THE UNIVERSITY OF QUEENSLAND AUSTRALIA

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DEEP MINING QUEENSLAND (DMQ) PROJECT [2015-2017]

Prospectivity for deep, mineable Cu-Au deposits in the Cloncurry district, Queensland.

Project Completion Forum – Tuesday May 16th, 2017; 8:30am – 12:30pm,
University of Qld, St Lucia, Sir James Foots Bldg 47a (SMI), Level 4 seminar room

Discussions and presentations to include:

- New insights into the litho-stratigraphic architecture of the Cloncurry region
- Geologically constrained gravity inversion applied to subsurface geological modelling
- Deposit controls: district to local scale
- Prospectivity analysis: expert-informed process utilizing 3D geology inputs
- Methodology and tool for early-stage prospect economic evaluation

Please register your interest in attending this **FREE** event by emailing: Dr Travis Murphy (travis.murphy@uq.edu.au).
For more information about DMQ, see: https://brc.uq.edu.au/project/brc-deep-mining-queensland

Project Sponsors:

Queensland Government
Department of Natural Resources and Mines

Geological Survey of Queensland

chinova resources

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DMQ Wrap-up – May 2017

Introduction

Brisbane, Queensland

16th May, 2017

The University of Queensland
Australia

Support

The Deep Mining Queensland (DMQ) project, a 2 year project commencing in April 2015, is part of the Queensland State Government's investment in priority geoscience projects identified by the mining and petroleum industries. This initiative is part of the Geological Survey of Queensland's (GSQ) Future Resources Program.

The DMQ project represents a wholistic approach to resource prospectivity, from discovery through to an assessment of 'mineability', and will focus on the highly endowed Cloncurry Cu-Au district from Cloncurry township to south of the Osborne mine (totalling 8,743km2).

Sponsored by: Queensland Government, Department of Natural Resources and Mines — Geological Survey of Queensland

In-kind support: chinova resources

Software & data processing: DATAMINE, Fullagar Geophysics, HiSeis

DMQ Project Team

Dr Travis Murphy (Exploration and Mine Geology)

Dr Mark Hinman (Exploration and Mine Geology)

Dr Mark Pirlo (Exploration Geochemistry)

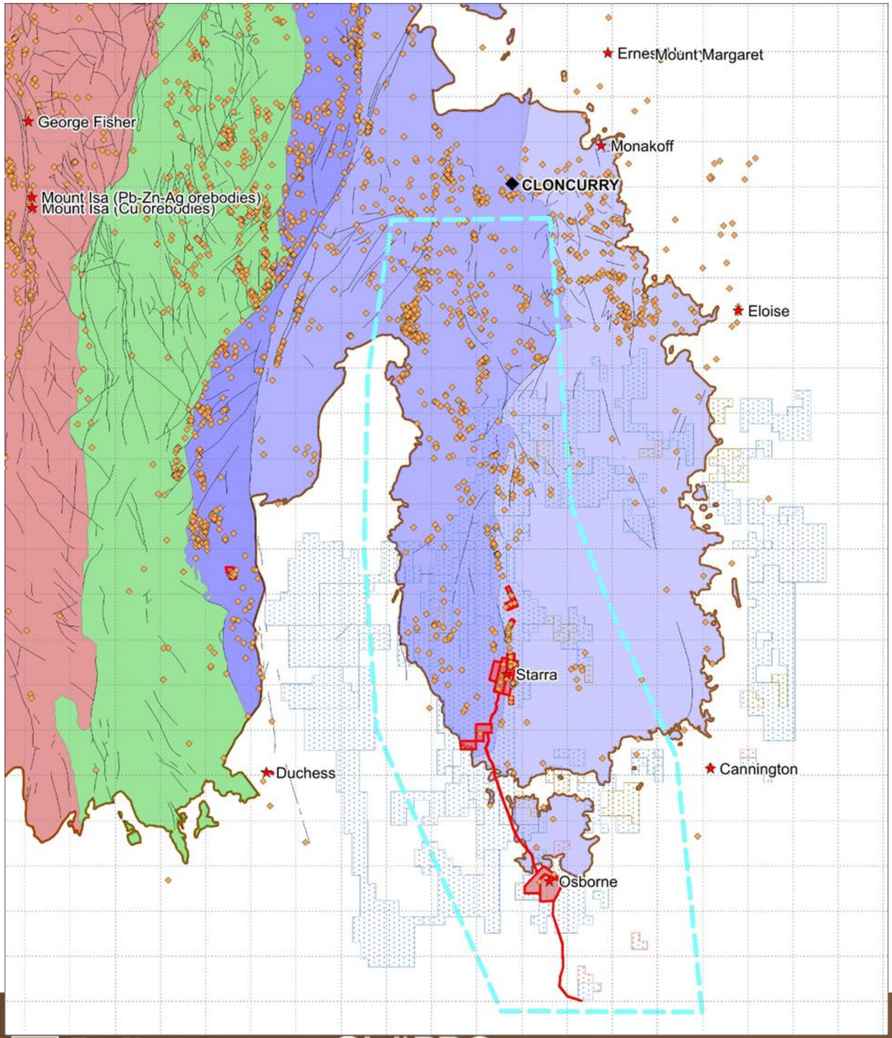
John Donohue (Exploration Geophysics)

