SUPERGENE DERIVED MCKINNONS GOLD DEPOSIT AND ASSOCIATED FEATURES IN THE SURROUNDING WEATHERED ROCK

[1]S.M. MARSHALL AND [2]K.M. SCOTT,

[1]*CRC LEME (University of Canberra), P.O Box 136, North Ryde, NSW 1670, Australia.*
[2]*CRC LEME (CSIRO), P.O. Box 136, North Ryde, NSW 1670, Australia.*

ABSTRACT

The McKinnons gold deposit (37 km south of Cobar) is located in the oxide zone above low grade pyrite-sphalerite galena mineralisation in the fresh rock. Pyrite occurs underneath and in the lower parts of the deposit, decreasing almost to nothing outward into barren wall rocks. In the weathered zone kaolinite gradually decreases towards mineralisation. Acid conditions created by the weathering of pyrite would have prevented the formation of kaolinite after chlorite in mineralised profiles. Acid conditions are also responsible for a colour gradient around the deposit, following removal of Fe and outward deposition into nearby and barren profiles. Fe was totally removed virtually from the upper part of the profile, whereas in the lower part of the profile fluctuating watertables led to incomplete removal. As a result, bleached colours are found overlying pink brown in the mineralised profile. Iron deposition is reflected by unusual colours in the profiles and as pisoliths. Antimony, As and Zn accompany Fe, and enriched pisoliths appear to occur below overburden around the deposit. Gold is supergene, concentrated in the profiles. It occurs in various forms, intimately associated with supergene minerals. Gold is likely to have originated in a rock pile that was once above the deposit. Supergene silica is associated with the gold mineralisation. Acid weathering of chlorite in mineralised profiles provided the silica.

Key words: Gold, silicification, pisoliths, pyrite, supergene, iron, iron oxides, weathered, mobilisation and remobilisation, ore, calcrete, deposit

INTRODUCTION

The McKinnons Gold Deposit is located 37 km south of Cobar. The mineralisation, 2.2 m tonnes @ 1.91 g/t Au occurs in the oxide zone above Au-poor, Zn-Pb-Ag mineralisation (Bywater et al. 1996). Initial studies of the deposit considered the Au to be epithermal in origin (Rugless & Elliott 1995; Bywater et al. 1996) but this paper presents arguments for a dominantly supergene origin.

A study of weathered profiles at the McKinnons gold deposit was carried out, with additional studies of a neighbouring smaller anomaly. Chemical analysis, X-ray diffraction and PIMA were the main methods used for this study. The two anomalies display the same characteristics approaching mineralisation.

Host rocks in the area are turbidites, similar to those found throughout the rest of the Cobar Region (Elliott et al. 1998). The barren profile at McKinnons is composed of quartz, muscovite, chlorite and carbonates (fresh turbidite), passing upward to quartz, muscovite, kaolinite and goethite when weathered. Transported overburden occurs at the top of the profile. The mineralised profile contains pyrite at the base, passing upward to hematite; there is no hematite in the upper part of the profile. Kaolinite is absent from the mineralised profile.

DISPERSION/ CONCENTRATION OF AU, ZN, SB, AS AND PB IN WEATHERED PROFILES

Significant amounts of Au, Zn, Sb, As and Pb are present in the unweathered zone underneath the McKinnons deposit (Elliott et al. 1998). The main gold mineralisation is entirely located within the oxide zone, only low values occurring in the fresh turbidite (below 0.3 ppm). Gold increases upward throughout the weathered profile, with values reaching 50 ppm in the bleached horizon. There is a lowering of Au values near the surface, most likely caused by rainwater movements through the top layer.

As pyrite and minor accompanying sulfides weather at depth, Zn is directly eliminated, Sb and As associate with the hematite formed after the pyrite and Pb is accommodated in plumbogummite/hindsdalite. Above 30 m, Sb, As and Fe are depleted, whilst Pb persists throughout the profile (Figure 1). Antimony, As and Fe reappear at the surface in the form of pisoliths.

