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Geological Survey of Canada
Scientific Presentation 56

Iron-oxide and alkali-calcic alteration ore systems and their polymetallic IOA, IOCG, skarn, albitite-hosted U±Au±Co, and affiliated deposits: a short-course series

Part 1: Introduction

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2017

Celebrating 175 yrs

Canada

This short course series updates courses given nationally and internationally in the last decade. Even if their titles are similar, the presentations in English and in French may differ in their content and their format.

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Publications in this series have not been edited; they are released as submitted by the author.

Acknowledgments

The course summarises research on the geology of iron-oxide and alkali-calcic alteration ore systems undertaken at the Geological Survey of Canada by the Targeted Geoscience Initiative and the Geo-mapping for Energy and Minerals programs in collaboration with territorial and provincial surveys, academia and private sector.

The author acknowledges Dr. Pedro Acosta-Góngora, Dr. Alain Plouffe and Mr. Roman Hanes for their review of this short course series.

Additional acknowledgments can be found at slide 63.

Sunil S. Gandhi (1935 – 2017)

After working for the exploration industry in Quebec, Saskatchewan and Labrador (involved in discovery of the Michelin deposit), Sunil joined the GSC as research scientist (1977 – 1996) to carry out annual assessments of uranium resources in Canada.

His research focus was on Great Bear and East Arm regional metallogeny, particularly on “Olympic Dam type” deposits that would later become known as IOCG deposits. His research in 1980’s & 1990’s was instrumental in the discovery of the NICO deposit (1994). He was among the first to suggest linkages between IOA veins and IOCG systems.

After retiring from the GSC in 1996, Sunil consulted for exploration industry in Canada and abroad. He continued metallogenic research at the GSC as a Visiting Scientist and published his last synthesis map (southern Great Bear) in 2014.

Celebrating 175 yrs

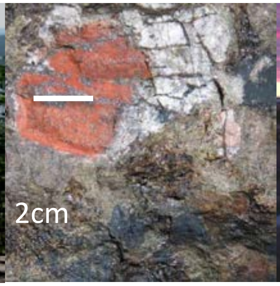
General information on the short course series

Abstract — short course series

Worldwide, iron oxide copper-gold (IOCG) deposits form world-class mining districts. In a single deposit, such as Olympic Dam, resources can reach 10 billion tons at 0.78% Cu, 0.25kg/t U3O8, 0.30g/t Au, 1.0g/t Ag. Rare-earth resources can also be significant. Systems that form IOCG deposits also host many other deposit types.

This short course illustrates the metasomatic growth of polymetallic magmatic-hydrothermal iron-oxide and alkali±calcic alteration systems and the genetic linkages among their iron oxide-apatite (IOA), iron oxide copper-gold (IOCG) and affiliated deposit types, using the Great Bear magmatic zone (Northwest Territories, Canada) as a prime example. Complementary information are also sourced from the Central Mineral Belt of the Makkovik Province (Labrador), the Romanet Horst of the Labrador Trough (Quebec) and the Bondy gneiss complex of the Grenville province (Quebec) in Canada as well as from deposits worldwide.






Abstract — short course series

The Great Bear systems are differentially uplifted, tilted, transcurrent-faulted, and locally exhumed. They escaped orogenic metamorphism and pervasive deformation. Their former sedimentary covers are largely eroded and Quaternary glaciation left only a sporadic till cover. Consequently, outcrops are non-weathered, glacially polished and nearly continuous exposing in structural 3D the metasomatic growth of iron-oxide and alkali±calcic alteration ore systems from paleo-depth to paleo-surface.

Abstract — short course series (cont.)

Within systems, metasomatism is pervasive and intense at regional to deposit scale. From paleo-depth to paleo-surface and away from heat sources (sub-volcanic intrusions), the diagnostic alteration facies prograde from:From depth to surface and away from heat sources, the diagnostic alteration facies prograde from:

- Facies 1 Na, transitional Na-Ca-Fe and skarn,
- Facies 2 high temperature Ca-Fe,
- Facies 3 high temperature K-Fe,
- Facies 4 transitional K and K-skarn,
- Facies 5 low temperature K-Fe (± low temperature Ca-Mg), and
- Facies 6 epithermal alteration.

The prograde, retrograde, telescoped and cyclical metasomatic reaction paths lead to a regular series of deposit types with varied metal associations and mineralisation styles from paleo-depth to paleo-surface:

- Iron oxide-apatite (IOA) and their REE mineralised variants,
- Iron oxide copper-gold (IOCG) and low Cu, Co, Bi variants,
- Polymetallic potassic-skarns,
- Albitite-hosted U and Au-Co-U,
- Mo-Re and other affiliated deposits.

Abstract — short course series (cont.)

Space-time relationships between metasomatism, magmatism, deformation and mineralisation constrain element addition and depletion in ore fluids from sources to deposits. They also record fluid pathways, sources of fluid rejuvenation, and heat sources across the ore-forming environments. The information is synthesised into an ore deposit model adaptable to the variety of fluid (and potential melt) sources, host rocks and compositions these ore systems have.

New petrological mapping protocols, rock nomenclatures, chemical map methodologies, discriminant chemical diagrams, and geological vectors to mineralisation stem from these findings. They collectively unify the complex and disparate attributes of these ore systems into effective exploration concepts and provide a novel geoscience framework to explore Canada's prospective terrains for IOCG and affiliated deposits.

Short course series presentations

1. **Introduction**
2. Overview of deposit types, distribution, ages, settings, examples, alteration facies and deposit model
3. The Great Bear magmatic zone and other Canadian districts
4. Alteration facies, metasomatic reaction paths and ore genesis
5. Na to Na-Ca-Fe facies
6. Skarns, HT Ca-Fe facies and IOA (iron oxide-apatite) deposits
7. HT to LT K-Fe facies, IOCG (iron oxide copper-gold) deposits, Co-Bi and K-skarn variants and albitite-hosted U or Au-U-Co deposits
8. Breccias
9. Geochemical footprints and element mobility
10. Metasomatic facies as an exploration tool: The NICO deposit
11. Footprints at granulite facies in the Bondy gneiss complex

Overview of presentations within the series

This presentation synthesises key elements of the short courses. Corriveau 2017 introduces a similar series in French.

Corriveau et al. (in press a) reviews the deposit types, mineral resources, distribution, ages, settings, alteration facies, and ore deposit model(s) for iron-oxide and related alkali-calcic alteration systems and provide classical examples of deposits.

Corriveau et al. (in press b) overviews the geology of the Great Bear magmatic zone and provides additional information on other Canadian prospective settings (Central Mineral Belt, Labrador; Romanet Horst and Bondy gneiss complex, Québec).

Corriveau et al. (in press c) synthesises the mineral parageneses (mineral assemblages), morphology (replacement, vein, breccia), crosscutting relationships and prograde metasomatic paths of Na, skarn, high temperature Ca-Fe, high and low temperature K-Fe, K-skarn, K and low temperature Ca-Mg alteration facies. It also discusses briefly alteration mapping protocol and nomenclature.

Corriveau et al. (in press d, e, f) are subdivided according to alteration facies Na, Ca-Fe, K-Fe. Geological attributes of alteration facies are reviewed with respect to prograde metasomatic paths, facies transitions, mineralisation, deposit types and brittle to ductile deformation. Comparison with Australian and Chilean case examples is also provided.

Overview of presentations within the series (cont.)

Montreuil et al. (in press) overviews the geochemical footprints of the Na, Ca-Fe, K-Fe alteration facies of the Great Bear systems and the net element addition and depletion host rocks have undergone across ore-forming environments.

Corriveau et al. (in press g) illustrates how the iron-oxide and alkali±calcic alteration ore system model can be used for effective prognostication of mineral potential and exploration for IOA, IOCG, IOCG related skarn, and albitite-hosted U and Au-Co-U deposits. The main testing ground is the NICO deposit.

Corriveau et al. (in press h) illustrates breccia development within iron-oxide and alkali-calcic alteration ore systems.

Corriveau et al. (in press i) illustrates iron-oxide and alkali-calcic alteration ore systems metamorphosed at upper amphibolite and granulite facies using the Bondy gneiss complex of the southwestern Grenville Province as an example. Topics include how to identify such systems and not miss alteration facies because of the mineral parageneses they may share with metasedimentary rocks, including metapelites, meta-arkoses, impure marbles, iron formations, and amphibolites.

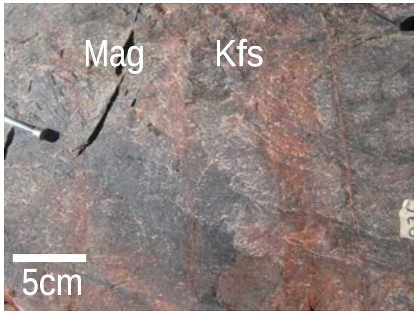
This course

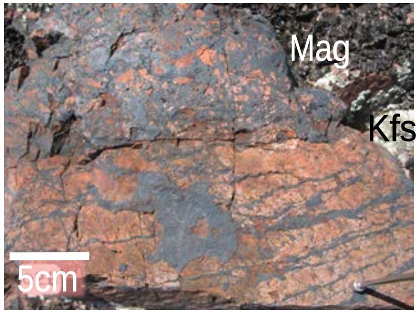
This presentation introduces and defines deposit types within iron-oxide and alkali-calcic alteration ore systems, deposit continua, and acronyms used to facilitate delivery of information. It also briefly reviews representative deposits globally, deposits distribution, and resources of Australian districts and discovery dates. The information highlights how significant these deposits are for the renewal of base, precious, strategic and actinide resources in the 21st century.

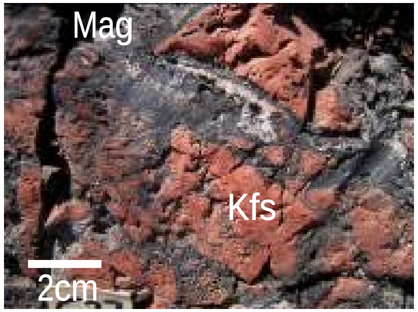
Geosciences needs and examples of impediments to mineral exploration and mineral potential assessments follow, complemented by a display of geological and chemical techniques to map and explore these ore systems.

Finally we introduce research topics addressed by and results of Geological Survey of Canada (NRCan) programs having targeted these ore systems with many collaborators in recent times, namely the Geomapping for Energy and Minerals (GEM) and the Targeted Geosciences Initiative (TGI) programs.

A reference list is provided at the end of the presentation.







Note

Previously published figures and photos included in this short course series are veiled by a figure caption referring to their source publication. This editorial choice is prompted by the importance of linking the abundant and more detailed illustration of the ore systems provided in this short course series with our published description and discussion of the systems.

In case of copyright issues with material presented in this short course series, please contact Dr. Louise Corriveau at Louise.Corriveau@canada.ca

Acronyms and abbreviations

IOCG-iron oxide copper-gold deposits; **IO±A-**iron oxide±apatite deposits

IOAA-iron oxide alkali-calcic alteration systems; **Grp-**group

HT-high temperature; **LT-**low(er) temperature

REE-rare-earth elements and Y; **PGE-**platinum-group elements

GSC-Geological Survey of Canada; **NTGS**-Northwest Territories Geological Survey

GEM-Geomapping for Energy and Minerals program

TGI Targeted Geoscience Initiative

Minerals

Ab-albite, **Act**-actinote, **Amp**-amphibole, **Ap**-apatite, **Apy**-arsenopyrite, **Bn**-bornite, **Brt**-barite, **Bt**-biotite, **Cb**-carbonate, **Cc**-calcite, **Ccp**-chalcopyrite, **Cct**-chalcocite, **Cof**-coffinite, **Cpx**-clinopyroxene, **Cum**-cummingtonite, **Ep**-epidote, **Fl**-fluorite, **Gn**-galena, **Grt**-garnet, **Hbl**-hornblende, **Hem**-hematite, **Kfs**-K-feldspar, **Mag**-magnetite, **Mol**-molybdenite, **Pl**-plagioclase, **Py**-pyrite, **Rbk**-riebeckite, **Ru**-rutile, **Scp**-scapolite, **Sd**-siderite, **Ser**-white mica (sericite), **Sp**-sphalerite, **Sil**-sillimanite, **Sul**-sulphides, **Ttn**-titanite (Whitney and Evans 2010)

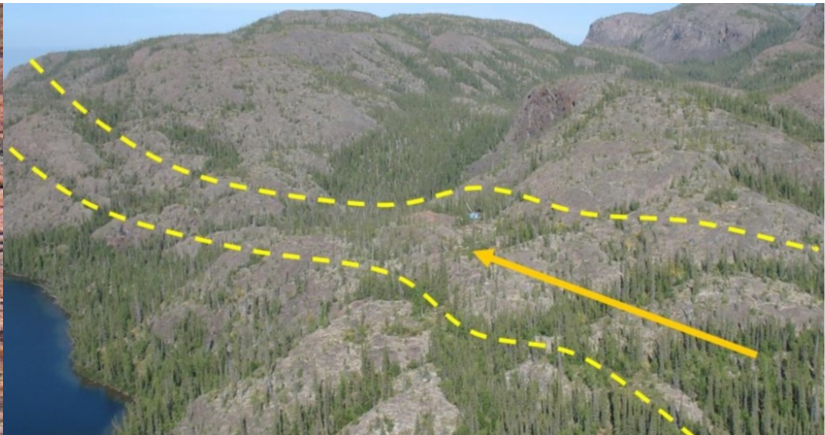
Deposits and deposit types in iron-oxide and related alkali-calcic alteration ore systems

