

ALTERATION MINERALOGY AND ACID SULPHATE WEATHERING AT MOONTA COPPER MINES, SOUTH AUSTRALIA

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INTRODUCTION

Shear-hosted Cu-Au deposits in the Moonta mining district on northern Yorke Peninsula, South Australia, were an important source of Cu from 1860 to 1920, making a major contribution to the 355,000 tonnes of Cu and 2 tonnes of Au recorded for the Moonta-Wallaroo mining district (Conor 1996). The Moonta orebodies are narrow hydrothermal vein deposits largely confined within shear zones and fractures in Palaeoproterozoic Moonta Porphyry (1760 Ma). Copper mineralisation was introduced in fluids emanating from Hiltaba Suite granite emplaced at depth at about 1600 Ma (Conor 1996, Raymond *et al.* 2000, Both *et al.* 2003).

Recent mining operations at Poona and Wheal Hughes Cu mines provided an opportunity to study mineralisation, alteration mineralogy, and geochemical dispersion in the deposits (Janz 1990, Hafer 1991, Both *et al.* 1993, Mauger *et al.* 1997, Hartley 2000). Timing and distribution of alteration minerals relative to Cu mineralisation were determined and data collected on the geochemical dispersion of ore-associated elements, particularly in the 5-15 m thick cover of Quaternary sediments. This paper reviews data from earlier work on alteration mineralogy and speculates on the role of acid sulphate weathering in geochemical dispersion processes and certain mineralogical changes observed in the host porphyry and sedimentary regolith. The aim is to identify changes in the host rock and younger cover that reflect the presence of nearby mineralisation. From a mineral exploration perspective these changes need to be measurable, ideally at shallow depth and with a footprint some orders of magnitude greater than the target mineralised shears.

ORE GEOLOGY AND ALTERATION MINERALOGY

At Moonta, mineralised veins, or lodes, up to 12 m in width and several hundred metres in length, were mined to depths of 650 m. In all cases, the host is Moonta Porphyry, a foliated rhyolite to rhyodacite complex. The lodes are mainly tabular veins within fractures and shear zones that make a series of concentric arcs trending from NNE to ENE. Mineralisation includes chalcopyrite, bornite, chalcocite, pyrite, molybdenite, hematite and magnetite, with traces of Au, Ag, Bi, fluorite, fluorapatite and uraninite.

Recent workings, 1988-92, at the Poona Mine were on an offset of the main Poona lode. The orebody is a thin fissure vein, striking 070°, dipping 50° NW and plunging 22° W. The vein incorporates brecciated and replaced host porphyry and has a strike length of some 160 m, being terminated at either end by steeply dipping faults that cut the lode almost at right angles. The lode has an average width of 3-4 m and a maximum width of some 6 m (Janz 1990). Primary ore minerals at Poona include chalcopyrite and pyrite, with minor bornite and gold. Wheal Hughes Mine operated from 1991-94 on several ore lenses hosted by a 25 m wide NE-trending shear zone. The northeast part of the deposit, known as Leighton's Lode, consists of a single vein separated from the main part by a cross-cutting fault. Main mineralisation is in two, parallel veins, 2-5 m wide, trending 045° and 25 m apart, called the hanging wall and footwall lodes. The "middle lode" trending at 030°, joins the two parallel lodes. Ore was enhanced at the intersection of the "middle lode" with the 045° trending lodes. Primary ore minerals are as at Poona. Combined production was around 18,000 tonnes Cu from 450,000 tonnes of ore grading between 4.6-5.3 % Cu and 0.7-1.5 g/t Au (Conor 1996, Both *et al.* 1993).

Both *et al.* (1993) recognised a paragenetic sequence of mineralisation involving 3 hydrothermal stages separated by episodes of fracturing and shearing (Table 1). The first stage was characterised by iron oxides; magnetite deposited initially and subsequently replaced by hematite. Iron sulphides dominated the second stage, mainly pyrite with minor marcasite. The third stage was responsible for deposition of chalcopyrite, with bornite and gold mainly as small inclusions within chalcopyrite. A fourth stage is added here to include supergene effects that both depleted and upgraded sections of the ore zone and generated additional alteration minerals.

Alteration minerals most closely associated with the Cu-depositing third stage include chlorite, sericite and

tourmaline. These formed at the expense of feldspar and biotite during the second stage and continued throughout the third stage. Spectral logging of drill core (Mauger *et al.* 1997) recorded a change in the chemical composition of chlorite in the vicinity of mineralisation due to partial replacement of Fe by Mg. However the patchy nature of the alteration in individual chlorite grains made it difficult to interpret and map from spectral data alone. Muscovite shows a distinct shift in spectral absorption near copper mineralisation due to compositional change resulting from substitution of Al by Si, Mg and Fe to approach a phengite composition. The phengite alteration zone is readily mappable where sericite is present, but at Poona the alteration was restricted to less than 10 m either side the ore zone.