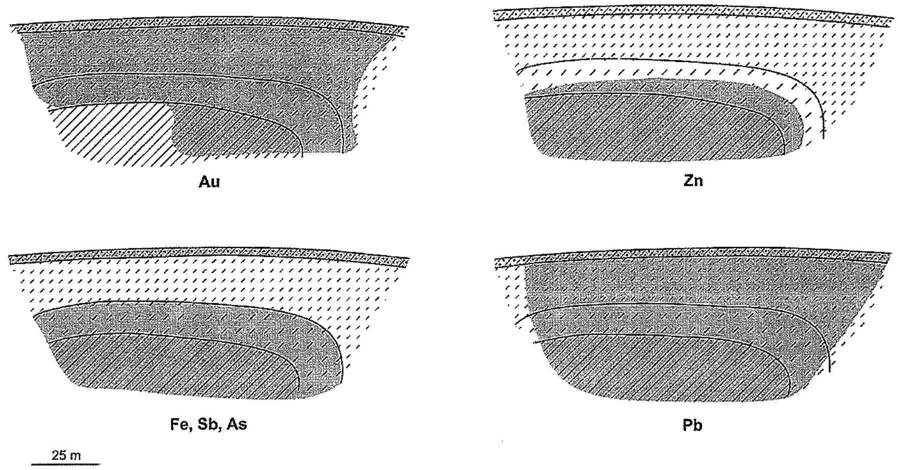


Fig. 1 Evolution of mineralised weathered profiles and anomaly at McKinnons.

Au from 0.3 to 50 ppm, Zn between 50 and 10000 ppm, As between 50 and 1500 ppm, Sb between 80 and 1000 ppm, Pb between 200 and 4000 ppm.

dark grey pyrite zone (containing minor amounts of other sulfides)
pink brown hematitic horizon
bleached horizon
top brown pisolitic horizon

COLOUR GRADIENT TOWARDS MINERALISATION

Mineralised profiles are dark grey at the base due to disseminated pyrite This evolves upward into a pink-brown coloured horizon, passing upward to a bleached horizon in the upper part of the profile (Figure 2) Barren profiles are pale grey at the base, passing upward to pale grey-mustard or beige-brown colour, evolving upward into mustard colours Around the deposit, profiles show intermediate grey colours at the base, owing to the presence of minor pyrite Purple-pink and beige-pink colours occur above that, passing upward into the bleached horizon Barren profiles show a continuous evolution of colours which contrasts with mineralised profiles Acid conditions have prevailed around the deposit, created by the weathering of pyrite. This created Fe mobility, with removal of some of the Fe and a lot of other elements. In the upper part of the mineralised profiles, a very long weathering period led to complete removal of Fe, hence the bleached horizon Under subsequent less stable conditions, Fe from pyrite was partially left behind to form hematite (pink-brown coloured horizon). The purple and pink colours from around the deposit indicate minor hematite precipitation. Goethite is responsible for mustard colours in barren profiles, chlorite and siderite from the fresh turbidite having provided the Fe

LANDSCAPE EVOLUTION AND LATERAL DISPERSION

Acid conditions created by the weathering of pyrite induced iron movement from the mineralised area into surrounding barren profiles The Fe partly removed from the pink-brown coloured zone may be expressed laterally as far as 1 km away, as pink-purple colours injected into otherwise barren profiles at a watertable level 40 m below the surface (Figure 2) The Fe removed from the bleached zone would have concentrated at a watertable near a surface that is now mostly eroded. This Fe was further dispersed mechanically and is now lying as pisoliths on a paleosurface buried under transported overburden Calcrete is found on the paleosurface, which can be observed as small lumps in RAB drilling and should also help identify the paleosurface Antimony and As are found accompanying Fe near the deposit, whilst Zn may be found accompanying Fe further away from the deposit. Antimony and As were found at the paleosurface 1 km away The lesser dispersion at the paleowatertable 40 m down resulted in Zn mostly being deposited at that distance

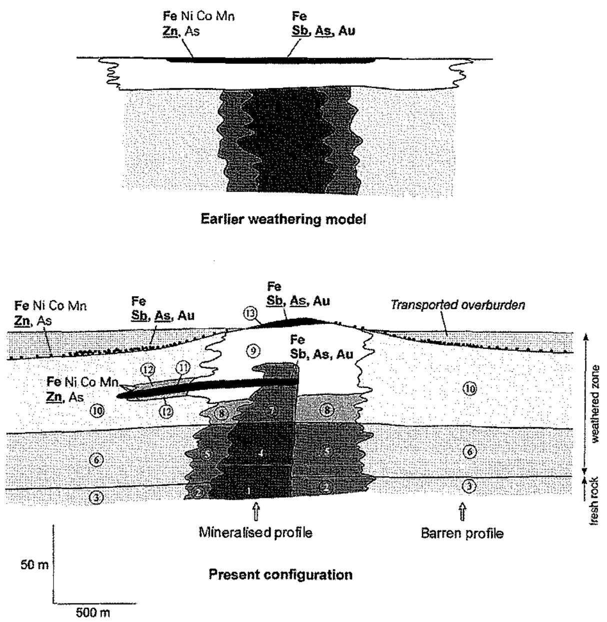


Fig. 2 Colour gradient and lateral dispersion around the McKinnons deposit.

