

## AN INTEGRATED GEOCHEMICAL AND PARAMAGNETIC EXPLORATION AT THE MCKINNON'S GOLD DEPOSIT, COBAR, NSW

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### ABSTRACT

A geochemical and paramagnetic study has been carried out at the McKinnons gold mine to investigate the potential of acid insoluble residues from regolith samples as a sample medium in the search for buried gold deposits. Residues derived by sequential treatment of regolith samples with hot aqua regia and sulphuric acid are composed of quartz with a minor amount of muscovite.

Zones of enrichment in Cu, Zn, Pb, Ag, As, and Sb (as indicators of mineralisation) and depletion in K, Al, Fe, Mg, Ca, Na, Ti and Sr (as indicators of wall-rock alteration) in acid insoluble residues from regolith samples outline the gold deposit and also extend to the surface. Regolith samples also preserve a geochemical zonation characterised by enrichment in Cu, Pb, Ag, As, Sb, Ba, Bi and W, and depletion in Zn and Ni at the upper level of the deposit. The geochemical indices of  $Zn \times Pb \times As$ ,  $Cu \times Pb \times As$ ,  $Zn \times Pb$ ,  $Ca \times Na \times Sr$ ,  $(Zn \times Pb \times As)/(Ca \times Na \times Sr)$ ,  $(Zn \times Pb)/(Na \times Sr)$ ,  $(Cu \times Pb \times As)/(Zn \times Ni)$  and  $(Pb \times Ag \times Sb)/(Zn \times Ni)$  are useful indicators of mineralisation and associated hydrothermal alteration in the area studied. These indices define the gold mineralisation, and clearly distinguish between gold mineralised and barren areas. Electron paramagnetic resonance (EPR) signatures of the acid insoluble residues also show significant differences between mineralised and barren areas. A strong paramagnetic halo outlines the gold mineralisation, while barren areas have weak paramagnetism. The EPR spectra are considered to reflect lattice imperfections in quartz related to substitutions, with mineralised quartz containing more imperfections and substitutions.

Significant geochemical and paramagnetic expressions in acid insoluble residues from regolith samples at the surface above and adjacent to the McKinnons gold deposit demonstrate that this integrated exploration method has potential for detecting buried gold deposits in highly weathered terrains.

**Key words:** regolith, gold exploration, acid insoluble residues, geochemistry, EPR, McKinnons gold deposit

### INTRODUCTION

The McKinnons gold deposit, located 37 km southwest of Cobar, NSW (Figure 1) occurs in a highly prospective region for gold and base metal mineralisation. This study used acid insoluble residues of regolith samples for an integrated geochemical and paramagnetic exploration program. The objectives were: to determine the spatial distribution patterns of major, minor and trace elements, and EPR signal intensity, in the acid insoluble residues of regolith samples around the McKinnons gold mineralisation and its associated wall rock alteration; to examine geochemical zonality of the mineralisation system; and to define exploration vectors for buried ore deposits.

The method was developed from a series of studies by

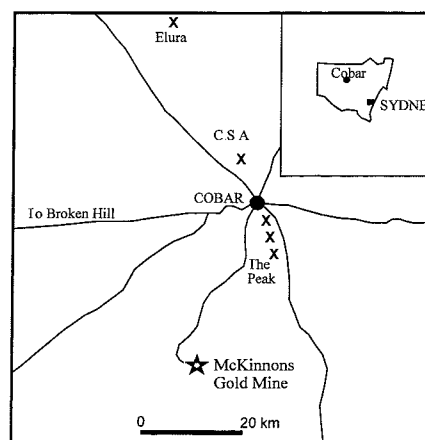


Figure 1: Location of McKinnons gold deposit

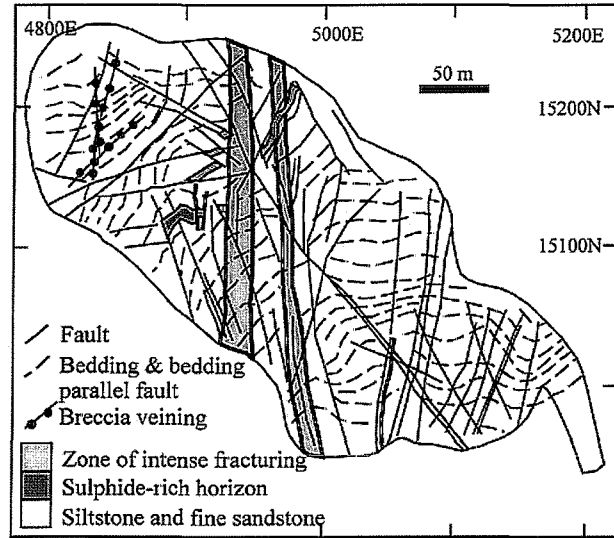
Aung Pwa et al. (1992), Aung Pwa (1995), Russell and van Moort (1998), van Moort et al. (1995) and Aung Pwa and van Moort (1998) on VHMS and gold mineralisation. The study at McKinnons follows initial regolith studies on gold deposits in the Tanami Desert, NT, Mt Percy, Kalgoorlie and the Rand Pit, Meekatharra, WA (Xu Li and van Moort, 1998; Stott et al., 1998).