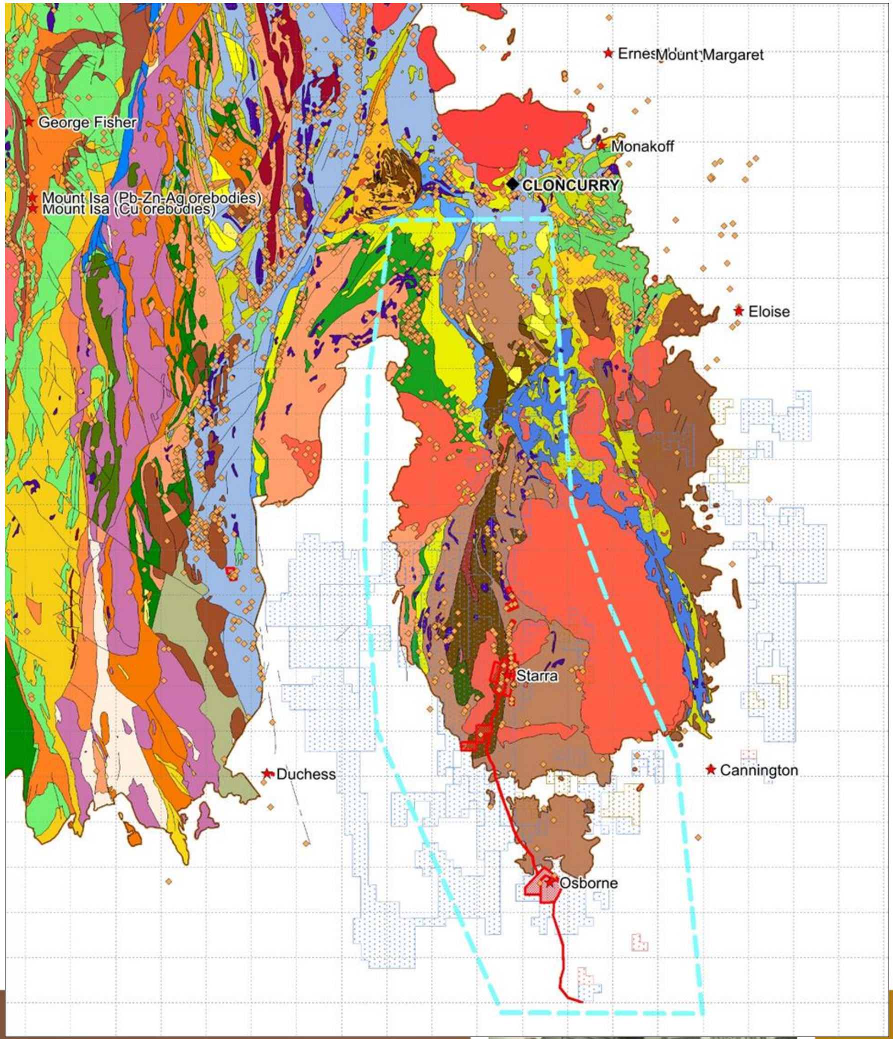
Prof. Rick Valenta (Exploration and Mine Geology)

Adrian Pratt (Mining Engineering)

Mark Jones (Database support)

DMQ1: Cloncurry-focussed project





Deep Mining Queensland (DMQ) Project

Deep exploration is an industry area of focus given depletion of shallow resources and the likely/predicted mineral endowment under-cover adjacent to mature mining fields.

The DMQ project aims to reduce the risk profile of exploring at depth in the Cloncurry field by identifying tracts of ground, through enhanced understanding of the mineral systems architecture, which are:

- **Prospective for deep, large and/or high-value deposits (of IOCG affinity), and**
- **Are amenable to cost-effective extraction.**

The research draws on local expertise in the BRC with respect to mass-mining methods and the qualitative assessment of geological impacts on mass-mining design and operation.

Project Aims (1)

The main aims of the project are as follows:

1.Through review of IOCG provinces both in Australia and globally, characterise:

(a) the key structural-tectonic, stratigraphic, magmatic and fluid systematic conditions affecting deposit formation, and

(b) geophysical and geochemical responses of known deposits, with the intention of building controls and parameters for prospectivity analysis.

(c) IOCG deposit associations as an indicator to what other styles of mineralization may be possible in the Cloncurry district.

Project Aims (2)

2. Where more detailed geological data has become available, validate/update the district-scale 3D geological modelling of the project area.

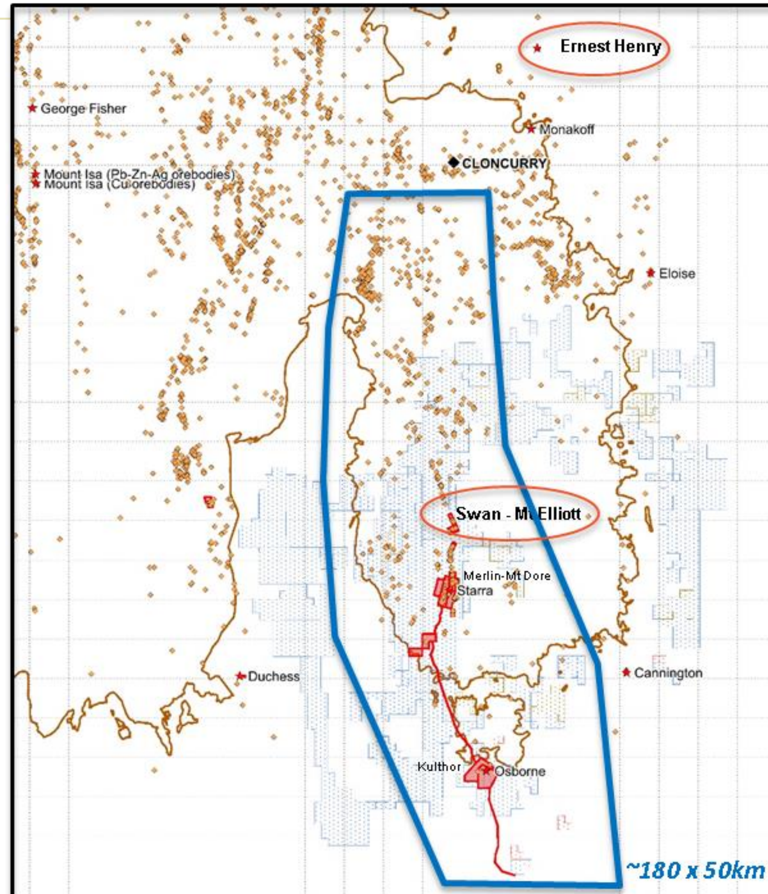
   This would focus on district-scale resolution of intrusive geometries at depth and hitherto-little-emphasised structural controls and geometries that may have influenced fluid systematics at the time of IOCG mineralisation. This information will be used to build a cohesive understanding of the geological controls on Cu-Au mineralization at the deposit/shoot scale.