Vertical scale has been made 10 times the horizontal scale for the sake of clarity.
The colour spread around the deposit is therefore much more extensive than it appears here.

① *dark grey*	⑦ *pink brown*
② *grey*	⑧ *purple pink and beige pink*
③ *pale grey*	⑨ *whites*
④ *dark grey beige*	⑩ *mustard*
⑤ *grey beige*	⑪ *purple red (minor purple brown)*
⑥ *mustard pale grey*	⑫ *purples*
	⑬ *brown, red brown*

SILICA FORMATION, A RESULT OF SUPERGENE ACTION

Silicification is found in mineralised weathered profiles as cementing of detrital grains by supergene silica. The original fabric of the rock can be seen and felt through the silica cement. Iron oxides can occur intermixed with the silica. Proportions of supergene silica and hydrothermal quartz were assessed in the various horizons of both mineralised and barren profiles (Table 1). Fluid inclusions studies of the supergene silica revealed small inclusions (2-5?m) that are single phase liquid inclusions, typical of a cool temperature environment. The inclusions occur both in the silica cement and silica fill along cracks. Much larger inclusions (20-30?m) occur in hydrothermal quartz as typical high temperature two phase inclusions.

Chlorite is likely to have provided Si for the supergene silica. Indeed kaolinite is absent from mineralised profiles, but is precipitated from chlorite elsewhere. Extreme acid weathering would be responsible for the formation of silica rather then kaolinite. Supergene silica can easily precipitate in such low drainage conditions as those observed here. A gentle sloping would be responsible for the lateral dispersion of some Si towards the lower part of the downslope barren profiles.

DEPOSITION OF GOLD IN THE SUPERGENE MINERALS MATRIX

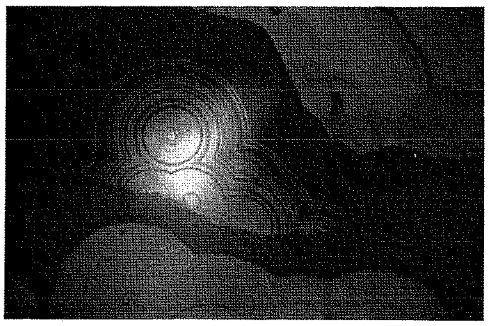
Gold was observed in hematite all the way down to the grey zone along oxidized fractures, with values reaching 50 ppm. The gold occurs within a particular layer of hematite, coprecipitated with the hematite. Hematite concretions are observed around the gold centres (Figure 3). Gold also deposited outside the hematite forming a coating on the outer surface of the concretions. Gold is also found precipitated within the illite matrix or together with the supergene silica, sometimes in pore fills.

As depth the Au occurs in pyrite (Bywater et al. 1996), Au is liberated and is likely deposited with illite and supergene silica forming at that time. Gold within the porous illite matrix and in open pores in the silica would have redissolved over time and precipitated in other pores of the same nature. This recycling of gold would have continued below the watertable prior to any drop in watertable levels. The gold coprecipitated with hematite would have formed during that period. Following each drop in watertable level, gold may have moved down, into illite and silica again and along fractures (as coatings along hematitic fractures for example). Low level pyrite

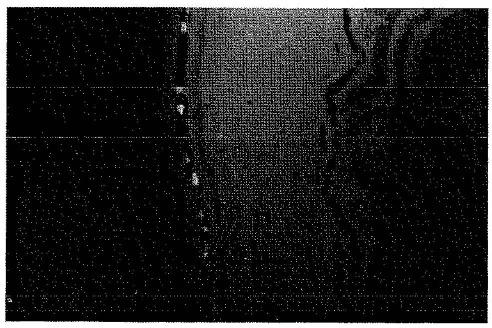
Table 1: *Proportions of Supergene Silica and Hydrothermal Quartz*

Various size fractions were isolated and weighed and the largest fractions had their proportions calculated through a system of grain counting and weighing

