

WEATHERING-CONTROLLED FRACTIONATION OF ORE AND PATHFINDER ELEMENTS AT COBAR, NSW

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INTRODUCTION

Polymetallic sulfide ores in the Cobar gold field (Figure 1) have undergone prolonged weathering where they have been exposed at the surface or intersected by the water table. This has led to oxidation, chemical leaching and element dispersion, variable supergene enrichment and eventual mechanical dispersal of the weathering products across an evolving landscape. In addition to predominant Au and Cu, the ores have associated Zn, Pb, Ag, Bi, As, Sb and W, which provide useful pathfinders for geochemical exploration. Understanding how these different ore and pathfinder elements behave during formation of the ore weathering profile and its subsequent dispersal is important for developing appropriate and robust geochemical exploration models in the region.

The regolith mineralogy and mineral distribution of major, minor and trace elements through the weathering profile have been investigated at three mineralised sites in the Cobar gold field. This has been linked with a study of residual and transported lag at these sites and an area down-catchment of the gold field.

AN IN SITU PROFILE

Mineralogical and geochemical trends at the New Cobar Au-Cu deposit indicate a progressive change in mineral hosts from primary sulfide and specific secondary minerals in the lower part of the weathering profile to more generic Fe- and Mn-oxides/oxyhydroxides towards the top (Figure 2). Goethite is an important host for Zn, Cu, As and to a lesser extent Pb, Bi and Sb. Hematite, where predominant, is an important host for Cu, Pb and Sb. Cryptomelane and alunite-jarosite group minerals are important hosts for Pb and As and lithiophorite for Co, Cu and Ni (Scott & McQueen 2000; 2001, McQueen *et al.* 2001). Geochemical data on bulk samples from the lower part of the oxidised zone show very poor correlation of ore and pathfinder elements with Fe because they are hosted by a range of secondary minerals and not just the iron oxides/oxyhydroxides (Figure 3). Closer to the surface, where most of the intermediate secondary minerals have been broken down, goethite and hematite are more important host minerals and a stronger correlation between these elements and Fe is evident in the bulk geochemical data (Figure 3).

NEAR-SURFACE PROFILES

At the Wood Duck and Peak South prospects (Figure 1) detailed mineralogical and geochemical investigation of the upper 15 m of the weathering profile indicates that there has been significant leaching of metals and sequestering of the remnant geochemical signal in goethite and hematite (Cairns *et al.* 2001). Bulk samples from near-surface RAB drilling at the Wood Duck prospect contain less than 450 ppm Cu, 100 ppm Zn, 150 ppm Pb, 10 ppm As and generally less than 20 ppb Au (with up to 180 ppb in several samples near the very top of the profile). Primary mineralisation contains 1.75% Cu and 2.23 g/t Au, with trace Pb and Zn. Marked positive correlation between Cu and Fe in the near surface oxidised zone is consistent with concentration of Cu in abundant hematite within the profile. Lead and Zn contents are not significantly correlated with Fe (Figure 3). Similar sampling at the Peak South prospect indicates less than 100 ppm Cu, 250 ppm Zn, 100 ppm Pb, 300 ppm As and less than 100 ppb Au. Primary mineralisation here contains 4.24% Zn, 1.72% Pb, <0.02% Cu and 0.4 g/t

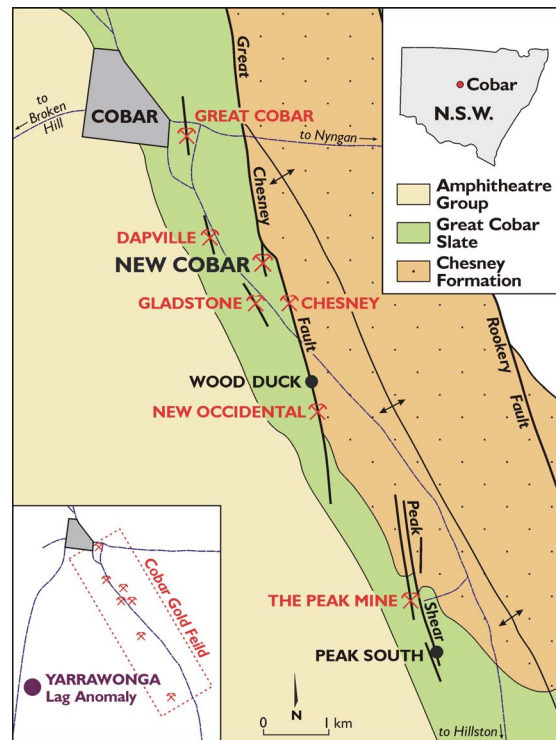


Figure 1: Location and geology of the Cobar gold field also showing known ore deposits and sites examined in this study. Insert shows the location of the Yarrowonga lag anomaly.