Detailed geochemical and mineralogical studies of the McKinnons deposit have been undertaken by Rugless and Elliott (1995), Tan (1996) and Marshall et al. (1996). They all described geochemical and mineralogical signatures in relation to the McKinnons gold mineralisation and associated hydrothermal alteration. A large epithermal/mesothermal hydrothermal alteration system associated with the McKinnons gold mineralisation coincides with multielement geochemical halos in the primary zone. These are retained within the regolith. The saprolitic profile has preserved primary lithic fabrics. Rugless and Elliott (1995) found that both soil and lag geochemical techniques were useful in the initial exploration phase in the McKinnons area. The gold mineralisation is defined by multielement anomalies characterised by positive Sb, Mo, Ba, Ag and As, and negative Mn, Cu, Zn, Sn, P, V and Fe values. Marshall et al. (1996) indicate that the regolith profile over mineralisation can be distinguished from a barren one by the presence of illite. The barren profile contains muscovite and kaolinite.

## GEOLOGY AND MINERALISATION

The McKinnons deposit is located near the western margin of the Cobar Basin, and occurs in sedimentary rocks of the Amphitheatre Group of the Devonian Cobar Super group. These and similar rocks also host base metal and gold-copper deposits (e.g. Elura Pb-Zn, CSA Cu-Pb-Zn and Peak Au-Cu deposits) on the eastern margin of the basin (Glen, 1987). The host rocks mostly consist of weakly metamorphosed siltstones and sandstones deposited as distal turbidites in a shallow marine environment. The McKinnons deposit contained 2.2 Mt at 1.9 g/t Au (135,000 ozs) in the weathered zone (Bywater et al., 1996).

The deposit is structurally controlled, and mineralisation appears to follow the NW trending Nullawarra Anticline which has been effected by NE-SW and NS structures (Rugless and Elliott, 1995). Detailed geological mapping (Figure 2) has revealed four major structures associated with mineralisation (Bywater et al., 1996): a subvertical to easterly dipping  $330^\circ \pm 20^\circ$  trend; a subvertical  $010^\circ \pm 10^\circ$  trend; a subvertical to east dipping trend at  $035^\circ \pm 10^\circ$ ;



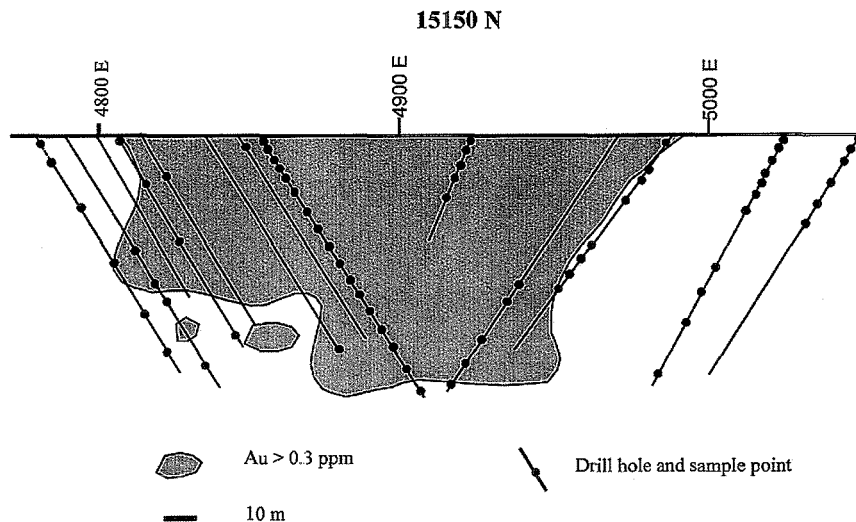
**Figure 2:** Interpretative geology map of McKinnon mine pit at 180RI (20 metres below the surface). Modified after Bywater et al. (1996).

and a subvertical  $090^\circ \pm 20^\circ$  trend. The intersection of these trends produced zones of intense fracturing and jointing and provided favourable conditions for ore fluid flow and consequently major mineralisation and associated alteration (silicification). Gold mineralisation occurs in the brecciated and silicified sediments associated with pyrite mineralisation. Numerous quartz veins are recognised near and around the mineralised zone. Silicification, sericitisation and clay alteration are the dominant alteration features associated with the McKinnons deposit (Rugless and Elliott, 1995; Bywater et al., 1996). Figure 3 shows gold mineralisation (more than 0.3 ppm; Marshall et al., 1996) along the mine section 15150 N. The mineralisation system at the McKinnons deposit is zoned with gold mineralisation near surface changing to gold-poor Zn-Pb-Ag sulphide mineralisation in unweathered rock at depths below 100 m (Bywater et al., 1996).

## WEATHERING PROFILE

Weathering profiles of the McKinnons area have been studied by Rugless and Elliott (1995), Tan (1996) and Marshall et al. (1996). Detail mineralogical and geochemical variation in the regolith horizons were cited in the last two papers.

Over the mineralised area the profile consists of brown pisoliths at the top; overlying an upper layer composed



**Figure 3:** Locations of drill holes and samples selected for this study (from Marshall et al., 1996)

of quartz, illite with a minor amount of kaolinite, muscovite and hematite/goethite; overlying white saprolite, consisting of quartz, clay minerals (mainly illite) and muscovite, and a lower zone of grey brown saprolite comprising quartz, clay mineral (illite), muscovite; pyrite, goethite and hematite. There is a significant difference in mineralogical composition between barren and mineralised profiles. The mineralised profile is mainly composed of quartz and illite in the upper level while the barren profile contains quartz, kaolinite and muscovite (Marshall et al., 1996). Mineralogical compositions at the lower levels of both profiles do not show significant difference between each other.

