CRITICAL METALS IN MINERAL SYSTEMS WITH
IRON OXIDE COPPER-GOLD (IOCG) AND
AFFILIATED DEPOSITS

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Field exposures of mineral systems,
Great Bear magmatic zone (CA)

Critical Minerals Mapping Initiative Update
American Geoscience Institute, 2022
Archetype IOCG deposit: Olympic Dam (11 Bt of resources in Cu-U-Au-Ag + Co-REE-Re...)
Archetype field exposures of systems: Great Bear magmatic zone (CA)

Resources, by-products enrichment, endowment
Ag, Al, Au
Bi, Co, Cu
Fe, In, Mg
Mn, Ni, Pb
PGE, LREE to HREE
Sb-Se-Te (Bi leach)
Ta, Te, U
V, W, Zn

Surface
Steep, fluid-induced thermal gradient
Continuous recharge & discharge of metals in the fluid plume through regional-scale metasomatism
Consecutive alteration facies
3-10 km depth

Ascent of voluminous hypersaline to saline fluid plumes pooled in mid-crust (multiple metal and fluid sources)

Depth to surface evolution of metasomatic iron and alkali-calcic (MIAC) mineral systems with IOCG and affiliated deposits in a pristine, extremely well exposed Paleoproterozoic setting

Mineral systems
Sue Dianne Au-Cu-Ag (IOCG)
NICO (Au-Co-Bi-Cu)
Fe-rich Au-Co deposit

Corriveau et al. 2010b, 2016, GAC SP 52 in press
Corriveau et al. EG 2016

CORRIVEAU et al. 2022
Timeline + depth to surface evolution of alteration

Metasomatic fluid pathways

Fluids recharged in metals in host rocks

As, Pb, Cl, H₂O, CO₂, U, Mg, Mn, Mo, Si, Pb, Br, Au, Ag, Zn, Na, Ca, Fe, Cu

Na precipitates
Al + some Si is retained
Other elements leached

Reaction of highly saline fluids with host rock

≤ 900°C

Ascent of hypersaline fluid plume

Alteration facies

6 LT Si, K, Al, Ba, Fe (vein, epithermal)

5 LT K/Ca/Mg(H-CO₂,F)-Fe
Hem, Kfs, Ms, Chl, Cb, Fl, Brt
Cu Sul
Cu, Ag, Au, LREE, U, Mo, W, Co

4 K felsite and/or K skarn
Kfs or Cpx, Grt, Kfs, base metal Sul

3 HT K-Fe
Kfs, Bt, Mag, Cu Sul
Au, Ag, Co, Cu, REE, U

2-3 HT Ca-K-Fe
Amp, Mag, Bt, Kfs, Co-As-Sul
As, Au, Bi, Co, Ni, ± Cu

2 HT Ca-Fe (peak temperature)
Amp, Mag, Ap, Ep Fe, LREE+HREE, Th, V, W

1-2 Skarn
Cpx-Grt, W

1 Na albite
Ab-Scp

Corriève et al. GAC SP52 in press

Natural Resources Canada
Ressources naturelles Canada

CORRIVEAU et al. 2022
Metasomatic chain reactions through the upper crust
Form metasomatic iron and alkali-calcic (MIAC) mineral systems with consecutive alteration facies and associated deposit types

Igneous + sedimentary host rocks contain 3-4 dominant cations

MIAC alteration facies contain 1-3 dominant cations
- Strong coupling/decoupling of cations & metals as fluid plume ascends

Na alteration facies = albite = NaAlSi$_3$O$_8$ = albitite
- Intense albition totally changes bulk composition and proportions of Na-Ca-Fe-K-Mg of host rocks to form albitite
- Na (+Al-Si) is dominant
- Other cations transferred to the fluid plume

Ascent of hypersaline to saline fluid plume
NICO deposit (CA): 33Mt at 1.02g/t Au, 0.12% Co, 0.14% Bi, 0.04% Cu at Facies 2-3 HT Ca-K-Fe

