GEOCHEMICAL DISPERSION IN RESIDUAL AND TRANSPORTED REGOLITH ALONG DRAINAGE SYSTEMS NEAR THE CSA MINE, COBAR, NEW SOUTH WALES

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In the vicinity of the CSA Mine, Cobar, New South Wales, partially stripped residual regolith is overlain by transported regolith of variable thickness (up to 40 m), including a series of modern and palaeo-drainage channels The transported regolith is composed of silt with gravel lenses containing clasts of ferrolithic lags, pisoids and vein quartz The ferruginous clasts are predominantly maghemite-rich, as indicated by their high magnetic susceptibility and patterns in the airborne magnetic images Goethite rims on maghemite clasts and Fe cementing of gravel matrices indicate some in-situ ferruginisation Metal dispersion patterns in the residual and adjacent transported regolith display three distinct geochemical associations These associations are all located in the vicinity of recent or palaeo-drainage channels Elevated concentrations of Cu-Zn-Mn±Au±Pb, in deeper parts of the saprolite, are coincident with extensive Zn-Cu anomalies in Chesney Formation siltstone, previously defined by shallow auger and RAB sampling Zinc levels are usually depleted in the upper part of the saprolite, except for a widespread but weak enhancement near surface (around 5 m depth) and at the interface with the transported regolith A series of weak, irregular Au anomalies occur at the base of near-surface carbonate accumulations and in association with zones of Fe enrichment deeper in the saprolite An As-Sb±Au association is observed in the residual regolith, especially along the faulted contact between the Chesney Formation siltstone and older Girilambone Group phyllites where recent transported cover is less than 5 m thick Arsenic is depleted in the upper saprolite but increases with depth The Au component of this association is most coherently developed at the base of the near-surface carbonate accumulation zones The As-Sb-Pb-Fe association is present in interbedded gravels and silts in a palaeo-channel of a tributary to Yanda Creek Persistent anomalies closely follow Fe concentrations but no primary As-Sb source has been detected in the underlying saprolite Goethitic rims on buried lag also tend to carry slightly elevated Cu concentrations Lateral transportation of these metals, along palaeo-channels extending from the CSA Mine, related to stripping of the upper portions of the weathered profile, seems likely In the transported regolith, the distribution of Cu and Zn appear largely correlated with Mn, whereas As, Sb and Pb are controlled by the Fe (lag) abundance

Key words: lag, maghemite, saprolite, carbonate, palaeo-drainage

INTRODUCTION

Deep weathering and sporadic transported regolith are two features of the gently undulating Cobar region (Gibson 1996) Where transported regolith is developed, reliance is placed on the use of auger or rotary air blast (RAB) drilling, however, recognition of the boundary with underlying saprolite is often uncertain in bottom-of-hole programs (Ford 1996) Geochemical studies in the Cobar region published by Dunlop *et al* (1983), Govett *et al* (1984), Taylor *et al* (1984), Alipour *et al* (1997), together with the review by Cohen *et al* (1996), largely focus on residual profiles or adjacent areas with thin veneers of transported regolith Investigation of geochemical patterns in deeper transported regolith and the underlying saprolite are lacking in this region

A reverse circulation (RC) drilling program through drainage channels in the vicinity of the CSA Mine was carried out by Cobar Mines Pty Ltd to examine patterns of Au and base metal dispersion in residual and transported regolith This drilling program followed the delineation of several Au and base metal anomalies by an earlier auger and RAB drilling program designed to sample upper saprolite, though no metal sources of economic interest were found This study examines geochemical associations and discusses possible controls on the distribution of trace and major elements within the RC profiles

DESCRIPTION OF STUDY AREA

In the study area, located around 13 km north of Cobar, New South Wales, outcrop is generally poor Gold and base metal mineralisation in the Cobar mineral field is hosted by slates, siltstones and sandstones of the Devonian Cobar Supergroup, and includes The Peak (Au), Elura (Zn-Pb) and CSA (Cu-Zn) deposits To the northeast of the CSA Mine, the Cobar Supergroup includes the Biddabira Formation and Upper Amphitheatre Group, CSA Siltstone, Great Cobar Slate and the Chesney Formation (Figure 1) and is unconformably bounded in the east by the Ordovician Girilambone Group phyllites