Iron oxide and alkali-calcic alteration ore systems

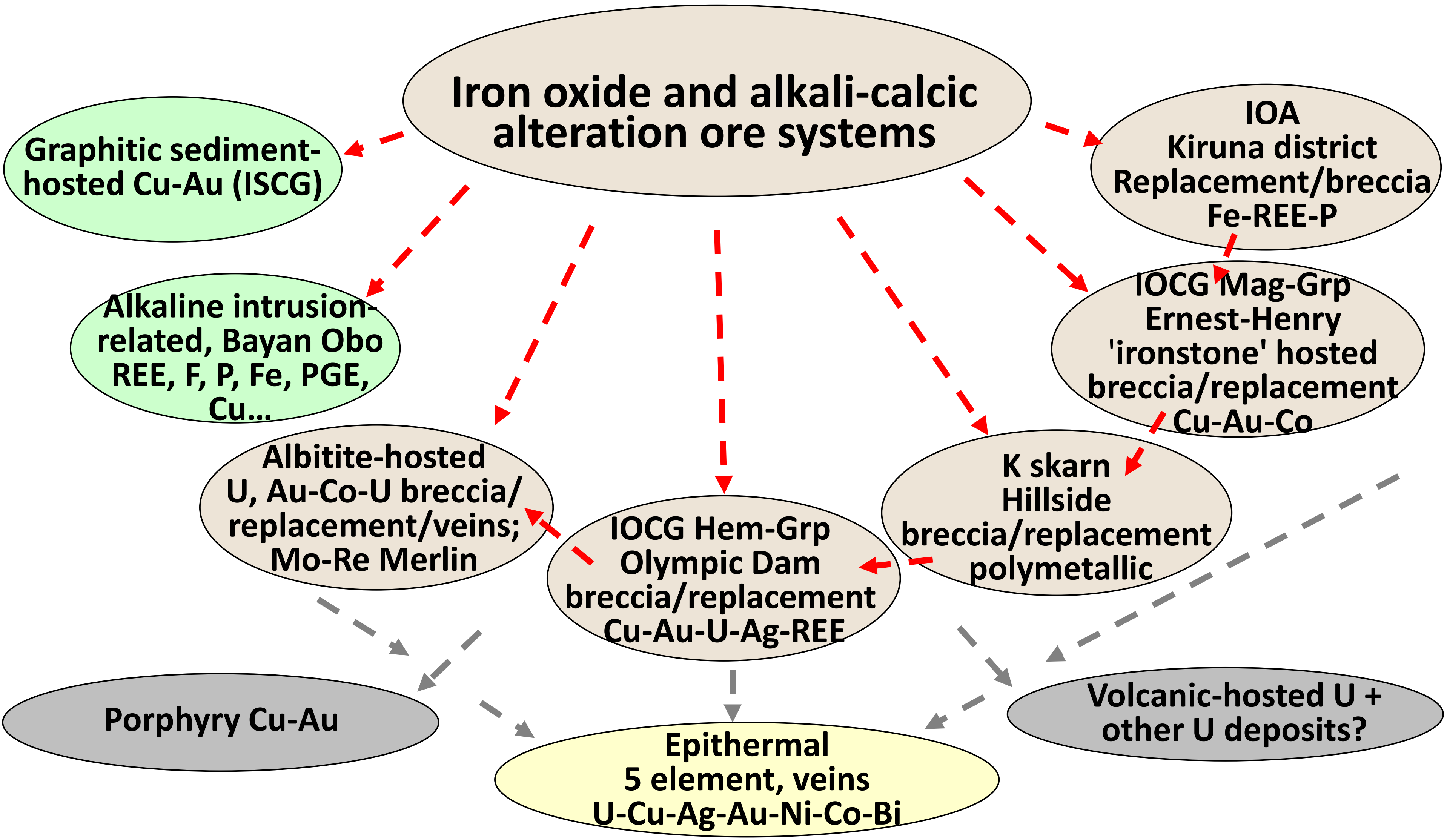
A series of fluid-rock reactions triggered by high salinity fluids across high geothermal gradients in tectonically active settings (800 to 250°C; spatial extent ~35x15x10 km)

Intense and pervasive Na, HT Ca-Fe, HT–LT K-Fe, LT Ca-Mg metasomatism leads to:

- **IOCG** – Iron oxide copper-gold deposits: polymetallic, base and precious-metal hydrothermal deposits with economic copper (± gold)
  (Williams et al. 2005; Groves et al. 2010; Porter 2010a, b; Williams 2010a, b; Skirrow 2010; Barton 2014)
- **IO±A** – Iron oxide±apatite±REE deposits: magnetite dominant, Ti-V< igneous Fe-Ti-V-P deposits (Hitzman et al. 1992; Porter 2010 a, b; Williams 2010a, b; Knipping et al. 2015; Tornos et al. 2016)
- Albitite-hosted U±Au ±Co; albitite-hosted 'orogenic' Au-U; some skarns, mantos, Mo-Re and alkaline intrusion-related iron oxide deposits
  (Porter 2010a; Wilde 2013; Corriveau et al. 2014, 2016; Montreuil et al. 2015)
- Epithermal polymetallic mineralisation (Mumin et al. 2010; Kreiner and Barton 2011)



Deposit spectrum and continuum



Modified from Mumin et al. 2010; see also Porter 2010a; Day et al. 2016; Tornos et al. 2016

Iron oxide copper-gold deposits

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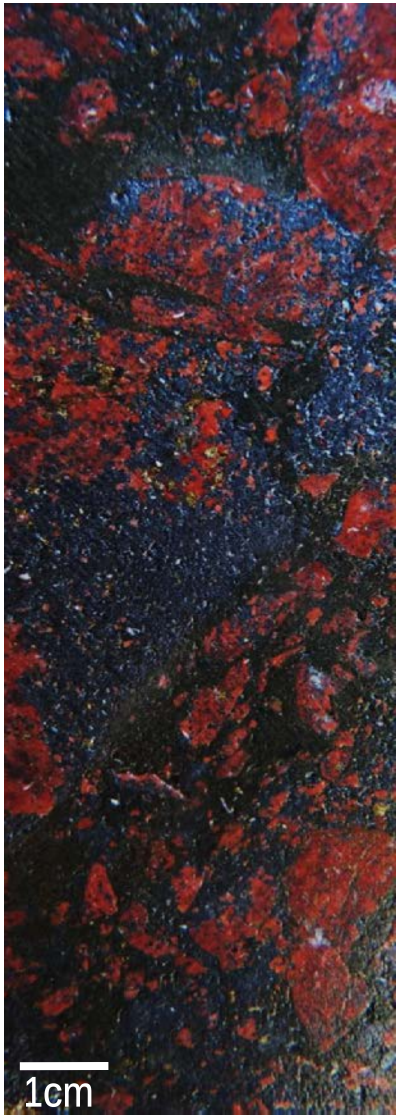
- Extraordinary range of polymetallic hydrothermal deposits rich in iron oxides (> 15-20% magnetite and/or hematite) with economic copper ± gold
- Can have resources in iron, and base (Cu, Ni, Pb, Zn), precious (Ag, Au, PGE), specialty (rare-earths, Bi, Co, Mo, V, F, Nb) and actinide (U, Th) metals
- Potentially very large tonnage, intermediate to low grade
- Varied mineralisation styles and metal associations
- Within highly diagnostic iron-oxide and alkali±calcic alteration systems coalescing over 35x15x10 km (length/width/depth)
- Continuum with other deposit types
- Deposits cluster into districts that line up along 500-1500 km belts
- Target identification can pose significant challenges
- Host terrains commonly under explored, under mapped, under valued in terms of mineral and energy potential

Hitzman et al. 1992; Hitzman 2000; Williams et al. 2005; Corriveau 2007; Corriveau and Mumin 2010; Corriveau et al. 2010a, 2016; Mumin et al. 2010; Porter 2010a, b; Williams 2010a, b; Ehrig et al. 2012, 2017



Reference IOCG deposits

Hematite-group IOCG deposits (Hem>>Mag; classification of Williams 2010a)

- Olympic Dam, Carrapateena, Prominent Hill (Gawler craton, Australia)
- Mina Justa (Central Andes, Peru)

Magnetite to hematite-group IOCG deposits (+low-Cu) variants)

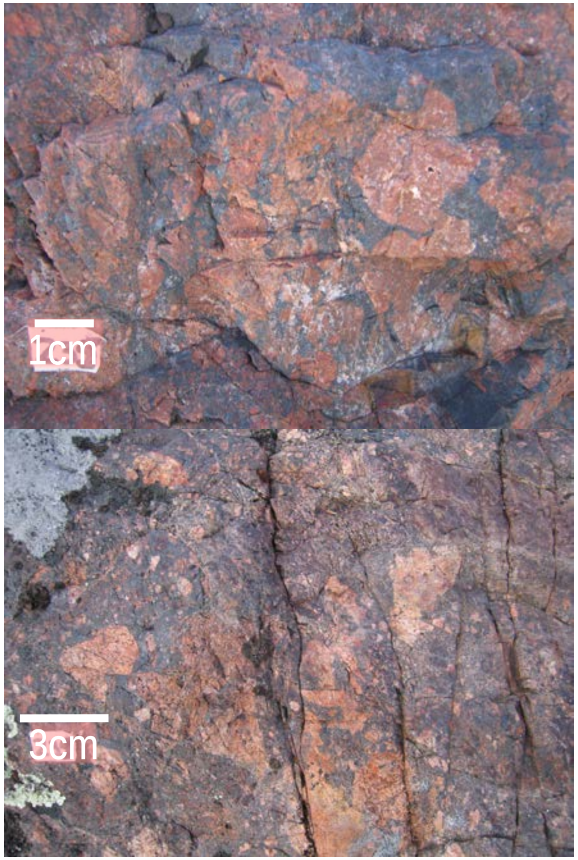
- Sue Dianne (Great Bear magmatic zone, Canada)
- Raul-Condestable (Central Andes, Peru)
- Mantoverde (Central Andes, Chile)

Magnetite-group IOCG deposits

- Ernest Henry (Cloncurry, Australia)
- Candelaria (Central Andes, Chile)
- Sossego, Salobo (Carajás, Brazil)
- Guelb Moghrein (Mauritania)
- Boss (SE Missouri, US)

IOCG-hosted skarn and K-skarn variants

- Hillside (Gawler, Australia)
- Hannukainen (Finland), Kaunisvaara (Sweden)



Williams et al. 2005; Porter 2010a; Williams 2010a,b; Chen 2013

Australian resources

(discovery date, province) within IOAA systems

Olympic Dam (1975; Gawler)
10,100 Mt at 0.78% Cu, 0.25kg/t U_3O_8, 0.30g/t Au, 1.0g/t Ag (+ REE)

Geoscience Australia Gawler Project (2000-04)

Prominent Hill (2001; Gawler)
178 Mt at 1.1% Cu, 0.7g/t Au, 2.7g/t Ag, 103ppm U

Carrapateena (2005; Gawler)
134 Mt at 1.5% Cu, 0.6g/t Au, 6.3g/t Ag (+U)

Hillside (2009; Gawler)
337 Mt at 0.6% Cu, 0.14g/t Au, 15.7% Fe

Khamsin (2012; Gawler)
202 Mt at 0.6% Cu, 0.1 g/t Au, 1.7 g/t Ag, 86ppm U

Oak Dam (Gawler)
~560 Mt at 41–56% Fe, 0.2%Cu, 690ppm U

Rover 1 (Tennant Creek)
6.81 Mt at 1.73g/t Au, 1.20% Cu, 0.14% Bi, 0.06% Co

Peko (Tennant Creek) production
3 Mt at 4.1% Cu, 0.3% Bi, 3.5g/t Au, 14g/t Ag

Ernest Henry (Cloncurry)
167 Mt at 1.1% Cu, 0.5g/t Au (+ Co)

Mt Dore (Cloncurry)
111 Mt at 0.53% Cu, 0.09g/t Au, 0.06% Pb 0.31% Zn

Mount Elliot-Swan (Cloncurry)
353.7 Mt at 0.6% Cu, 0.35g/t Au

Merlin (Cloncurry)
6.4 Mt at 1.5% Mo, 26 g/t Re (reserves)

Osborne (metamorphosed) **(Cloncurry)**
12 Mt at 1.4% Cu, 0.88g/t Au

Monakoff (Cloncurry)
2.4 Mt at 0.95% Cu, 0.3g/t Au (112 ppm U_3O_8)

E1 (Cloncurry)
10 Mt at 0.7% Cu, 0.22g/t Au

Valhalla (Mt Isa)
34.7 Mt at 830ppm U_3O_8

Mt Gee (Mt Painter)
51 Mt at 0.11% Cu, 525ppm U

See slide 28

Affiliated deposits

Iron Oxide±Apatite (IOA)

- Kiirunavaara, Malmberget, Grangesberg (Sweden)
- El Laco (Chile); El Romeral, Marcona, Los Colorados (Central Andes, Chile and Peru)
- Oak Dam, Lightning Creek, Acropolis (Australia)
- Cerro del Mercado (Durango, Mexico)
- Pea Ridge and Pilot Knob (Missouri, US)
- Kwyjibo (Grenville Province, Canada)
- Esfordi (Bafq, Iran)
- Washan (China)

Au/Cu-Co-Bi (±REE,Y) variants of IOCG

- Idaho Co belt (US)
- Mt Cobalt ? (Cloncurry, Australia)
- NICO (Great Bear, Canada)

Mo-Re deposit

- Merlin (Cloncurry, Australia)

Albitite-hosted U

- Valhalla (Mt Isa, Australia)
- Lagoa Real (Brazil)
- Michelin (Central Mineral Belt, Canada)
- Southern Breccia (prospect; Great Bear, Canada)

Albitite-hosted Au±Co±U

- Kuusamo (Finland)
- Larafella, Loraboué (Burkina Faso)
- Turamdih (India)
- Romanet Horst (prospects; Canada)

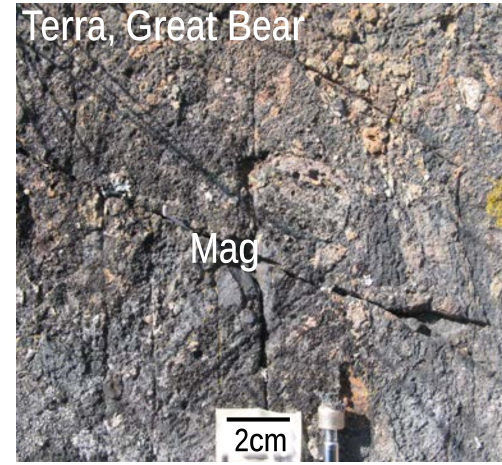
Alkaline intrusion-related IOAA

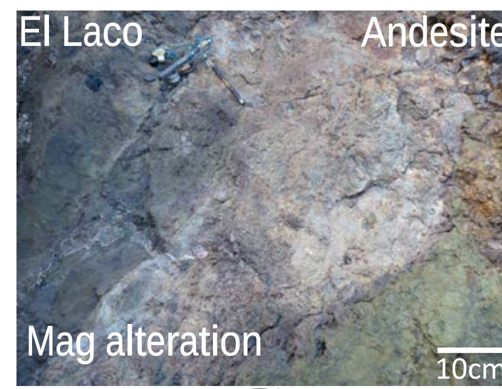
- Bayan Obo (China)
- Phalaborwa, Vergeneog (S. Africa)

See slide 28

IOA deposits

- Iron oxide deposits (Fe >50%) ± REE mineralisation
- Iron resources can reach 2 Gt
- Systematically associated with Na, Na-Ca-Fe and Ca-Fe alteration facies at deposit to regional scale
- REE-rich variants are replaced or spatially associated by Ca-K-Fe or K-Fe alteration
- Poor in sulphides and U unless overprinted by fertile alteration
- Form at depth within IOAA systems that evolve to IOCG mineralisation (Great Bear) or are emplaced at or near surface (El Laco)
- High to very high temperatures (600-800ºC)
- Have conclusive field evidence of metasomatic attributes (replacement, breccia filling, fluidisation breccias)
- Components may crystallised from iron oxide magmas
- Fluidisation of hydrothermal precipitates, flotation of igneous magnetite are also invoked for their genesis