Project Aims (3)

3. Engineering scenarios will be undertaken, constrained by knowledge of the geotechnical properties of the host-rocks in the area, stress conditions, geothermal gradient, 'mineability', mining options available etc, to determine what size/footprint of deposit is required by depth; to sustain a deep mass-mineable operation in the area.

Mining Informed Targeting/Prospectivity

- The research project is centred on part of the Eastern Fold Belt encompassing the Osborne-Kulthor Cu-Au mine, Starra line of Au-Cu deposits and mines, Mt Dore Cu deposit, Merlin Mo deposit, Mt Elliott Cu-Au complex (SWAN, Domain 81, Corbould, Mt Elliott) and numerous historic mining operations and prospects.
  - District with multiple Cu-Au mines, lots of smoke, yet only one large mass-mineable deposit (Ernest Henry), and a large prospective resource (SWAN – *Mt Elliott*).
- What are the prospects for discovery of additional mass-mineable deposits if we deepen the search space to 2km below surface?.....and what would a mineable deposit need to look like at this depth?

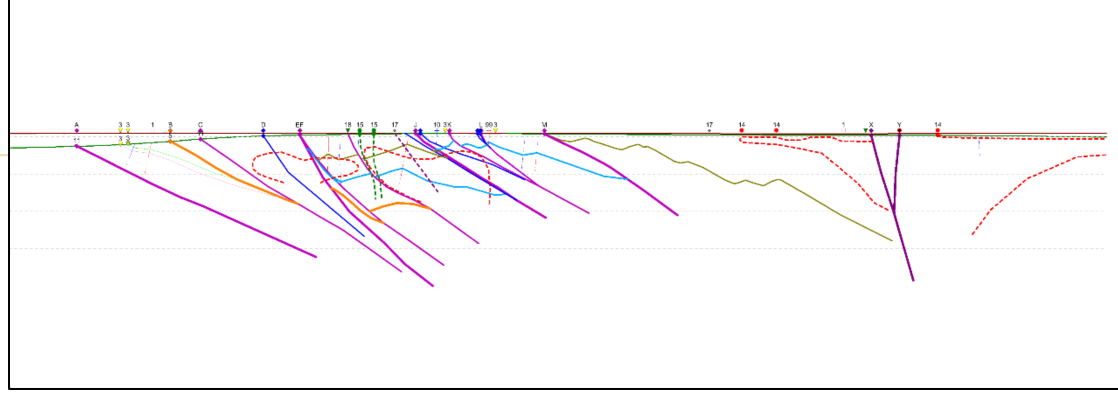


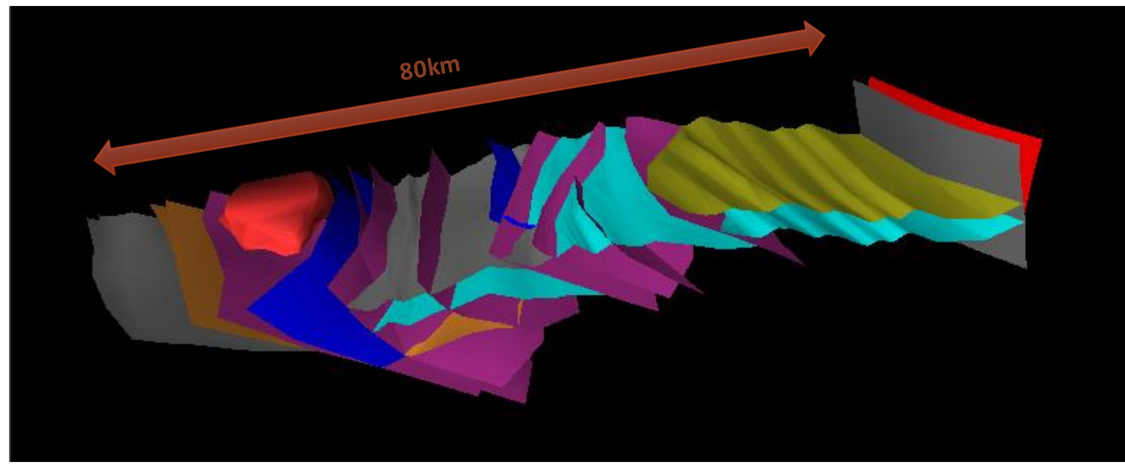
	Mt	Cu (%)	Au (g/t)
Ernest Henry[1]	220	1.1	0.5
Swan[2]	375	0.44	0.25