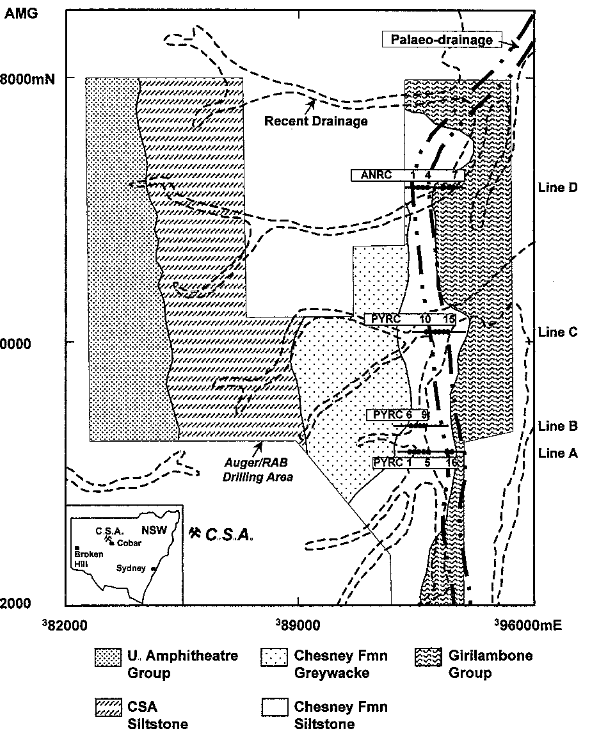

Figure 1. *Map of the CSA Mine area with location of palaeo- and modern drainage channels Geology is based on auger/RAB data provided by Cobar Mines The position of the palaeo-drainage channel is based on Ford (1996).*

The primary deep weathering profile in the area has mostly been stripped to the lower saprolite, removing any mottled zone and old cappings that may have existed Some remnant mottled zones are preserved at various localities The remaining profile is covered by a thin (< 1 m) layer of residual and colluvial soil in erosional landforms The contact between the saprolite and fresh bedrock may reach 80 - 100 m below the surface In the depositional regimes, the residual profiles can be overlain by up to 40 m of transported regolith, usually in the form of channel fill

Erosion in the Cobar region is chiefly by sheet erosion and gullying Drainage systems in the area are tributaries of the intermittent Yanda Creek and consist of both present day channels and palaeo-channels Soils are dominantly massive red earths (reddish brown loam and clay loam with a thickness of less than 2 m; Walker 1978) that shows little profile differentiation Jessup (1961a,b) has suggested that the soils in this area are not entirely residual and contain an aeolian component derived from the west

The composition and thickness of the transported regolith is dependent upon whether the associated drainage channel is modern, ancient or at the intersection of the two The transported regolith developed in a recent drainage channel is generally 1 to 4 m thick and consists of a discontinuous and weakly calcareous soil layer, usually within the top 1 or 2 m, and a hardened clay-rich or ferruginous layer Buried lags are rare within the soil layer, but common to abundant in the underlying layers The main palaeo-channel around PYRC16 is slightly elevated and contains abundant pisoids (mostly magnetic), ferrolithic/lithic lags, vein quartz and rounded quartzite gravels in a matrix of either kaolinite clay, sand or highly ferruginous material The palaeosol appears to have been partially removed during the process of topographic inversion Transported regolith at the intersections of the recent and palaeo-channels exhibits a soil layer at the top of the profile, a ferricrete within the upper to middle parts of the channels, and a clay rich, bleached "mottled zone" in the deeper parts of the channels.

Calcrete occurs as thin crusts overlying outcrops in shallow gullies Pedogenic carbonate occurs in the top few metres of profiles Calcrete developed near the interface between bedrock and overburden commonly forms coatings around saprolitic fragments and cavity fills The lateral variability of the calcretes is highlighted by the difficulty in correlating between drill hole intersections only 30 m apart (Ford 1996). Silcrete is less common than calcrete but shows similar lateral variability. Silcrete is usually located near the top of bleached clay horizons, and varies from weakly silicified clay layers to lenses of chalcedonic quartz (Ford 1996).