Au. Goethite is the predominant Fe phase in the weathering profile and there is marked positive correlation of Zn and As with Fe. Copper is low in abundance and does not show significant correlation with Fe. There is no apparent correlation between Pb and Fe contents (Figure 3). Ferruginous lag immediately overlying the mineralisation at these sites contains variable mixtures of hematite and goethite and anomalous concentrations of Cu, As, Zn and in some cases Au and Ag. These concentrations are significantly greater than in the underlying regolith. Sequential leaching analysis of these lag samples indicates that these elements are largely bound within the crystalline component of the iron oxide/oxyhydroxides (Cairns *et al.* 2001).

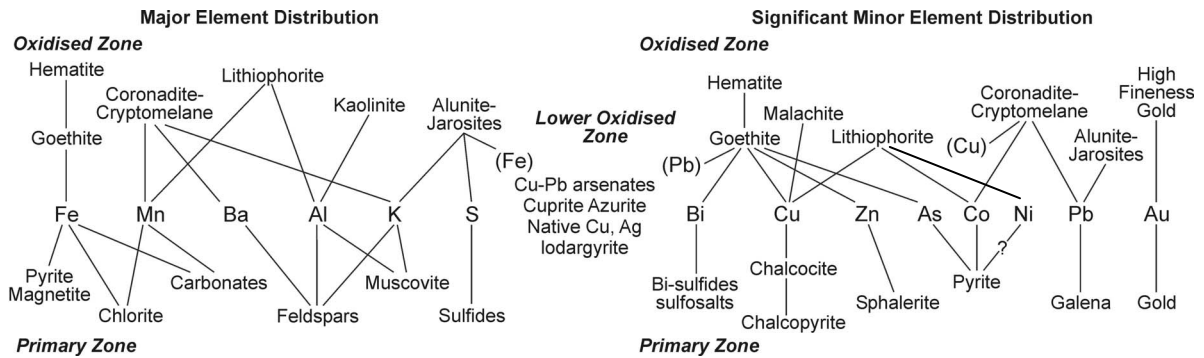


Figure 2: Connectagrams showing the mineral host pathways for major and minor elements through the primary and oxidised zones at the New Cobar deposit.

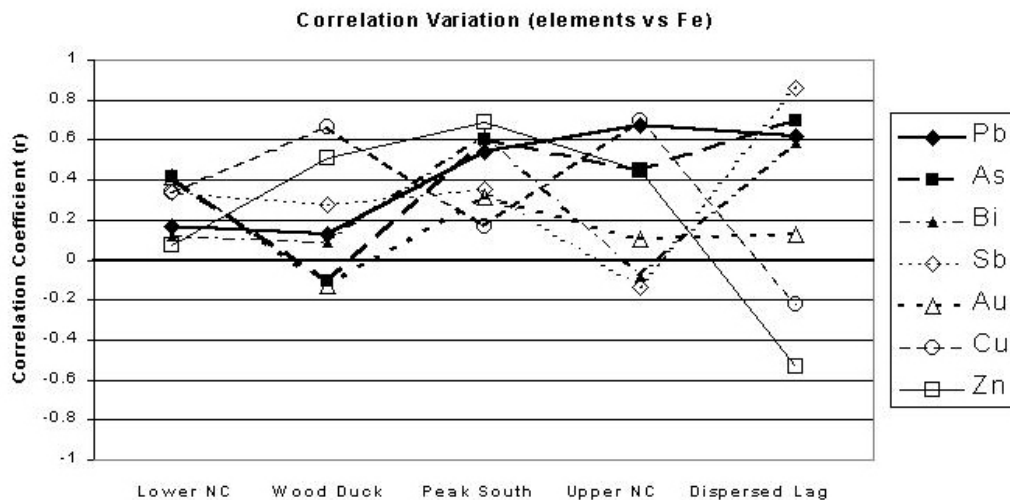


Figure 3: Correlation variation diagram showing correlation coefficients for Fe with pathfinder elements in the lower part of the New Cobar (NC) profile, the Wood Duck profile, the Peak South profile, upper part of the New Cobar profile and for dispersed lag at the Yarrowonga anomaly and up catchment. Geochemical analysis was by INAA and ICP OES.

