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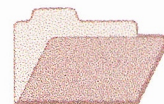
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# **PETROLOGY AND GEOCHEMISTRY OF SURFACE MATERIALS OVERLYING THE BOTTLE CREEK GOLD MINE, WA**

## **Volume I**

*I.D.M. Robertson and R. Wills*

**CRC LEME OPEN FILE REPORT 56**

November 1998

(CSIRO Division of Exploration Geoscience Report 394R, 1993.  
Second impression 1998)

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## RESEARCH ARISING FROM CSIRO/AMIRA REGOLITH GEOCHEMISTRY PROJECTS 1987-1993

In 1987, CSIRO commenced a series of multi-client research projects in regolith geology and geochemistry which were sponsored by companies in the Australian mining industry, through the Australian Mineral Industries Research Association Limited (AMIRA). The initial research program, "Exploration for concealed gold deposits, Yilgarn Block, Western Australia" (1987-1993) had the aim of developing improved geological, geochemical and geophysical methods for mineral exploration that would facilitate the location of blind, buried or deeply weathered gold deposits. The program included the following projects:

**P240: Laterite geochemistry for detecting concealed mineral deposits (1987-1991).** Leader: Dr R.E. Smith.  
Its scope was development of methods for sampling and interpretation of multi-element laterite geochemistry data and application of multi-element techniques to gold and polymetallic mineral exploration in weathered terrain. The project emphasised viewing laterite geochemical dispersion patterns in their regolith-landform context at local and district scales. It was supported by 30 companies.

**P241: Gold and associated elements in the regolith - dispersion processes and implications for exploration (1987-1991).** Leader: Dr C.R.M. Butt.

The project investigated the distribution of ore and indicator elements in the regolith. It included studies of the mineralogical and geochemical characteristics of weathered ore deposits and wall rocks, and the chemical controls on element dispersion and concentration during regolith evolution. This was to increase the effectiveness of geochemical exploration in weathered terrain through improved understanding of weathering processes. It was supported by 26 companies.

These projects represented "an opportunity for the mineral industry to participate in a multi-disciplinary program of geoscience research aimed at developing new geological, geochemical and geophysical methods for exploration in deeply weathered Archaean terrains". This initiative recognised the unique opportunities, created by exploration and open-cut mining, to conduct detailed studies of the weathered zone, with particular emphasis on the near-surface expression of gold mineralisation. The skills of existing and specially recruited research staff from the Floreat Park and North Ryde laboratories (of the then Divisions of Minerals and Geochemistry, and Mineral Physics and Mineralogy, subsequently Exploration Geoscience and later Exploration and Mining) were integrated to form a task force with expertise in geology, mineralogy, geochemistry and geophysics. Several staff participated in more than one project. Following completion of the original projects, two continuation projects were developed.

**P240A: Geochemical exploration in complex lateritic environments of the Yilgarn Craton, Western Australia (1991-1993).** Leaders: Drs R.E. Smith and R.R. Anand.

The approach of viewing geochemical dispersion within a well-controlled and well-understood regolith-landform and bedrock framework at detailed and district scales continued. In this extension, focus was particularly on areas of transported cover and on more complex lateritic environments typified by the Kalgoorlie regional study. This was supported by 17 companies.

**P241A: Gold and associated elements in the regolith - dispersion processes and implications for exploration.** Leader: Dr C.R.M. Butt.

The significance of gold mobilisation under present-day conditions, particularly the important relationship with pedogenic carbonate, was investigated further. In addition, attention was focussed on the recognition of primary lithologies from their weathered equivalents. This project was supported by 14 companies.

Although the confidentiality periods of the research reports have expired, the last in December 1994, they have not been made public until now. Publishing the reports through the CRC LEME Report Series is seen as an appropriate means of doing this. By making available the results of the research and the authors' interpretations, it is hoped that the reports will provide source data for future research and be useful for teaching. CRC LEME acknowledges the Australian Mineral Industries Research Association and CSIRO Division of Exploration and Mining for authorisation to publish these reports. It is intended that publication of the reports will be a substantial additional factor in transferring technology to aid the Australian Mineral Industry.