The climate is semi-arid, with a median annual rainfall of about 400 mm. The vegetation cover is sparse, partly due to the extensive clearing during the early part of this century, and mainly consists of Bimble Box-Cypress Pine associations

SAMPLING, ANALYSIS AND DATA PROCESSING

A total of 620 profile samples were obtained at 1 metre intervals from 24 RC drill holes on four traverse lines (Figure 1). Milled sample splits were digested in a mixture of nitric-perchloric-HF and analysed by ICP-AES for Cu, Pb, Zn, As, Sb, Bi, Ag, Ca, Mn and Fe. Gold was determined on samples, following aqua-regia digestion, by GF-AAS (with Zeeman background correction). The magnetic susceptibility (MS) of the samples was also measured.

X-ray diffractometry and XRF have been used to establish mineralogy and help define the weathering profiles. XRD traces of 95 samples (75 for bulk mineralogical analysis and 25 for clay fraction analysis) were recorded on a Phillips X'Pert system using monochromatised CuKα radiation (40 kV, 30 mA) over a two theta angular range of 2 - 70° (bulk samples) or 2 - 30° (oriented clay separates) at approximately 1° per minute. The presence (or absence) of various Fe-oxide species was determined by comparison against the PDF database (ICDD, 1997). XRF major and trace element analysis (pressed powders) was performed using a Philips PW2400 for 49 samples.

For subsequent bar plots and correlation analysis, trace element values have been truncated at the outer fence [$Q_3 + 3 (Q_3 - Q_1)$, where Q_1 is the 1st quartile and Q_3 is the 3rd quartile]. The MS data is reported in SI units ($\times 10^{-5}$) and has been $\log_e$-transformed for the bar plots.

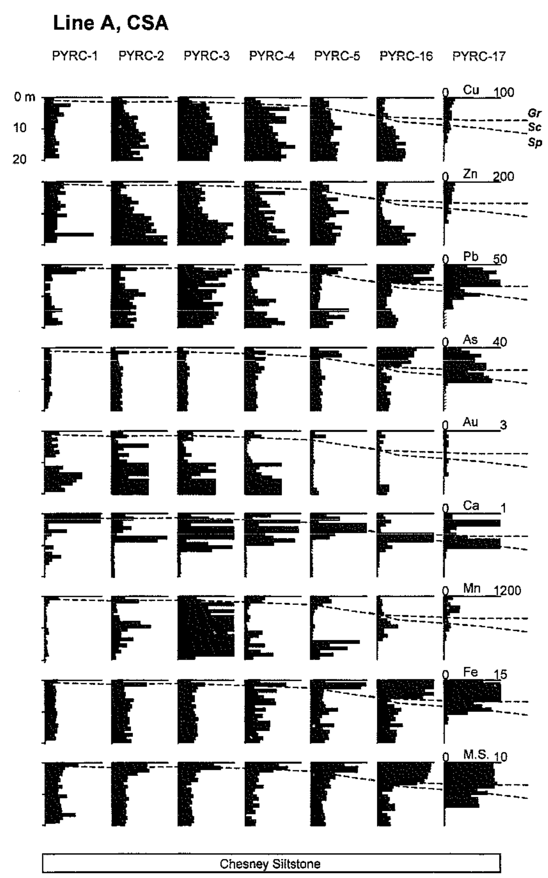

Figure 2. *Element distributions for RC drilling line A. Values of Cu, Zn, Pb, As and Mn are in ppm, Au in ppb; Ca and Fe in %; and MS in SI units x10⁻⁵. Holes PYRC-1 to 5 are located in the present drainage channel and PYRC-16 and 17 in a palaeo-channel. Regolith units: Gr - Gravel zone; Sc - Sandy clay; Sp - Saprolite. The top metre of the drilling profile is typically soil or recent sediments (clay, silt) and is not shown in the figure.*