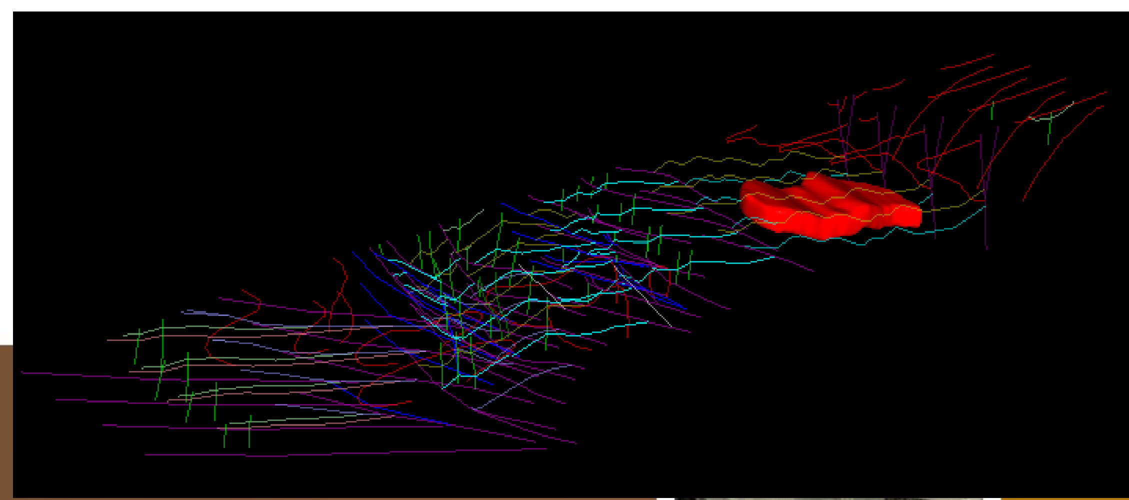
[1] Glencore Reserves & Resources, 2014 [2] AMC – Mt Elliott Scoping Study, 2012

DMQ aims to reduce the risk of deep exploration in the Cloncurry Cu-Au district through:

- Detailed geological understanding, informed by comprehensive analysis of geological, geophysical and geochemical datasets
- Considered interpretation of the controls on known orebody location, geometry, and tenor
- Insights into economic viability as affected by variations in deposit size, geometry, grade, depth, and proximity to transport and services infrastructure.







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DMQ – summary of activities

- Synthesis and interpretation of government and Chinova datasets
- Updated solid geology interpretation
- Detailed 4D tectonostratigraphic interpretation based on solid geology
  - 47 4km-spaced sections
  - 3D surfaces for structures and key stratigraphic boundaries
- Updated model of granite geometries in the region
  - Qualitative interpretation of gravity data
  - Geologically-informed gravity inversion modelling of intrusive geometries
- Analysis of geochemical datasets
  - Assessment of potential methods for exploration under cover
- Consideration of grade and depth constraints for (deep) underground mining
  - Target and prospect evaluation tool…..for geologists
- Analysis of existing mineralization in light of new model
  - Key process criteria for localization of mineralized systems
- Propagation of those criteria to search for new targets in the district model

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DMQ Wrap-up – May 2017

Global IOCG review

May, Queensland
16th May, 2017

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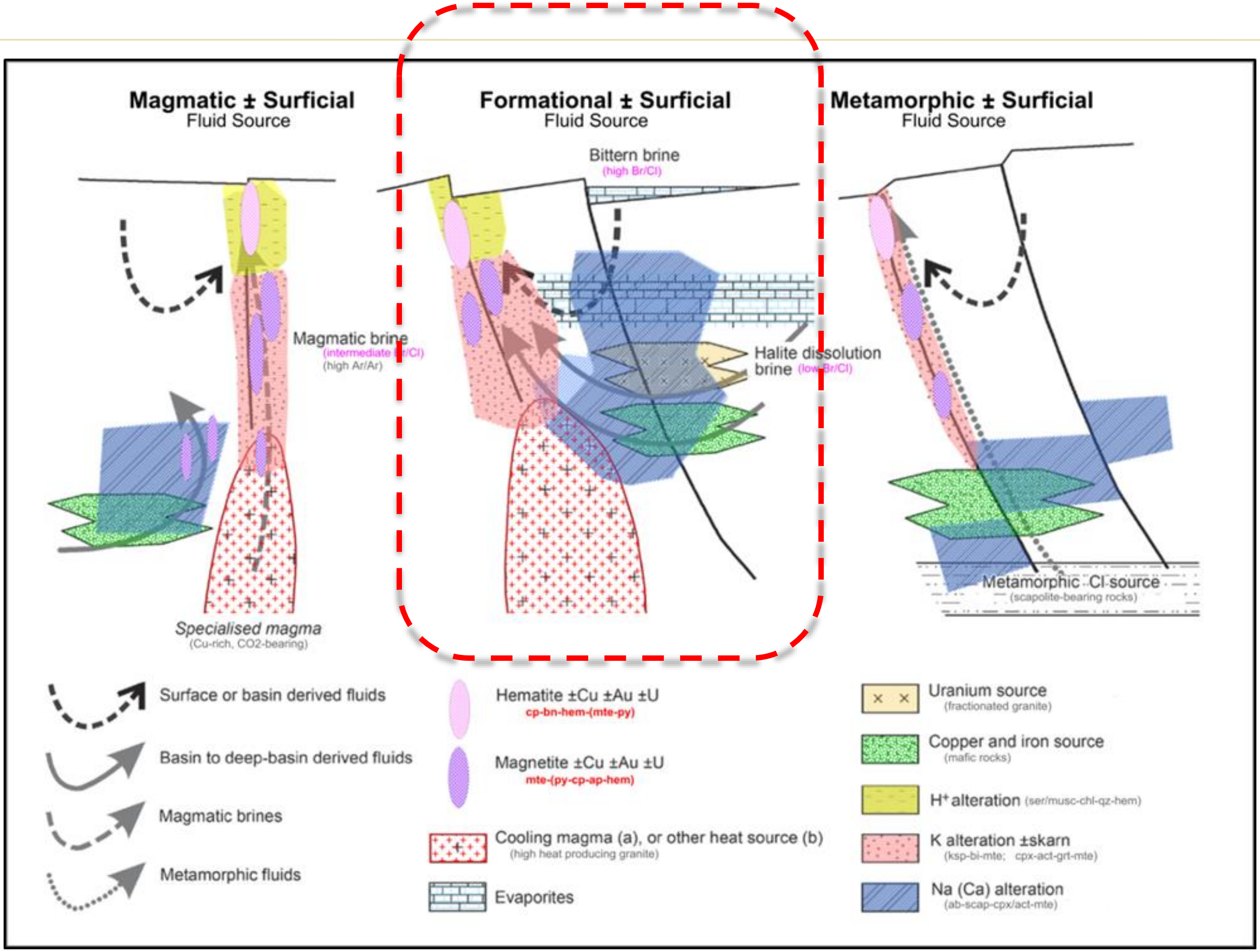
DMQ: Cloncurry-focussed project

