Cu-Au mineralisation of the Cloncurry district: Recognising diversity within a mineralised province

Presented by: Glen Little
Mt Isa Inlier - World Class Base Metals Province

- Giant Cu deposit at Mount Isa
- Giant Pb-Zn-Ag deposits at:
  - Century
  - Mount Isa (Mt Isa, Hilton, George Fisher)
  - Cannington
- Very large Cu-Au deposit at Ernest Henry
- Modest sized Cu (-Au) deposits at:
  - Osborne
  - Starra
  - Mt Elliott/SWAN
  - Mt Gordon (Gunpowder)
  - Eloise
  - Jericho
  - Rocklands
  - Little Eva
  - Mt Dore
- Modest sized Pb-Zn-Ag deposits at:
  - Dugald River
  - Lady Loretta
  - Maronan
Cloncurry District – regional geology

Eastern Fold Belt

- 3 main periods of volcanosedimentary accumulation
  - 1890-1850Ma
  - 1800-1750Ma (Cover Sequence 2)
  - 1680-1610Ma (Cover Sequence 3)

- Main deformation phase (Isan Orogeny) commenced around ~1600Ma and ceased ~1500Ma

- Metamorphic grade greenschist to near granulite
  - peak m/m 1600-1590Ma (D2)
  - produced N-S trending sub-vertical penetrative fabric
  - transition from ductile – brittle deformation 1550-1500Ma

- Major magmatic event 1550-1510Ma with intrusion of Williams-Naraku felsic plutons
2 main periods of mineralisation

- First phase was Pb-Zn-Ag mineralisation during deposition of Cover Sequence 3 between 1675-1650Ma
  - Still plenty of debate on timing of this event
- Second phase was primarily Cu-Au mineralisation
  - Most Cu-Au mineralisation occurred late Isan Orogeny during transition from ductile – brittle deformation (1550-1500Ma?)
  - Still plenty of debate on timing of this event that could be pushed out to 1590Ma??
Cloncurry District – regional mineralisation

**Cu-Au mineralisation**

- Host rocks greenschist to granulite facies metamorphism (m/m grade generally increases north to south)
- Host rock types highly variable
- Lots of mafic intrusives (mostly sills/dykes) of variable age
- Major magmatic event 1550-1510Ma with intrusion of Williams-Naraku felsic plutons
- Regional-scale Na, Na-Ca, and Ca-Fe hydrothermal alteration with similar age to Williams-Naraku plutons
- Typically a lack of Pb-Zn in the Cu-Au deposits, BUT, not ubiquitous
- Magnetite very common, BUT, not ubiquitous
- Pyrrhotite common, with or without magnetite, not well documented
- Some Cu-Au systems have no magnetite or pyrrhotite
Cu-Au mineralisation...........continued

- Mineralisation characteristics different for each main deposit, e.g.
  - Host rocks include intermediate volcanic, mafic igneous, carbonate, pelite, shale, psammite, ironstone
  - Association with magnetite, association with pyrrhotite, association with both
  - Highly variable Cu:Au ratios
  - Potassic alteration
  - Skarn-like alteration
  - Silica flooding
  - Mafic alteration
  - Breccia-hosted shear-related replacement

- Mineralisation commonly thought to be all relatively late and structurally controlled......there are certainly favourable localities at the camp scale
  - Mt Dore Fault Zone (Starr, Mt Dore, Mt Elliott, SWAN)
  - Levuka Shear Zone (Eloise, Jericho)
  - Mt Rosebee corridor (Little Eva, Blackard)
  - Pilgrim Fault Zone (Tick Hill, Kalman)

- No two Cu-Au deposits are the same.........but there are some themes
Olympic Dam Domain “Clones”

Olympic Dam
Prominent Hill
Carrapateena
Oak Dam West

Yes the same

Image from K. Ehrig SAEMC 2015
Image courtesy OZ Minerals
Image courtesy OZ Minerals
Cloncurry is more a mixed bag