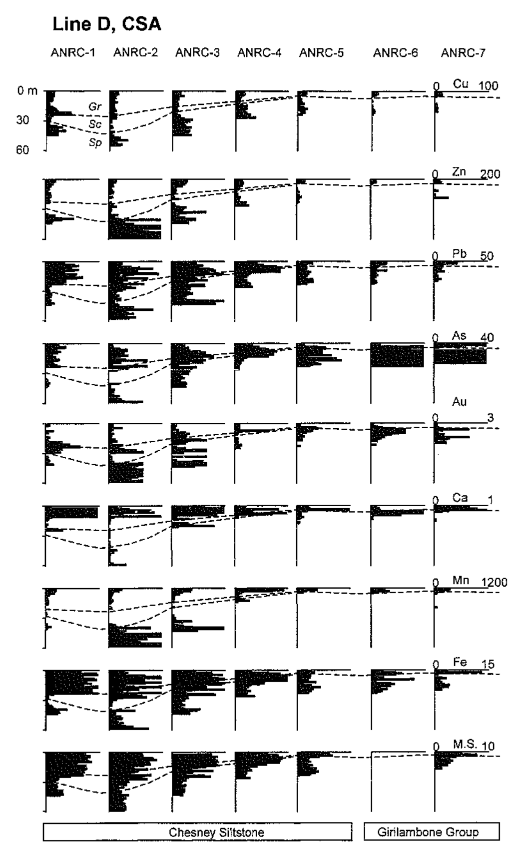

Figure 3. *Element distributions for RC drilling line D. Holes ANRC-1 to 4 lie within the intersection between the present drainage and the palaeo-channel and ANRC-5 to 7 are in a recent channel. Other notes as in Figure 2.*

GEOCHEMICAL PATTERNS

Figures 2 and 3 display variations in MS and the Cu, Pb, Zn, As, Au, Ca, Mn and Fe concentrations for RC drill holes on lines A and D The patterns indicate the presence of three main element associations

Cu-Zn-Mn±Au±Pb association

On lines A and D (Figures 2 and 3) elevated Cu and Zn values are present in the lower part of the saprolite, forming part of an extensive Cu-Zn feature in the Chesney Formation The Zn values range from 50 - 250 ppm and Cu from 35 - 105 ppm. The prominent Zn feature in the lower part of ANRC2 (up to 900 ppm) is strongly correlated with Fe. No sulphides have been observed in this hole and S values are less than 120 ppm Zinc concentration typically decreases upwards the saprolite, being relatively depleted at the top, in contrast to the weak Pb component that shows no such depletion The pattern for Mn is spatially more restricted than Cu-Zn, with depletion in the upper saprolite Within the zones of elevated Cu-Zn there are narrower zones of weakly enhanced Au values, typically 1 - 20 ppb. The peak value was 49 ppb in the base of ANRC2. In the upper 5 m section of the silts and gravels (the transported regolith in the recent drainage line) enhanced Mn levels are associated with very weak Zn and to a lesser extent Cu accumulation. This may be coincident with, or underlain by, dolomitic carbonate development in both recent and palaeo-drainage lines, and includes thin zones of weak Au enhancement (0 5 - 1 ppb) in the lower parts At the base of the transported regolith and the top of the saprolite, sporadic, weakly enhanced Cu values are associated with higher Fe and lower MS This reflects goethite development, as confirmed by XRD

In the upper part of the saprolite and the base of the transported regolith, enhanced Au values occur immediately below, and in some cases just above, more extensive zones of patchy carbonate development (Figure 3), while in the lower part of the saprolite Au is in part associated with weak Fe and carbonate enrichment. The 33 samples with > 2 % Ca were isolated from the total dataset The relationship between Au and Ca in these calcareous samples is ambiguous: a few samples showing a significant correlation, but others bearing no correlation In some cases, however, a close spatial relationship between Au and Ca can be observed in samples with locally elevated Ca In one section of hole ANRC1 on line D, for instance, contents of Au and Ca increase sympathetically towards the boundary between the gravel zone and sandy clay zone in the transported regolith (Figure 4)

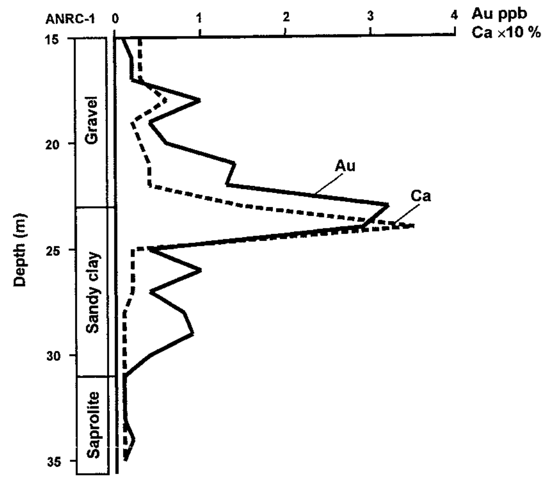

Figure 4. *Comparison of Au and Ca distributions near the boundary between the gravel zone and sandy clay zone in ANRC1.*

