dilatational nature of the uraninite crystal structure at high-temperatures (>350°C) permits inclusion of large amounts of REEs without fractionation during crystallization (Mercadier et al., 2011). Remobilized uraninite (e.g. Southern Breccia) has a distinct REE pattern, reflecting precipitation from lower temperature fluids, where the REE pattern mimics the host rocks.



Representative chondrite-normalized REE patterns of uraninite from Mercadier et al., (2011; intrusive, syn-metamorphic, Cigar Lake, SIMS method) and this study (Key Lake; LA-ICP-MS method)

Preliminary Observations

- Preliminary REE concentrations in uraninite measured by LA-ICP-MS from IOCG and affiliated occurrences indicate that the chondrite-normalized REE patterns are remarkably consistent and are inferred to reflect precipitation from high temperature fluid(s) (>350°C). The resulting REE signatures are very similar to intrusive or magmatically precipitated uraninite.
- Moderate to high Th contents in uraninite also mirror magmatic-derived compositions, ranging from 0.25 to 12.9 wt. % Th.
- Negative Eu anomalies are interpreted to reflect scavenging of metals during reduced Na alteration and subsequent precipitation from fluids that evolved and equilibrated through progressive Na (albite), Ca-Fe (amphibole + magnetite) and ultimately K-Fe (K-feldspar/biotite + Fe-oxides) alteration (Fig. 2).
- Mineral parageneses indicate precipitation of U minerals during K-Fe alteration wherein the alteration assemblages record a significant change in fluid(s) conditions. During this stage of IOAA evolution, magnetite-dominant (reduced) K-Fe alteration is overprinted by hematite-bearing (oxidized) K-Fe alteration.
- Alteration of uraninite to coffinite at most of the occurrences also points to increasing silica activity in the residual fluids, consistent with field observations noting the presence of epithermal-style veining peripheral to the IOAA systems.
- Secondary or re-mobilized uraninite is characterized by chondrite-normalized REE patterns similar to the altered host rocks (e.g. Southern Breccia), typical of lower temperature, vein-type U mineralization (Mercadier et al., 2011).

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