Table 1: Paragenetic sequence of mineralisation at Poona Copper Mine (after Both *et al.* 1993).

	STAGE 1	STAGE 2	STAGE 3	STAGE 4
Magnetite	—			
Hematite			—	
Pyrite		—		
Marcasite		—		
Chalcopyrite			—	
Bornite			—	
Gold			—	
Carrollite			—	
Quartz	—	—	—	—
Chlorite		—	—	—
Sericite		—	—	—
Tourmaline		—	—	
Smectite			—	
Supergene				—
Cu minerals				—
Alunite				—
Kaolinite				—
Halloysite				—

ACID SULPHATE WEATHERING

The Moonta Porphyry at Poona and Wheal Hughes shows weathering as variably kaolinised saprolite of 10-15 m in thickness, approximating the depth to the water table at around 20 m below surface. At Poona, weathering extends to around 35 m depth in the footwall adjacent to the lode due to highly acidic conditions developed during sulphide weathering. Weathering products include iron oxide, kaolin and alunite. In the saprolite, alunite is found in patches in the hangingwall and footwall close to line of lode. Tourmaline and quartz remain largely unaltered and can be used to identify the approximate position of the lode in the clay saprolite. While sulphides are mostly leached from the weathered zone, a 3-4 m thick zone of supergene copper mineralisation was encountered at Poona at around 15 m depth. Secondary sulphides were principally chalcocite and covellite with minor digenite and djurleite, plus native copper. This zone produced 1,000 tonnes of enriched ore that was shipped, without treatment, direct to Port Kembla for smelting.

At Poona, halloysite, a kaolin polymorph, is typically found together with kaolinite throughout the saprolite. Beyond the base of weathering, halloysite is also present as patches and a thin coating on fractures in fresh porphyry (Figure 1). Halloysite distribution is confined to close proximity of the mineralised shear, and persists to around 80 m depth (Mauger *et al.* 1997). The distribution, lack of feldspar alteration, and layering in halloysite (Figure 2) are consistent with crystallisation of halloysite from Al/Si-rich acidic groundwater circulated downwards from the weathered footwall and channelled along permeable shear zone fractures. The layered deposits (Figure 2) indicate cyclic crystallisation possibly related to water table fluctuation. Deposition of halloysite was triggered by either increased pH through groundwater mixing or evaporative concentration and precipitation related to lowering of the water table. Kaolin coated fractures below the base of weathering are more extensive at Wheal Hughes and although the distribution has not been the subject of investigation this probably reflects the more complex, broader shear zone.

