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Targeted Geoscience Initiative 4: Increasing Deep Exploration Effectiveness

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/ unmetamorphosed 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 these younger deposits (Kidd and Haycock, 1935; Lang et al., 1962; Gandhi et al, 2013).

The GBMZ is interpreted as an continental arc that is composed 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).

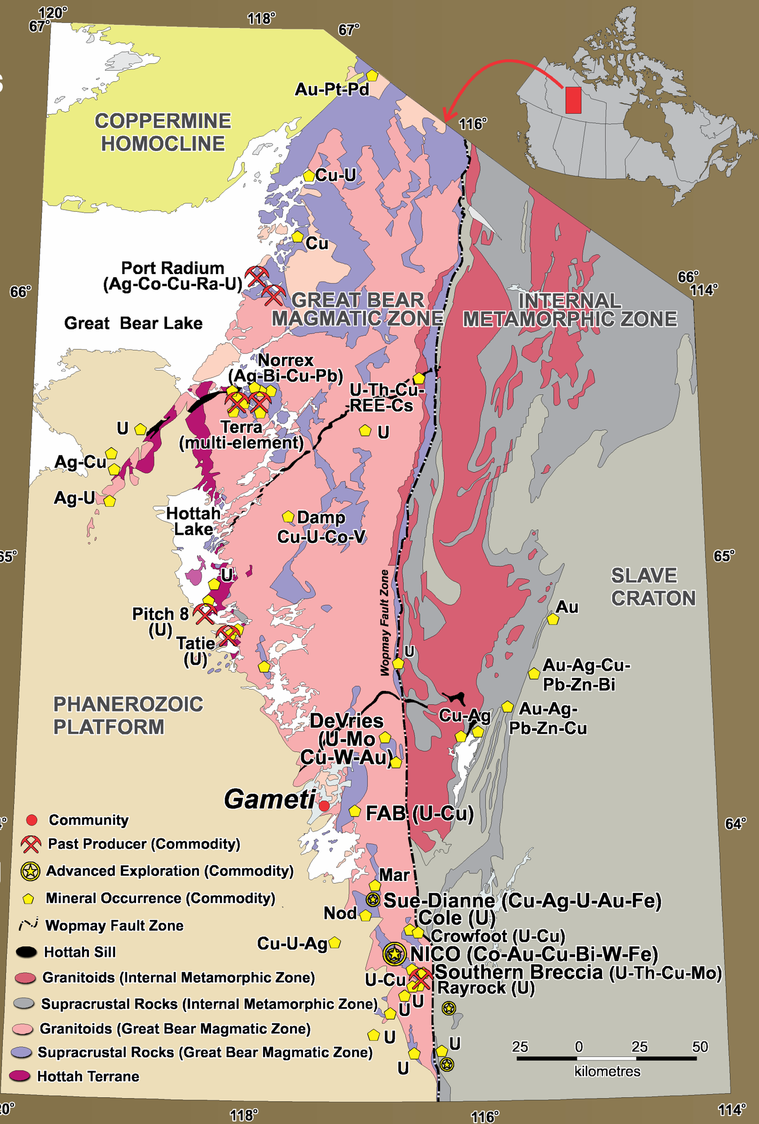


Figure 1. The GBMZ continental arc is situated on the western margin of the Wopmay orogen. It developed on the composite Hottah terrane, overlying the ca. 1.88 Ga Treasure Lake Group sedimentary basin following the short lived Calderian orogeny (Gandhi et al., 2001; Hildebrand et al., 2010).