- Variety appears the theme
- Despite the variety there is some commonality (next slide)
- Some varieties more prized than others
  - South Australian style hematite IOCG’s do not appear to be present
  - Iron oxides still very important in Cloncurry but the flavour is magnetite-dominant
  - Pyrrhotite becoming progressively more important but not as well documented
  - Copper (+/- gold) with no iron oxide or pyrrhotite is common but to date these are the ones left wanting
The Cloncurry spectrum

Spectrum of deposit styles but appears to be 3 main groups

1. Magnetite (+/- hematite) occurrences:
   - Mid-range average Cu grade
   - Highest average tonnage
   - Most number of deposits developed into mines

2. Pyrrhotite (+/- magnetite) occurrences:
   - Highest average Cu grade
   - Lowest average tonnage

3. No magnetite-hematite-pyrrhotite occurrences:
   - Lowest average Cu and Au grades
   - Only 2 mines developed (historic)

<table>
<thead>
<tr>
<th>Deposit</th>
<th>Mt</th>
<th>Cu %</th>
<th>Au g/t</th>
<th>Cu:Au ratio</th>
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Average based on table to right
Deposit Examples: Starra Cu-Au deposit

- Mined: 11.4Mt @ 2.1% Cu and 3.2g/t Au (Global resource 254Mt @ 0.34% Cu, 0.48g/t Au)

- Key Features:
  - IOCG style mineralisation (magnetite-hematite)
  - Cu% - Au g/t ratio 1:1.5
  - High magnetite content with substantial hematite
  - Outcrops as a continuous ironstone ridge within the 500m-wide, +10km long Starra Shear
  - 5 main (discrete) orebodies 222, 244, 251, 257, 276
  - Hosted in lower to upper greenschist metamorphic rocks
  - Host rocks are quartz-magnetite ironstone, magnetite-chlorite/biotite-bearing schists and interbedded calcareous meta-siltstones and arenite
  - Alteration
    - Early – alb-qtz-act-scaphite
    - Mid – mgt-hem-bt-qtz-py
    - Mineralisation – qtz-ahy-cal-hem with py-cpy-bn-cc-native gold

Image: Northwest Qld Mineral Province Deposit Atlas
Deposit Examples: Starra Cu-Au deposit

Interbedded calcareous siltstone and sandstone

Strongly deformed hem-albite altered host with multiple generations of magnetite with late cpy

Strongly deformed chlorite altered host with magnetite with late shear/extensional cpy-filled veins

Strongly Na-Ca-K altered breccia with coarse magnetite and cpy-fracture-fill

Images: Duncan et al. (2014)
Deposit Examples: Starra Cu-Au deposit

- **Discovery History**
  - Exploration may date back to 1956 (not well documented)
  - Ironstone outcrops along a ridge for several km of strike
  - Extensive mapping and rock chip sampling conducted by Anaconda in late 1960’s. Several drill holes completed early 1970’s by Newmont at 244.
  - Between 1978 – 1988 Cyprus drilled 314 airtrac holes, 80 RC holes, 29 percussion holes, 259DD holes
  - Commenced mining 1988
  - Starra line is a discrete arcuate intense magnetic anomaly
  - Implications for later exploration in areas under cover (linked to Ernest Henry discovery)

Images: Northwest Qld Mineral Province Deposit Atlas
Deposit Examples: Ernest Henry Cu-Au deposit

- Pre-mining resource: 166 Mt @1.1% Cu, 0.54 g/t Au

- Key Features:
  - IOCG style mineralisation (magnetite+/−hematite)
  - Cu% - Au g/t ratio 2:1
  - Cu-Au mineralisation has strong As-Mo-U-F-Ba-Mn enrichment
  - Strong potassic alteration as precursor to mineralisation (K-feldspar & biotite)
  - High magnetite content developed in very discrete breccia pipe
  - Lots of carbonate veining/breccia fill in late stages of mineralisation
  - Carbonate vein mineralogy zoned outward – key for vectoring toward mineralisation
  - Hosted in intermediate volcanic unit – this rock type rarely seen in district
Deposit Examples: Ernest Henry Cu-Au deposit