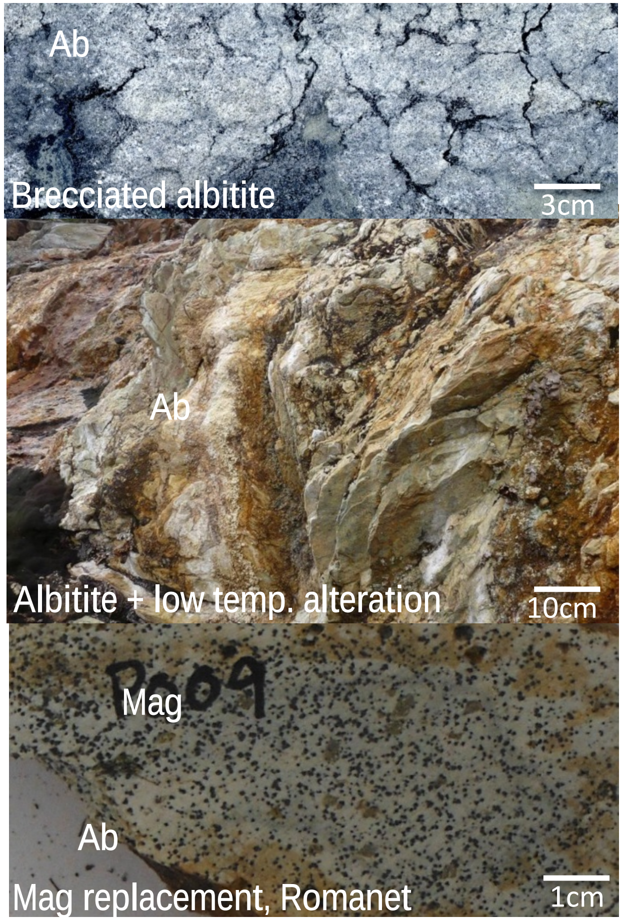




Hitzman et al. 1992; Williams et al. 2005; Corriveau et al. 2010a, 2016; Porter 2010a, b; Williams 2010a, b; Knipping et al. 2015; Bilenker et al. 2016; Tornos et al. 2016

Albitite-hosted U, Au±U±Co

- **Also called Na-metasomatic U, metamorphic-metasomatic U, orogenic Au-Co-U**
- **Multiple stages of Na** (Ab ± Rbk, Na-Cpx)**, HT Ca–Fe** (Amp, Cpx, Mag)**, K** (Kfs)**, HT K-Fe** (Bt) **metasomatism, commonly syn-deformation + LT Ca–Fe–Mg** (Chl, Cb, Hem) **overprints**
- **Elevated Zr, Nb, Ta, Sn in albitites**
- **May be hosted by IOAA ore systems forming regional scale albitites** (Michelin, Kitt in Central Mineral Belt, Canada; Kuusamo, Finland; Valhalla, Mt Isa; Southern Breccia, Great Bear magmatic zone)
- **Occur in Cu in districts** (Turamdih and other U–Cu–(Fe) deposits in the Singhbhum Shear Zone, India) **which affinity to IOAA systems remain uncertain**



Gandhi 1978; Béziat et al. 2008; Cuney and Kyser 2008; Wilde 2010; Dragon Mining 2014; Kontonikas-Charos et al. 2014; Montreuil et al. 2015; Sparkes 2017

Resources of affiliated deposits

Iron oxide-apatite

Kiirunavaara 682 Mt at 47.5 % Fe (reserve)

El Laco 376 Mt at 56.7% Fe (reserve); 734 Mt at 49.2% Fe (resource)

Malmberget 271 Mt at 41.8 % Fe (reserve)

Marcona ~1940 Mt at 55.4% Fe, 0.12% Cu (LKAB 2013; CAP 2013)

Albitite-hosted uranium

Valhalla 34.7 Mt at 830 ppm U_3O_8 (resource; Paladin Energy 2015)

Michelin 37.5 Mt at 0.10 % U_3O_8 (resource; Sparkes 2017)

Albitite-hosted Au-U and Co-Cu-U

Kuusamo 3.8 Mt at 4.1 g/t Au, 9.1 Mt à 0.12% Co (resource; Dragon Mining 2014)

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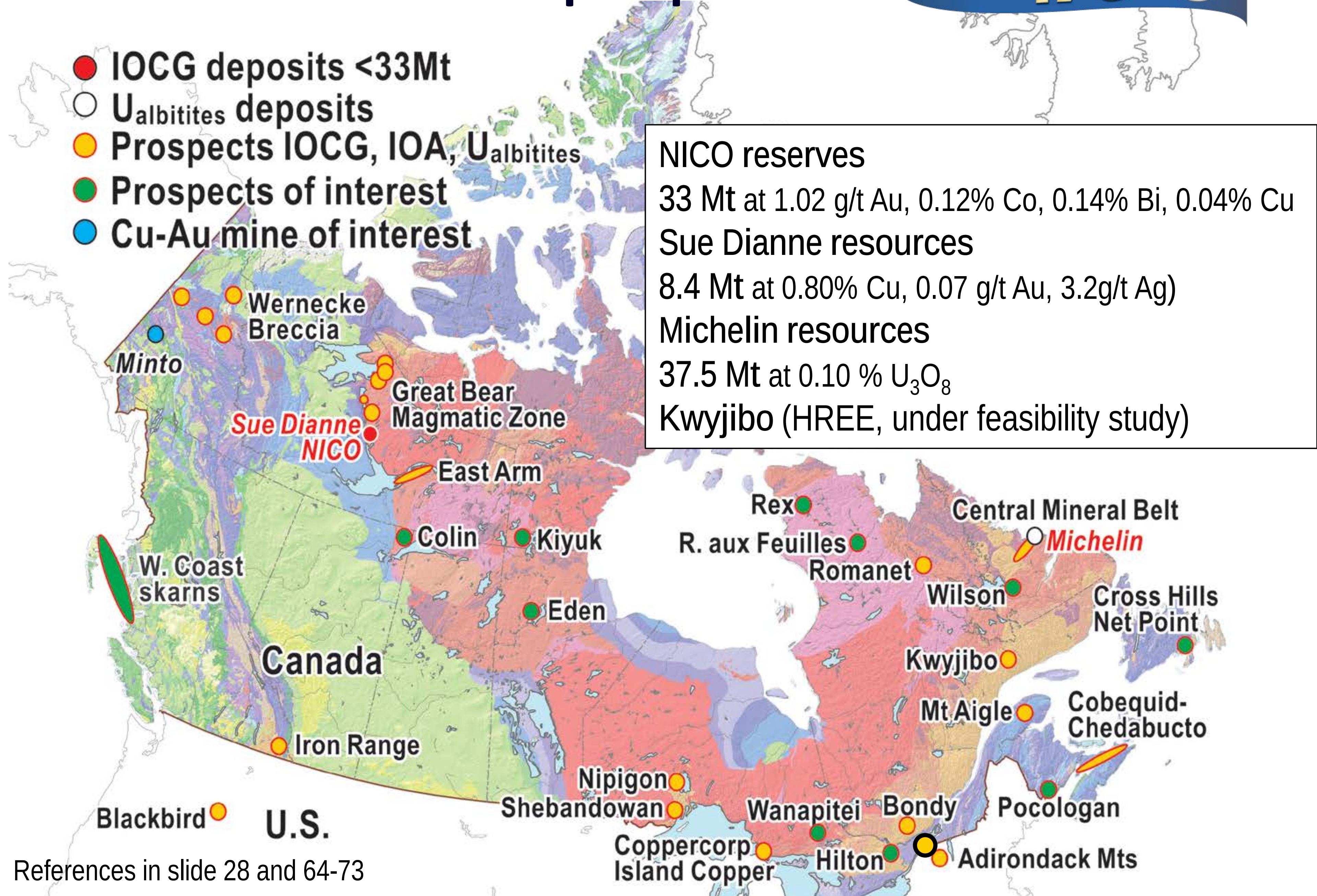
Distribution of deposits/prospects

References in slide 28

(modified from Corriveau 2007; Porter 2010a)

Canadian districts and prospects



NICO reserves

33 Mt at 1.02 g/t Au, 0.12% Co, 0.14% Bi, 0.04% Cu

Sue Dianne resources

8.4 Mt at 0.80% Cu, 0.07 g/t Au, 3.2g/t Ag)

Michelin resources

37.5 Mt at 0.10 % U_3O_8

Kwyjibo (HREE, under feasibility study)

References in slide 28 and 64-73

References for location and resources of deposits

Jones 1974; N9GBYBGMR 1983; Lyons 1988; Porto da Silveira et al. 1991; Skirrow 2000, 2010; Vanhanen 2001; Knight et al. 2002; Oyarzun et al. 2003; Hitzman and Valenta 2005; Williams et al. 2005; Belperio et al. 2007; Benavides et al. 2007; Davidson et al. 2007; Doebrich et al. 2007; Béziat et al. 2008; Hennessey and Puritch 2008; Wu 2008; Polito et al. 2009; Zhu et al. 2009; Chen et al. 2010; Clark et al. 2010; Daliran et al. 2010; Groves et al. 2010; Lobo-Guerrero 2010; Porter 2010a, b; Rieger et al. 2010; Williams 2010a, b; Baker et al. 2011, 2014; Zulinski and Osmani 2011; Chen and Zhou 2012; Dragon Mining 2012, 2014; Puritch et al. 2012a, b; Turner 2012; CAP 2013; Chen 2013; First Quantum Minerals 2013; LKAB 2013; Nold et al. 2013, 2014; Oz Minerals 2013, 2014a, b, 2017; Potter et al. 2013; Slack 2013; Barton 2014; Burgess et al. 2014; Chinova Resources 2014, 2017; Corriveau et al. 2014; Couture et al. 2014; Desrochers 2014; Duncan et al. 2014; Intrepid Mines 2014; Ismail et al. 2014; Waller et al. 2014; BHP Billiton 2015; Fan et al. 2015; Graupner et al. 2015; GTK 2015; Li et al. 2015; Montreuil et al. 2015, 2016a, b, c; Paladin Energy 2015a, b; Perreault and Lafrance 2015; Rex Minerals 2015; Woolrych et al. 2015; Day et al. 2016; Martinsson et al. 2016; Metal X 2016; Veríssimo et al. 2016; Babo et al. 2017; Camprubí and González-Partida 2017; Zhao et al. 2017

Impediments to Exploration

Assignment of historical prospects to disparate deposit types

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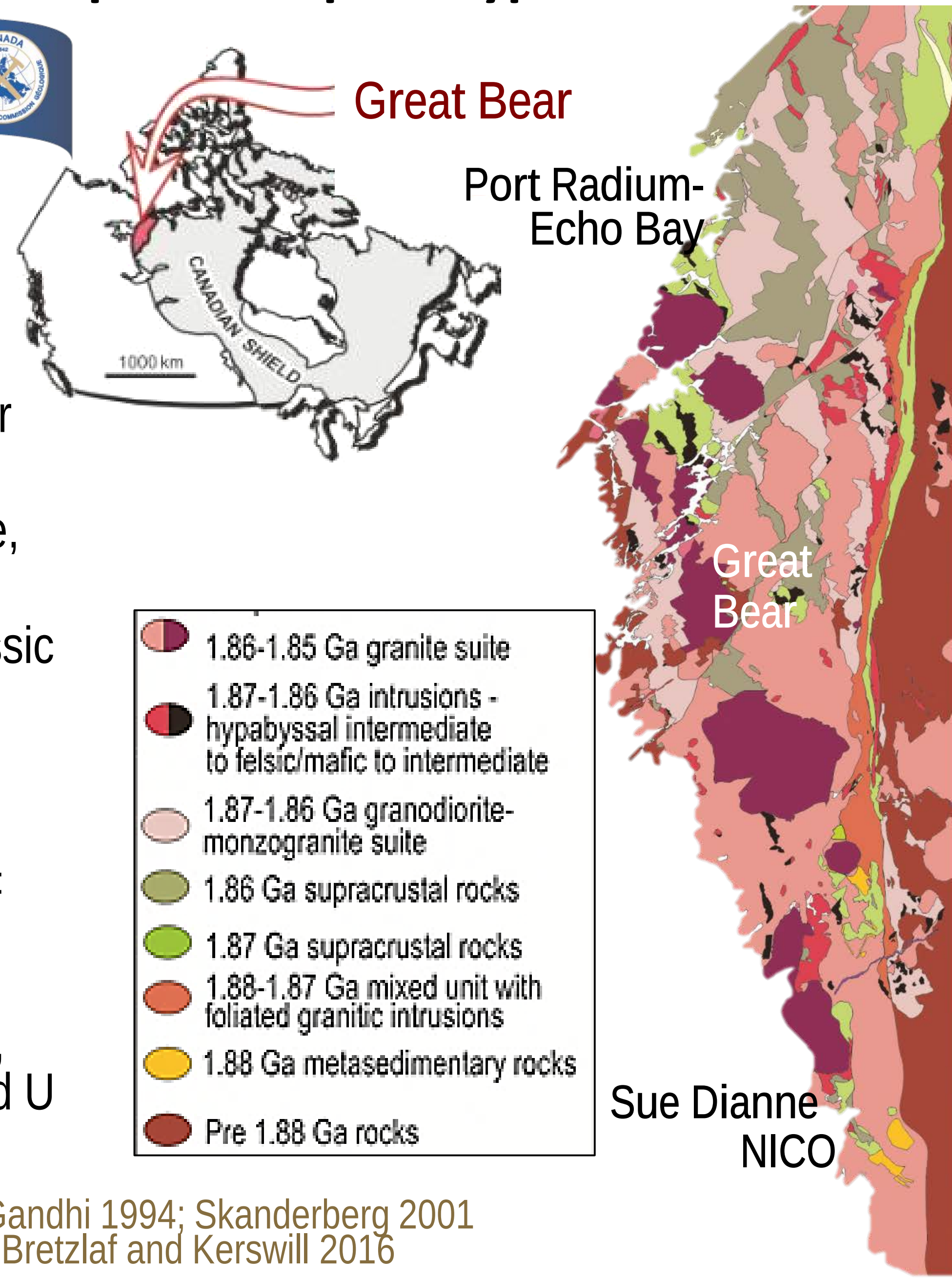
Great Bear example

- **Sedimentary:** iron formation-hosted, SEDEX
- **Volcanic:** volcaniclastic-hosted Au, Cu, Ag; diatremes
- **Intrusion-related:** skarns
- **Ironstone-hosted:** hydrothermal magnetite or hematite ironstones
- **Uranium:** intrusion-related, unconformity-type, volcanic-hosted, albitite-hosted
- **Alteration-hosted:** potassic Cu; phyllic-potassic Ag, Cu, Zn, Pb
- **Breccia-hosted** Fe-oxide
- **Vein-hosted:** epithermal Cu-Ag ± Au, Pb, Zn, Co, Bi, U; quartz-carbonate veins Cu, Ag, U ± Co, Bi, Ni; five-element veins; giant quartz complexes ± Cu, U
- **IOA** (Kiruna type), **IOCG** (Olympic Dam type), variants, and newly discovered: albitite-hosted U