Host siltstone  Facies 1 Na  Facies 1-2 skarn  Facies 2 HT Ca-Fe  Facies 2-3 HT Ca-K-Fe  Facies 3→5 HT→LT K-Fe

Corriveau et al. GAC SP52 in press

Natural Resources Canada  Ressources naturelles Canada
Facies 2-3 HT Ca-K-Fe: critical metal rich Fe-rich Au-Co-Bi deposits

**NICO (CA):** 33 Mt at 1.02 g/t Au, 0.12% Co, 0.14% Bi, 0.04% Cu (reserves\(^1\))

**Blackbird (US):** 16.8 Mt at 1.04 g/t Au, 0.73% Co, 0.14% Cu (resources\(^2\))

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Data: representative surface and decline samples of host mineral system and representative samples from the muck piles across the NICO ore zone from Corriveau et al. (2015); samples from drill cores (96-01–06, 96-11, 96-13, 96-16, 96-17, 96-24, 96-25, 96-30) in Mumin (1997).

\(^1\) Burgess et al. (2014); \(^2\) Slack (2013)
Precipitating 10,100 Mt @ 0.62% Cu, 0.21 kg/t U₃O₈, 0.28 g/t Au, 1 g/t Ag at the Olympic Dam IOCG deposit (AU)
Olympic Dam deposit

Corriveau et al. GAC SP52 in press

Au, Cu and U grades in open pit and in underground resources

CORRIVEAU et al. 2022
REE deposits: Remobilization of primary REE endowment of iron oxide-apatite (IOA) deposits precipitated at the HT Ca-Fe facies leads to resources of 6.9 Mt at 2.72 % REE2O3 (i.e. 1.83% LREE, 0.89% HREE) at the Josette deposit (QC) and historic resources of 0.2 Mt at 12 % REE2O3 at the Pea Ridge deposit (MO)

Facies 2 HT Ca-Fe

Great Bear IOA prospects (NT)

Kwyjibo system and Josette deposit

Great Bear IOA
Josette REE vein-type ore in IOA

IOA (Mag)
Apatite-Britholite veins

See Corriveau et al. in press; Sappin and Perreault 2021; Data: Magrina et al. 2005; Perreault and Artinian 2013; Weng et al. 2013; Corriveau et al. 2015, Day et al. 2016a, b; Taylor et al. 2019
### Foundation of wealth:
Critical metals in metasomatic iron and alkali calcic (MIAC) mineral systems

#### Depth to surface timeline of alteration facies

<table>
<thead>
<tr>
<th>Alteration</th>
<th>°C</th>
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</thead>
<tbody>
<tr>
<td>LT Si, K, Al, Ba, F, CO₂</td>
<td></td>
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<tr>
<td>LT K-Fe – LT Ca-Mg-Fe</td>
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</tr>
<tr>
<td>Hem-Ser-Ccp-Bn-Cct → Cb-Chl-Ep</td>
<td></td>
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<tr>
<td>K-skarn – HT K</td>
<td></td>
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<tr>
<td>Cpx-Kfs → Kfs</td>
<td></td>
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<tr>
<td>HT K-Fe</td>
<td></td>
</tr>
<tr>
<td>Mag-Kfs-Bt-Ccp</td>
<td></td>
</tr>
<tr>
<td>HT Ca-K-Fe</td>
<td></td>
</tr>
<tr>
<td>Amp-Mag-Bt-Kfs-Apy</td>
<td></td>
</tr>
<tr>
<td>Skarn – HT Ca-Fe</td>
<td></td>
</tr>
<tr>
<td>Cpx → Amp-Mag-Ap</td>
<td></td>
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<tr>
<td>Na</td>
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<tr>
<td>Ab-Scp</td>
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</tr>
</tbody>
</table>