### SAMPLE SELECTION AND COLLECTION

This study involved a total of one hundred and one regolith samples from fourteen reverse circulation percussion drill holes. Eighty-eight powdered regolith samples from thirteen drill holes, of which twelve holes are located along the mine section 15150 N (Figure 3), were obtained from Marshall et al (1996). The other drill hole is MB4 which is known to be a barren hole. An additional thirteen regolith samples were collected by the authors from drill hole MKD 64 and crushed in a jaw crusher and ground in a swing mill to 75  $\mu\text{m}$ .

### SAMPLE PREPARATION AND ANALYSIS

#### SAMPLE PREPARATION

Two grams of each powdered sample were digested in 20ml of aqua regia (3 HCl: 1 HNO<sub>3</sub>) at 60°C for 12 hours in test tubes in order to remove iron and manganese

oxides and hydroxides, sulphides, carbonates and most sulphates. The test tubes were intermittently stirred with a glass rod. The acid was discarded, and the residues in the test tubes were washed once with distilled water. Then the residues in the test tubes were digested with concentrated H<sub>2</sub>SO<sub>4</sub> (15 ml) at 60°C for 12 hours to dissolve clay minerals. The acid was discarded, the residues in the test tubes were washed with distilled water four times, and dried in an oven at 90°C for 12 hours.

#### ANALYSIS

The study involved mineralogical determination by semi-quantitative X-ray diffraction (XRD), EPR measurement by electron spin resonance spectroscopy and chemical analyses by proton induced X-ray emission (PIXE) and proton induced gamma ray emission (PIGME) and ICP-MS.

X-ray diffraction (XRD) revealed that the residues are mainly composed of quartz (probably more than 90%), and a minor amount of mica. The surface soil samples consist partly of microcrystalline chalcedony aggregates with inclusions of iron oxide, and the deeper samples consist of quartz, with only a few inclusions. Quartz and mica are considered to be the sources of the various elements in the residues of the regolith samples. The chemical composition of the samples reflect the composition of these minerals, their lattice substitutions and also their inclusions.

EPR measurement was made on 100 mg of the residual powders from the acid leach. These were placed in a Wilmad annealed silica EPR tube inserted in a multipurpose cavity of a JEOL FE3X ESR spectrometer of the Central Science Laboratory at the University of Tasmania. Samples were subjected at room temperature to a microwave frequency of 9.15 GHz, 10 mW microwave power, modulation frequency at 100 KHz modulation width at 0.2 mT, amplitude at  $5 \times 10$  and a magnetic flux density with a median value of 326.5 mT. Spectra of the first derivative of the absorption of the microwave power were run over sweeps of  $326.5 \pm 5$  mT and  $326.5 \pm 100$  mT. The first spectrum ( $326.5 \pm 5$  mT) provides details of the shape of the central section of the spectrum. The large sweeps are all very similar and will not be further considered in this report. Instrument settings for EPR measurements were, except for instrument gain, the same as the ones used by van Moort and Russell (1987) for their study of the Beaconsfield gold deposit. The sweeps over  $326.5 \pm 5$  mT all show a rather strong signal at  $g \sim 2.0025$ . Because of the strength of the signal, the gain (amplitude) of the instrument was set at  $5 \times 10$ , five times less than in the standard condition routinely applied in our other EPR studies.

For chemical analysis (proton induced X-ray emission (PIXE) and proton induced gamma ray emission (PIGME)), residual powder samples were weighed and mechanically mixed with spectrographically pure graphite powder in a ratio of 4:1 (eg. 400 mg sample : 100 mg graphite powder) in an acrylic vial (containing an acrylic ball) for 10 minutes in a SPEX mixer. The mixed powder was pressed into a small aluminium cap (12 mm in diameter). Each sample was analysed for 22 elements, K, Fe, Ca, Ti, Mn, Cl, Ga, Rb, Sr, Zr, Y, Cu, Zn, Pb, Ni, As, V and Mo by PIXE, and Al, Na, Mg and F by PIGME on the 3MV van de Graaff accelerator at ANSTO, Lucas Heights, Sydney. A detailed discussion of this analytical method was recently presented by van Moort et al. (1995). The PIXE method is not suitable for some elements contained in the regolith residues from the McKinnons area (eg. Ag, Sb, Ba and W), particularly for low level concentrations.

Determination of Ag, Ba, Sb, Bi, W, Pb and Tl by ICP-MS for 66 acid insoluble residue samples from 12 drill holes along 15150 N section was arranged by Becquerel Laboratories, Lucas Heights, Sydney. These analyses were designed to examine possible geochemical zonality. It should be noted that Pb was determined by both PIXE and ICP-MS analyses and was used to compare the distribution patterns.

## ELEMENT DISTRIBUTION IN ACID INSOLUBLE RESIDUES FROM MINE THE SECTION

### 15150 N

Mine section 15150 N was selected to illustrate the spatial distribution of K, Al, Fe, Mg, Ca, Na, Ti, Cl, F, Ga, Rb, Sr, Zr, Y, Cu, Zn, Pb, Ni, As, V and Mo (by PIXE/PIGME) and Tl (by ICP-MS) in acid insoluble residues from the regolith across the McKinnons gold deposit.

### DISTRIBUTION OF K, AL, FE, CA, NA, MG AND TI

The major and minor elements are dealt with as a special group as they represent essentially the silicate minerals in the sediments and their alteration products. Spatial distributions of K, Al, Fe, Mg, Ca, Na and Ti in the acid insoluble residues of regolith samples along the 15150 N section reveal depletion of all these elements at the centre of the gold mineralisation which occurs along the intense fracture zones (between 4900 mE and 5000 mE) trending NS (Bywater et al., 1996). The concentrations of these elements tend to increase toward the eastern and western peripheries of the mineralised zone. Figure 4a shows a depletion zone of K (< 1.5%) within the gold mineralised zone, and an increased concentration toward the eastern and western peripheries.