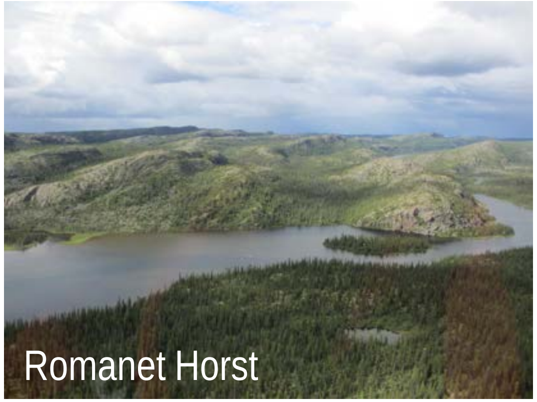


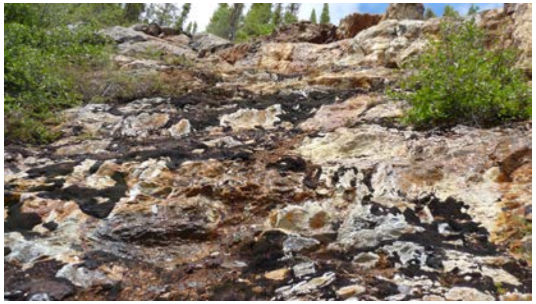
Hildebrand 1986; Gandhi 1994; Skanderberg 2001
Mumin et al. 2010; Bretzlaf and Kerswill 2016

Same problem worldwide…

Historic prospects and deposits interpreted as

- **Idaho belt (USA)** (see Slack 2013): Post-metamorphic granite-related hydrothermal replacement; Syngenetic VMS/SEDEX; Syngenetic/diagenetic stratiform Cu; Synmetamorphic vein and replacement; Premetamorphic IOCG
- **Romanet Horst (Quebec)** (Corriveau et al. 2014; Desrochers 2014): Syngenetic and diagenetic Cu ± U (Kuperschiefer, red beds); Epigenetic Cu ± U ± Au quartz-carbonate-sulfide veins; Volcanic-hosted massive sulfides; Albitite breccia, etc.
- **Central Mineral Belt (Labrador**) deposit models focus on host rock types, structural styles, metal associations, metamorphism (see Gandhi 1978; Kerr and Sparkes 2009; Sparkes 2017). Similar approach in Scandinavian districts: Martinsson et al. 2016; Engvik et al. 2014, 2017): Unconformity, volcanic-hosted, syngenetic sedimentary, syngenetic magmatic, epigenetic-hydrothermal, shear zone-hosted, metamorphic-metasomatic, and stratiform U; Syn-sedimentary base metal, etc.





Another challenge: metamorphism

Iron-oxide and alkali±calcic metasomatites and epithermal alteration zones metamorphosed to upper amphibolite and granulite facies resemble to and can be misinterpreted for :

- Metapelites (argillic, advanced argillic, phyllic, sericitic alteration facies)
- Amphibolites (HT Ca-Fe alteration facies)
- Calc-silicates (skarns)
- Orthogneisses (albitite, Kfs felsites)
- Meta-arkoses (Kfs-dominant K alteration facies)
- Quartzites (silicification)
- Meta-exhalites (tourmaline-rich alteration; magnetite-breakdown to garnet forming garnetites and garnet-rich gneisses)
- etc.

Bonnet and Corriveau 2007; Corriveau 2013; Corriveau and Spry 2014

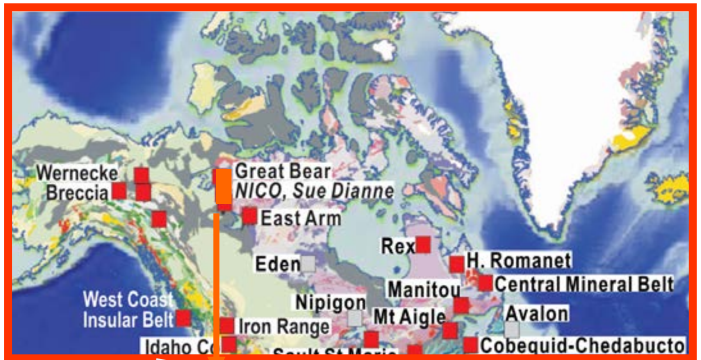
Public geoscience needs in a Canadian perspective

(or how to help enhance Canadian IOCG resources from the current two deposits to Australia's resources)

1. **Recognise, decode, map, document, explore ore systems with iron-oxide and alkali-calcic alteration**
2. **Extend knowledge to systems metamorphosed at low to high grades**
3. **Explore for and discover IOA, IOCG and affiliated deposits to renew resources and respond to minerals and energy needs of 21st century high technology and green society**
4. **Foster collaboration between governments, academia, private sector, communities from project conceptions to implementation, discoveries, development, remediation, regulations, etc.**
5. **Provide the geoscience fundation for informed investment and societal decisions including for land-use planning and resources development**
6. **Train and transfer knowledge broadly**

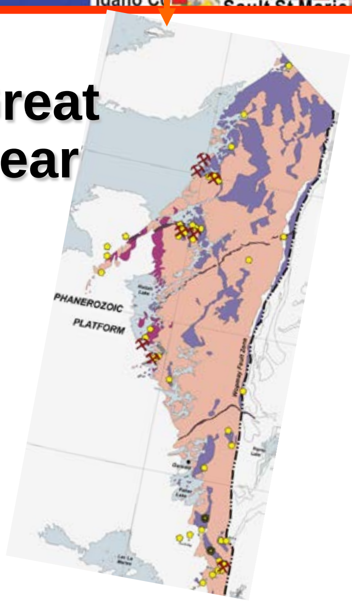
Corriveau 2007; Corriveau and Mumin 2010; Potter et al. 2013

Canadian prospective settings: under-explored, under-mapped and under-valued



- IOCG and affiliated deposits under explored compared to other deposit types
- Prospects drilled prior to definition of IOCG deposit type
- Targets largely **outside** known mining camps
- 2 IOCG deposits known (+ Minto?)

Great Bear

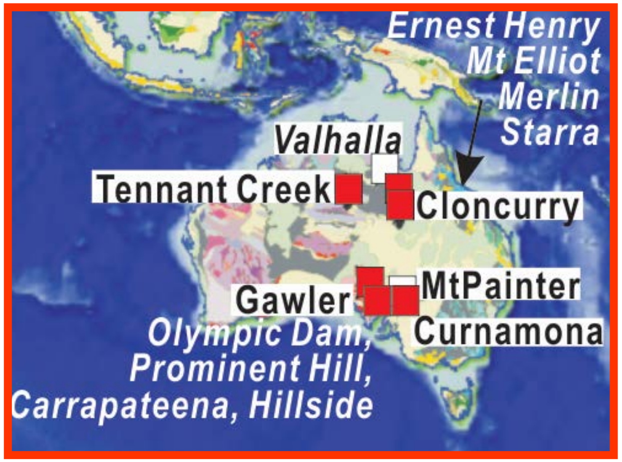


NICO: Au-Co-Bi in amphibole-magnetite-biotite-K-feldspar metasomatites

- Drilling started in 1997
- Bulk sampling in 2007
- Permitting completed in 2015
- Mining in 20??

Metal endowment of prospective settings unknown

CANADA = GAWLER CRATON in the 1970s (when Olympic Dam, Prominent Hill, Carrapateena, Hillside, Khamsin had not been discovered)



Australia's giant and world-class mines, deposits

~10 years of exploration for Olympic Dam prior to disclosure of the 1975 discovery. Resources keep increasing since then to current 10 400 Mt

Took another

- **25 more years to find Prominent Hill (2001)**
- **4 more years for Carrapateena (2005)**
- **4 more years for Hillside (2009)**
- **3 more years for Khamsin (2012)**

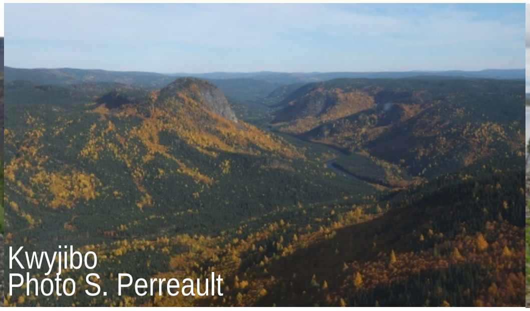
+ a lot of prior and coeval government and academic research

In IOCG district expects surprises: Merlin Mo-Re deposit in Cloncurry IOCG district (Babo et al. 2014)

See slide 28 for references

A need to re-examine Canada’s prospective terranes

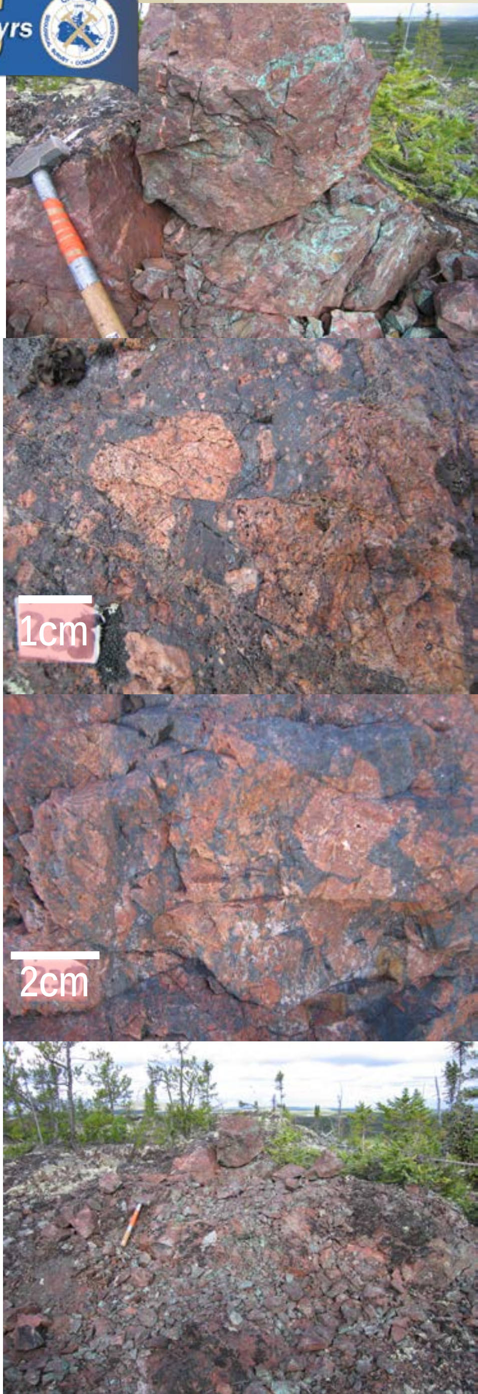
- Host terranes under explored, under mapped, under valued
- Immature exploration models but prospect information can be reinterpreted in terms of modern ore system knowledge
- Poor logistical infrastructures, local high wilderness values
- Fertile attributes rarely reported; in some cases key metasomatic hosts to mineralisation mapped as common sedimentary, igneous or metamorphic rocks
- Fairly cryptic ore and common lack of gossan or malachite staining at surface
- Potential resources extremely varied and largely untapped
- Geosciences can help diversify mineral exploration strategies and protocols and serve as foundation for environmentally responsible stewardship of IOCG resources development
- Value added for metallurgy, societal decisions, policy development, regulations, etc.



Rationale for increased public geosciences

Geological mapping, mineral potential assessment, exploration, and environmental reviews require:

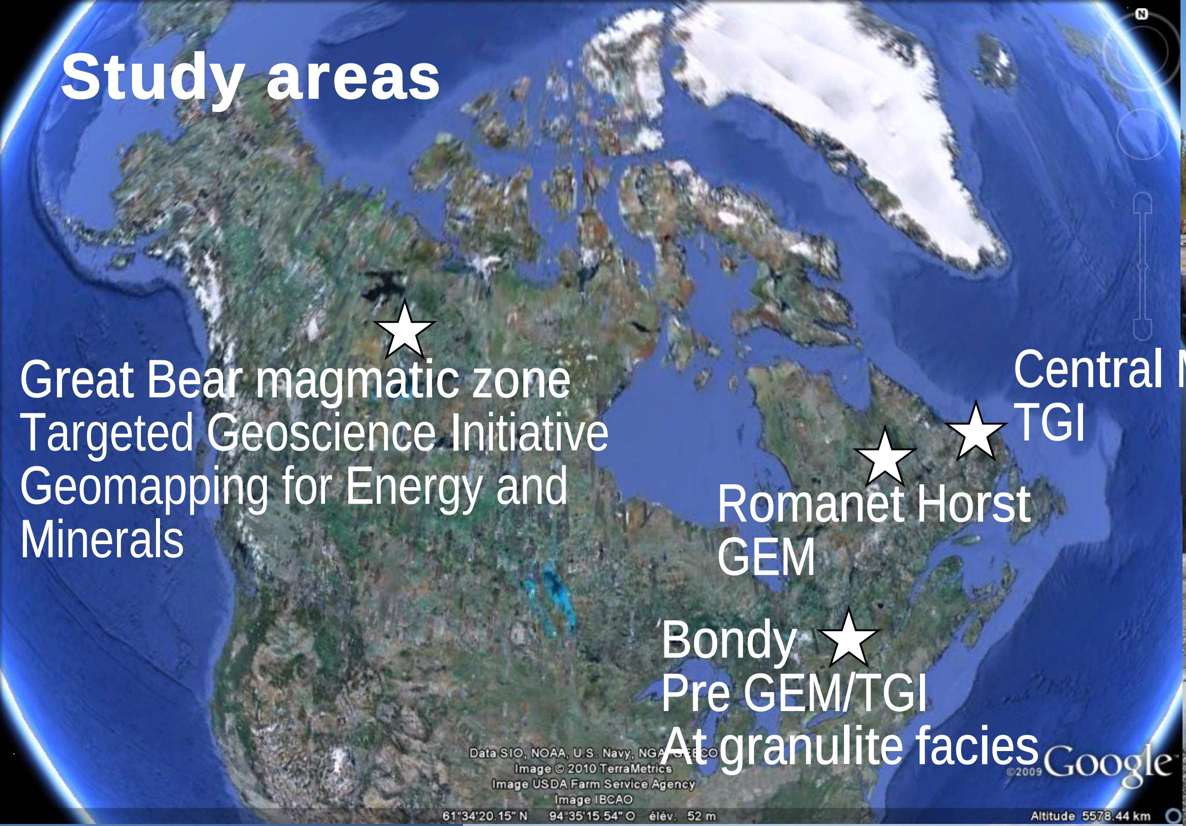
- Modern geoscience information at regional to deposit scale
- Lithological maps and field datasets with information on hydrothermal alteration and mineralisation
- Geological, geochemical, mineralogical, mineral chemistry, isotopic, geochronologic and rock physical property datasets with contexts, sound quality controls, and interpretation
- High-resolution geophysical maps and 3D models (gravity a must)
- Till geochemical and mineral indicator datasets and contexts
- Remote-predictive maps
- Comprehensive ore deposit model with prognostication capabilities for under-explored and under-mapped regions
- Reference case examples, scientific papers, short courses, presentations, site examination