DISTRIBUTED LAG

A detailed study was made of lag from the Yarrowonga anomaly located down-catchment of the Cobar gold field (Figure 1). Lag collected from 8 sites was subdivided into different fractions including: a micro lag component (< 120 μm), quartz lag, lithic lag, ferruginous lag and magnetic ferruginous lag. The last three categories were further subdivided into angular and rounded categories as an approximate means of separating the less reworked lag from the more reworked or transported lag. Geochemical trends (Figure 4) in the lag indicate progressive increase in Fe content with rounding and presumably exposure and transport/reworking. Some other elements including As, Pb, Sb, Bi and Ba show a similar increase suggesting that these elements are being stably fixed in the more Fe-rich lag and their relative abundance increased as the non Fe oxide components of the lag are leached and removed. This represents a type of weathering fractionation of these particular trace elements driven by chemical leaching and mechanical reworking. A good marker for this process is the Th versus Fe fractionation trend (Figure 4). The rounded (more reworked) ferruginous lag can contain up to twice the levels of Pb, As, Sb and Th found in the less Fe-

rich angular fraction. This suggests that lag geochemical data should be normalised to Fe content for these elements during interpretation.

Quantitative XRD analysis of representative lag samples from the Yarrowonga sites indicates that hematite (19-64 wt. %), quartz (16-54 wt. %) and muscovite (3-14 wt. %) are the dominant mineral constituents. The magnetic lag contains up to 15 wt. % maghemite, which is generally more abundant in the rounded fraction. Amorphous (poorly crystalline) components comprise 5-17 wt. % and lesser kaolinite up to 6.5 wt. %. Goethite comprises less than 2 wt. % in this lag.

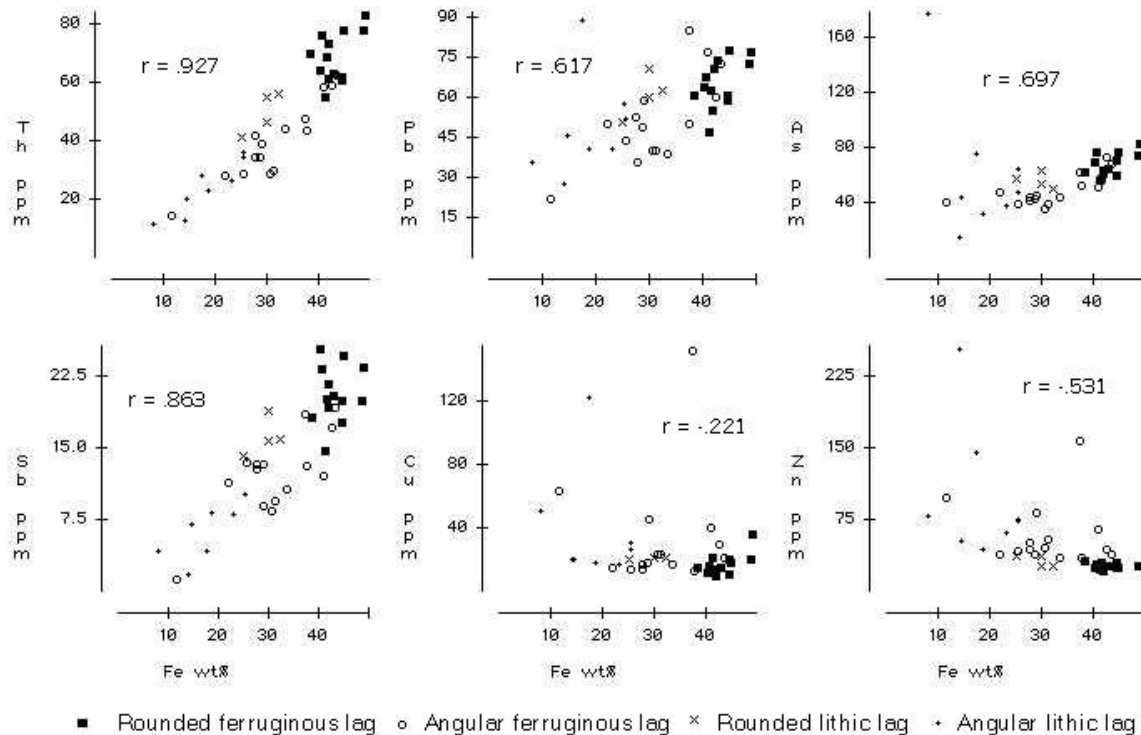


Figure 4: Bivariate plots of Fe versus pathfinder elements for lag samples from the Yarrowonga area. Each lag type has been subdivided into angular and rounded variants (r = correlation coefficient). Geochemical analysis was by INAA and ICP OES.