### DISTRIBUTION OF CU, ZN, PB, NI, AS AND MO

The spatial distributions of Cu, Zn, Pb, Ni, As and Mo in the acid insoluble residues from regolith along the 15150 N section demonstrate that these elements show high values within the mineralised zone, although their distribution patterns are different to each other. Zinc and Ni are generally concentrated at the lower level of the mineralisation, and Cu, Pb, As and Mo are relatively enriched at the upper level. A zone of high Cu (> 4 ppm) occurs at the upper level and extends to the surface (Figure 4b). A zone of high Zn (> 5 ppm) occurs at the lower level of mineralised zone (Figure 4c). Lead also shows a significant zone of more than 50 ppm at the upper level (Figure 5a). These elements demonstrate a geochemical zonation associated with the gold mineralisation.

### OTHER TRACE ELEMENTS

Chlorine, F, Ga, Rb, Zr, Y, V and Tl are relatively depleted within the gold mineralised zone, and increase toward the periphery of the mineralised zone. Strontium is enriched in concentration in the upper regolith and depleted at the lower levels of the mineralised zone.

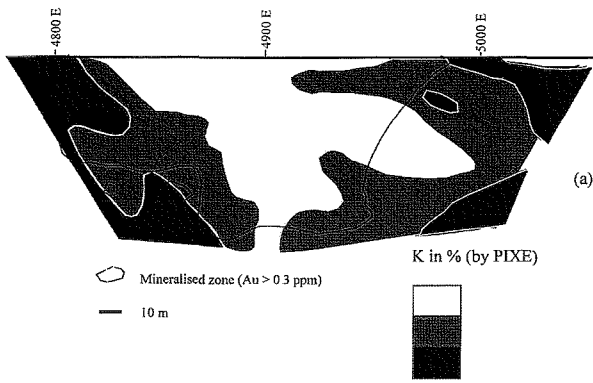


Figure 4(a): Distribution of K

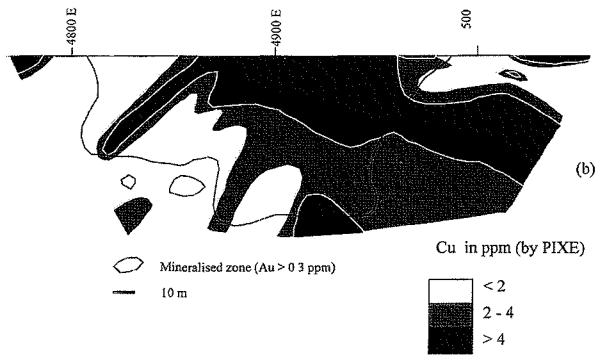


Figure 4(b): Distribution of Cu

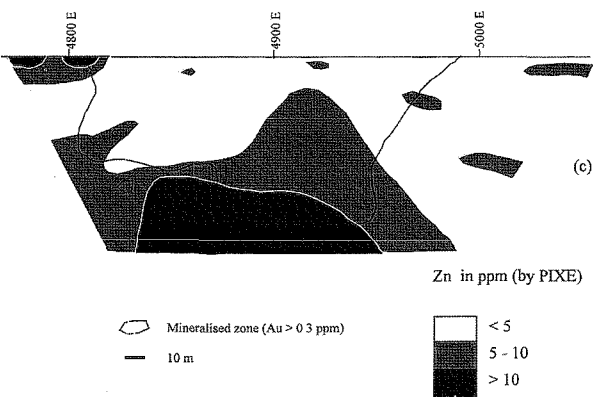


Figure 4(c): Distribution of Zn

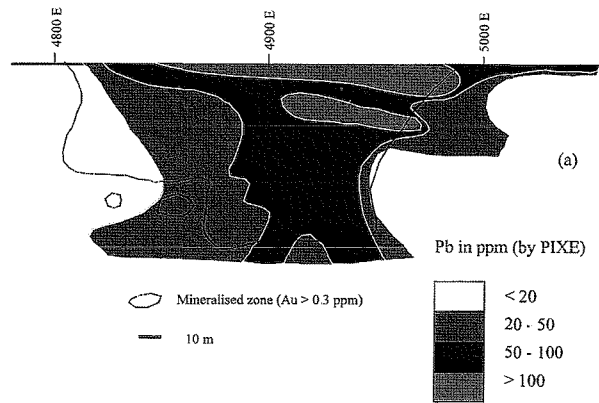


Figure 5(a): Distribution of Pb

**MULTIPLICATIVE INDICES AND RATIOS OF THE ELEMENTS DETERMINED**

A multiplicative index is defined as a multiplication of indicator elements (to detect mineralisation or wall rock alteration) and a multiplicative ratio is defined as a ratio of multiplicative indices. Halos, as defined by multiplicative indices are, in some cases, larger and more distinct than the geochemical halos defined by single elements. Multiplicative indices of multi-element data have been successfully used to delineate geochemical halos related to mineralisation (Grigorian, 1974; Beus and Grigorian, 1977; Rugless, 1983; Govett, 1983; Gundobin, 1984; Aung Pwa, 1995; Aung Pwa and van Moort, 1995). They are often used as an alternative to computer-based statistical methods such as discriminant analysis or factor analysis.