Legend:
- High Grade (>1% Cu) Matrix Supported Breccia
- Medium Grade (0.5%-1.0% Cu) Clast Supported Breccia/Sulphide Veining
- Low Grade (0.3%-0.5% Cu), dominated by crackle veining and clast supported brecciation
- "Red Rock" Altered Felsic to Intermediate Volcanics
- Undifferentiated Meta-volcanics
- Marble Matrix Breccia (Dolomite)
- Shear Zone
- Diorite

High-grade, magnetite-rich Cu-Au ore (central breccia)

Low-grade Cu-Au halo with characteristic carbonate veined/filled crackle breccia

Images: Northwest Qld Mineral Province Deposit Atlas
• **Discovery History**

  • WMC targeted Starra style ironstone-hosted Cu-Au mineralisation under cover

  • Numerous magnetic anomalies were identified and given a number – Ernest Henry was FC5 which had maximum 12,000nT response

  • 1991 ground TEM conducted over FC5 produced discrete EM conductor (under 60m of cover)

  • Magnetic/EM target drilled October 1991 intersected supergene copper zone (source of EM conductor) returning:
    • 7.1m @ 4.95% Cu, 0.8g/t Au from 97.35m

    And primary sulphide intercept of

    • 114.2m @ 1.75% Cu, 0.9g/t Au from 120.5m

  • Commenced O/P mining 1997, switched to U/G mining 2011

  • Magnetics key to discovery (EM helpful)
Deposit Examples: Ernest Henry Cu-Au deposit

12,000nT magnetic anomaly lying adjacent a large sigmoidal-shaped shear zone

EM conductor lying over discrete portion of magnetic anomaly

300m diameter, magnetite-rich breccia pipe surrounded by intensely feldspar-altered volcanics bound by HW & FW shear zones

Images: Modified after Lilly 2015

Image: Northwest Qld Mineral Province Deposit Atlas
Deposit Examples: Osborne Cu-Au deposit

- Mined: 27.3Mt @ 2.46% Cu and 0.95g/t Au

- Key Features:
  - IOCG style mineralisation (magnetite-pyrrhotite)
  - Cu% - Au g/t ratio 2.6:1
  - Very high magnetite content
  - Hosted in upper amphibolite/granulite facies rocks
  - Host rocks quartzofeldspathic gneiss and banded ironstone
  - Dominant alteration is silica and magnetite
  - Pyrrhotite common in silica-flooded zones
  - Lies under ~40m cover

Image: Northwest Qld Mineral Province Deposit Atlas
Deposit Examples: Osborne Cu-Au deposit

Lodes controlled by shear zones deforming/disrupting pre-existing ironstones, focusing silicification and sulphide deposition.

Images: Northwest Qld Mineral Province Deposit Atlas
Deposit Examples: Osborne Cu-Au deposit

**FW**
- Predominantly psammitic rock

**ORE**
- Amphibolite with cpy-py-po-mt + silica
- Cg Quartz with cpy-py-po-mt veining
- Sica flooded, folded ironstone with cpy-py-mt +/- po

**HOST ROCKS**
- Calc-silicate alt of Psammite
- Recrystallised pelite
- Un-mineralised host ironstone

**HW**
- Predominantly granofels rock

Images: Jungmann 2018
Deposit Examples: Osborne Cu-Au deposit

- **Discovery History**
  - 1974 - airborne magnetics survey flown – bullseye magnetic anomaly of 16,000nT
  - 1976 - 7 percussion holes drilled intersected banded ironstone with only weak Cu-Au (best 2m @ 0.13g/t Au, 230ppm Cu)
  - 1985 – 11 RC holes drilled and again ironstone with only weak Cu-Au (Billiton – CSR JV)
  - 1986-1989 – 36 DD holes and 80 RC holes completed still only intersected sub-economic mineralisation (Placer took over CSR and become manager of JV)
  - 1989 – discovery hole TTHQ029 intersected 32m @ 5.8% Cu, 3.2g/t Au
  - Commenced mining 1995
  - Magnetics key to discovery (and persistence)
Deposit Examples: Eloise Cu-Au deposit

- Mined: +10Mt @ ~3% Cu and 0.8g/t Au??