#### Known resources + byproducts – CA critical minerals in blue

| Elements | Fe | P | HREE | Nb | V | F | Ni | W | As | Se | Te | Bi | Co | Pd | Pt | Au | Ag | Cu | U | LREE | Mo | Re | Zn | Pb |
|----------|----|---|------|----|---|---|----|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
|          |    |   |      |    |   |   |    |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |

#### Deposit types

- Epithermal
  - Vein-type, others
- Hematite-group IOCG
  - Mo-Re, ISCG, others
- Polymetallic skarn
- Magnetite-group IOCG
- Fe-rich Au-Co-Bi/Ni
- IOA, IOA+REE, IOA-Ni
  - Fe skarn, W skarn
- Albite-hosted U, Au-Co, Cu-Au-Ag-(Co-Zn) ‘orogenic’ Au

#### Corrineau et al. GAC SP52 in press

- Natural Resources
  - Canada
  - Ressources naturelles
  - Canada

**Fluid plume ascent** = intense fluid-rock reactions + metal recharge/discharge

Metal precipitation along metasomatic path = distinct deposit types

Mantle to crust to surface metal-fluid-magma pathway image geophysically

**CORRIVEAU et al. 2022**
Foundation of wealth: MIAC systems and their critical metal resources

Timeline of alteration facies

Alteration °C  Deposit types

LT Si, K, Al Ba, F, CO₂  Epithermal Veins

LT K-Fe – LT Ca-Mg-Fe  Hematite-group IOCG

K-skarn– HT K  Polymetallic skarn

HT K-Fe  Magnetite-group IOCG

HT Ca-K-Fe  Fe-rich Au-Co-Bi/Ni

HT Ca-Fe skarn  IOA+REE Fe skarn

Na  Albitite-hosted U, Au-Co, ‘orogenic’ Au

Resources + byproducts – CA critical minerals in blue

Fe P HREE Nb V F Ni W As Sb Se Te Bi Co Pd Pt Au Ag Cu U LREE Mo Re Zn Pb

K-felsite: barren during primary crystallization

Dark: known resources
Pale: potential commodities
Blue: Canada’s critical metals

Albitite: barren during primary crystallization

Additional mineralization types (system disruption, atypical hosts)

+ LT fluids

Faulting + Overprints

+ Heat + HT fluids

Ascending fluid plume = intense fluid-rock reactions + metal recharge/discharge + precipitation of distinct metal associations = distinct deposit types
Alteration facies: record the metal pathways to ore + vector to the realm of potential mineralization types within deposits and systems

Systems can precipitate extremely high contents of any commodities e.g. Merlin reserves 6.4 Mt at 1.5% Mo, 26 g/t Re

Critical metal associations vary as systems evolve

Giant Qz veins
- NICO, Summit, Chalco, SBx
  - Mag to Hem IOCG in K-Fe Bx
  - SBx albitite hosted U
- NICO Au-Co-Bi ore
- NICO main alteration + relic skarn + W

Southern Breccia (SBx)
- brecciated albitite corridor

LT Si, K, Al, Ba, CO₂
LT K-Fe-H⁺ – Ca-Fe-Mg-CO₂
K-felsite breccia
K-skarn breccia (in Cb)
HT K-Fe
HT Ca-K-Fe
HT Ca-Fe
HT Na-Ca-Fe
Skarn (in Cb)
Na-Ca
Na
Beyond sciences:
The teams, the colleagues, our mentors

Merci! Masi! Thank-you!


Targeted Geoscience Initiative Program (Geological Survey of Canada) and Critical Mineral Mapping Initiative (Geoscience Australia, Geological Survey of Canada, USGS)

GEM task shared agreement with Fortune Minerals (Robin Goad, CEO, NICO deposit)
For more information Louise.Corriveau@nrcan-rncan.gc.ca

Cited references can be found in Corriveau et al., 2021, Metasomatic iron and alkali-calcic (MIAC) system frameworks: A TGI-6 task force to help de-risk exploration for IOCG, IOA and affiliated primary critical metal deposits. Geological Survey of Canada, Scientific Presentation 117, 103 p. https://doi.org/10.4095/329093

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