IOCG - IOAA Zoning Model

	Alteration Facies	Breccia Type	Mineralization
	6. LT silicification (epithermal assemblages)	(Veins/stockworks)	Epithermal deposits
Shallow & Lower Temp. (~350°C)	5. LT K-Fe (K-feldspar / sericite-hematite-carbonate - chlorite-epidote-sulphides)	Hydrothermal	Hem-group IOCG ±U
	4. 'Felsite' or skarns (K-feldspar or clinopyroxene- garnet-sulphides)	Hydrothermal	Mag- to hem-group IOCG and skarns
	3. HT K-Fe (K-feldspar / biotite - magnetite-sulphides)	Hydrothermal	Mag-group IOCG (Cu, Au, Co, Bi, ...)
Early Deeper/Core High Temp. (~700°C)	2. Ca-Fe (±Na) (amphibole-magnetite ± apatite)	Structural and incipient hydrothermal	Iron oxide apatite (IOA) deposits
	1. Na (albite - scapolite)	Structural	

After Corriveau et al. (2010)

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 potential enrichment in Ag, U, REE, Bi, Co, Ni, P, Nb, etc., set in abundant low-Ti iron-oxide (magnetite, hematite) gangue minerals or associated alteration. The sulphide-deficient ore includes 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 are enclosed within regional-scale, alteration haloes of intensely iron oxide-alkali-altered metasomatized rocks and breccias (Fig. 2).

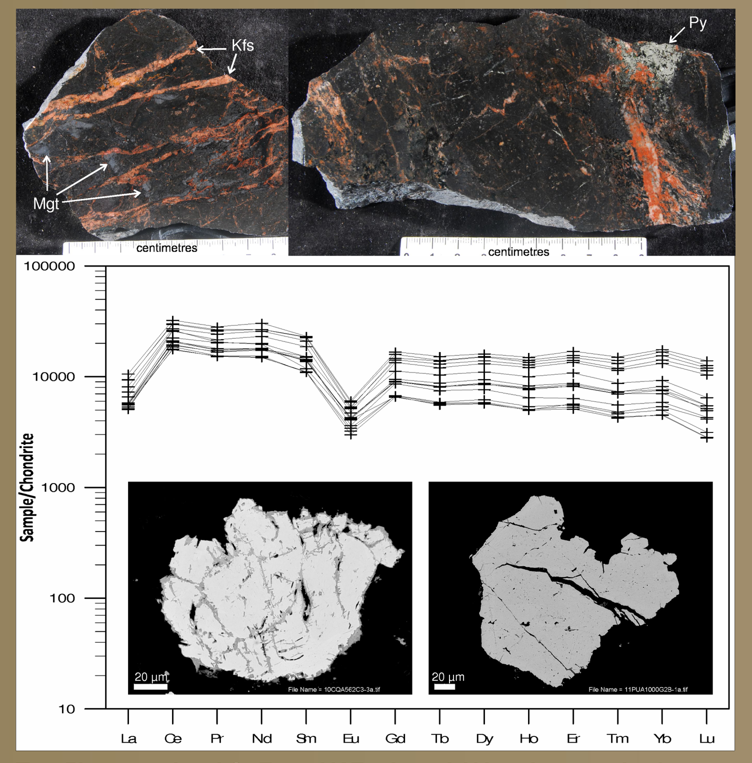
Geochemical signatures of uraninite in IOCG and affiliated systems from the GBMZ and East Arm

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 high-temperature K-Fe assemblages.

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

Uraninite forms anhedral grains in magnetite+K-feldspar veins associated with chalcopyrite and pyrite.