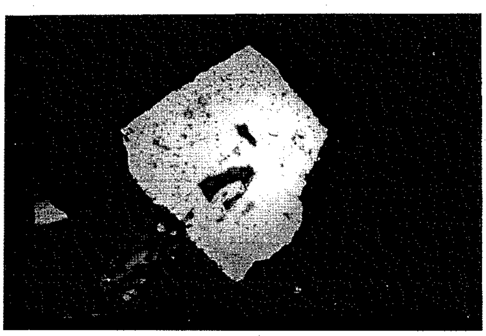
	TRUE DEPTH (M)	SUPERGENE SILICA	HYDROTHERMAL QUARTZ	DETRITAL QUARTZ
Mineralised profile				
Top brown pisolitic horizon	0-3	21%	1%	48%
Bleached horizon	3-25	23%	1%	41%
Pink brown hematitic horizon	25-60	18%	1%	41%
Dark grey pyrite zone (slightly oxidized)	60-75+	19%	1%	38%
Barren profile				
Mustard horizon	10-60	1%	0%	38%
Mustard grey horizon	60-95	6%	0%	48%
Ancient watertable accumulations (iron deposition)				
In minralised pink brown horizon	40	21%	0%	41%
In mustard horizon (otherwise barren), identifiable as purple injections	40	2%	0%	50%



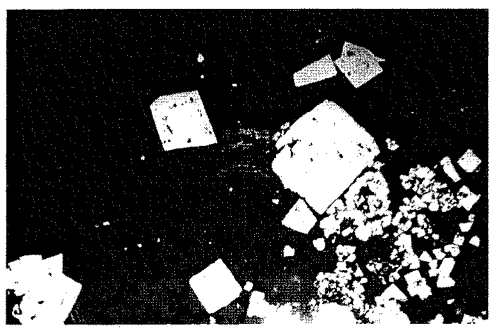
Gold at the center of hematite concretions
x 800



Gold coating the outer surface of hematite layer
(with later Au-free hematitic coating) x 400



Supergene pyrite containing inclusions of supergene silica
x 400



Supergene pyrites (large) against corroded primary pyrites (small)
x 160

Figure 3: *Some gold forms and features of the supergene pyrite*

mineralisation cannot account for all the gold found in the weathered profiles The gold in the weathered zone is likely to have come from prolonged accumulation of gold from above, the now eroded overlying rock. The same turbidite is likely to have occurred above and it is the gradual downward accumulation of gold that would be responsible for the gold ore at McKinnons

KAOLINITE GRADING INTO ILLITE IN THE MINERALISED ZONE

Kaolinite is absent from mineralised profiles, as extreme acid conditions created by the weathering of pyrite prevented its formation. Minor kaolinite is present in the top part of the grey zone, which is partially weathered, indicative of a recent change in underground water chemistry Jarosite is also found there There is a gradient in kaolinite abundance around the deposit, from kaolinite-rich barren profiles to kaolinite depleted profiles in the mineralised zone The gradient is a reflection of an increase in pyrite abundance towards the deposit and corresponding increase in acidity. The Portable Infrared Mineral Analyser (PIMA) proved useful in observing this kaolinite gradient. Locally kaolinite may be found neighbouring the zone of acid weathering, probably from delayed weathering of chlorite in areas of lower pyrite content. A poorly crystallised illite is the dominant clay in weathered mineralised profiles, evolved from the muscovite, again as a result of acid conditions in the mineralised zone Illite would also occur towards the top of some barren profiles as muscovite eventually decomposes, kaolinite remaining present in this case

SECONDARY PYRITE FORMATION DURING THE EARLY STAGES OF WEATHERING

Supergene pyrite as well as primary disseminated and vein pyrite is present in the upper part of the grey zone (top 15 m). Supergene pyrite is usually larger than primary disseminated pyrite and sometimes precipitated around a primary pyrite core. Supergene pyrite contains large inclusions of supergene silica as massive supergene silica occurs in this part of the grey zone (Figure 3). Supergene pyrite would occur in areas of primary pyrite concentration, as reducing conditions are retained there, whilst more disseminated primary pyrites are dissolving elsewhere The Fe and S for the supergene pyrite needs to have come from zones of pyrite oxidation, most likely 10 or 20 m away However microdomains of oxidation are likely to occur on the outside of the reducing zones, along microfractures for example. Because of this, supergene pyrite can be found against corroded primary pyrite on occasion (Figure 3) As reducing areas gradually disappear, supergene as well as primary pyrite oxidize and migration may occur to larger areas of pyrite concentration Primary pyrites contain As (0 6-0 8%) whilst supergene pyrites are low in As (<0.1%) although zones with 0 2% can occur Fe oxides after primary pyrite would thereby tend to be higher in As, providing a way to tell them apart even though they occur together

