Controls on copper mineralising processes in the central McArthur Basin, NT, and its implication for the metallogeny of extensional basins: Coppermine Creek case study

Final report December 2017

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Sponsor: Northern Territory Geological Survey
NTGS Collaborators: Dorothy Close, Andrew Wygralak
History

- Project commenced as a PhD in mid-Aug 2014 (Larriana Morgan)
- Larriana withdrew mid-2015
- Project renegotiated as a single funding block to complete study on the samples acquired to that point; intended to run through 2016.
- Most sampling had focussed on the Amelia style mineralisation
  - Regional baseline holes through the Amelia Dolomite sampled
  - Coppermine Creek MYD7 sampled
- To obtain a more comprehensive view of Coppermine Creek, Sandfire Resources and Pacifico Minerals were contacted (currently hold the ground in JV)
- Some old holes are held in the MMG Leila Yard core farm; access at end of 2016 was prevented for S Bull by poor working conditions
- Pacifico supplied 2 samples from best mineralisation at Coppermine Creek in CCD03.
• Cu mineral locations from the NTGS MODAT database Mar 2014 were assessed. Two major clusters are evident, each breaking into two further clusters
• Main sampling is on northern section of the Batten Fault Zone cluster NW of HYC
McArthur Cu

- Amelia style Cu mineralisation
  - 1648 ± 3 Ma
  - McArthur Group
  - Batten & Emu Fault Zones
  - First major reduced sediments above the oxidised Redbank Package

- Stanton/Redbank style Cu mineralisation
  - 1729 ± 4 Ma
  - Tawallah Group
  - Eastern McArthur Basin

- Wollogorang Formation
  - Tawallah Group
  - associated with Stanton & Redbank Co/Cu deposits

Stratigraphy taken from Rawlings 1999
Stratigraphy of Sediment-hosted Stratiform Cu systems

A - Lacustrine evaporites and shales (reductant and possibly sulfur source) within a red-bed package containing volcanic rocks

B - Evaporites in the transgressive marine sedimentary sequence overlying continental red beds with lacustrine, carbonaceous shales, and volcanic rocks

C - Red beds lying above a marine sequence containing evaporites and carbonaceous units

Figure taken from Hitzman et al 2005
The site lies adjacent to the major Four Archers Fault zone, between the Scrutton Range and the Tawallah Range.
Amelia Style Cu
Stratigraphy - BFZ

- Roper Group (Limmen SS / Mainoru Fm / Abner SS)
- Nathan Group (Balbarini Dolomite)
- Glyde Package - McArthur Group
  - Batten Subgroup - Lynott Fm (Hot Spring Member)
  - Umbolooga Subgroup - Reward Dolomite / Barney Ck Fm
  - Umbolooga Subgroup – Amelia Dolostone / Mallapunyah Fm
- Redbank Package - Tawallah Group
  - Settlement Creek Dolerite
  - Wunumnantyala Sandstone
  - Seigal Volcanics
  - Yiyintyi Sandstone
Location and detail from the 1:100000 sheet:

**major features**

- Major east-west fault with north block down
- Evidence for north-south fold axes
- Evidence for east-west fold axes cut by NW and NE faults
- However, investigation by Pacifico indicates that many of the faults shown here are photo-interpreted and need testing.
The situation in December 2015

- A large number of drillholes, gossans and historical workings had delineated a mineralised site called Gordons Fault.
- One of the deepest holes had been drilled by BHP, MYD07, and intersected mineralisation coincident with evaporites.
- Pacifico had drilled CCD02-3 close to Gordons Fault Cu trend and returned further good copper grades (slide 12).
- Sandfire flew AEM and identified a large anomaly connecting to the known mineralisation.
- Pacifico drilled CCD04 into the peak of this anomaly in approx Sept 2015 to 464 m, finding only minor mineralisation at ~200 m. Although the target depth was 600 m, the hole did penetrate into the Mallapunyah Fm (slide 13); a DHEM survey did not find a conductor.
- The AEM anomaly was attributed to surficial effects and attention has returned to outlining the Gordons Fault mineralisation (CCD08).
Supporting the opportunity for the presence of a major copper mineralised system of the Mount Isa Copper (approximately 250Mt of 3% Cu) or Nifty (approximately 100Mt of 2% Cu) style are the following key geological factors:

- Distinctive ex-evaporite beds in the overlying Amelia Dolomite contain disseminated copper mineralisation.
- The mineralisation lies close to the redox contact between hematitic siltstones (oxidised) of the Mallapunyah Formation, and the overlying Amelia Dolomite.
- Reverse faulting at Coppermine Creek indicates that copper mineralisation could be related to a compressive regional event.
- The copper mineralisation appears to be spatially related to a major north-south trending regional fault system that may provide access to copper-bearing basin fluids.
- Intense fracturing, brecciation and dolomite (− silica) alteration is widespread and related to the copper mineralisation.
- Coppermine Creek lies within the McArthur Basin, where there are known large base metal mineralised systems, in an area that has only been patchily explored previously.
MYD07
modified from the original BHP X-section
CCD02-CCD03 long section: 556 300 mE (CCD02 projected 100 m west)
Source: Pacifico Minerals
Long section, and the Sept 2015 exploration model prior to drilling CCD04 at the ‘planned drill hole’ site (below). An interesting aspect is whether the change in Amelia Dolomite thickness north of CCD03 (across the major E-W fault) could be real, although it is schematic here (Pascoe pers comm 2017). Recent discoveries in the McArthur Basin mean that E-W faults (as well as N-S faults) are now of particular metallogenic focus.

Source: Pacifico Minerals Sept 2015 quarterly rpt
MYD07 this study

BHP X-section. CODES isotopic samples.

- CODES sampling rationale: MYD07 was available in the NTGS corestore. It transects the whole of the Amelia Dolomite and a significant part of the Mallapunyah Formation, as well as providing a good cross section of the ex-evaporite zone which appears to host the best mineralisation. There is an NTGS SWIR log of the hole.
- MYD07 was sampled at 5-10 m intervals, yielding ~60 samples
- Polished thin sections have been obtained from ~20 of these, and of these 6 have been imaged with high resolution MLA SEM
- 39 (MYD07) + 5 (CCD03) C-O isotope analyses (see left)
- 8 S isotope samples
Highest grade ore features: CCD03 I

- Limitations: only two samples have been seen to date, sampling a 30 m @0.5% Cu zone, incl 10 m @1.3%. (For location see slide 12)
- These show strong similarities to MYD07 samples
- Main alteration is carbonation of black dolomitite
- Chalcopyrite masses up to 15 cm wide appear to post-date dolomite veining; they contain 0.5 cm kernels of pyrite
- Chalcopyrite masses have planar but sinuous margins, internal subgrains, and internal cracks filled with dark chlorite (?)

CCD03/40.3m
Depth: 40.30 m - 40.46 m
Highest grade ore samples: CCD03 II

- Sub-vertical carbonate veins also occur, with sinuous to ragged margins
- These margins are consistent with replacement of stylolites and/or subsequent stylolitic overprint of the veins
- Some chalcopyrite has developed along the outer margins of these veins, partly having replaced vein carbonate, and partly having replaced wallrock alteration carbonate. This is a common feature in MYD07 too.
MYD07 important textures:
1. Dolomitisation over evaporites within dololutite

Dolomite replacement of tabular crystals (gypsum?).

A039/159.00 m

Hole: MYD7
MYD07 important textures:
2. Increasing abundance of dolomite vein gapes and vein networks downhole, affecting dolomitised fabrics
MYD07 important textures:

3. Bitumen-filled stylolites sub-parallel bedding, but one set also occurs at a high angle to bedding. This set controls the extent of some pervasive dolomitisation, and also the location of some Cu mineralisation.
4. In the mineralised zone, steep sub-vertical bitumen-filled stylolites, have been partly replaced by chalcopyrite. This indicates that one mineralising reaction could involve the oxidation of organic C to reduce fluid sulfate (see also frontis).
MYD07 important textures:
5. In the mineralised zone, steep calcite veins replace along sub-vertical stylolites, and are themselves partly replaced by chalcocpyrite. The dolomitised hostrock displays brecciation.
MYD07 important textures:
6. In the transition to Mallapunyah Fm, some Cu mineralisation is associated with reddened haloes around fractures, whereas some exhibits stylolite replacement.