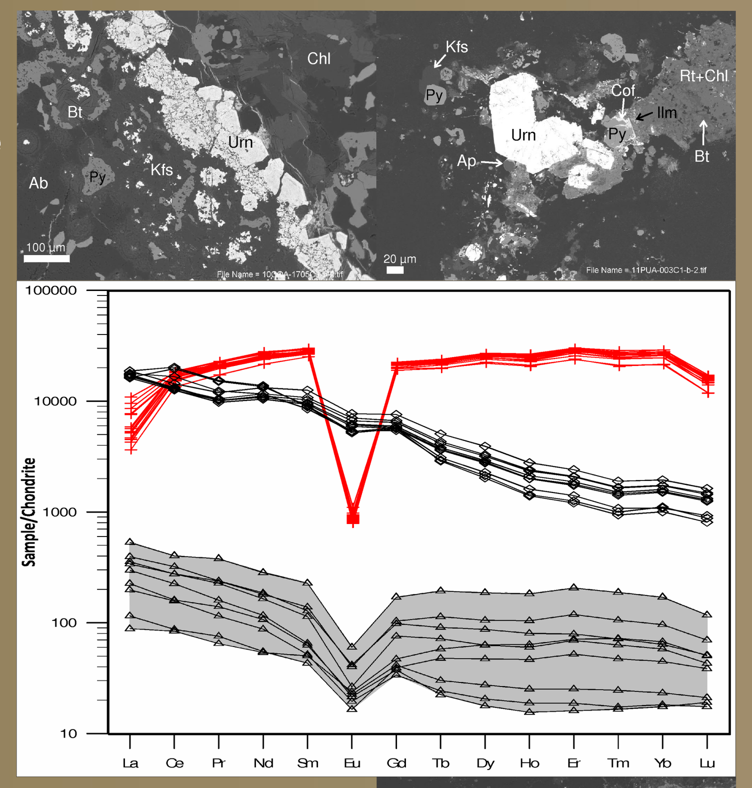
Top: Photographs of Ca-Fe and K-Fe altered, U-bearing samples from the Fab prospect. Middle: chondrite-normalized REE patterns of uraninite from the Fab IOCG prospect. Chondrite normalization values of McDonough & Sun (1995). Insets: Representative BSE-images of uraninite grains with variable coffinite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

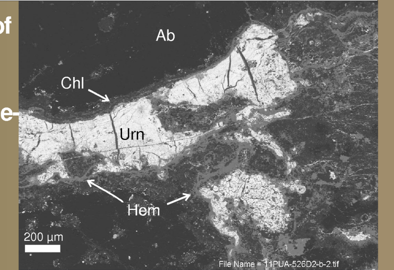
The Southern Breccia is a 3 km-long corridor of U-rich polymetallic showings developed within the albitite zone of the Lou IOAA system which also hosts the co-genetic NICO Au-Co-Bi-Cu magnetite-group IOCG deposit (Montreuil et al., accepted).

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.

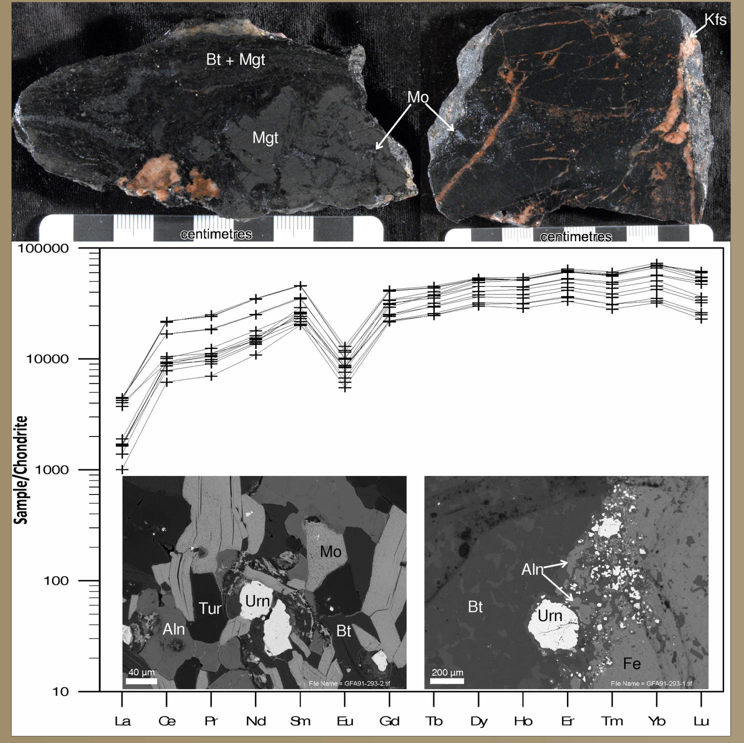
Ab=albite, Ap=apatite, Bt= biotite, Chl=chlorite, Cof=coffinite, Hem=hemaite, Kfs=K-feldspar, Ilm=ilmenite, Py=pyrite, Urn=uraninite.