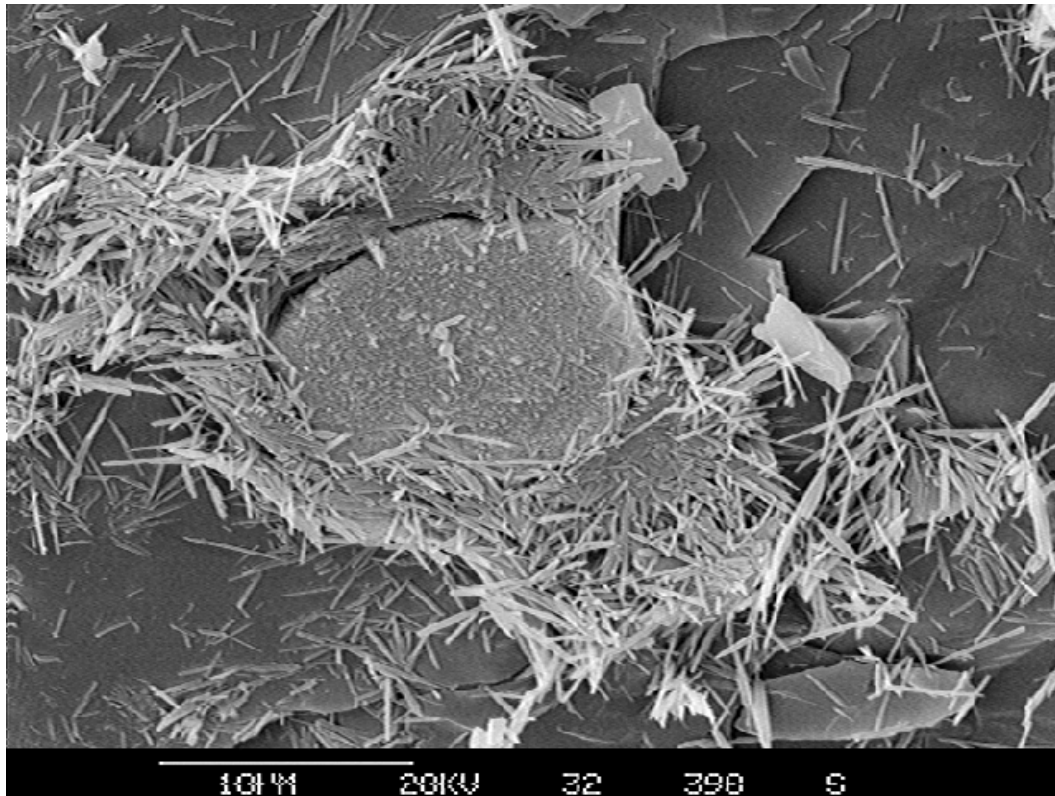


Figure 1: Scanning electron micrograph of tubular halloysite coating the surface of an unaltered albite grain. Sample from Poona Cu Mine, drill hole DDH 235, depth 40.3 m. Scale bar is 10 μm .

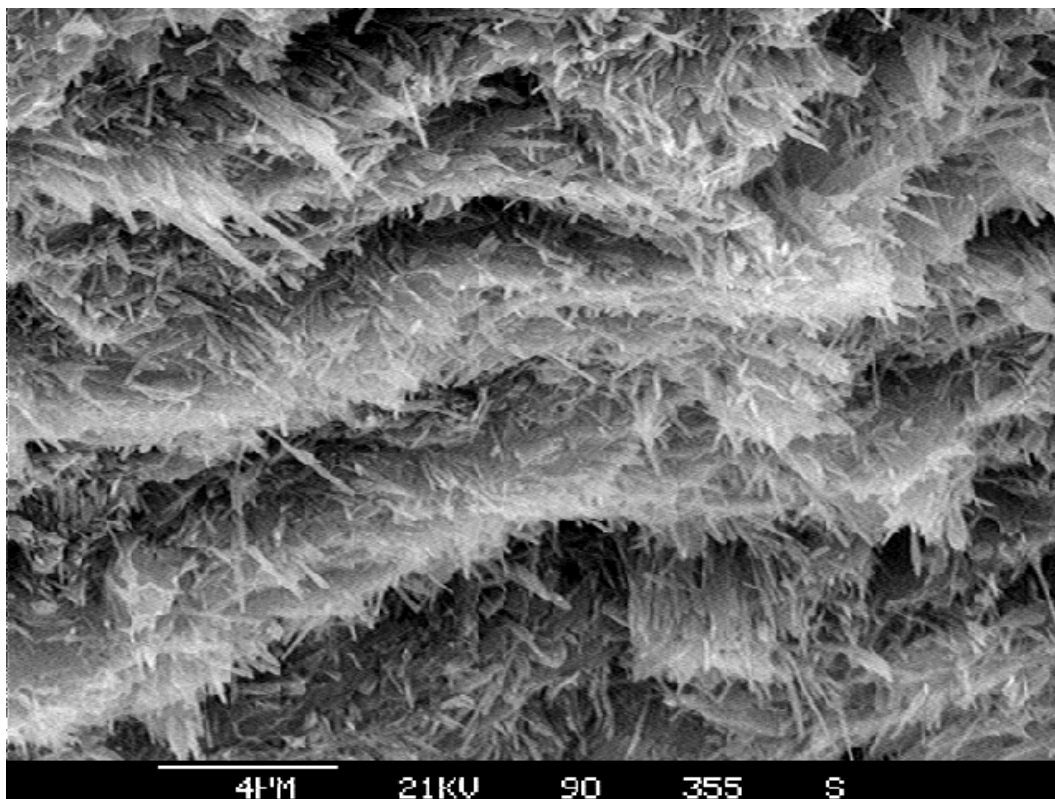


Figure 2: SEM image of kaolin coating a fracture surface in Moonta Porphyry. Kaolin is dominantly tubular halloysite deposited in layers. Poona Copper Mine, drill hole DDH231, depth 34.1 m. Scale bar is 4 μm .