As-Sb-Pb-Fe association

Weak but persistent anomalous As values (10 - 35 ppm), Sb (1 - 7 ppm), Pb (20 - 45 ppm) (±Bi) are associated with strongly elevated Fe levels of 10 - 20 % related to gravel horizons interbedded with silts These gravel units range in thickness from 2 to 25 m (with 1 - 6 m on individual gravel lenses) and are developed in both palaeo-drainage and recent drainage lines. These gravels contain well rounded vein quartz and a range of ferrolithic and massive pisolithic fragments Internal textures suggest complex histories of accretion and disintegration similar to those reported by Alipour *et al.* (1996) from surface lags in other parts of the Cobar district.

This association is closely linked to the distribution of magnetic lag, as indicated by the MS values for individual samples, the airborne magnetic images and the correlations between the various trace elements, Fe and MS (Figure 5). The XRD traces for lags collected from different depths indicated abundant maghemite (Figure 6b-d). Maghemite is dominant in pisoids and detrital massive lags, and common to abundant in ferrolithic lags, as revealed by the polished sections.

Though a strong correlation between Fe and As and between Fe and Pb is indicated by the scatterplots, these elements show lower metal/Fe ratios in the upper gravel layers where the higher MS values suggests an increase in the maghemite/hematite ratio In the lower parts of the gravel units and contacts with adjacent silts and saprolite, patchy goethite development can be observed Polished sections indicate that the goethite occurs in the matrices of the gravel and partially replaces the hematite-maghemite rich clasts. Such zones are reflected by lower relative MS values and the presence of XRD goethite peaks (Figure 6). In and immediately adjacent to such sites, localised high As to Fe ratios occur (Figure 7), suggesting limited mobilisation and reprecipitation of As and probably Pb In the near surface zones of the transported regolith the As-Sb-Pb-Fe association is not reflected along the recent drainage line where silt is accumulating and lags are sparse. However, along the palaeo-drainage line, where landscape inversion has resulted in partial dissection of the overburden sequence, the association is present in lag dominated surface and near surface samples.

As-Sb±Au association

This association is developed as persistent, moderate strength anomalies with values reaching 25 - 250 ppm As and 5 - 60 ppm Sb in the lower and middle portion of the saprolites The association is developed in or adjacent to the faulted contact of the Chesney Formation and the Girilambone Group. Sporadic zones of weak Au enhancement in ANRC6 and 7 reach 1 - 8 ppb in the upper saprolite and base of the thin veneer of transported regolith This Au enhancement coincides, in part, with the lower portion of a calcareous zone Enhanced As and Sb levels extend into the lower parts of gravel and silt in the palaeo-drainage line but are only present at the surface in the lag fraction

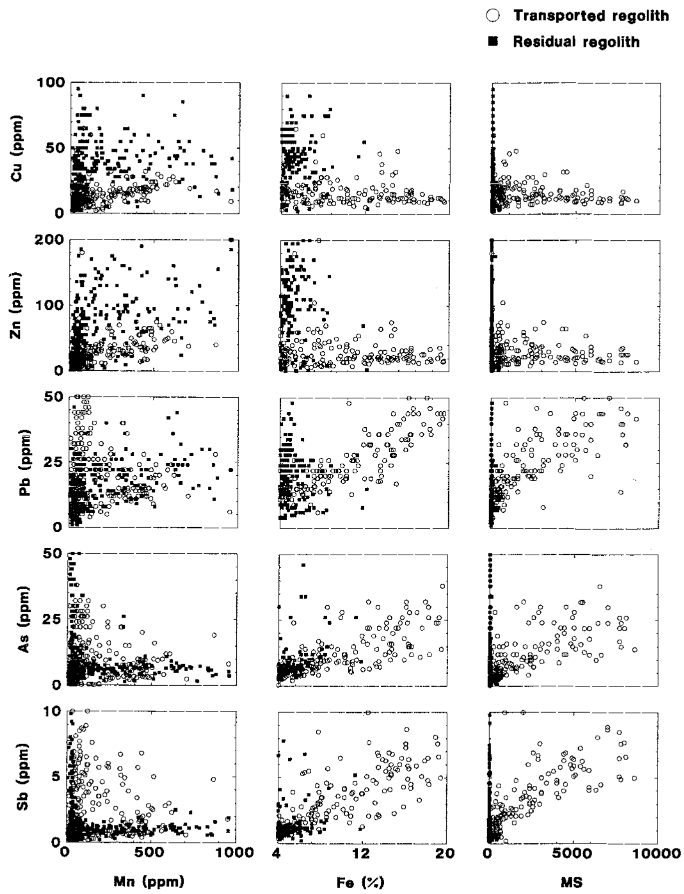

Figure 5. *Scatterplots of Cu, Pb, Zn, As and Sb versus Mn, Fe and MS (SI units (10^{-5}) Solid squares represent residual regolith and open circles the transported regolith.*