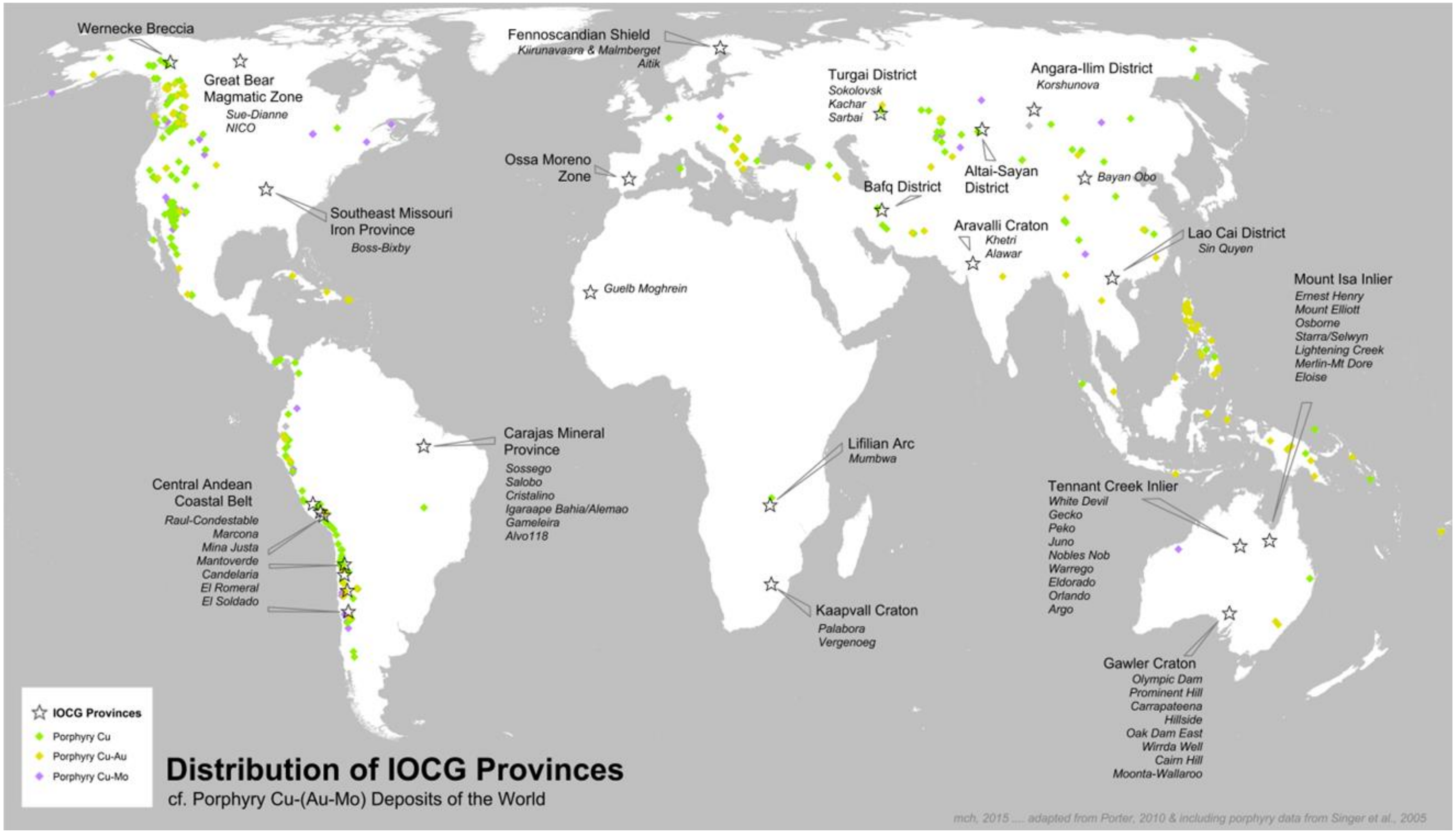
The generally-agreed, empirical/geochemical, uniting characteristics of the IOCG family are (Barton & Johnson, 1996, 2004, 2015; Hitzman, 1992, 2000; Williams et al., 2005; Porter, 2010):

- abundant, low-Ti, Fe-oxides: magnetite and/or hematite,
- Cu ± Au at economic grades
- a distinctive suite of minor elements: (differing mixes of) Ag, REE, U, Mo, F, P, Ni, As, Co, & Ba
- an association with extensive & pervasive alkali alteration – both sodic-calcic, Na-(Ca) and potassic, K
- formed in shallow crustal environments, in brittle regimes (in the 2-12km depth range)
- prominent structural ± lithological control
- most commonly coeval, but (usually) not proximal to magmatism (in the form of plutons & batholithic complexes)
- common district association with Cu-Au-barren, Fe-oxide deposits