- Key Features:
  - IOCG - ISCG style mineralisation (pyrrhotite +/- magnetite)
  - Cu-Au ration 3.8:1
  - Hosted in shear zone near psammite-schist contact
  - Large amphibolite body between lodes
  - Main alteration with sulphide is biotite-hornblende
  - Largest lodes hosted in brecciated quartz (quartz-filled shear zones) with semi-massive pyrrhotite-chalcopyrite
  - Southern magnetic bullseye related to magnetite-pyrite-carbonate
  - Semi-massive sulphide has ductile deformation textures
  - Mineralised to +1400m depth
  - Lies under ~60m cover

Image: Baker and Laing 1998
Deposit Examples: Eloise Cu-Au deposit

Early albite-quartz alteration, o/printed by biotite-hornblende, o/printed by cpy-po

Strong biotite-hornblende alteration with retrograde chlorite and cpy-po

Biotite altered psammite, folded/boudinaged quartz veins parallel to compositional layering, o/printed by cpy-po fill and replacement

As above but thicker quartz veins and stronger sulphide developed – note ductile deformation of sulphide preserved

Classic advanced durchbewegung structure preserved as product of ductile deformation of in/around sulphide-rich zones

Image: Hodkinson et al., 2004
**Discover History**

- BHP were targeting BHT-style Ag-Pb-Zn mineralisation under cover (~60m thick)
- BHP discovered nearby BIF-hosted Ag-Pb-Zn mineralisation at Altia
- Conducted ground EM north of the Eloise magnetic anomaly and drilled a conductor in 1986; that hole intersected ~70m @ 0.1% Cu with pyrrhotite-chalcopyrite stringers thought to be footwall zone to Pb-Zn-Ag system
- Followed EM conductor south toward magnetic anomaly; in 1988 the 4th follow-up hole (END017) intersected 112m @ 2.1% Cu, 2.1g/t Au from 172m
- Subsequent drilling showed too small for BHP, later decision to mine, by then owners Amalg Resources NL, was based on resource of 3.1Mt @ 5.5% Cu, 1.4g/t Au, 16g/t Ag
- EM key to discovery (but mineralisation model wrong)
Deposit Examples: Mt Dore/Merlin Cu-Au-Mo deposit

- **Resources:**
  - Mt Dore: 110Mt @ 0.55% Cu, 0.1g/t Au, 0.3% Zn, 0.05% Pb
  - Merlin: 6.4Mt @ 1.5% Mo

- **Key Features:**
  - Cu-Au-Mo-Zn-Pb (Ag) mineralisation
  - Hosted in brecciated and veined phyllite, calc-silicate, carbonaceous metasiltstone and shale below granite (granite overthrust)
  - Main alteration is alb-act-scapolite-apatite-qtz-tour-Kspar-chl
  - Sulphide mainly Cpy-Mo (py-sph-gal)
  - Two main zones mineralisation as sheet-like bodies, Merlin typically lies in footwall to Mt Dore
  - Upper portion strongly weathered/leached
Deposit Examples: Mt Dore/Merlin Cu-Au-Mo deposit

Early albite-quartz alteration (bleaching) carbonaceous metasiltstone – Mt Dore

Early alb-hem-act-scap-apatite alteration of calcareous sediment - Merlin

Silica-alb alteration of calc-silicate with fracture-fill Cpy

Alb-Kspar altered metasiltstone with high-grade chalcocite (supergene) – Mt Dore

Silica-alb-Kspar metasiltstone with fracture/stylolite fill molybdenite - Merlin

Images: Duncan et al., 2015
Discovery History

- Mt Dore outcrops with copper oxides discovered in the early 1900’s
- Drilling recorded from at least 1957
- Cyprus and Amico post-1975 drilling comprised 30 DD holes and unknown number of RC holes
- A resource defined to 300m depth as early as 1980 from this drilling
- Ivanhoe acquired from Administrators in 2003 and completed 19,273m up to 2008 and updated resource
- During 2008, when extending drilling northward, high-grade Mo mineralisation intersected at Merlin
- Ivanhoe completed nominal 50m-spaced drilling at Merlin in 2010 leading to current resource
- Mt Dore - Merlin would be invisible in geophysical data sets if under cover