Multi-element indices used in this study include multiplicative indices and multiplicative ratios of both elements. The indices are presented as expressions of concentrations in ppm. Copper, Zn, Pb, As and Ni, which

are commonly enriched in the McKinnons mineralised zone are used as the indicators of the mineralisation, while Ca, Na and Sr are generally depleted in the alteration associated with mineralisation. The McKinnons gold deposit is well defined by multiplicative indices of  $Zn \times Pb$ ,  $Zn \times Pb \times As$ ,  $Cu \times Pb \times As$  and  $Zn \times Ni$  as indicators for mineralisation, and multiplicative ratios of  $(Zn \times Pb \times As)/(Ca \times Na \times Sr)$ , and  $(Zn \times Pb)/(Na \times Sr)$  possibly indicating the combined effect of mineralisation and alteration associated with the mineralisation. The distributions of  $Zn \times Pb$  and  $(Cu \times Pb \times As)/(Ca \times Na \times Sr)$  are shown in Figures 5b and 5c, and the McKinnons mineralised zone is associated with high values of  $Zn \times Pb (> 50)$  and  $(Cu \times Pb \times As)/(Ca \times Na \times Sr) \times 10^{-2} (> 1)$ .

The above multiplicative indices and ratios (except for  $Zn \times Ni$ ) reveal significant and extensive geochemical halos on the surface of the mineralised zone at McKinnons. A significant zone of high  $Zn \times Ni$  occurs at the lower level of the mineralisation. These indices and ratios imply enrichment in Cu, Zn, Pb, As and Ni, and depletion in Ca, Na and Sr within the mineralised zone.

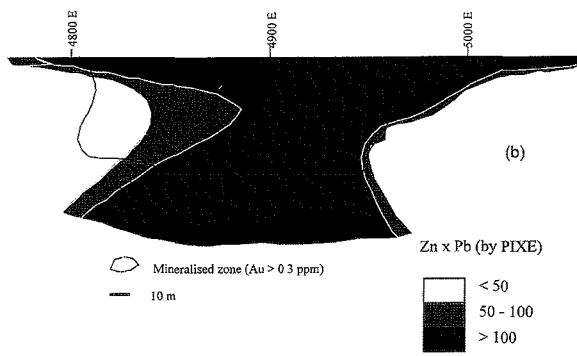


Figure 5(b): Distribution of Zn x Pb

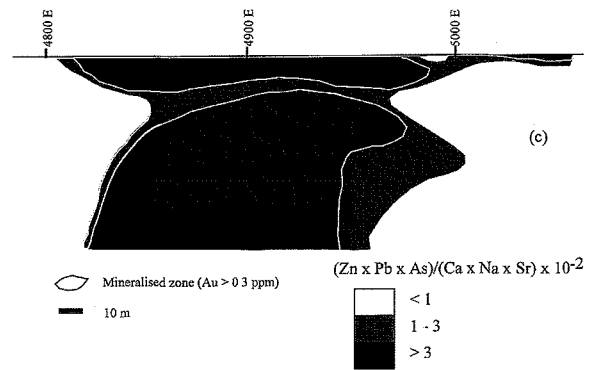


Figure 5(c): Distribution of  $(Zn \times Pb \times As)/(Ca \times Na \times Sr) \times 10^{-2}$

**COMPARISON OF GEOCHEMICAL SIGNATURES BETWEEN MINERALISED AND BARREN REGOLITH SAMPLES**

Geometric means of element concentrations in acid insoluble residues determined by PIXE/PIGME were used for a comparison of elemental abundance and geochemical indices between mineralised and barren areas. Most of the elements, except those associated with gold and base metal mineralisation, are depleted in the mineralised regolith. The depleted elements include K, Al, Fe, Mg, Ca, Na, Ti, Cl, F, Ga, Rb, Sr, Zr, Y and V (Table 1). Copper, Zn, Pb, As,  $(Zn \times Pb)$ ,  $(Zn \times Pb \times As)$ ,  $(Cu \times Pb \times As)$ , and  $(Cu \times Pb \times As)/(Zn \times Ni)$  as indicators for the gold and base metal mineralisation, exhibit higher values in the mineralised zone compared to the barren area. Figure 6 shows the binary relation of  $(Zn \times Pb)$  and  $(Cu \times Pb \times As)$  between mineralised and barren zones. More than 80% of the mineralised and barren samples are correctly classified as their respective group.

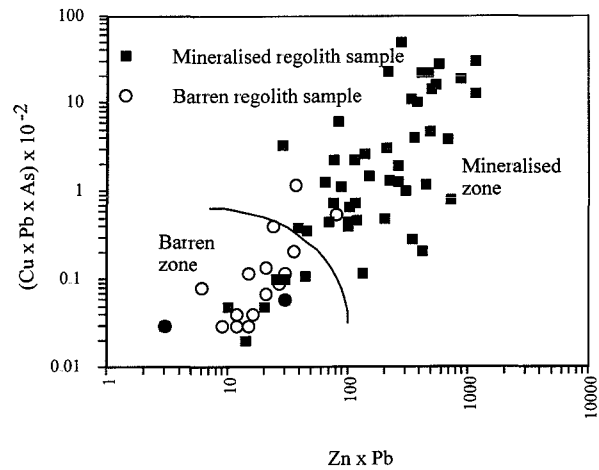


Figure 6: Binary relation of  $Zn \times Pb$  and  $(Cu \times Pb \times As) \times 10^{-2}$  (by PIXE) in the mineralised and barren regolith samples at McKinnons

Table 1 Comparison of geometric means of some element concentrations determined by PIXE/PIGME.