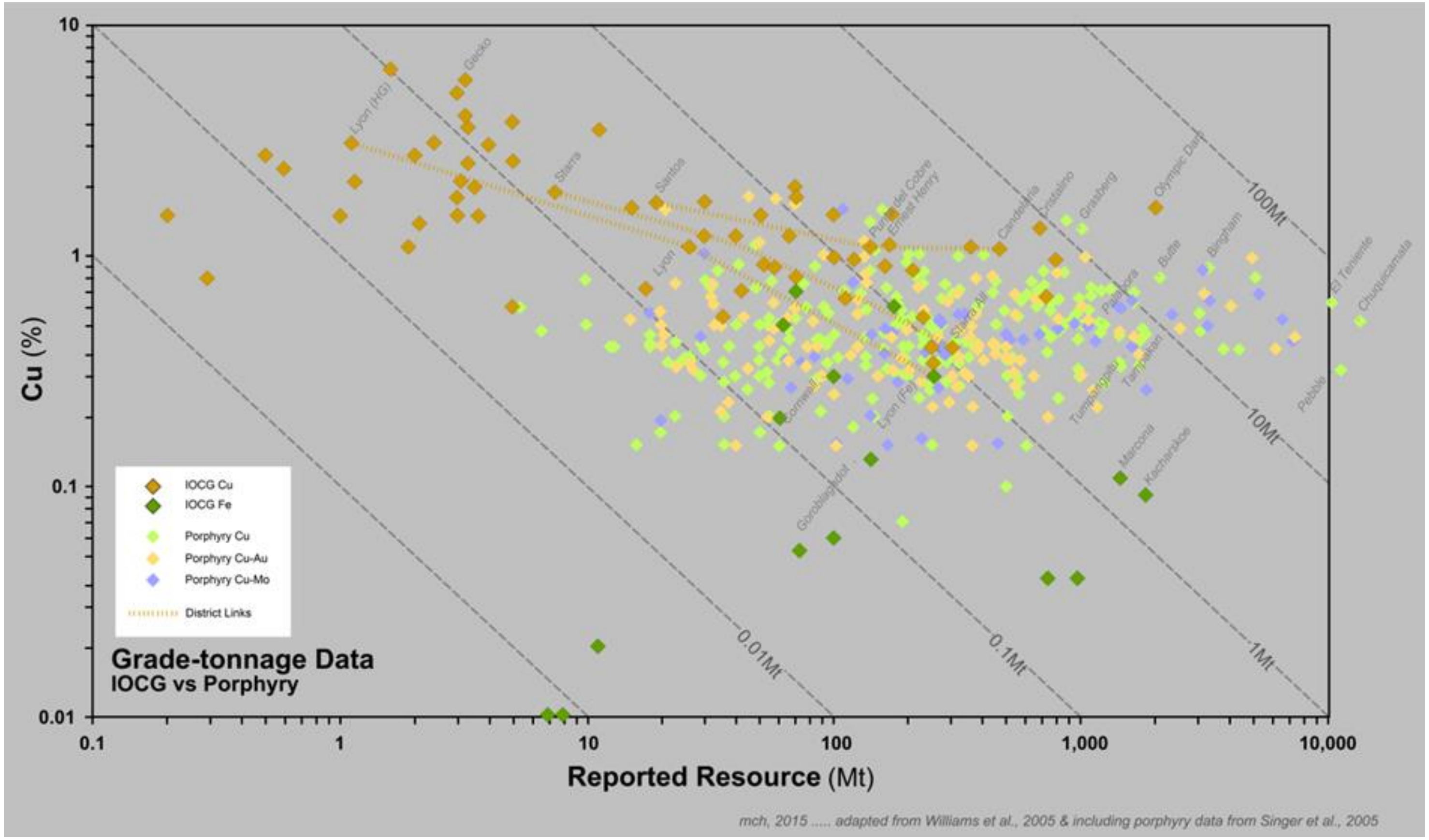
Schematic end-member models of IOCG formation highlighting the diverse range of fluid system permutations. Figure originally produced by Barton & Johnson (2004) and subsequently modified by Williams et al. (2005) and Williams et al. (2010) incorporating source rock concepts of Hayes et al. (1995), Williams (1994) and Hitzman & Valenta (2005).