Celebrating 175 yrs

The Great Bear mineral systems 25 years after Hitzman et al. 1992


Study areas



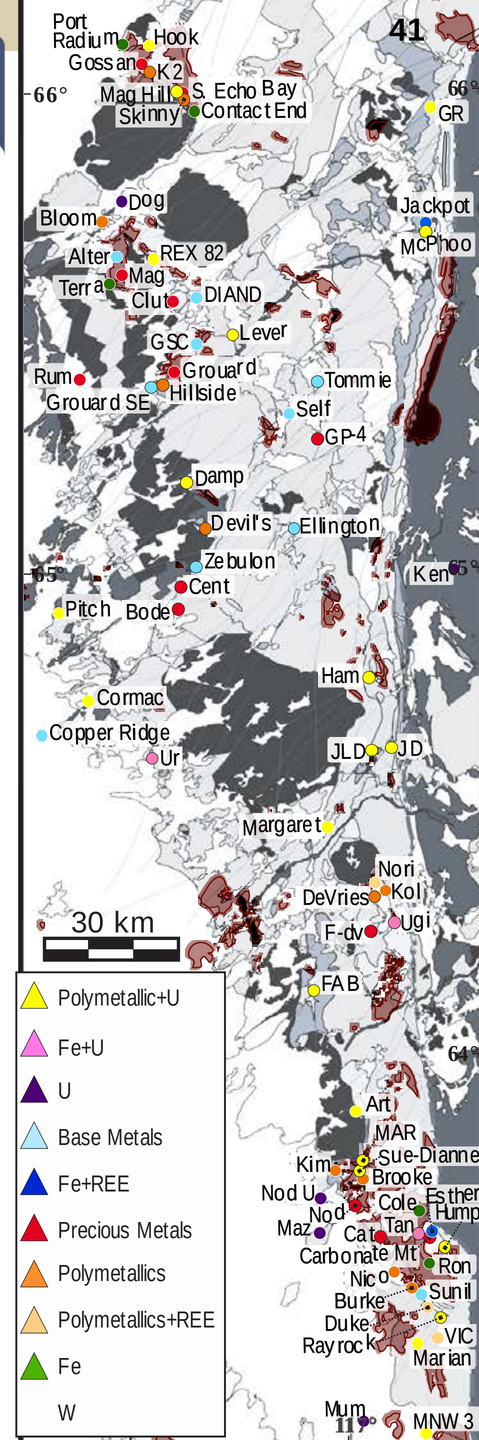
Celebrating 175 yrs

Great Bear footprints

- Series of Paleoproterozoic (1.87 Ga) iron-oxide and alkali±calcic alteration ore systems
- Prospects and deposits belong to the IOA, IOCG, albitite-hosted U and skarn deposit types
- Nearly continuous field exposure due to erosion of former Proterozoic and Paleozoic sedimentary cover and Quaternary glacial polish
- Paleo-depth transects available as a consequence of differential uplift and tilting during the development of the systems, and subsequent broad arching of the belt
- Ore systems not entrained in orogenesis; original footprints remain pristine
- Minor metal remobilisation locally (late veins coeval with late stage magma emplacement and giant quartz veins along transcurrent fault zones)
- Within a large igneous province with strong time constraints between metasomatism, magmatism and mineralisation
- Field, geochemical and petrological attributes intrinsic to the space, time and compositional evolution of metasomatism and associated mineralisation
- Genetic linkages among IOCG, IOA, albitite-hosted uranium and skarn mineralisation

Great Bear mineralisation

- Extraordinary range of mineralisation types, styles, metal associations and Cu, Co, Ag, Au, U, Ni occurrences
- Two IOCG deposits (NICO, Sue Dianne)
- IOA-IOCG-albitite-hosted U- porphyry Cu-epithermal continuum
- Unconformity, volcanic, albitite and vein-hosted U within ore systems
- Mineralised tailings
- Fullfill all criteria for terranes with a high potential in U-rich, polymetallic, hematite group IOCG deposits (cf. Skirrow 2008)
- Case examples to develop new exploration methods
- Till cover sufficient for till and mineral indicator studies
- Excellent lithological map coverage
- Archive collection of samples across areas difficult to access and field databases



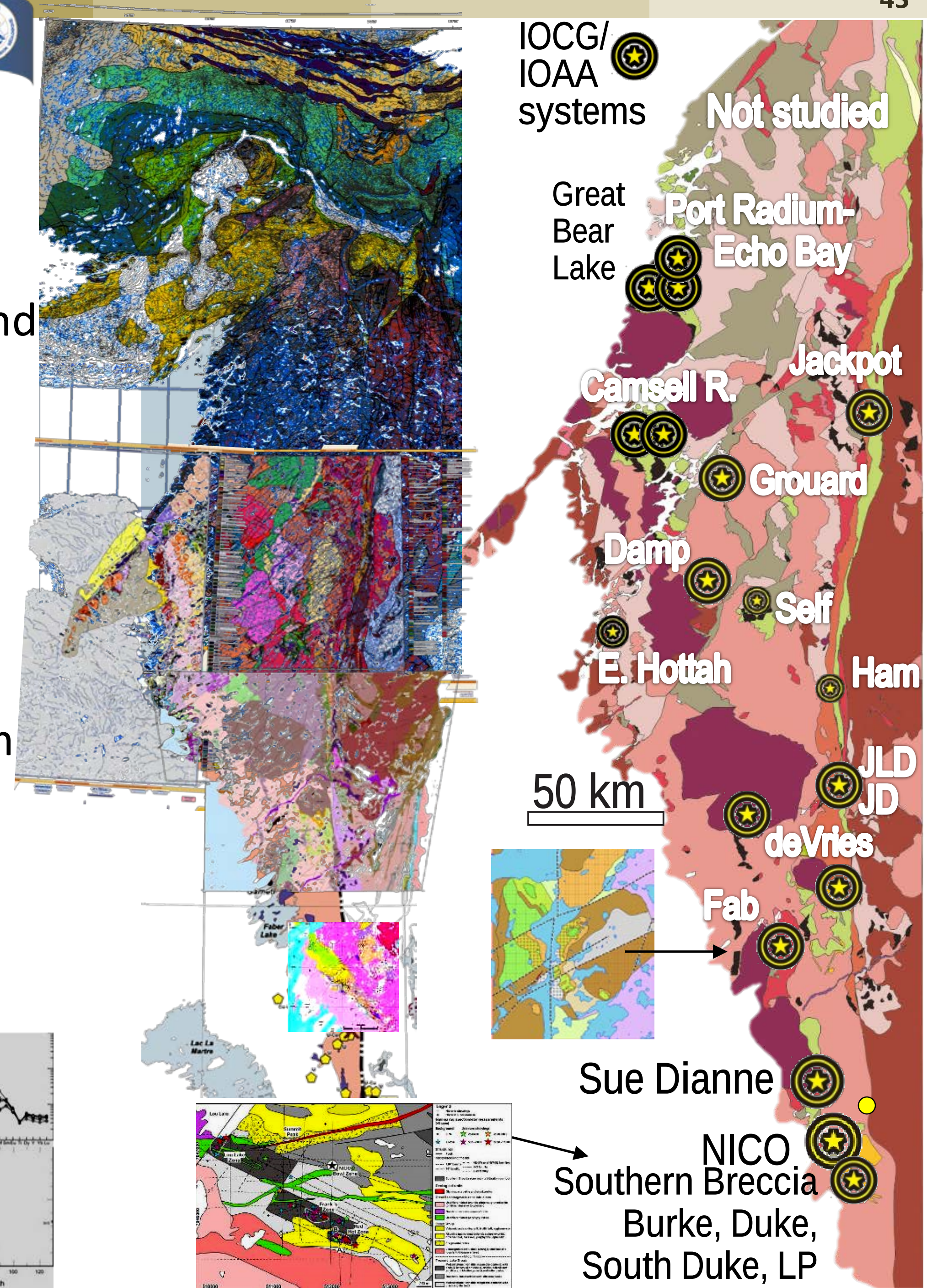
Great Bear GEM and TGI research
A GSC-NTGS-academia-industry collaboration

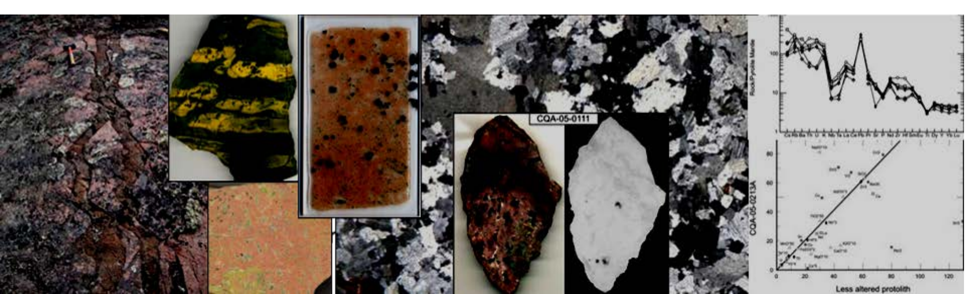
Geological and Geophysical Framework			Exploration Vectors & Methods		External Contributions	
Regional geology	Lithospheric architecture	GIS	Till chemistry	Physical properties	4 PhD students	6 MSc students
Prospective environments	Tectonic and magmatic triggers	Databases Datasets	Indicator minerals	Geophysical surveys	35 BSc students	10 First Nations field trainees
Timing of events	Fluid pathways	Legacy maps & data	Alteration evolution zoning	3D geophysical models	Assessment report compilation	Publication legacy data 1970-1995
Metal sources	Hydrothermal processes	Samples collections	Geochemical discriminants	Paleo-magnetic constraints	Private sector logistic hubs	Letters of agreements
Fluids sources	Metallogeny	Mapping protocol + terms	Metallogenic model	Magnetite apatite chemistry	Publication of private sector maps & data	Private Sector funding
Mineral chemistry	Magneto-telluric	Teleseismic	*Regional mapping and research by NTGS; mapping and exploration by industry; research by academia*			With Fieldwork

Celebrating 175 yrs

Data collections

50 maps (protolith + alteration facies)
62470 bedrock stations (GEM, TGI + R. Hildebrand) + 290 till stations
4516 samples (+ S. Gandhi + R. Hildebrand collections)
18000 photos
20 IOAA systems
2600 geochemical analyses
200 CTscan, 100 ITRAX™
1100 eU, eTh, K,
900 density/susceptibility/resistivity/rem
114 mineral indicator + till analyses
Geophysical surveys
50 papers published or in progress
22 open files (in progress, published)





Research results

Celebrating 175 yrs

IOAA ore systems

- Terminology
- Geological attributes
- Metasomatic processes
- Element mobility
- Triggers of metasomatism
- Space-time relationships
- Metal associations
- Linkages among deposits
- Ore deposit model
- Geodynamic settings
- Lithospheric to local architecture/structures
- Criticality of attributes
- Mineral potential

Geological attributes

- Host rocks, magmatic suites, sedimentary basins
- Alteration-facies geology, petrology, mineralogy, geochemistry and rock physical property attributes and footprints
- Breccias, mineralisation
- Textures, structures
- Spatial patterns
- Timing relationships
- 3D architecture
- Mapping challenges and likelihood of alteration zones (mis)identification

Tools, tracers

- Mapping protocols
- Portable field devices
- Geophysical targeting
- Rock physical properties
- Till geochemistry
- Mineral indicators
- Geochemical indices
- Chemical profiles
- Impediments and challenges to discovery

Publications

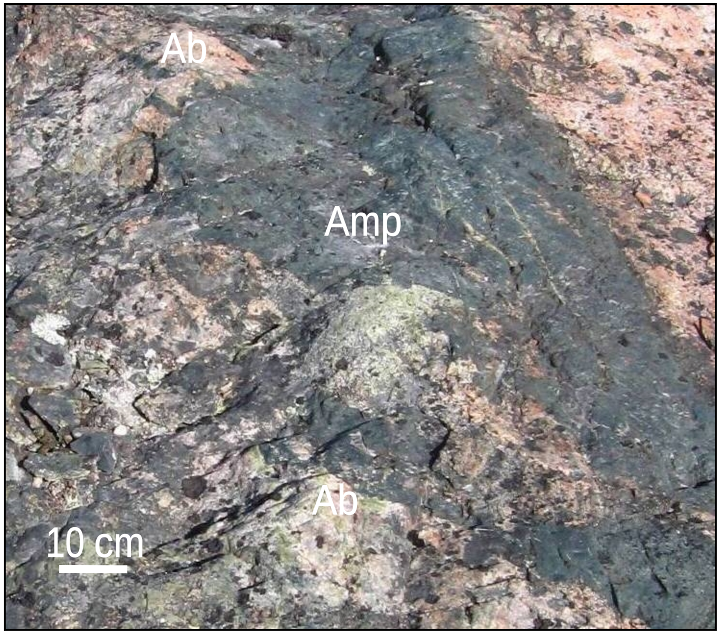
- Geological and chemical alteration maps
- Bedrock, mineralogical geochemical, petrologic, geochronological, isotopic and rock physical property datasets
- Till geochemical and mineral indicator datasets
- High-resolution geophysical surveys (magnetic, radiometric, gravity, magnetotelluric)
- Remote-predictive maps
- 50 scientific papers and 22 open files (in progress -published)

With a strong focus on geological attributes to optimise recognition of IOAA systems, understanding critical linkages among deposit types, alteration mapping, rock physical properties, geophysical footprints, mineral indicators and till chemistry for exploration

Footprints of ore environments in 3D from paleo-depths of 5 km to surface

Alteration footprints

- Great array of mineral assemblages, grain size, textures, intensity of alteration, density of vein networks and types of breccias across ≤35 x 15 x15 km^3 (length, width, depth)
- Mapping complex without appropriate tools