AREA	SAMPLE NO	K	Al	Fe	Mg	Ca	Na	Ti	Cl	F	Ga
Mineralised	65	1.15	2.32	0.17	0.04	0.010	0.02	0.21	55.01	284.25	6.45
Barren	19	1.40	3.01	0.26	0.05	0.012	0.24	0.34	71.67	304.75	7.16
AREA	SAMPLE NO	Rb	Sr	Zr	Y	V	Cu	Zn	Pb	As	
Mineralised	65	67.19	5.24	109.06	4.28	41.12	2.39	4.68	21.31	2.17	
Barren	19	72.47	8.07	178.08	10.11	65.16	1.90	4.10	4.19	1.06	

**GEOCHEMICAL ZONALITY**

Geochemical zoning within the McKinnons deposit was investigated by examining the distributions of Pb, Ag, Sb, Ba, Bi and W (by ICP-MS), and Zn, Ni, As and Mo (by PIXE) in the acid insoluble residues of the regolith samples. Sixty-six regolith samples from 12 drill holes along the 15150 N section were involved in this study.

The distributions of Pb, Ag, Sb, Ba, Bi and W in the acid insoluble residues of regolith samples (by ICP-MS) demonstrate that these elements are enriched at the upper level of the McKinnons mineralised zone and at the surface above the gold deposit compared to the lower level. Zones of high Ag (> 1 ppm) and Sb (> 20 ppm) occur at the upper level of the McKinnons mineralised zone (Figures 7a and 7b). The distribution of Pb by ICP-MS (not shown) is identical to that by PIXE. As discussed before, As and Mo (by PIXE) are also concentrated at the upper level, while Zn and Ni (by PIXE) are enriched at the lower level of mineralisation.

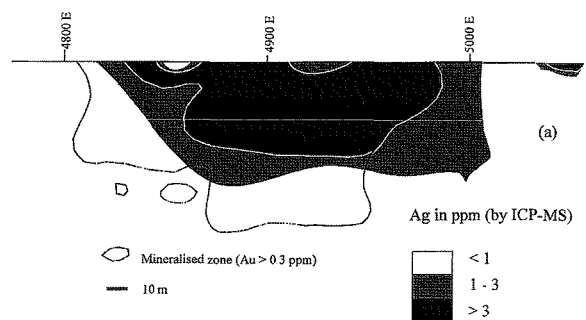


Figure 7(a): Distribution of Ag

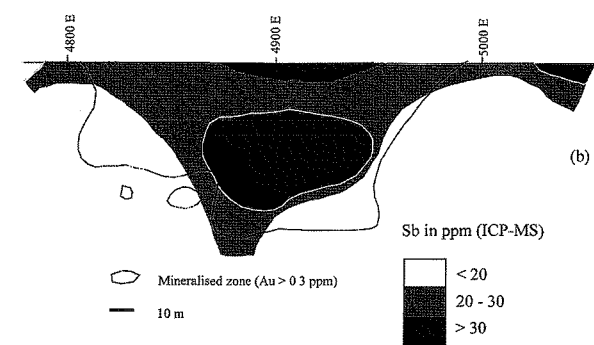


Figure 7(b): Distribution of Sb (by ICP-MS) in the acid insoluble residues of regolith samples from 15150 N section, McKinnons gold deposit

The multiplicative index  $(Pb \times Ag \times Sb)$  and ratios  $(Pb \times Ag \times Sb)/(Zn \times Ni)$  and  $(Cu \times Pb \times As)/(Zn \times Ni)$  are high at the upper level of the mineralised zone, and extensive on the surface, and decrease downward, indicating enrichment in Pb, Ag, As and Sb and depletion in Zn and Ni at the upper level of mineralisation. The distribution of the multiplicative

ratio values  $(Cu \times Pb \times As)/(Zn \times Ni) \times 10^{-1}$  shown in Figure 8 reveals a significant halo greater than 1 associated with the McKinnons mineralised zone. The halo is extensive at the surface and narrows at depth.

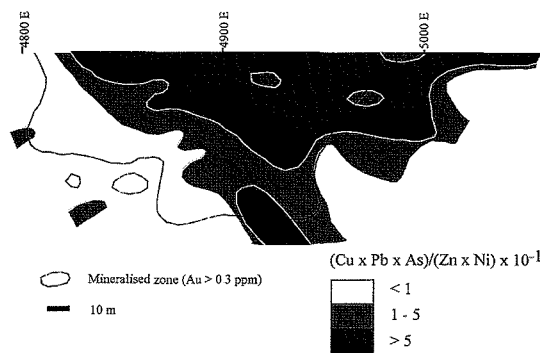


Figure 8: Distribution of  $(Cu \times Pb \times As)/(Zn \times Ni) \times 10^{-1}$  (by PIXE) in the acid insoluble residues of regolith samples from 15150 N Section, McKinnons gold deposit

The above geochemical signatures, together with the distribution of K, Al, Fe, Mg, Ca, Na, Ti and Tl make it possible to formulate specific geochemical zonality within the regolith. The signatures of major elements are considered to be a result of wall rock alteration during mineralisation. The geochemical halo in the regolith associated with the McKinnons gold deposit exhibits depletion in K, Al, Fe, Mg, Ca, Na, Ti, Cl, F, Ga, Rb, Zr, Y, V and Tl, and the halo is characterised by enrichment in Cu, Pb, Ag, As, Sb and possible Ba, Bi, Mo and W, and depletion in Zn and Ni at the upper level of mineralised zone or at the surface above the gold deposit (Figure 9). It should be noted that geochemical halos of ore associated elements particularly Pb, Ag, As, Sb, Mo and Bi are more extensive at the surface than major element halos.