The pattern of weathering is consistent with a pool of acidic groundwater developed in the footwall below oxidising sulphide ore. This would contain high levels of dissolved Al and Si in addition to Cu and other metal ions associated with the mineralisation. Strong evidence for the upward migration of Cu-bearing solutions into the overlying Quaternary clay unit is provided by the presence of atacamite ($\text{Cu}_2\text{Cl}(\text{OH})_3$) nodules formed in the clay directly above the ore zone. The early miners noted the presence of dark green copper chloride in transported clay and made extensive use of shallow auger drilling to 10 m depth as an effective prospecting technique to locate buried Cu lodes in the Moonta area (Jack 1917). Experience showed that atacamite was concentrated above the back of the lodes, i.e., directly above the leached ore zone, and was only present where the Quaternary clay unit directly overlay the Cu lodes in weathered porphyry. In these situations, nodular masses of atacamite, some reportedly weighing 300-400 kg, were encountered and were valuable additional sources of Cu (Jack 1917). Atacamite nodules were present in Quaternary clay at Poona but not Wheal Hughes.

Detailed study of the chemical dispersion of a wide range of elements in regolith units at Poona and Wheal Hughes confirms increased levels of Cu, Au, Zn, Mn and REE in transported clay at or below the contact with carbonated-cemented surficial deposits (Hartley 2000). The highest levels were recorded in profiles at Poona and were associated with alunite patches and seams in the clay. Spectral identification of halloysite, associated with alunite, was confirmed by electron microscopy of the sediment. Migration of acidic fluids up into the overlying sedimentary clay and concentration, probably through evaporation, is thought to have resulted in crystallisation of atacamite and patchy alteration of the interstratified kaolinite/illite/smectite clay sediment to halloysite and alunite. Alunite was not observed in the sediments above Wheal Hughes lode and the presence of a 1-4 m thick unit of Cambrian sandstone between Moonta Porphyry and overlying Quaternary clays is believed to have modified groundwater flow and reduced the movement of elements into the clay.

CONCLUSIONS

Alteration mineralogy closely associated with Cu mineralisation in unweathered porphyry at Moonta is recognised in chemical changes in chlorite and muscovite. At the Poona Mine, Mg alteration of chlorite proved difficult to map while phengite alteration was limited to close proximity to the mineralised shear. At Poona, acid sulphate weathering results in a broad envelope of halloysite precipitated about the mineralised vein to around 80 m depth. A similar distribution is indicated for Wheal Hughes. Anomalous values of Cu and other metal element are present in the < 10 m thick transported clay above the ore zone provided the clay is in direct contact with weathered porphyry. Alunite and halloysite layers in transported clay result from chemical reaction between the clay and acidic pore water, most probably derived from sulphide weathering, and are therefore a favourable site for metal ion accumulation.

REFERENCES

- BOTH R.A., HAVER M.R., MENDIS D.P.J. & KELTY B.T. 1993. The Moonta copper deposits, South Australia: Geology and ore genesis of the Poona and Wheal Hughes ore bodies. *In*: FENOLL HACH-ALF, TORRES-RUIZ & GERVULLA eds. *Current Research in Geology Applied to Ore Deposits*, 49-52.
- BOTH R.A. MORALES-RUANO S. & GOLDING S.D. 2002. Fluid inclusion and stable isotope evidence for the origin of the Moonta copper-gold deposits, South Australia. *Geological Society of Australia Abstracts* **67**, p. 328.
- CONOR C.H.H. 2002. The Palaeo-Mesoproterozoic geology of northern Yorke Peninsula, South Australia: Hiltaba Suite-related alteration and mineralisation of the Moonta-Wallaroo Cu-Au District. South Australia. *Department for Primary Industries and Resources Report Book 2002/007*.
- JANZ J. 1990. *The mineralogy and paragenesis of the Poona Mine copper deposit*. Flinders University, B.Sc. Honours Thesis, unpublished.
- HARTLEY K.L. 2000. *Regolith studies of the Moonta copper mines, Yorke Peninsula, South Australia*. University of Melbourne, B.Sc.(Hons) thesis, unpublished.
- JACK R.L. 1917. The geology of the Moonta and Wallaroo Mining District. *South Australia. Geological Survey Bulletin* **6**, 135 pp.
- MAUGER A.J., KEELING J.L., LUONG L. & SCOTT K.M. 1997. Poona Copper Mine, Moonta South Australia: investigation of alteration mineralogy using short wave infrared analysis. *South Australia. Department of Primary Industry and Resources. Report Book 97/51*.
- RAYMOND O.L., FLETCHER I. & MCNAUGHTON N. 2002. Copper-gold mineral systems in the south-eastern Gawler Craton - Another Mt Isa Eastern succession? *Geological Society of Australia Abstracts* **67**, p. 69.