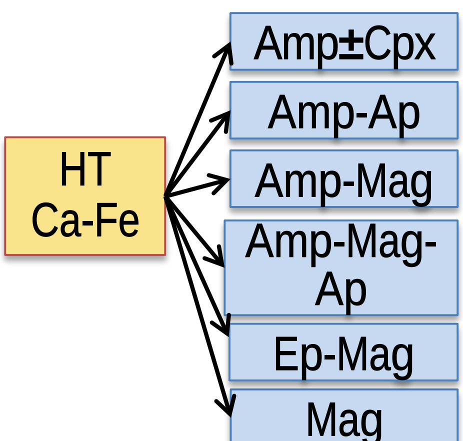


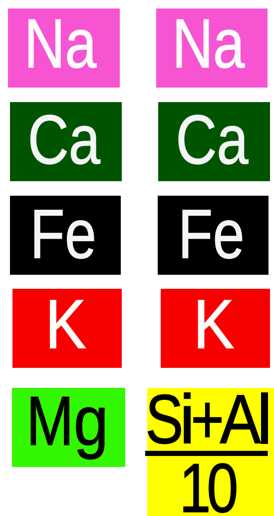
Kfs -Mag
Ab -Amp-Mag -Ap
Kfs -Bt -Mag
Amp -Mag -Bt
Chl-Hem-Kfs-Cb-Ser
Chl-Cb-Hem
Chlorite
Qtz vein
Cpx - Kfs
Silicification
Ab - Amp
Kfs
Propyllitic
Cpx-Grt-Kfs
Hem
Ab -Amp-Ap
Chl -Hem
Amp-Mag -Bt -Kfs
Ep -Mag
Ser-Hem
Kfs -Hem
Tourmaline
Amp -Mag
Cpx
Amp
Ab -Amp-Mag
Bt
Ab
Ep -Hem - Qz -Cb
Jasper
Mag
Acid
Cpx - Amp-Mag
Ser
Ep-Qz -Cb
Phyllic / sericitic
Ep
Amp -Mag -Kfs
Ep -Hem -Qz
Amp-Mag -Ap
Bt -Mag
Ep -Hem
Carbonate
Hem-Kfs-Ser

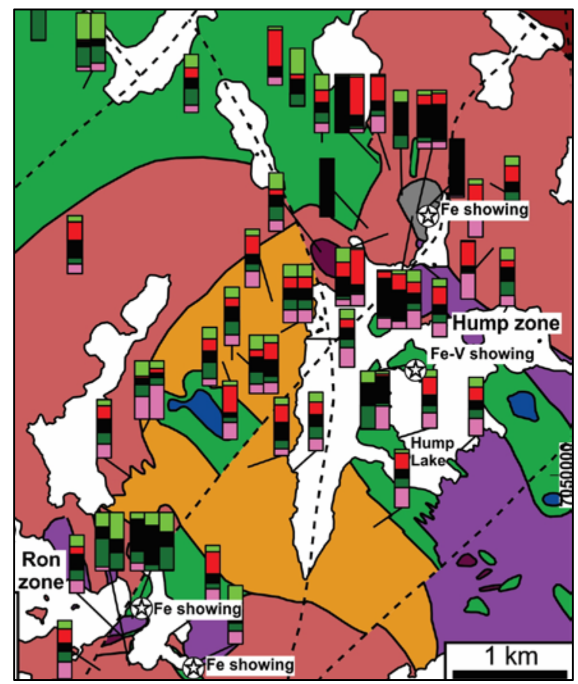
Metasomatic facies and chemical bar codes as mapping and exploration tools

Efficient for:

- Alteration discrimination, characterisation and mapping
- Geological and geochemical exploration
- Mineral potential assessment
- Ore deposit model

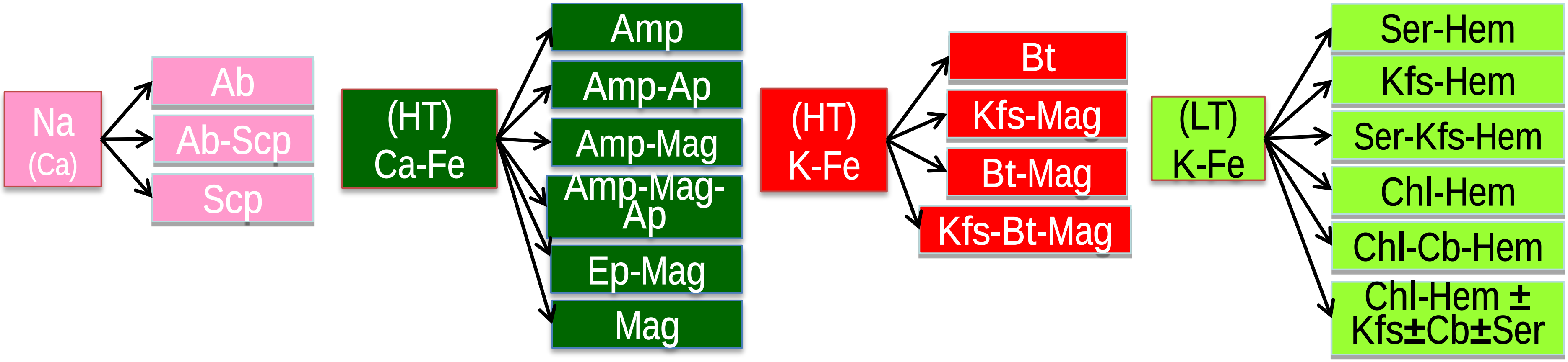






Alteration facies

Regrouping mineral assemblages into alteration facies provides an effective mean to map and explore ore systems with iron-oxide and alkali-calcic alteration



To each set of mineral parageneses its own alteration facies and chemical signatures

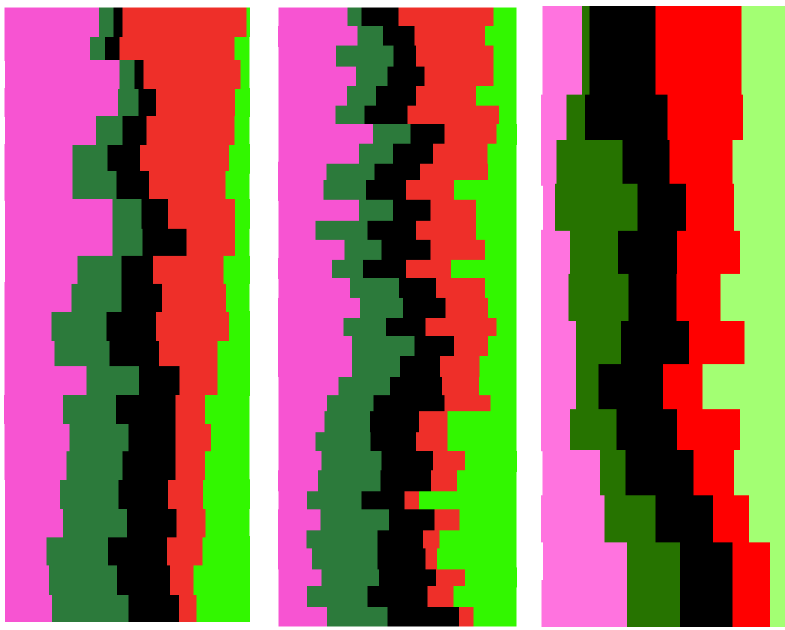
Corriveau et al. 2010b, 2016, 2017, in prep a-h.
Montreuil et al. 2013, 2016a, b, c; De Toni 2016