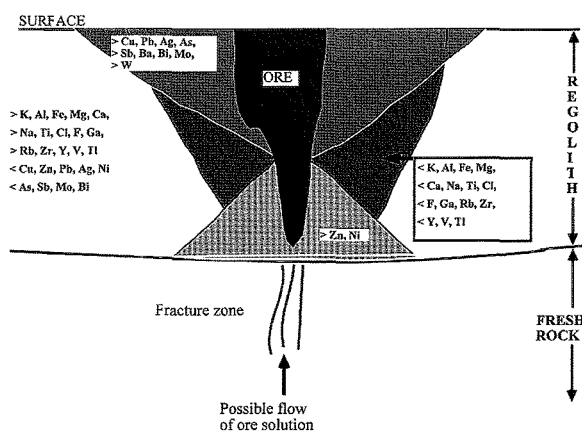


Figure 9: Geochemical zonality model associated with the McKinnons gold deposit

## ELECTRON PARAMAGNETIC RESONANCE

The EPR study is based on the major signal in quartz powder EPR spectra, observed between an effective spectroscopic splitting factor  $g = 2.0127$  and  $1.9969$  in X-band spectroscopy (Russell and van Moort, 1998). The intensities of these signals were measured on analogue charts. The signal is generally absent in quartz not related to mineralisation and represents lattice imperfections in general, and the presence of substitutional Al in the quartz lattice in particular.

Comparison of the spectra of barren and mineralised samples shows an obviously stronger signal in the mineralised samples compared to the barren hole (MB 4) sample (Figure 10). It is considered that the EPR spectra reflect the lattice imperfection in the quartz due to impurity substitutions which occur during mineralisation and alteration processes (van Moort and Barth, 1992).

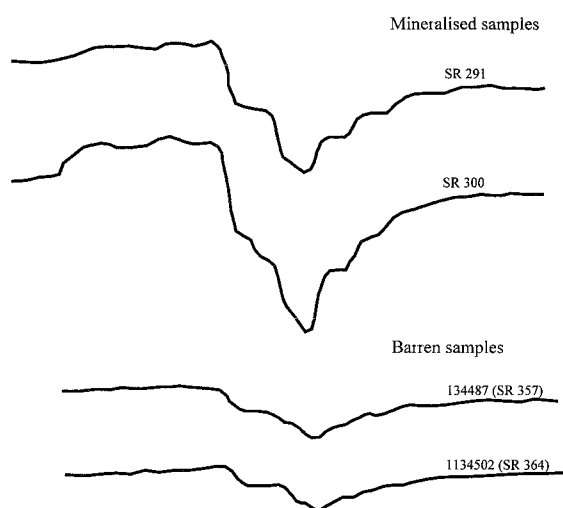


Figure 10: EPR spectra (observed in  $326.5 \pm 5 \text{ mT}$  sweeps) of mineralised and barren regolith samples

### DISTRIBUTION OF EPR SIGNAL INTENSITIES IN THE RESIDUES OF REGOLITH SAMPLES FROM MINE SECTION 15150 N

As with the geochemical study, samples were separated into two groups representing mineralised and barren areas respectively. The EPR signal intensities (measured at magnetic flux density sweeps  $326.5 \pm 5 \text{ mT}$ ) for regolith samples from the barren group vary from 0 to 5.5 cm and have a geometric mean of 1.2 cm. Those from the mineralised group range from 0.1 to 12.5 cm and have 5.3 cm geometric mean.

The distribution map of EPR intensities (measured at magnetic flux density sweeps of  $326.5 \pm 5 \text{ mT}$ ) in the drill core regolith samples from the 15150 N section (Figure 11) reveals a significant EPR halo or zone defined by values greater than 5 cm which outlines the McKinnons gold mineralised zone. The halo opens to the west suggesting mineralisation extends downward to the west. There is no significant extension of the EPR halo to the east beyond the gold mineralisation.

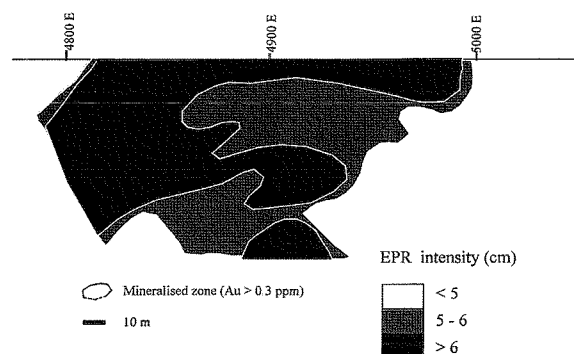


Figure 11: Distribution of EPR signal intensities measured at magnetic flux density sweeps  $326.5 \pm 5 \text{ mT}$  in the acid insoluble residues of regolith samples from 15150N section, McKinnons gold deposit.