Hole: MYD7
A064/199.6 m
MYD07 important textures:
6. Mallapunyah Fm is typically hematitic dolostone cut by irregular carbonate veins (some with minor chalcopyrite)
MYD07 important textures:
7. Mallapunyah Fm can contain sections of near-pure hematite (ironstone), cut by tension gash carbonate with red goethite (?) haloes. This attests to Fe addition and mobility in several episodes.

Hole: MYD7

Post-hem carb veins with goethite rims that cut massive replacive hem: creates red networks

Later carb veins ± cpy

Massive blue hematite

A078/290.5 m
MYD07 important textures:
7. Mallapunyah Fm can contain sections of dolomitised black shales or laminated primary marine carbonate that are not red; in places these are strongly veined and replaced

Intense vein infill, with associated severe replacement of stylolitised black shale;

Intense replacive Fe-dolomite

Hole: MYD7

A076/271.8 m
### Sulfur isotope results

Stable Isotope Analysis Batch Results Sheet, SO2

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### Carbon-oxygen isotope results

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Oxygen isotope variation in carbonate

We preferentially sampled veins because they are a pure medium with no organic C or other phase. The veins are mainly lighter than hostrock. No clear trend in veins approaching the ore zone, although there is a cluster of low values around the Cu section. Hostrock O is lowest in and around the mineralisation, except for one spike. In hindsight, the spacing of C-O hostrock samples should be increased to the same density as the vein samples, given that the preliminary observations look interesting.
Carbon isotope variation in carbonate

- Host samples might be expected to be more negative because they likely contain some organic C (which is very negative)
- However, instead, most host veins are more negative than the nearby host dolomite
- No clear trend around the mineralised zone in either vein or hostrock populations, although a cluster of more negative values occur in veins near the Cu zones
Now it gets interesting (a bit)

- When plotted as C vs O for hostrock, a trend is observed, in the MYD07 data.
- One endmember coincides with the samples from CCD03, in which Cu grades are the highest in the prospect.
- This merits comparison to the positively correlated trend of the Mt Isa copper ore halo (next slides).
Vein data in carbonate

- When plotted as C vs O for veins, a trend is again observed, with some outliers.
- However, CCD03 samples do not lie at the most negative end, unlike the host carbonates.
- Overall it appears that the host carbonates, themselves a product of a dolomitising fluid, are most sensitive to the presence of copper.
Comparison to the isotopic features of the Mt Isa copper ore halo, which have been well documented by Chris Waring (PhD studies)
Copper orebody

Mt Isa Copper C-O isotope halo, with a fluid-rock interaction exchange line shown

Figure 4. Mount Isa Mine environs carbonate isotopic data, from Smith et al. (1978), corrected Heinrich et al. (1989), and Waring (1990a).
Comparison to the Mt Isa copper system

The trend of the Coppermine Creek hostrock data is similar to the low water-to-rock portion of the Mt Isa Cu trend, and is consistent with an external fluid with light O and C values having reacted with the sequence. Neither the carbonate veins nor the dolomitisation of the hostrock appear to be syn-copper in individual samples, but could still all have been part of one evolving hydrothermal system (theory). Alternatively, earlier formed carbonates were susceptible to further alteration by the later Cu-forming fluid. This suggests that delineation of the shape of the isotopic contours may give a guide to Cu-related fluid flow, as it does at Mt Isa.
Comparison to the Mt Isa copper system II

It is evident that adding in the vein data does reveal an overall trend which is even more similar to the Mt Isa Copper trend, parallel to it but with more positive C values.