Célébrons 175 ans

Diagnostic composition of alteration facies

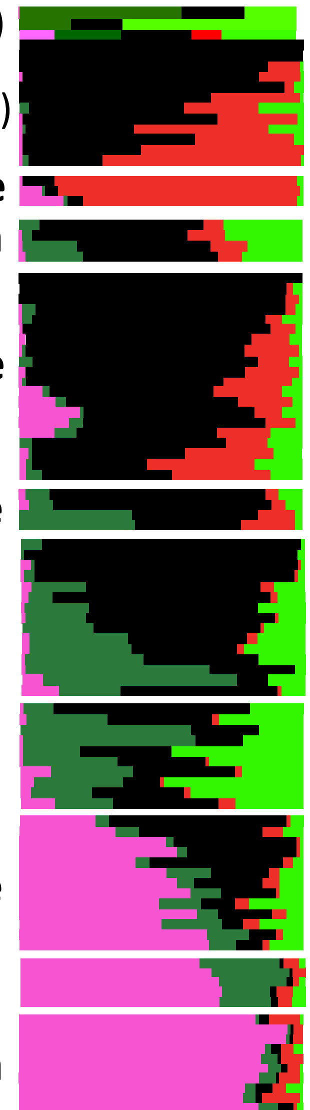
Common rocks

Calco-alkaline and shoshonitic | **Shale**



Na Ca Fe K Mg

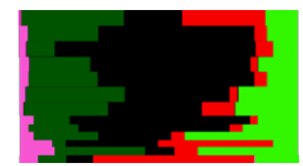
Alteration facies



Deposits

IOCG Cu-Ag-Au HT K-Fe

IOCG variant with Au-Co-Bi HT Ca-K-Fe

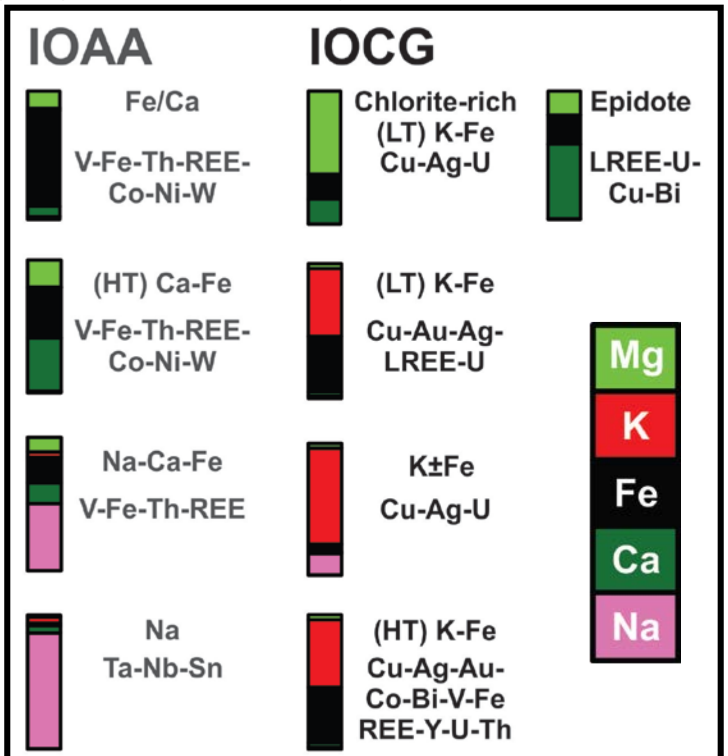


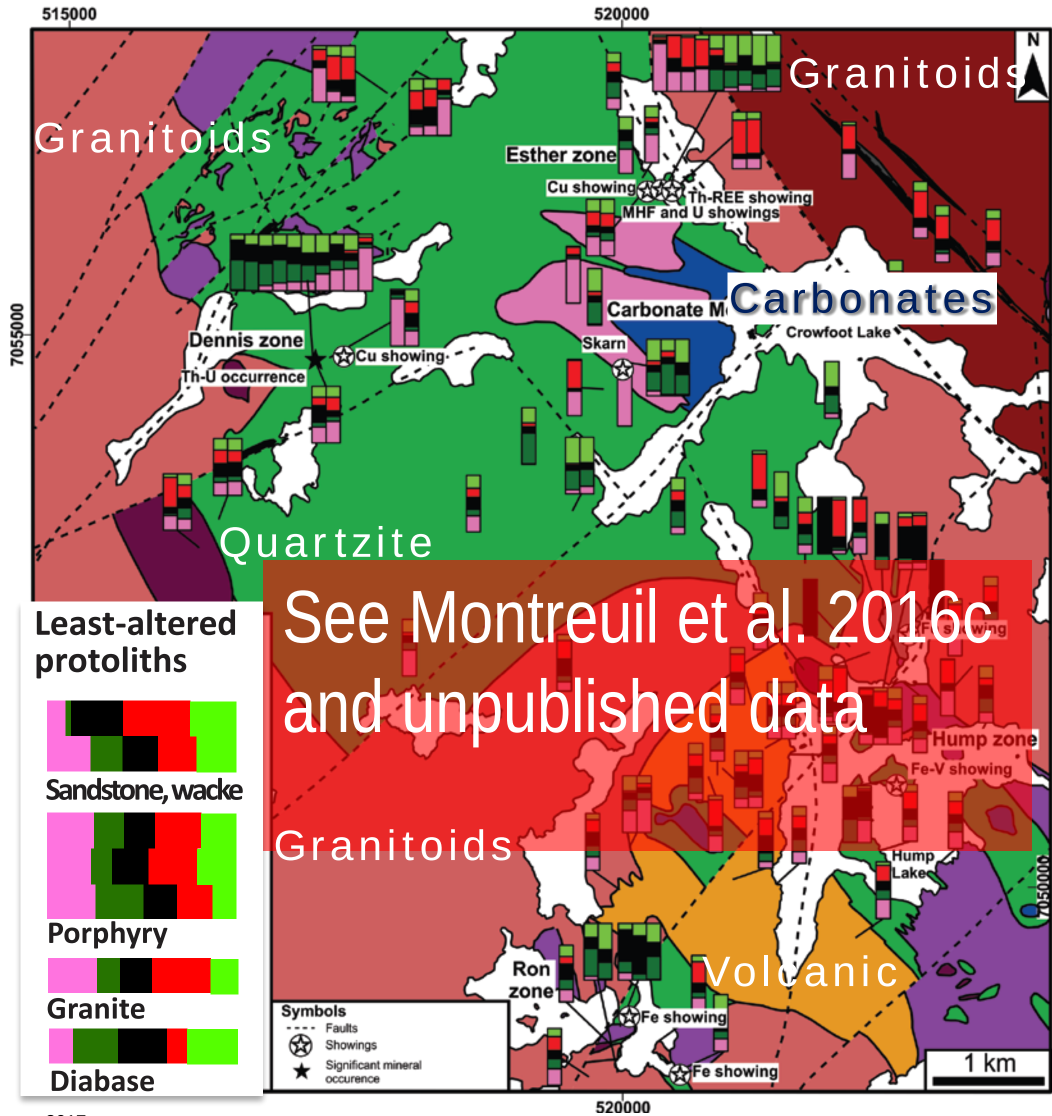
IOA-REE HT Ca-Fe to HT Ca-K-Fe

Lithochemical maps

A mineral potential framework

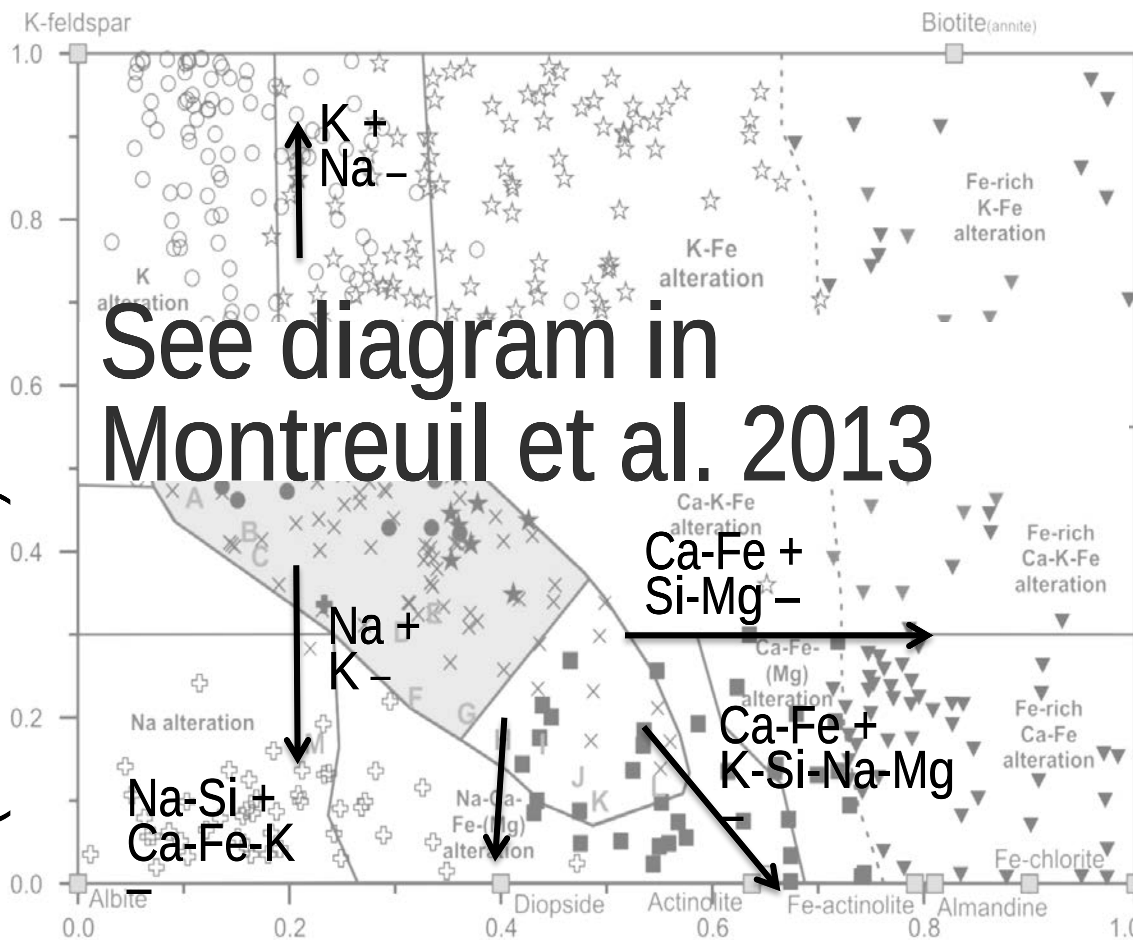
The proportion of the diagnostic cations of alteration facies provides an effective mean to locate iron-oxide and alkali-calcic alteration ore systems and to prognosticate fertility





Celebrating 175 yrs

Alteration indices and footprints



K + Na –

See diagram in Montreuil et al. 2013

Ca-Fe + Si-Mg –

Na + K –

Ca-Fe + K-Si-Na-Mg –

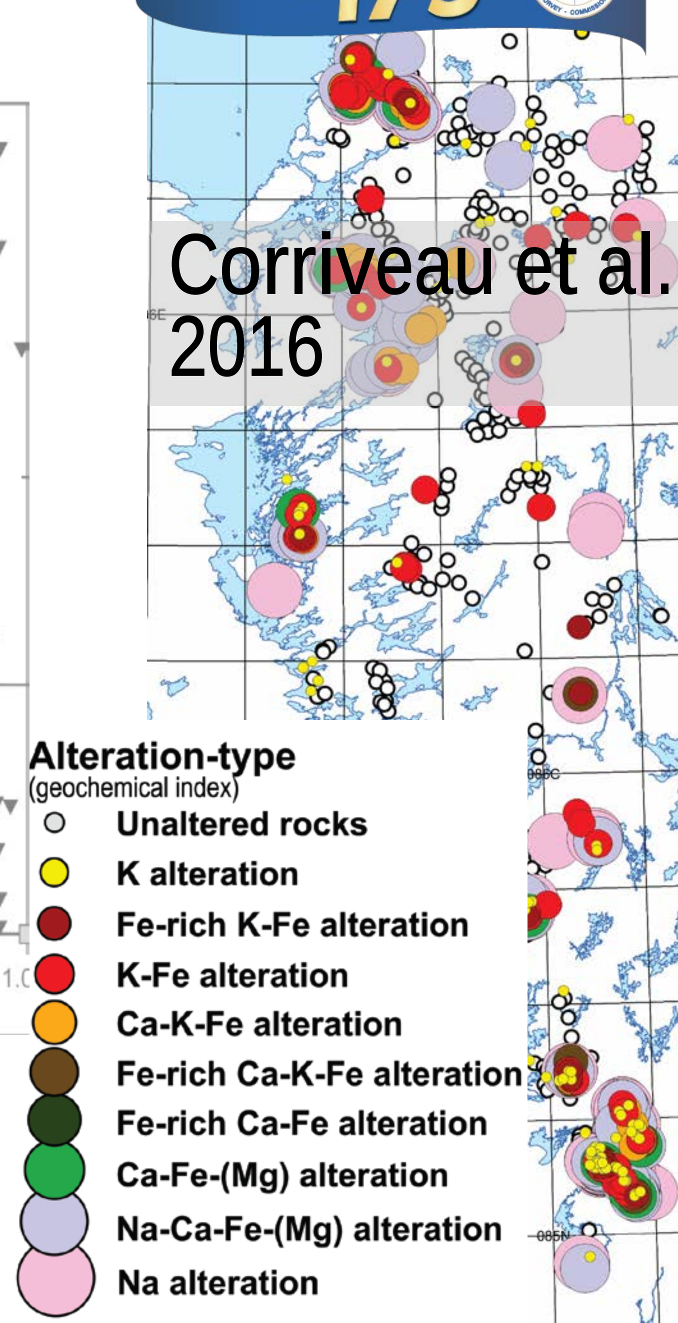
Na-Si + Ca-Fe-K –

K(K+Na+0.5Ca)mol

2Ca+5Fe+2Mn)/2Ca+5Fe+2Mn+Mg+Si)mol

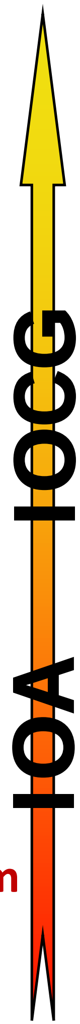
Adapted to magnetite chemistry (DeToni 2016)

Corriveau et al. 2016



Alteration facies in known deposits

Distal
Lower Temp.
Shallow <1km
Later



Thermal core
High Temp.
Deeper 3-10km
Earlier

6 LT Si, K, Al, Ba — **Epithermal cap**
Central Andes, Olympic Dam, Great Bear

5 LT K-Fe (Ca, Mg, H^+-CO_2) hematite-K-feldspar /sericite-carbonate-chlorite-sulphides — **Immediate host to Hem-group IOCG deposits**
Component of Mag–Hem-group IOCG deposits
Olympic Dam, Prominent Hill, Carrapateena, Great Bear

4 K-felsite K-feldspar
K-skarn clinopyroxene-garnet-K feldspar-sulphides — **Immediate host to Hem-toMag and Mag-group + K skarn IOCG**
Candelaria, Mt Elliott (Cloncurry), Hillside (Gawler), Great Bear

3 HT K-Fe magnetite-biotite/ K feldspar-sulphides — **Immediate host to Mag-group IOCG**
Ernest Henry, Salobo, Candelaria, Great Bear

2-3 HT Ca-K-Fe — **Immediate host to Co-IOCG and REE-IOA variants**
NICO, Idaho Co belt

2 HT Ca-Fe amphibole-magnetite ± apatite — **Wallrocks of Mag-Ap (IOA) Fe±REE deposits**
Kiruna, Chilean Iron Belt, El Laco, Great Bear

1-2 skarn if carbonate host — **Outer zones of IOCG deposits**
Ernest Henry, Starra, Central Andes, Great Bear

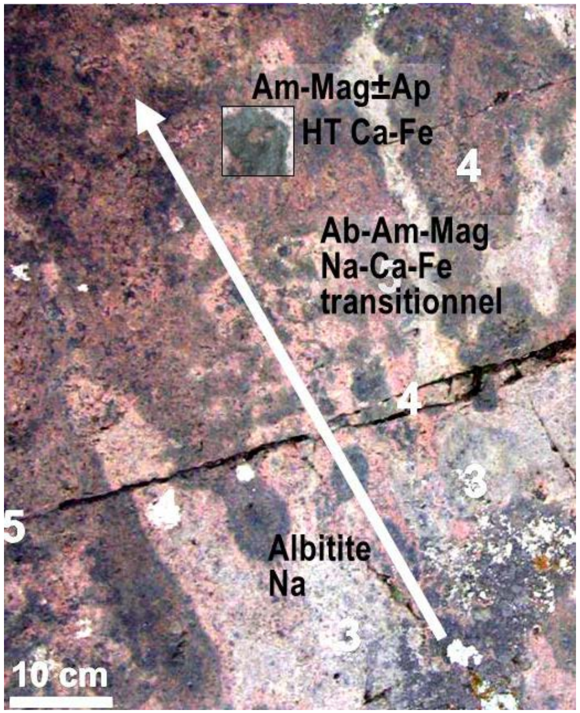
1-2 HT Na-Ca± Fe

1 Na albite, albitite — **Regional scale, barren, preferential host for albitite-hosted U + some IOCG**
Cloncurry + Mt Isa, Gawler, Chilean Iron Belt, El Laco, Kiruna, Great Bear

Modified from Corriveau et al. 2010b, 2016

Alteration mapping as a vector to mineralisation

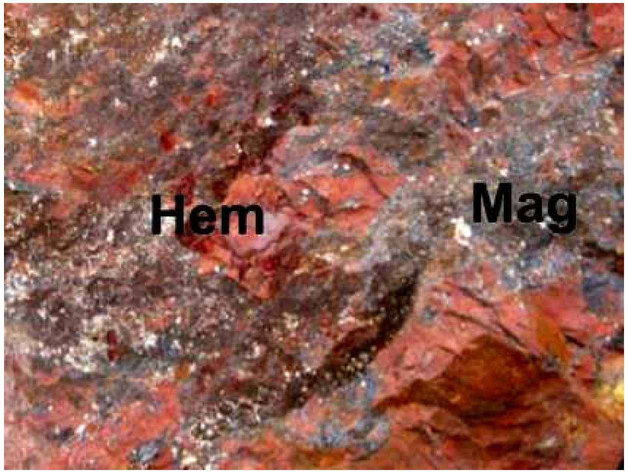
- Alteration mapping and chemical staining of rock slabs provide space-time relationships of alteration facies and mineralisation types at local to regional scale as well as a first order understanding of the chemical changes undergone by host rocks as alteration facies prograde, retrograde, cycle or are telescoped across mienral systems
- Whole rock geochemistry constrain chemical transformation of host rocks + metal associations for each alteration type



Albitites

Magnetite Fe, REE

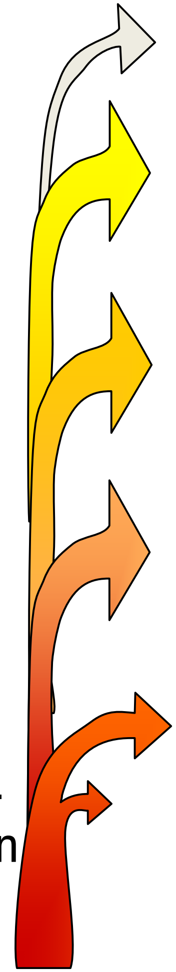
IOA



Iron oxides
Cu-sulphides
U-Th-Mo-REE

IOCG

Revisiting historic prospects based on alteration facies



Deposit types of historic prospects	Examples
Epithermal, vein-hosted	6 Si Crowfoot, Echo Bay, Breccia Is.
Hematite-bearing volcanic/breccia/ sedimentary-hosted mineralisation; Hematite-hosted U, ...	5 LT K-Fe Sue Dianne, Southern Breccia, Terra, K2, Brooke, Mile L., Breccia Is., Hottah
Skarns	4 Skarn Mile Lake, Grouard
Magnetite-bearing volcanic/breccia/ sedimentary-hosted mineralisation; Unusual metasedimentary rocks	3 HT K-Fe NICO, Cole Lk, Fab, De Vries, Hump, Ham, Terra, Echo Bay, Southern Breccia, Peanut, Port Radium (Great Bear)
Magnetite-bearing volcanic/ sediment/breccia/amphibolite/shear-hosted mineralisation; Iron formation	2 HT Ca-Fe **NICO, K2↓, Mag Hill, Port Radium,** Fab, JLD, Ron, Terra, Hottah, Grouard, Mar, Hump (Great Bear); Central Mineral Belt
Hornfel-hosted U; Na metasomatic U; metmorphic-metasomatic U	1 Na Echo Bay, Mile L., Terra, Fab, DeVries, South of NICO (Great Bear); Central Mineral Belt; Romanet Horst

IOAA-Epithermal continuum

Alteration facies	Prospects & sectors
6 Epithermal	Crowfoot, Echo Bay Gossan, Gossan Is., Hook Is.
5 LT K-Fe	Sue Dianne, Southern Bx, Terra, K2, Brooke, Mile, Hook Is., Hottah, Hoy
4 K felsite breccia	Mile, Birchtree, Echo Bay
K skarn	Mile, Grouard
3 HT K-Fe	NICO, Southern Bx, Cole, Fab, deVries, Hump, Ham, Terra, Echo Bay, Mar, Hoy, South Duke
2 HT Ca-Fe (+early skarns)	NICO, Mag **Hill, Port Radium**↓, **K2**↓, Fab, JLD, Ron, Terra, Hottah, Grouard, Cat, South Duke
1 Na	Echo Bay, Mile, Terra, Fab, deVries, Southern Bx, Nod, Hoy, Grouard, South Duke