SUPERGENE PROCESSES - A SYNETHIS

Acid conditions created by the weathering of pyrite are responsible for the colour gradient and mineral evolution in weathered profiles at McKinnons Because of this, the colour gradient and the zone of gradual kaolinite depletion coincide, forming a supergene halo Kaolinite decreases gradually approaching mineralisation and is absent from mineralised profiles Iron removed from the mineralised profile and deposited further away, is responsible for the colour gradient Iron was completely removed from the upper part of the mineralised profile, whilst in the lower part some of the Fe was left behind Chalcophile elements were eliminated from the mineralised and nearby rock along with Fe Iron deposited in nearby profiles and at the level of paleo watertables mark periods of extensive remobilisation. Zinc, Sb and As accompany the Fe Watertable accumulations occur as red/brown colours in the profiles, and extend horizontally into barren profiles well beyond the zone of gradual kaolinite and colour change The ancient watertable accumulation near the surface was further dispersed as pisoliths that appear buried under overburden Kaolinite gradually decreases approaching mineralisation and is absent from mineralised profiles

The gold mineralisation, occurring in the weathered profiles, is likely to have originated in a rock pile that was once above the current deposit Intense weathering during the last 100 Ma or so (Leah, 1996), would have accumulated gold into the future bleached horizon, prior to erosion of overlying weathered profiles Bleaching subsequently occurred, with Fe spreading laterally at the much levelled Tertiary ground surface (Figure 2) During this extensive weathering period, the watertable would have remained close to the surface, undergoing only minor oscillations A subsequent drop in watertable level led to erosion and mechanical dispersion of the Fe oxide accumulation after the Tertiary (Figure 2) Strong watertable oscillations after the Late Tertiary prevented full bleaching in the lower part of mineralised profiles and pink brown colours are found there as a result. Minor stability during that period caused a minor Fe oxide accumulation to form at a watertable within that horizon, spreading laterally into barren profiles Following changes in drainage conditions between the two periods, this Fe accumulation was spread to one side of the deposit It gives rise to striking colours recognisable in drill spoil. Transported overburden now occurs on the eroded part of the Late Tertiary landscape, having apparently buried the Fe oxides from that surface Current arid conditions are reflected by a low watertable level, with oscillations apparently occurring in the grey zone A slight change in mineralogy is observed at that level Due to the low watertable, increased oxidation would now occur through the grey zone with rapid formation of Fe oxides As a result, the weathering upper grey zone would be exposed to less acid conditions than in the past and the mobility of Fe and that of other elements would be lower

Supergene silica is associated with gold mineralisation at McKinnons. Large amounts of silica are present through the various horizons, including the weathered upper grey zone (top15 m) Extreme acid conditions within the deposit zone would be responsible for the formation of silica from chlorite, whilst kaolinite was precipitated elsewhere Following the change in drainage conditions after the Tertiary, some silica was spread laterally into the lower part of down slope profiles. Nevertheless drainage remained limited which allowed silica to precipitate throughout the history of the deposit. In other areas where drainage may have been more active, similar mineral depositions may have formed without significant silica being deposited

ACKNOWLEDGMENTS

Burdekin Resources NL provided the background material for this work and imparted us with expert advice The people of Burdekin are greatly thanked for this support. The research was supported under the Australian Government's Cooperative Research Centre program

REFERENCES

Bywater, A., Johnston, C., Hall, C.R , Wallace-Bell, P. & Elliot, S M , 1996 Geology of the McKinnons gold deposit, Cobar, New South Wales in The Cobar Mineral Field - A 1996 Perspective (Eds WG Cook, AJH Ford, JJ McDermott, PN Standish, CL Stegman and TM Stegman), pp 279-291 (Australasian Institute of Mining and Metallurgy, Melbourne).

Elliott, S M , Bywater, A & Johnston, C , 1998 McKinnons gold deposit, Cobar in Geology of Australian and Papua New Guinean Mineral Deposits (Eds DA Berkman and DH McKenzie), pp 567-574 (Australasian Institute of Mining and. Metallurgy, Melbourne)

Leah, P A , 1996 Relict lateritic weathering in the Cobar district, New South Wales in The Cobar Mineral Field - a 1996 Perspective (Eds WG Cook, AJH Ford, JJ McDermott, PN Srandish, CL Stegman and TM Stegman), pp 157-177 (Australasian Institute of Mining and Metallurgy, Melbourne)

Rugless, C S., & Elliott, S M., 1995. Multielement geochemical exploration is deeply weathered terrain: the McKinnons gold deposit near Cobar, New South Wales, Australia - a case study 17th IGES Townsville, Australia (May, 1995), pp 100-102