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

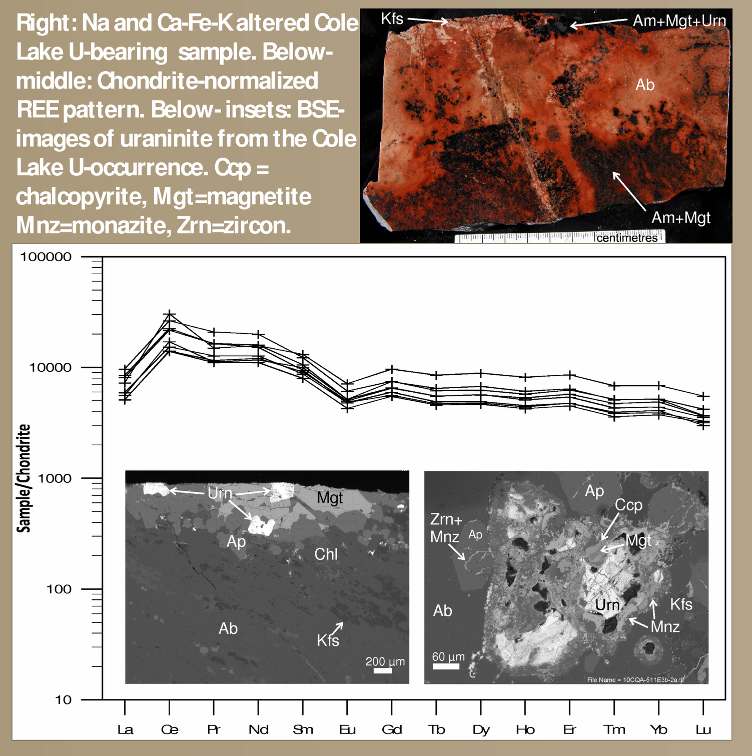
Alteration is stratabound to discordant high T K-Fe (biotite + K-feldspar + magnetite).

Uraninite is in veins of biotite + magnetite accompanied by 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: REE patterns of uraninite using 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).

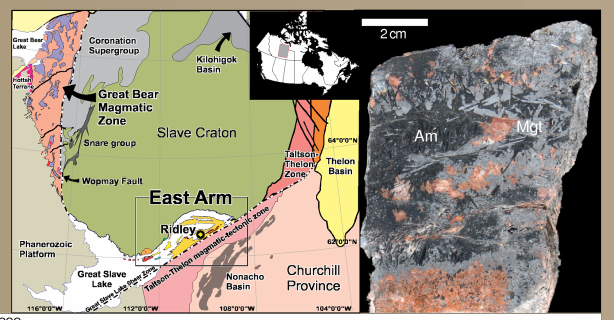


Right: Na and Ca-Fe-K altered Cole Lake U-bearing sample. Below-middle: Chondrite-normalized REE pattern. Below-insets: BSE-images of uraninite from the Cole Lake U-occurrence. Ccp = chalcopyrite, Mgt=magnetite Mnz=monazite, Zrn=zircon.

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.