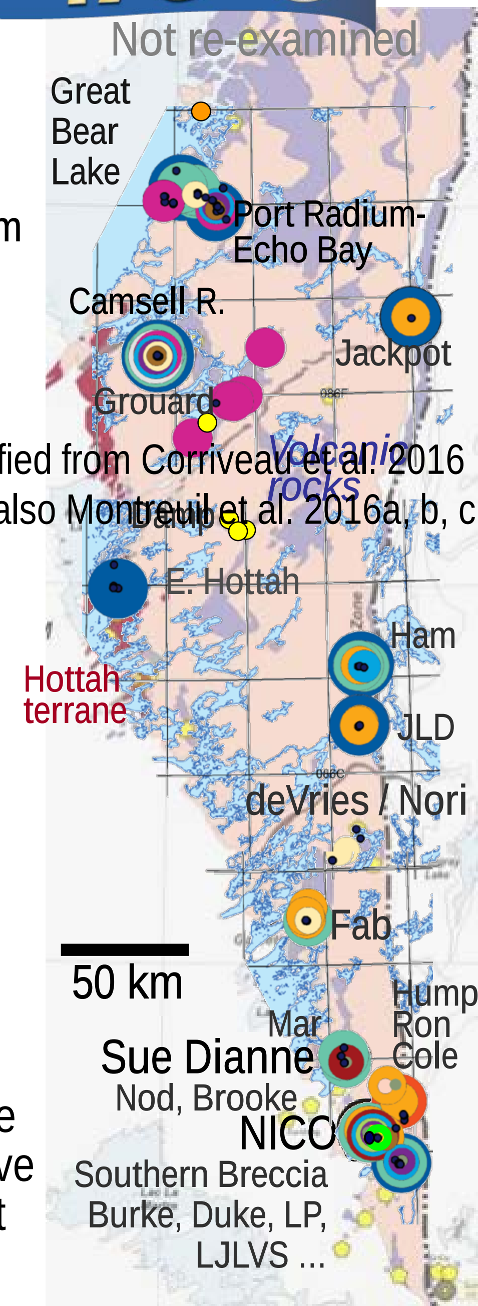
↓ drilling

Metals (ppm)

- Fe_2O_3>20 wt%
- WO_3>1000 ppm
- ThO_2>1000
- Au>0.5
- Ag>20
- V>1000
- Ni>2000
- Bi>1000
- Co>500
- Mo>500
- U_3O_8>300
- Zn>3000
- Pb>4000
- Cu>2000
- Ta>20
- TREE>2000

GSC representative hand samples above NORMIN grade cut off for 'showings'

Modified from Corriveau et al. 2016
See also Montreuil et al. 2016a, b, c



IOCG alteration-breccia-mineralisation model

Celebrating 175 yrs

Environment	Alteration facies	Targets & deposits
		Epithermal deposit (see Mumin et al. 2010)
Distal Low Temp. Shallower Later	5 *LT K-Fe*	**Hematite-group IOCG (Sue Dianne)** Targets: north and east of NICO, Terra, K2, Brooke, Mile, Hook Is., Hottah, Hoy, Duke, South Duke, Esther **Albitite-hosted U** Targets: Southern Breccia, Terra, Cole, Esther, Dennis
	4 *K felsite breccia* *Kskarn*	**Mineralised skarns in IOCGs** Prospects: Mile **Mag-to-Hem-group IOCG (Sue Dianne)** Targets: Brooke, Port Radium, Birtchtree,Terra
	3 *HT K-Fe*	**Magnetite-group IOCG (NICO)** Targets: NICO, Sue Dianne, Brooke, Cole, Fab, deVries, Hump, Ham, Terra, Echo Bay, Southern Breccia, Duke, Mar, LP 's, LJLVS, Esther **Albitite-hosted U** Targets: Southern Breccia, Terra, Cole, Esther, Dennis
	2 *HT Ca-Fe* *(skarn)*	**Specialised metals** **IOA magnetite-apatite** Prospects (at depth): Mag Hill, K2, Port Radium Targets: NICO at depth, Fab, Terra, Grouard, Duke, JLD, Ron, Hump, Carbonate Mountain, LP, LJLVS, Nod
Thermal core High Temp. Deeper Earlier	1 *Na albitite*	
	0 *Least-altered precursors*	

Corriveau et al. 2010b, 2016; Montreuil et al. 2015, 2016a, b, c

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Alteration facies model for IOA, IOCG and affiliated deposits

Alteration facies — Minerals in parageneses | **Molar proportions** — **Metal associations** | **Deposit types**

≤250°C

≤350°C

Steep thermal gradient

≤800°C

≤600°C

IOCG

IOA

5 LT K-Fe Ca-Mg-H^+-CO_2)
Hem-Kfs/Ser-Cb-Chl
sulphides + breccia

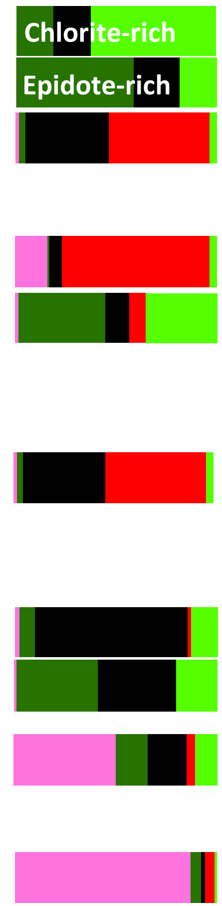
4 K-feldspar felsite breccia
Kfs
K skarn breccia (Kfs-Cpx-Grt+Suf)
over precursor with carbonates

3 HT K-Fe
Mag-Bt/Kfs-Suf + breccia

2 HT Ca-Fe
Amp-Mag±Ap
Skarn Cpx±Grt±Amp in carbonate rocks

1 Na albitite + high porosity
Ab-Scp

0 Least-altered precursors



Metal associations:

- Cu-Ag-U
- LREE-U-Cu-Bi-W-Mo
- Cu-Au-Ag-LREE-U
- Cu-Ag-U
- Cu-Ag-Au-Co-Bi/ Fe-REE-Y-U-Th (F)
- REE-Co-Ni (K-F)
- V-Fe-Th-W (P-Cl-F)
- Ta-Nb-Sn

Na | Ca | Fe | K | Mg

Geochemical analysis results (molar concentration)

Porphyry | Granite | Siltstone | Mafic dyke

Deposit types:

Epithermal deposit

Hematite-group IOCG
Cu-Au-Ag-REE-U-Pb-Zn-Mo-PGE …
Olympic Dam type
Albite-hosted U

Mineralised skarns in IOCG
Mag-to-Hem Group IOCG

Magnetite-group IOCG
Cu-Au-Co-Bi-…
Cloncurry (+Carajás) type
Albite-hosted U

Specialised metals

IOA magnetite-apatite
Fe, V, Th(?)
Kiruna type

Modified from Corriveau et al. 2016

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Alteration facies

6 LT Si, K, Al, Ba

5 LT K-Fe (H^+-CO_2)

4a K-felsite

4b K-skarn

3 HT K-Fe

2- 3 HT Ca-K-Fe

2 HT Ca-Fe

1-2 Skarn

1-2 HT Na-Ca-Fe

1-2 HT Na-Ca

1 Na

0 Host

Prograde
Retrograde
Cyclical
Telescoped

- **A petrological mapping tool**
- **A geological exploration tool**
- **A mean to unify ore systems with varied, even disparate, metal associations and deposit types and develop coherent exploration strategies**

Mineral Resources Development or on the importance of knowledge transfer and complementary studies of deposits (e.g., Australia) and regional-scale footprints (e.g., Great Bear magmatic zone Canada)


Cloncurry, Australia


Cloncurry, Australia


Ernest Henry mine

NRCan contributions to mineral resources development

Criteria, technologies, methodologies, baseline knowledge for mapping, mineral potential assessment, exploration, resources development, knowledge transfer

- Geological, petrologic, textural, structural, geochemical, mineralogical, mineral chemistry, isotopic, geophysical and metallogenic framework of mineral occurrences, systems, districts, provinces
- Holistic ore model highlighting metasomatic parameters and processes that control mineralisation and deposit types
- Structural and paleomagnetic record of tectonic control (uplift, exhumation, tilting) on alteration and mineralisation
- Potential sources of fluids and metals and metal traps
- Alteration mapping with field vectoring to ore capabilities
- Indicator mineral and till geochemistry tracers
- Remote-predictive-mapping ability
- 3D crustal to deposit-scale architecture
- >20 short courses (>600 registrants) + GAC short course notes 20 (>660 volume sold)

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Environmental stewardship – Paving the way for a geoscience foundation for environmentally responsible stewardship of geological resources

Baseline knowledge on bedrock and till geological, chemical and mineralogical environment within regional-scale IOAA footprints: impacts on natural metal distribution in soil, water, biomass

Geoscience undertakings can be environmentally sustainable through sound planning, rigorous health and safety measures, complying to all regulatory processes and earning a social license through collaboration

Canada has no IOCG mines yet, but Great Bear magmatic zone has mine tailings to study long-term weathering of IOCG wastes for environmental studies

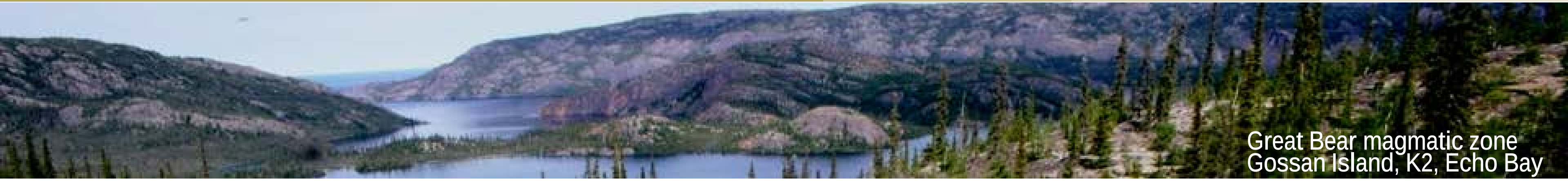
Importance of reassessing the metallogenic framework of:

- Disparate U, Au, Ag, Cu, Co, REE, Mo, PGE showings
- Former iron mines and prospects
- Kiruna-type mineralisation
- Alibitites
- Na-Ca-Fe alteration in under-explored territories

Some occurrences may lead to bona fide IOCG deposits, others may lead to affiliated deposit types, or deposits that form a continuum or are spatially associated with IOCGs and their host settings

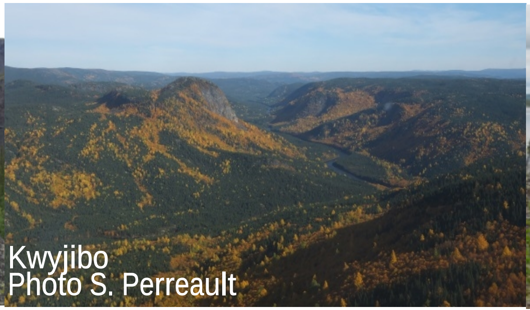
Persistence and partnership in mineral exploration, mapping and research are keys to mineral resources discoveries and development

IOCGs are perfectly suited to collaboration and transfer of knowledge between government, industry and academia and even between competing companies



Rationale of knowledge transfer

- **NRCan programs (GEM, TGI): New geological and geophysical exploration criteria, technologies, methodologies and reference case studies**
- **Superb 3D exposures of iron-oxide and alkali±calcic alteration ore systems from 3-10 km depth to epithermal caps from the Great Bear magmatic zone**
- **Alteration mapping genetically links IOCG, IOA, skarn, albitite-hosted U and mantos mineralisation types**
- **Alteration facies prograde to distinct metal associations** (base, precious, specialised metals including for nuclear energy, green energy technology and geothermal energy)
- **No subsequent orogenesis; very limited post IOAA systems remobilisation** (restricted to batholith emplacement, mafic dykes haloes and transcurrent faults)



Hildebrand 1986; Mumin et al. 2007, 2010; Corriveau et al. 2010a, b, 2011, 2016; Montreuil et al. 2013, 2015, 2016a, b, c; Potter et al. 2013

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South Wopmay Bedrock Mapping project participants and managers
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Fortune Minerals, Alberta Star, Diamonds North, Honey Badger Exploration, Energizers, Aurora Geosciences, Richmond Minerals
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Task-sharing agreements: RNCan-Fortune Minerals, RNCan-Honey Badger Exploration-Energizer Resources, RNCan-Community Government of Gamètì

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Additional information in
Geological Association of Canada Short Course Notes 20

Exploring for Iron Oxide Copper-Gold Deposits Canada and Global Analogues

Chapter 1 - Exploring for iron oxide copper-gold (Ag-Bi-Co-U) deposits – the need for case studies, classifications and exploration vectors, Louise Corriveau, Hamid Mumin

Chapter 2 - Classifying IOCG deposits, Patrick J. Williams

Chapter 3 - "Magnetite-group" IOCGs with special reference to Cloncurry and Northern Sweden: settings, alteration, deposit characteristics, fluid sources, and their relationship to apatite-rich iron ores, Patrick J. Williams

Chapter 4 - "Hematite-group" IOCG±U ore systems: tectonic settings, hydrothermal characteristics, and Cu-Au and U mineralising processes, Roger Skirrow

Chapter 5 - The IOCG-porphyry-epithermal continuum of deposits types in the Great Bear Magmatic Zone, Northwest Territories, Canada, Hamid Mumin, A.K. Somarin, B. Jones, L. Corriveau, L. Ootes, J. Camier

Additional information in GAC Short Course Notes 20

Chapter 6 - Use of breccias in IOCG(U) exploration, *Michel Jébrak*

Chapter 7 - Alteration Vectors to IOCG mineralization – from uncharted terranes to deposits, *Louise Corriveau, Patrick Williams, Hamid Mumin*

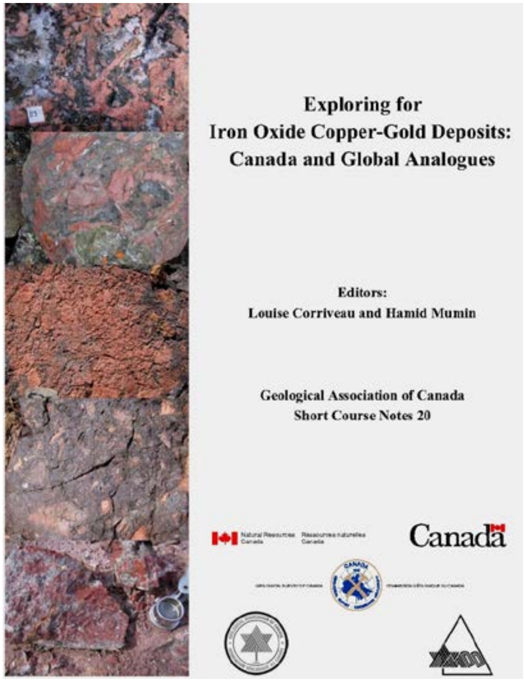
Chapter 8 - Iron oxides trace element fingerprinting of mineral deposit type, *Georges Beaudoin, Céline Dupuis*

Chapter 9 - Alterations in IOCG-type and related deposits in the Manitou Lake area, eastern Grenville Province, Québec, *Tom Clark, André Gobeil, Serge Chevé*

Chapter 10 - Lower Cambrian iron oxide-apatite-ree (u) deposits of the Bafq District, east-central Iran, *Farahnaz Daliran, Heinz-Günther Stosch, Patrick Williams*

Chapter 11 - Iron oxide-copper-gold mineralization in the Greater Lufilian Arc, Africa, *Alberto Lobo-Guerrero S.*

Chapter 12 - Alteration processes and impacts on regional-scale element mobility and geochronology, Tamlalt-Menhouhou deposit, Morocco, *Ewan Pelleter, Dominique Gasquet, Alain Cheilletz, Abdellah Mouttaqi*



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