The Cloncurry District Mineral System

• Case Study: Ernest Henry
Emerging Target Styles
• Case Study: Lorena
• Case Study: Great Australia
Role of Research
The Mount Isa Inlier, N.W. Queensland is one of most highly endowed metallogenic provinces in Australia.

Over 150 years of mining and exploration history (First discovery, Gt. Australia, Cloncurry 1867).

Proterozoic age host rocks (1.7-1.5 Ga),

Multiple periods of alteration and deformation.

Recognised for its abundance and diversity of mineralisation styles including:

- IOCG, skarn, BHT, ‘Roseby Style’, ‘ISCG’.....
The Cloncurry District Mineral System is complex, variable and extensively studied and we still haven’t scratched the surface.

Strong mineral endowment in a variety of commodities (Cu, Au, Pb, Zn, Ag, Co, REE)

Huge challenge for geologists (with or without beards), and that’s before we go looking under cover.

Many well established ore deposit models and every year somebody discovers something different…

What can emerging target styles teach us about the mineral system as a whole?

Some of the most metasomatised rocks on the planet (M. Rubenach)
Schematic diagram of the relationship between rock types, regional alteration, magmatism and Cu-Au mineralisation within the Cloncurry district (Mark et al, 2006)
Key Styles of Fe-Oxide Cu-Au Mineralised Systems in the Mt Isa Eastern Succession

- **Cu-Au mineralisation**
- **Magnetite-rich alteration**
- **Breccia**
- **Hematite overprint**
- **Fracture system**
- **Magmatic hydrothermal fluid**
- **Circulated fluids**

*SOURCE* – *FLUID* – *PATHWAY* – *TRAP*….. SIMPLES?
The Exploration Challenge: Ernest Henry before... and after...
Exploration Case Study

Ernest Henry IOCG
Ernest Henry IOCG Deposit - Discovery

- No outcrop - covered by 30-60m Mesozoic sediments
- Early exploration targeted role front uranium in the cover sequence
- In the late 1980’s -1990 WMC targeted magnetic anomalies (FC Targets)
- Exploring for Starra style Fe-stone hosted and skarn related Cu-Au deposits
- Also recognised potential for Olympic Dam style Cu-Au-U mineralisation.
- Transient Electromagnetic (TEM) conducted over FC5 in 1991
Ernest Henry RTP Magnetics 1992 airborne survey

Maximum Mag RTP: 12,000 nanoteslas

Acknowledgement to T. Harvey (MIM) for slide
Ernest Henry Discovery TEM over 1992 RTP magnetics

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Ernest Henry IOCG Deposit - Discovery

- Discovery hole drilled in Oct 1991 targeted on ground-derived EM anomaly.
- Anomaly response from small supergene chalcocite blanket
- Discovery Hole intersected; 7.1m @ 4.95% Cu, 0.8 g/t Au from 97.35 m
  114.2m @ 1.75% Cu, 0.9 g/t Au from 120.5m

- Ground magnetic, gravity and induced polarisation methods were subsequently used to help guide early delineation drilling
- In 1993 the deposit was determined to lie within Mining Lease 2671, owned by Savage Exploration
- MIM Holding Limited purchased 51% of Savage Exploration
- Pre-strip commenced 1996 (167Mt @ 1.1% Cu, 0.54g/t Au at discovery)
Ernest Henry IOCG Deposit - Overview

- Cu-Au ore hosted by brecciated and altered intermediate volcanic rocks of Proterozoic age
- Primary Cu mineralisation is chalcopyrite.
- ~2:1 Cu:Au grade ratio e.g. 1% Cu 0.5g/t Au
- Pipe-like breccia body dipping SSE at 30-50°
- 250m thick, 300m wide and a down-plunge length of over 1km (& open)
- Total Resource >200 Mt (& open)
- 2013 Underground Resource 81.8 million tonnes @ 1.25% Cu with 0.65 g/t Au.
- 6 Mt pa UG hoist operation with LOM to 2027
Current Underground Mine Design:
Sub-Level Cave

Acknowledgement to EHM Geology Team for slide
Emerging Target Styles: Lorena (Au)

Exploration Case Study
Emerging Deposit Styles: Lorena (Au)

• Pumpkin Gully Goldfield, located 30km south of Ernest Henry with plenty of outcrop.