DISCUSSION

Due to their overall abundance and ability to incorporate trace elements and trace element mineral inclusions, iron oxides/oxyhydroxides are major hosts for ore and pathfinder elements in the upper part of the regolith. As primary and intermediate oxide minerals weather and break down a proportion of the released elements are fixed in goethite and hematite. Trends in the correlation variation for Fe with pathfinder elements (Figure 3) are consistent with the increasing importance of iron oxides/oxyhydroxides as major host phases up the weathering profile. Interestingly, Au is not well correlated with Fe or other elements and rather than being chemically linked to the iron phases it is probably present as dispersed elemental particles.

Progressive conversion of goethite-hematite assemblages in the weathering profile to dominant hematite \pm maghemite near surface and in lag, also has an important influence on the element dispersion pattern. Hematite selectively incorporates elements such as Pb, As, Sb, Bi, Ba, Cr and Th. With surface exposure, mechanical degradation, chemical leaching and additional precipitation of iron oxide, surface lag is enriched in Fe and these pathfinder elements (Figure 4). Mineralogical analysis indicates that this increased Fe content of the geochemically mature lag is essentially due to increased hematite content (Figure 5). Strong positive correlation between hematite content and the strongly Fe-correlated elements is consistent with hematite being the main host mineral for these elements in the mature and dispersed lag. This contrasts with the pattern for largely *in situ* lag at the Wood Duck and Peak South sites (Figure 5). Maghemite abundance is not significantly correlated with Fe content.