IOCG Provinces - Worldwide



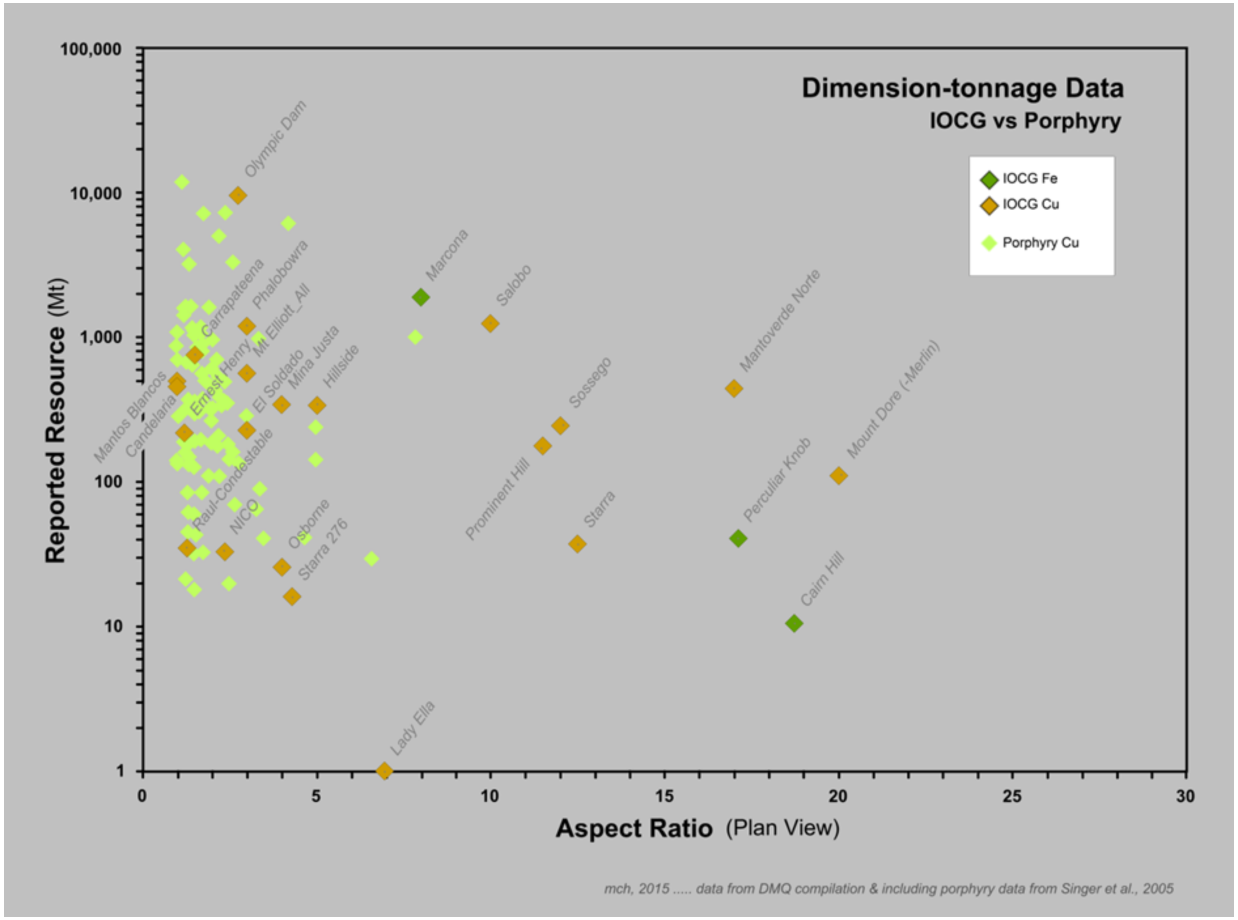
Distribution of global IOCG provinces. Figure adapted from Porter (2010) and includes data from Singer et al. (2005). Note the coincidence of IOCG province with Andean porphyry Cu belts and absence of IOCG deposits in other porphyry belts.

IOCG vs Porphyry: Resource Size & Grade



Grade-tonnage data for IOCG deposits compared to porphyry Cu deposits. Figure adapted from Williams et al. (2005) and includes data from Singer et al. (2005). Tie lines connect deposits within a single district and highlight the spread of deposit tonnages developed within districts.

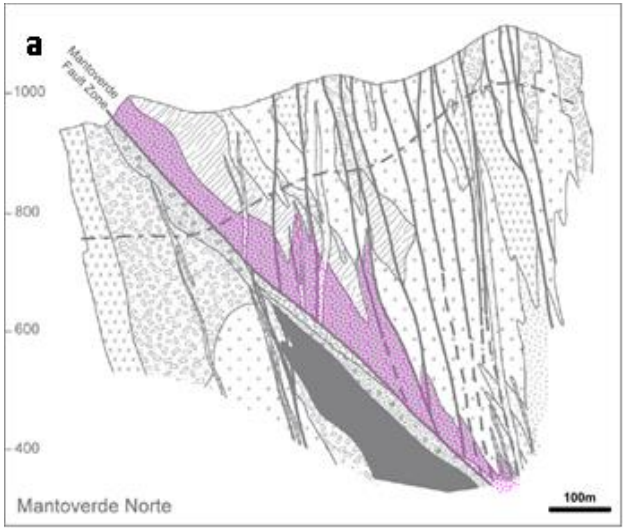
IOCG vs Porphyry: Resource Size & Geometry

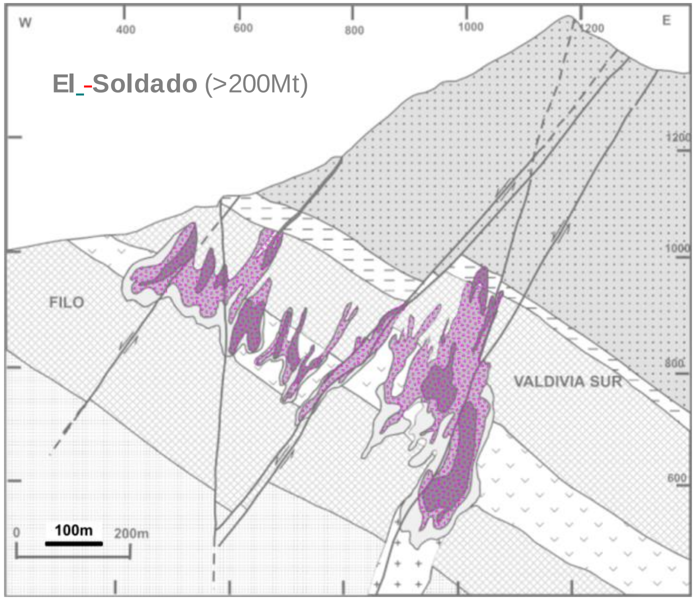


Plan View Aspect Ratios for IOCG deposits compared with porphyry Cu deposits. IOCG data from DMQ compilation and porphyry data from Singer et al. (2005).