• Goldfield worked from late 1880’s

• Mainly abandoned in 1910-20’s (drought and better money to be had in Cloncurry and Mount Isa)

• Deposit styles not described in detail.

• Do these smaller, poorly constrained deposits offer an opportunity?

• How do these Cloncurry-style Cu-Au deposits fit into the bigger picture? IOCG related?
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Emerging Deposit Styles: Lorena Au

• Lorena Au mine located directly adjacent to MIM tenements
• Strong potential for strike extension: same host units and structural controls.

Hosted at contact of CS3: Toole Creek Fm (volcanics-metasediments) and CS2: Corella Fm (calcsilicates)
Emerging Deposit Styles
‘Lorena Au’

• First visit April 2013.
• High grade, structurally controlled breccia zones
• Open at depth and along strike.
• Polymetallic, system (Au, Cu, Co, As, Bi, Zn, Pb) + magnetite
• Arsenopyrite + phryrotite infill
• Similarities to local Monakoff deposit ……..but where does Lorena fit in?

• Measured and Indicated: 183,000t at 8.8g/t Au (for 51,000Oz (at 2g/t cut off)
• Inferred 21,000t at 7.7g/t (for 5,000Oz)
Where does Lorena fit in? WHERE IS THE GOLD?

**EHM:**
Au as native Au and electrum associated with arsenian pyrite and As-Co
(Foster et al, 2006)

**Monakoff:**
Au as late AsPy stage, overprinting F-Ba stage (and with rare Bi-sulphosalts).

**E1:**
Au predominantly assoc with pyrite in early banded (replacement) metasediments and rare Bi sulphosalts.

...BUT overprinting Au observed recently...

**Lorena:**
Au with late AsPy stage, locally overprinting F-Ba stage (and with rare Bi-sulphosalts)

**Genetic Links but Not All Stages Present Everywhere**

**Gt. Australia**
Assoc with Py and Co...still work to do.
Lorena Arsenopyrite (70g/t Au+), High As = High Au

*Is Lorena an ‘end-member’ mineralisation style for the district?*

Craddock, 2014

![Diagram of mineralogy](Image)
E1-N late Arsenopyrite...

Does this contain the other gold?
Does this event overprint other IOCG’s in the district?
Have these fluids utilised the same pathways as IOCG fluids?

**E1:** At least 2 gold-bearing stages: Cu-Au and Au
Arsenopyrite noted at E1-N, S and E

Craddock, 2013
Main aims:

- Investigate spatial and temporal district fluid pathways using Cu:Au ratios, trace metals, gangue minerals, fluid composition, etc.

- Investigate Au-As(Bi-Co) distribution (noted at Monakoff, Williams et al, 2012, 2013), as a possible control on Cu and Au mineralisation in the region.

- Primary samples from E1, Monakoff, Lorena, Great Australia (and district prospects)

Mineralogical and fluid characteristics of a distinct Au-As-Bi-Co mineralising style and the implications for exploration

Lisa Craddock (MGeol) 2013-2014, Leicester University (UK)

• As and Bi are indicators for prospectivity for Monakoff, E1 and ‘Lorena-type’ deposits (including Chinova’s Confucius prospect).

• Lorena represents a distinct (late) Au-As-Bi-Co mineralisation style for the Eastern Cloncurry District

• Geological constraints on spatial and temporal distribution of this fluid stage assist with modeling of the ‘plumbing’ of Cloncurry area and has direct exploration implications.

Fluid Inclusions:
• Multi-phase inclusions with daughter minerals (e.g. halite) are present, supporting the occurrence of a high salinity, >26wt% NaCl

Group 1: aqueous inclusions, ice melt –0.5°C
Group 2: multiphase inclusions $T_h > 345^\circ$C

Thanks to John Walton and Lorena Team
Emerging Target Styles: Great Australia (Cu-Au) and the ‘Magpie Trend’
Emerging Target Styles: 
Great Australia – Magpie Trend