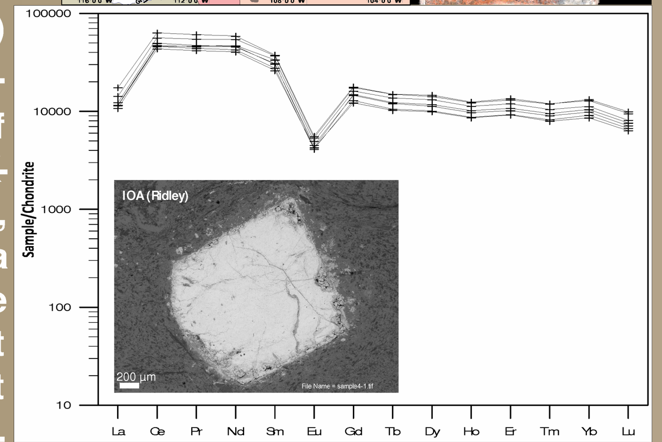
Uraninite occurs in magnetite, K-feldspar, amphibole and apatite veins with trace chlorite, zircon, monazite, chalcopyrite, titanite and rutile.



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

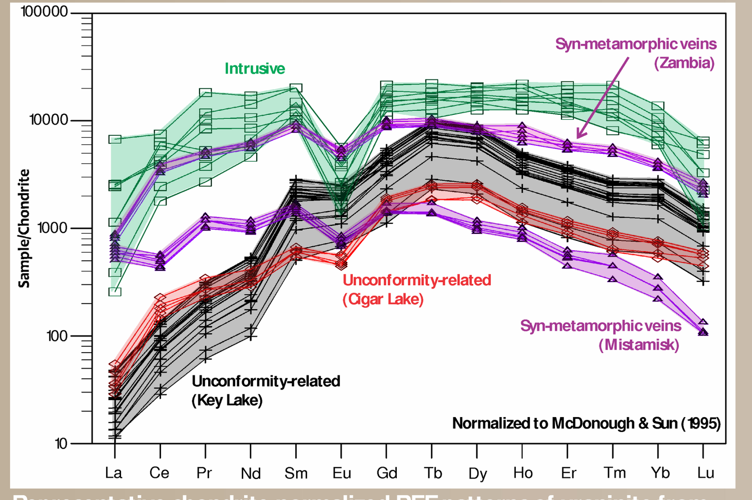
The Ridley iron oxide-apatite (IOA or Kiruna-type) veins are located in the East Arm of Great Slave Lake.

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 Analysis

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 diagnostic for deposit types, reflecting distinct genetic conditions (different combinations of fluid chemistry, T, source materials, etc.). Recent technological advances permitting in-situ analysis (SIMS and LA-ICP-MS methods) have facilitated analysis of least-altered grains with greater accuracy and precision. REE signatures of uraninite from IOCG and affiliated systems are most similar to intrusion related U deposits, wherein the dilational nature of the uraninite crystal structure at high-T (>350°C) permits inclusion of large amounts of REEs without fractionation during crystallization (Mercadier et al., 2011). The REE pattern of remobilized uraninite (e.g. Southern Breccia) mimics that of the host rocks, reflecting precipitation from lower T fluids. It distinctly contrasts the flat pattern with deep Eu anomaly of primary high-T uraninite.



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 Interpretations

- REE concentrations in uraninite determined by LA-ICP-MS from IOCG and affiliated occurrences produce remarkably consistent chondrite-normalized REE patterns that are inferred to reflect precipitation from high temperature fluid(s) (>350°C) and are remarkably similar to those of intrusion-hosted, magmatically precipitated uraninite.
- Moderate to high Th contents in uraninite also mirror magmatic-derived compositions, ranging from 0.25 to 12.9 wt. %Th.
- Strongly negative Eu anomalies are interpreted to reflect scavenging of metals during high temperature Na alteration under reducing conditions 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 phases (Fig. 2).
- Mineral parageneses record precipitation of U minerals during K-Fe alteration accompanied by significant changes in fluid conditions and compositions. During this transitional stage of IOAA evolution, magnetite-dominant (reduced) K-Fe alteration was 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 of epithermal-style veins peripheral to the IOAA systems.
- Secondary (interpreted as re-mobilized) uraninite is characterized by chondrite-normalized REE patterns similar in slope to those of the altered host rocks (e.g. Southern Breccia), typical of lower temperature, vein-type U mineralization (Mercadier et al., 2011).

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