Structural Control

Deposits with high degrees of structural control (and lesser lithological control) can tend to be highly planar. At Mantoverde Norte (440Mt), ore is hosted in breccias directly associated with the Mantoverde Fault Zone (Reiger et al., 2010a, 2010b) and the ore body has a high degree of planarity.





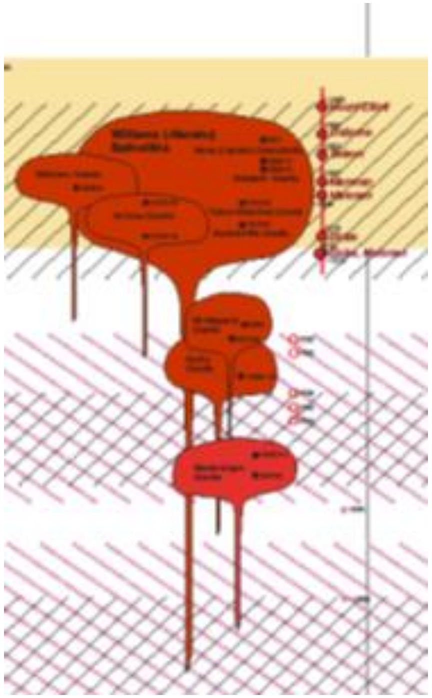
In many IOCG deposits replacement is a stronger control on orebody geometry. At El Soldado (>200Mt), ore is most strongly developed within a particular rhyodacite unit where it is intersected by identified fluid feeder structures (Boric et al, 2002). Ore is in lobate 'cigar-shaped' bodies lying along the intersection of variably-striking, steep structures with the dipping, receptive lithology.

Very commonly a 'late', brittle reactivation of pre-existing ductile structures is implicated in mineralisation.

Magmatism & Alteration

- The broad synchronicity of crustal magmatism with IOCG formation has been highlighted by many researchers in numerous review papers: Hitzman (1992, 2000), Williams et al. (2005), Porter (2010), Barton & Johnson (2004, 2015).

- Alteration systems associated with 'IOCG' systems are regional in extent (10 to >1000sqkm) and have been interpreted to extend to at least mid-crustal depths (Haywood & Skirrrow, 2010; Porter, 2010). These characteristics demonstrate the lithospheric scale of the 'IOCG' magmato-fluid systems, focussed by intrusion geometry and pre-existing and re-activating crustal architectures.



Early Sodic-Calcic Alteration

Commonly the earliest, pre-mineralisation fluid circulation and alteration is broadest and deepest in extent and is characterised by sodic-calcic±iron alteration. It is hypothesised to involve deep circulation of high salinity fluids which have been shown (and modelled) to scavenge solutes and metals from rocks they alter (Oliver et al., 20014). Precise timing constraints on early Na-Ca alteration with respect to magmatism is scant, but this 'early' alteration is commonly assumed to temporally overlap with, and be driven by, the spatially associated phases of intrusive magmatism.

Alteration Minerals: albite-scapolite-quartz-(magnetite-actinolite)

Later Potassic-Iron Alteration

Whether systems smoothly evolve from the Na-Ca phase to ore-forming, or are catastrophically driven into the ore-forming phase, remains unclear but the latter seems more probable due to their generally-strong structural control. Notwithstanding, at the time of Cu-Au mineralisation, fluid systems become significantly more focussed and evolve towards strongly potassic alteration with major accompanying iron oxides. Assemblages show variable proportions of potassium, iron and calcium minerals dependant on fluids and host rock compositions.

Alteration Minerals (K-rich): biotite-K feldspar-magnetite

Alteration Minerals (Fe, Ca-rich): magnetite-K feldspar-(actinolite-carbonate-apatite)

IOCG + ISCG = Cloncurry Cu-Au

- In reduced hosts, with significant reduced sulphur availability, iron oxides may not be developed at all and ore assemblages may comprise chalcopyrite-pyrrhotite-pyrite. The coexistence of this style of iron oxide-free, Fe sulphide-rich deposits in districts also containing iron oxide-rich IOCGs (eg. Cloncurry Belt) has resulted in the coining of the acronym 'ISCG' for Iron Sulphide Copper Gold. The very close proximity of ISCG and IOCG systems and their similar timing and kinematic control attests to their familial genetic linkage.

- At the other extreme, pre-existing iron-oxide formations (Mte-IF and/or Hem-IF), some of early syn-sedimentary origin, present more oxidised host conditions to the mineralising fluid (eg Osborne, Starra) and result in more typical IOCG assemblages.

Essential Ingredients

A number of critical features of IOCG systems are becoming clearer (Williams et al., 2010) and should influence robust targeting and prospectivity analysis:

1. The primary **fluid systems are regional in scale**, are high temperature and have extreme metal-scavenging capacity (ie hypersaline).

2. **Cool, oxidised, surficial fluids have interacted with the more deeply-sourced, high temperature hypersaline fluids** to produce high grade ore in many deposits. Alteration mineral assemblages and oxide/sulphide mixes can be highly variable and their diversity needs to be appreciated in geochemical and geophysical exploration planning.

3. Deeper systems may not manifest cool, surficial fluid interaction and will present different alteration and ore assemblages. **Some but not all deeper systems do exhibit geochemical evidence of magmatic input** but only rare examples (of the handful of well-studied deposits) display dominantly magmatic input.

4. **Hypersaline IOCG ore fluids demonstrate a significant contribution from evaporitic sources**; either surficial (bitterns, drawn down into circulation), formational (in the path of circulation) or metamorphic (also in path of circulation, or via metamorphic release).