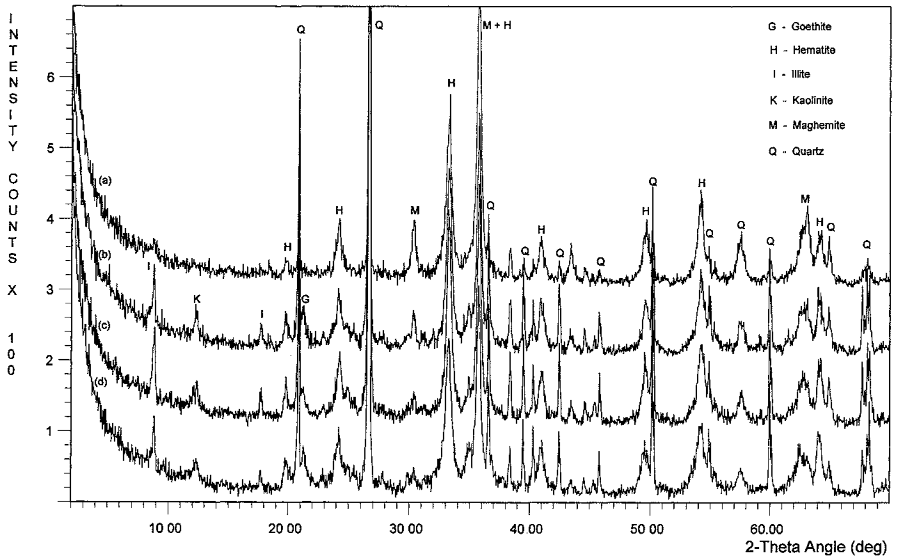

Figure 6. *X-ray diffraction traces of bulk surface and buried lag samples using monochromatised CuKα radiation (a) Surface lag, collected at the site of PYRC16 (b) Buried lag, collected from PYRC13 at 5-6 m depth. (c) Buried lag, collected from ANRC3 at 14-15 m (d) Buried lag, collected from ANRC2 at the depth of 25-26 m.*

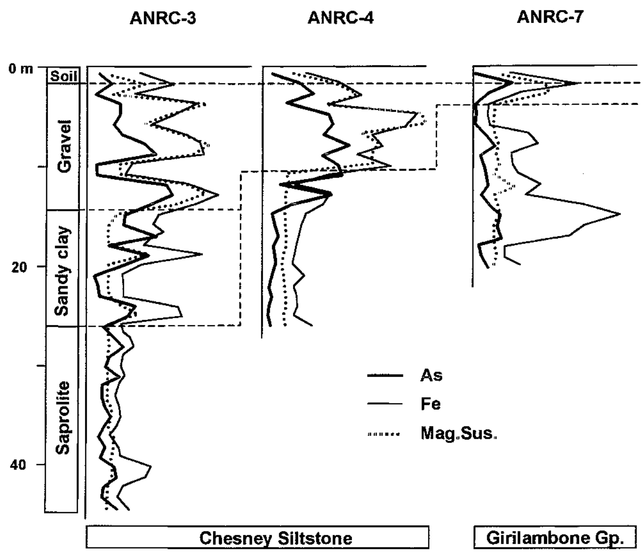

Figure 7. *Plot of As, Fe and MS versus depth for holes ANRC3 and 4 in Chesney Formation and ANRC7 in the Girilambone Group.*

DISCUSSION AND CONCLUSIONS

The patterns of trace element correlation and trends within the various regolith units are summarised in Figure 8. The close association between Au and pedogenic carbonates (usually within the top 2 m of the regolith) has been reported by Lintern and Butt (1993) from Yilgarn Craton of WA and by Anand et al. (1994) and Butt (1997) from Gawler Craton of SA. In the present study area, the bulk soil samples collected from the top 2 m generally contain < 0.5 % Ca and weakly enhanced Au values (0.5 - 1 ppb Au), compared with 2 - 25 % Ca and several hundred ppb Au as reported by Lintern and Butt (1996) from Bounty and Mulline. No indication of close correlation between Ca and Au has been observed in these samples, possibly due to the insignificant accumulation of pedogenic carbonates and absence of significant Au sources in the saprolite in this area. However, the correlation between elevated gold and carbonate concentrations observed in the deeper carbonate zones are not reflected in the near surface carbonate zones.