## DISCUSSION AND CONCLUSIONS

### SAMPLE MEDIUM AND GEOCHEMICAL ANALYSES

Acid insoluble residues of regolith and soil samples (after sequential treatment with hot aqua regia and  $\text{H}_2\text{SO}_4$ ) are evaluated as an exploration medium by geochemical and EPR analyses. Semi-quantitative XRD analysis of these residues indicates that these are mainly quartz (> 90%) with minor mica. The chemical compositions of the samples thus reflect the composition of these minerals, their lattice substitutions and their inclusions. In previous studies of the Rosebery volcanic-hosted Zn-Pb-Cu-Ag-Au massive sulphide deposit, the residues of quartz powder samples (after hot  $\text{HNO}_3$  treatment) showed enrichment in K, Rb, Zn, Pb, Mn and Ba in the mineralised area compared to the barren area (Aung Pwa, 1995). Muscovites have principal isomorphous replacements of K by Na, Rb, and Ca; Al by Mg,  $\text{Fe}^{2+}$ ,  $\text{Fe}^{3+}$ , Mn, Li, Ti and V; (OH) by F (Deer et al., 1965). Variations of F, Na, Al, K, Rb and possibly Ti and V in acid leached silicate (jasperoid) powder at Carlin, Nevada, relate to the presence of sericite (van Moort et al., 1995) and this is also likely to be the case at the McKinnons gold deposit.



### GEOCHEMICAL SIGNATURES

The elements in the acid insoluble residues of regolith from the McKinnons gold deposit display both enrichment and depletion patterns within the mineralised zone. The enriched elements include Cu, Zn, Pb, Ag, As, Sb, Bi and Mo which are associated with gold and base metal mineralisation. They form a specific vertical geochemical zonation characterised by enrichment in Cu, Pb, Ag, As, Sb, Ba, Bi, Mo and W, and depletion in Zn and Ni at the upper level of the mineralisation. Hydrothermal gold deposits commonly show geochemical zoning, and vertical zonation features indicate the direction of the ore solution from depth (e.g. Beus and Grigorian, 1977; Boyle, 1979) through fracture zones. Depletion in K, Al, Fe, Mg, Ca, Na, Ti, Cl, F, Ga, Rb, Zr, Y, V and Tl are considered to be related to the hydrothermal alteration involving destruction of primary muscovite during the mineralisation processes which occurred along the intense fracture zones (between 4900 mE and 5000 mE) trending N5 (Bywater et al., 1996). Strontium is enriched in the upper regolith over the mineralised zone and depleted at the lower level. This may be related to the presence of barite. Gundobin (1984) also found that Sr concentrates in the peripheral zones and upper level of Au-Ag deposits.

The geochemical signatures at the McKinnons gold deposit are considered to be related to primary geochemical dispersions which were preserved in quartz and mica in the regolith. This supports the contention of Rugless and Elliott (1995), that a large hydrothermal alteration system which coincides with multielement geochemical halos in the primary zone of the gold deposit is retained within the regolith. Robertson and Taylor (1987) described extensive depletions in alkalis (Li, Na, K, Rb) and alkaline earths (Sr, Ba), Ti and C related to destruction of feldspar and white mica in fresh rocks around Cobalt-style mineralisation. This study extends these depletions into the weathered zone.

### EPR SIGNATURES

The EPR spectra reflect the lattice imperfections in the quartz due to substitution of impurities during mineralisation and alteration. The mineralised samples show stronger signals than the barren samples in accordance with other published EPR data (Russell and van Moort, 1998; van Moort et al., 1995).

The distribution map of EPR intensities in the acid insoluble residues of the regolith samples from the 15150 N section reveals a significant EPR halo or zone outlining the McKinnons gold mineralised zone.

### IMPLICATIONS FOR EXPLORATION

- (1) The acid insoluble residue of regolith is a useful sample medium for chemical analysis, as it preserves primary geochemical signatures from the fresh rock into the regolith.
- (2) Acid insoluble K, Al, Fe, Mg, Ca, Na, Ti, Cl, F, Ga, Rb, Zr, Y, V and Tl are depleted in the regolith in and around mineralisation indicating associated wall rock alteration.
- (3) Copper, Zn, Pb, Ag, As, Sb, Bi and Mo are enriched in the mineralised zone, and are useful indicator elements together with the multiplicative indices of  $(Zn \times Pb)$ ,  $(Zn \times Pb \times As)$ ,  $(Cu \times Pb \times As)$ ,  $(Pb \times Ag \times Sb)$  and  $(Zn \times Ni)$ , and the ratios of  $(Cu \times Pb \times As)/(Zn \times Ni)$  and  $(Pb \times Ag \times Sb)/(Zn \times Ni)$ . The multiplicative ratios of  $(Zn \times Pb \times As)/(Ca \times Na \times Sr)$ , and  $(Zn \times Pb)/(Na \times Sr)$  possibly indicate the combined effect of mineralisation and alteration and hence also define the McKinnons gold deposit.
- (4) High EPR intensities measured on the acid insoluble residues of the regolith are indicative of significant mineralisation.

### ACKNOWLEDGEMENTS

C.R.M. Butt (CRC LEME/CSIRO Exploration and Mining, Wembley WA) initially encouraged us to investigate geochemical and EPR response in the regolith samples from the McKinnons gold deposit. The assistance of S.M. Marshall and K.M. Scott, CRC LEME/CSIRO Exploration and Mining, North Ryde, NSW, who provided most of samples for this study, is acknowledged. A. Bywater (Burdekin Resources) assisted in the collection of some drill core samples. They all provided information on the geology of McKinnons deposit, and on regolith geochemistry and exploration in general. The Australian Institute of Nuclear Science and Engineering (AINSE) grant 97/079 provided the PIXE/PIGME analyses. Xu Li assisted with sample collection of McKinnons and at CSIRO, North Ryde. Xiachu Shen (Department of Applied Geology, University of New South Wales) is thanked for providing some samples from the McKinnons area.

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