• Recently acquired tenement holdings allow extension of investigation into spatial and temporal variations in ore-fluids.
• Many historic (supergene) Cu workings west of Cloncurry (very limited >100m drilling)
• Associated with lithological contacts, dolerites and magnetic lineaments
• No late overprinting observed (Ba/F, As/Bi)
• What is the ore-deposit model for the Western Cloncurry dolerite-hosted deposits (IOCG?)
Emerging Target Styles:
Great Australia – Magpie Trend

Acknowledgement to M. Rough (MIM) for assistance with slide
Exploration Case Study

Great Australia Ore Mineralogy

Acknowledgement: The Great Australia Mine is 100% owned by CopperChem Ltd.
Great Australia Copper Minerals

• Most historical mining focussed on supergene ore zones
• Dominantly chalcocite, cuprite, malachite and native Cu

But normally looks like this....
Great Australia
Rare Cu Mineral Species

• Several very rare Cu minerals have been identified at Great Australia.
• Origin linked to mineralogy, complex NW Qld weathering history and variable water table (and termites!)

Connellite
• Copper Chloride
  • \( \text{Cu}_{19}(\text{SO}_4)(\text{OH})_{32}\text{Cl}_4 \text{3H}_2\text{O} \)

Gerhardite
• Copper Nitrate
  • \( \text{Cu}_2(\text{NO}_3)(\text{OH})_3 \)
Great Australia
Rare Cu Mineral Species

Barlowite
• Copper Bromine Halide
• $\text{Cu}_4\text{BrF(OH)}_6$

Cloncurryite
• Copper-Vanadium Phosphate
• $(\text{Cu,VO})\text{Al}_2(\text{PO}_4)_2(\text{F,OH})_2 \cdot 4.5-5\text{H}_2\text{O}$
  • Only recorded location
Great Australia Copper Minerals

- Hypogene vein-hosted and disseminated chalcopyrite
- No late overprinting observed
Great Australia: Paragenesis

Host Dolerite

- Carbonate
- Late pink ‘zeolite’
- Sulphides (py>cpy)
- Albite
- Magnetite
- Amphibole

Scale: ~10mm
Great Australia Paragenesis (Taylor, 2013)

Early Magnetite
• Major alteration of fine grained igneous host rocks, no veins
• Unusual for magnetite to be the initial paragenetic product in Cloncurry District (usually albite-dominant minerals)

Biotite
• As veins and alteration. Cut magnetite, associated with titanite/\(\text{TiO}_2\)

Albite
• Coarse grained, well developed.

Scapolite
• Hydrothermal scapolite (not metamorphic) – veins and alteration

Amphibole (carbonate-quartz)
• Hydrothermal origin

Pyrite-Chalcopyrite-Carbonate
• Veins and alteration. Always spatially linked; close timing suspected. Association of Co.
• Potentially multiple stages of carbonate: evidence of multiple fracturing. Always veins

Epidote
• Post-dates carbonate: last stage

Note: Samples not collected specifically for paragenetic work, further sampling may be warranted
Great Australia Paragenesis (Lilly-fied)

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Magnetite (Fe) alteration needs **hot** and **salty** brines

Think IOCG. Think SALTY

Unusual as 1st stage in Cloncurry area: Earlier system?

**HOT! 400-600C**

**WARM**

**COOLING DOWN 300C**
• 2014-15 research project with Leicester Uni (UK).
• Aim to date the single Chalcopyrite stage (Re/Os) at GAM-Mongoose-Magpie
• Au present as electrum and native Au (texturally the same as EHM)
• Magnetite has been modified to Wustite (Fe^{2+}), indicative of a highly reduced environment and typical of skarn systems.
• Several Palladium-bearing compounds have been identified as (Ag)-Pd-Tellurides and bismuthides as well as presence of Ni-sulphides and other PGE’s
• Indication of ultramafic influence? (Roger Taylor’s ‘Mafic Skarns’)
Emerging Deposit Styles: Magpie Trend Dolerite Discrimination: Ti-V (after Shervais, 1982)

- Immobile elements Ti-V can be used to discriminate volcanic events.
- 2014 RC (4 acid digest) data from ‘Magpie Trend’ records the change from an Ocean-Island tectonic setting, through a prolonged rifting stage with multiple volcanic events.
- Similarities of mantle source to Western Succession
- Can we use dolerite chemistry to vector for prospectivity?
Emerging Deposit Styles: Geochemical Discrimination

- Can we decipher the crustal evolution of the Eastern Succession from the mafics?
- Implications for exploration and ‘plumbing’?
Emerging Deposit Styles: Geochemical Discrimination

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• Implications for exploration and ‘plumbing’?