Local sources are not well constrained for the geochemical associations described for saprolite and transported regolith from this part of the Cobar district. Despite this, their mineralogical associations, spatial distribution of element abundance, and interelement associations as observed in spatial plots, scatter plots and correlation coefficients, allow some inferences to be drawn as to their evolution.

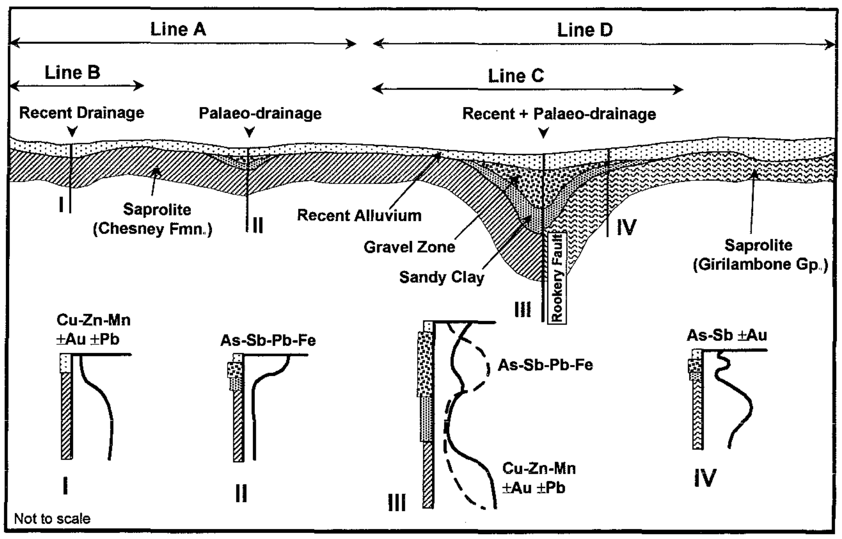

Figure 8. *Schematic diagram of geochemical dispersion patterns in landforms where residual regolith is capped by silt-rich transported regolith containing ferruginous lag lenses.*

The Cu-Zn-Mn±Au±Pb association (Figure 8; profiles I and III) appears to be related to deep weathering and leaching of lithostratigraphic or structural features in the Chesney Formation. Stronger anomalies associated with ANRC2 suggest proximity to a more localised carbonate rich source. The As-Sb-Pb-Fe (profiles II and III) association is clearly related to a refractory residue in ferruginous gravels within recent and palaeo-drainage systems of Yanda Creek. As no metal sources for the elevated As-Sb-Pb-Fe values associated with maghemite have been found in the underlying saprolite the ultimate source may be in part the mineralisation at the CSA Deposit (8 - 12) km to the SW. Similar relationships have been proposed by Dunlop *et al.* (1983) for Pb-As in the coarse ferruginous fraction in soils along drainage lines in the vicinity of the Elura Deposit. The As-Sb±Au association (profile IV) is associated with leached saprolite patterns adjacent to the faulted contact between the Chesney Formation and Girilambone Group. These associations are all consistent with evolution from a variably truncated and leached saprolite profile dominated by quartz-sericite/illite-kaolinite with localized hematite along joints and fractures. The stripping of the upper parts of the profiles contributes to the regolith silts and gravels dominated by quartz-kaolinite or hematite-maghemite. The spatial character of element patterns, particularly in the transported regolith, suggests continued redistribution of previous dispersion patterns during the present weathering cycle

Though the element patterns in the residual and transported regolith near the CSA Mine, as determined by total analysis, indicate continued near surface dispersion and accumulation, they do not provide a clear vector to point sources covered by transported regolith. However, they do raise the possibility that, within the region and in others with comparable weathering regimes, more significant buried sources could be detected through near surface signatures perhaps highlighted by partial extraction

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