In future work, it would be good to obtain unaltered Amelia Dolomite samples (Marjory Muir work needs compiling, for instance; regional Amelia Dolomite intersects, etc) to properly determine the trajectory of altered values.
Conclusions

- Work in the final period focused on Coppermine Creek
- Two samples of higher grade Cu were added to the extensive MYD07 sampling in the reporting period, courtesy of Pacifico Minerals. Fabrics in CCD03 are similar to those in MYD07, but are larger in scale.
- Paragenetic work is consistent with the Pacifico hypothesis that Coppermine Creek is an inversion-related sediment-hosted copper deposit (see slide 10), but there are unusual features, and faulting and drag-folding complicate our ability to know the original geometry of the system.
- Early fabrics of secondary gypsum (?) that randomly overgrew organic-rich dololutite are largely replaced by dolomite (full chemistry still to be determined).
- This dolomitised rock is cut by carbonate-filled gapes and veins of with sharp edges. These in turn are modified by families of stylolites filled with bitumen, and one of these forms steeply dipping networks suggesting development during compression.
- Chalcopyrite has replaced the bitumen-bearing stylolites suggesting it formed during or after compression. It also has replaced some early formed carbonate veins, particular on vein margins with dololutite.
- Model: fluids rose along a large structure or intersection and moved into synthetic structures that cut the gypisiferous Amelia Dolomite stratigraphy, where reaction-induced carbonate vein and breccia complexes with stylolitic margins developed, and were subsequently invaded by Cu fluids.
- Although the Mallapunyah Fm is regionally an oxidised unit, there are several indications in MYD07 that Fe was mobile in this unit, including addition of Fe to the point of forming massive fine grained hematite zones (ironstones).
- This requires further assessment to understand the timing of Fe mobility, and whether it is has implications for the formation of sediment-hosted copper mineralisation at this site.
- In some sed-hosted Cu districts, strong hematitisation underlies Cu mineralisation (for instance, ‘Rote Faule’ zones in the Kupfershiefer district).
- C-O stable isotopes on MYD07 shows a general depletion of hostrock carbonate O towards the mineralised interval.
- Plotted together, in terms of C vs O isotopes, the veins and hostrock from both holes form a linear array that shows a similarity to the Mt Isa Copper orebody halo trend (despite the fact that Mt Isa is a well known metamorphic orebody, whereas the CCM area is virtually unmetamorphosed; the two do share the fact that their only Cu mineral is chalcopyrite).
- C-O isotopes may be useful indicators of the locations of active conduits (for instance, see slides 33 and 314), which could help to unravel the paleo-fault architecture.
- Further comparison to C-O signatures of other ore types are warranted (see slide 39).
Recommendations for Future work

- Sulfur isotope characterisation of MYD07; infill C-O sampling of hostrock downhole in MYD07
- Compilation of previous regional S, C, O analyses in the Amelia Dolomite to assist with background determination
- MLA-SEM imaging for U-Pb dateable phases, coupled with petrography and microprobe analysis of selected phases. LA-ICPMS dating of any suitable phases
- Re-Os dating
- Search for phases that will provide primary Pb isotope compositions for comparison to other ore types in the basin.
- Whole rock analysis of MYD07 samples
- Fluid inclusion temp-salinity and Br-Cl determination for Cu-bearing fluids, if suitable material can be identified (for instance cpy-quartz veins with fluid inclusions)
- Acquisition of two appropriate drill profiles from the Coppermine Creek area; probably CCD03 and CCD04. Pacifico have found that all mineralised intercepts in the Sandfire holes have been removed, which limits the options.
- Comparative analysis of several other Amelia Dolomite least altered profiles for which samples already exist at Utas (L Morgan collection)
- Comparison to other possible analogues (Nifty (for instance Anderson et al 2001), Maroochydore (Reed, 1996) and similar deposits in the Zambian Copper Belt
- Resolve which faults were active for fluid flow throughout the history of the area
- Assess whether sufficient funds remain to tackle these recommendations for further work through an honours project, possibly including other Amelia-style copper sites
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• Isotopic analyses by Christian Dietz, Utas Central Science Laboratory

References