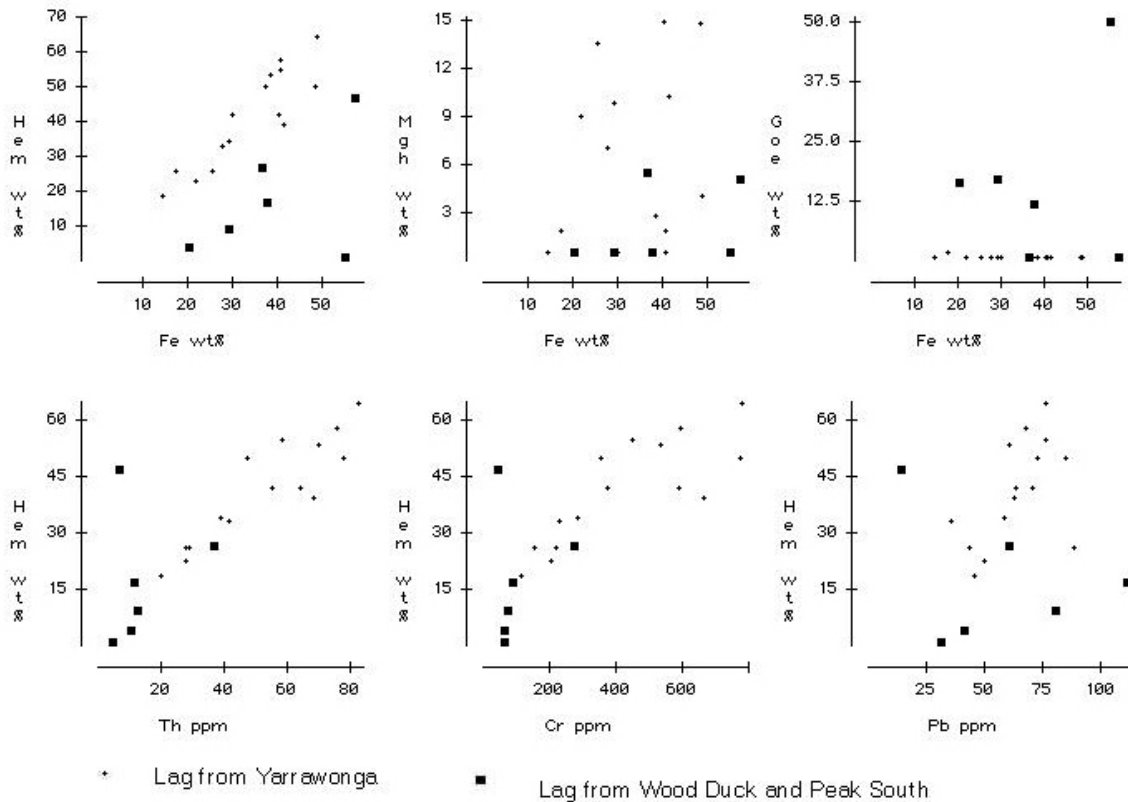


Figure 5: Bivariate plots of iron oxide/oxyhydroxide mineral contents with element abundance in lag from the Wood Duck, Peak South and Yarrowonga sites (Hem = hematite, Mgh = maghemite, Goe = Goethite). Mineralogical analysis by quantitative X-ray diffraction (SIROQUANT) and geochemical analysis by INAA.

CONCLUSIONS

To understand the behaviour of pathfinder elements in intensely weathered terrains it is important to identify their host minerals and understand how geochemical dispersion and weathering fractionation have affected the development of these minerals in different components of the regolith. The story can be complex. For example, in the Cobar gold field, Pb and As within deposit profiles show limited chemical mobility, but once fixed in goethite/hematite near-surface can become mechanically widely dispersed. The Cu and Zn signatures are typically broader around the deposit due to leaching and chemical dispersion, but become more strongly correlated with Fe closer to the surface where goethite-hematite assemblages take up these metals. Prolonged surface exposure of ferruginous materials leads to progressive conversion to hematite±maghemite, increase in overall Fe content and retention and relative concentration of Pb, As, Sb, Bi and Ba. This represents the end stages of a weathering fractionation of trace elements driven by chemical leaching and mechanical reworking. The process is indicated by a marked Th vs Fe fractionation trend. Interpretation of lag geochemistry should take into account the tendency for As, Pb, Bi and Sb in particular, to be relatively concentrated in the ferruginous component during surface exposure and transport. The overall weathering-driven fractionation process is summarised schematically in Figure 6.

REFERENCES

- CAIRNS C.J., MCQUEEN K.G. & LEAH P.A. 2001. Mineralogical controls on element dispersion in regolith over two mineralised shear zones near the Peak, Cobar, New South Wales. *Journal of Geochemical Exploration* **72**, 1-21.
- MCQUEEN K.G., SCOTT K.M., OGILVIE P.G. & CROWTHER B.R. 2001. Atlas of regolith materials from the weathered zone, New Cobar Deposit. CRC LEME **Restricted Report 162R/CSIRO Exploration and Mining Report 815R**, 25 pp.
- SCOTT K.M. & MCQUEEN K.G. 2000. The mineralogy and geochemistry of New Cobar Au-Cu mineralisation in the regolith and exploration implications for the Cobar district, Western NSW. CRC LEME **Restricted Report 137R/E&M Report 728R**, 35 pp.
- SCOTT K.M. & MCQUEEN K.G. 2001. The mineralogy and geochemistry of New Cobar Au-Cu mineralisation in the oxidate and supergene zones, Cobar district, Western NSW. CRC LEME **Restricted Report 167R/E&M Report 845R**, 36 pp.

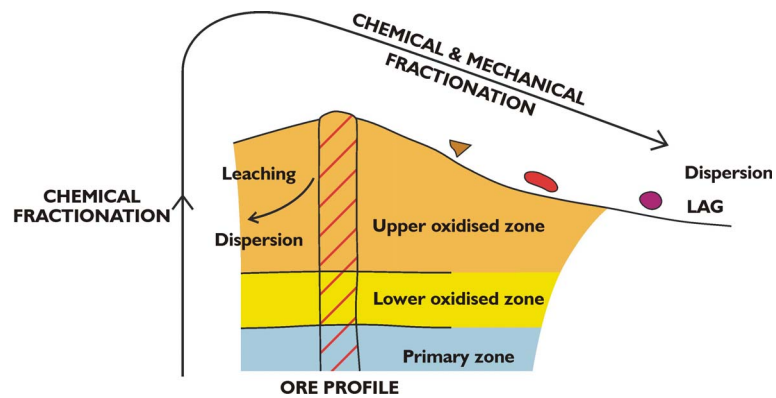


Figure 6: Schematic model summarising the weathering fractionation process.

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