Deposit Examples: Mt Dore/Merlin Cu-Au-Mo deposit
What are we seeing in SA??

- Gawler Craton has numerous examples of skarn-like, magnetite-bearing Na-Ca-Fe related IOCG type systems akin to those in Cloncurry (Mt Elliott/SWAN)
- Manxman – Joes Dam (Prominent Hill area)
- Cairn Hill appears to have strong similarities to parts of:
  - Osborne (Cu-Au overprinting banded ironstone) and, 
  - Mt Elliott with early Na-Ca alteration, later Cu-Au with garnet-scapolite-magnetite-diopside skarn and LREE enrichment
- Gawler also shows strong similarities to some of the Brazilian IOCG’s
- Hillside looks to be skarn-like and is shear-hosted (Yorke Peninsula)
- Shear-hosted ISCG style at Mutooroo shares strong similarities to Mt Elliott and Jericho
- Kalkaroo may have some similarities to Mt Dore
How does SA compare to Cloncurry

Mt Elliott v Manxman A1 v Cairn Hill v Sequerinho (Qld) (SA) (SA) (Brazil)

- Alteration and mineralisation assemblages near identical
- Early albite alteration ubiquitous
- Followed by various combinations of actinolite, scapolite, K feldspar, biotite, with associated chlorite, apatite, epidote, allanite, magnetite, quartz, carbonate and fluorite
- Strong magnetite component with chalcoprite-pyrite+/-pyrrhotite
- Cu-Au mineralisation has associated elevate U, LREE, Co, F
- Mt Elliott and Sequerinho have ore-grade Cu-Au mineralisation (Cairn Hill and Manxman A1 low grade)
How does SA compare to Cloncurry

**Eloise v Jericho v Mutooroo**
(Qld) (SA)

- Tabular shaped bodies hosted in shear zones
- Shear filled with quartz, competency contrast, re-broken and provided space for subsequent sulphide deposition
- Evidence for ductile deformation of sulphide syn- post formation (classic durchbewegung)
- Abundant pyrrhotite as part of ore-forming sulphide assemblage
- Cu-Au with associated Co
- Highly conductive thus amenable to EM geophysics

*Images: Teale and Price 2009 (SA Explorers Conf)*
How does SA compare to Cloncurry

**Mt Dore v Kalkaroo**

- Both appear to have magnetic footwall
  - Mt Dore: albite-hematite-actinolite-epidote-scapolite-apatite-magnetite
  - Kalkaroo: K-feldspar, ±quartz, biotite, magnetite, scapolite, calcite, ±epidote, ±hematite
- Both hosted by fine grained sediments that have been subjected to fine grained albite alteration
- Mineralisation likely structurally controlled but stratabound
- Mineralisation occurs as bedding-parallel veins and replacement and in breccia
- Both have Cu-Au-Mo with associated Pb-Zn
- Apparent zonation from Mo-rich (basal portion), Cu-Mo-Au, Cu-Au, Pb-Zn

**Mt Dore**
110Mt @ 0.55% Cu, 0.1g/t Au

**Kalkaroo**
100.1Mt @ 0.47% Cu, 0.44g/t Au

Kalkaroo Image: Havilah Website
How does SA compare to Cloncurry

What aren’t we seeing in SA??

• Breccia-pipe magnetite-rich IOCG like Ernest Henry
  ▪ BUT there is only one of these in Cloncurry

• Au-rich IOCG in magnetite-hematite ironstone like Starra
  ▪ There is also only one of these in Cloncurry