Fields from Pearce and Peate, 1995
Great Australia

Working Ore Deposit Model
Emerging Target Styles: Mongoose- Working Ore Deposit Model

- Original unconformable setting of Toole Creek Formation metasediments in a structural (faulted) contact with Corella Formation calc-silicates.
Emerging Target Styles: Mongoose- Working Ore Deposit Model

- Mongoose Magmatic Stage 1.
- Magmatic event(s) intrude multiple geochemically similar (andesitic) melts into the sediment pile along the structural control.
- The melt(s) cooled unevenly giving some areas variable basalt to gabbroic texture but dolerites predominate.
- Various breccia textures can be present at the margins and sedimentary clasts/fragments are regularly included in pile.
Emerging Target Styles: Mongoose- Working Ore Deposit Model

- Mongoose Magmatic Stage 2.
- After a magmatic hiatus, a second magmatic event intrudes dolerites and a stock of porphyritic melt along the pre-existing structural contact.
Emerging Target Styles: Mongoose- Working Ore Deposit Model

- Mongoose Magmatic Stage 2.
- After a magmatic hiatus, a second magmatic event intrudes dolerites and a stock of porphyritic melt along the pre-existing structural contact.
- Alteration; Early Magnetite-Biotite alteration pre-dates district scale Na-Ca alteration and amphibole stage.
- Potentially multiple stages of carbonate: evidence of multiple fracturing.
Mineralogical and Geochemical Signatures of the Dolerite-Associated Iron Oxide-Copper-Gold (IOCG) Prospects In the Western Cloncurry District, NW Queensland

Ben Francis-Smith (MGeol) 2014-2015, Leicester University (UK)

Intrusion-hosted deposits e.g. Mongoose

1. Uncomformable, faulted contact between TCV and CF, D2 structure.

2. Magmatic stage 1: Intrusion of Ti-rich, massive dolerite along faulted contact.
   Massive dolerite >6500 ppm Ti

3. Magmatic stage 2: Intrusion of Ti-poor, porphyritic dolerite along faulted contact.
   Porphyritic dolerite <6500 ppm Ti

4. Competency contrasts result in ‘focussing’ of brittle deformation within fine grained intrusive units relative to surrounding metasediments and volcanics.

Great Australia Deposit

1. Doleritic-andesitic meta-volcanics

2. Site of structural weakness located between the TCV/CF contact (Cloncurry Fault) and a lithological contact between two differing TCV units.

3. Early D3 fault reactivation of Cloncurry fault begins to forge zone of dilation via brittle deformation due to competency contrasts.

Greater potential for fluid flow through on-going development of permeable sites
Magpie Trend: 2 Drill Seasons Later
Cloncurry District Mineral System: an ‘à la carte’ menu

• Despite many common characteristics, the deposits are so variable that classification into smaller subgroups with similar geological and exploration characteristics is difficult.

• Interaction between alteration (and mineralising) fluids and host lithologies is key to understanding individual deposit characteristics and properties.

• Awareness that the mineral system has end members and variations on a theme, rather than trying to pigeon-hole deposits and their characteristics, (e.g. IOCG, ISCG)

Some of the other variable characteristics include... (Williams & Skirrow, 2000)

- Total metal content & grade
- Metal ratios
- Host rock age, lithology and metamorphic grade
- Chemistry and mineralogy of alteration assemblages
- Local structural controls and geometries
- Relative importance of breccia vein and replacement mineralisation styles
- Relationship between magnetite and Cu-Au distribution
- Minor (and trace) element associations
Cloncurry District Mineral Systems: ‘Curry End Members’?

Great Australia (Magpie-Trend) Deposits
All the ingredients, not quite mixed properly

Ernest Henry Deposit
All the ingredients, in the perfect setting

Lorena Deposit
Last orders!

Curry ‘end-members’?
Lots more varieties on the menu!
The importance of completing research into ore deposits while we can.......

Monakoff Pit Development
August 2012-April 2013

August 2012

April 2013

August 2012

April 2013