This report (CRC LEME Open File Report 56) is a Second impression (second printing) of CSIRO, Division of Exploration Geoscience Restricted Report 394R, first issued in 1993, which formed part of the CSIRO/AMIRA Projects P240A and P241A.

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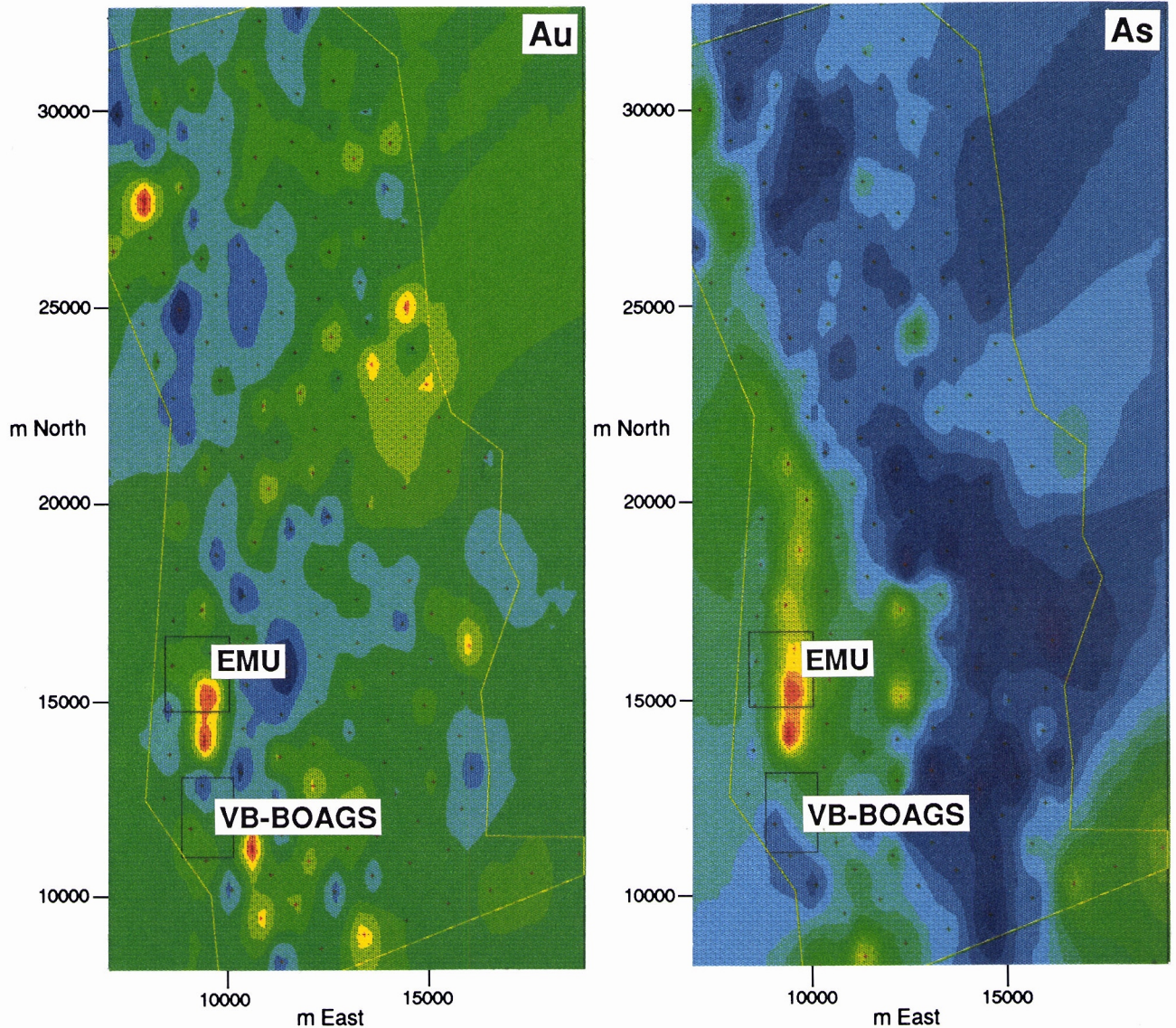
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## FRONTISPIECE



Coloured contour Au and As plots of 'Phase 1' magnetic lag sampling by Electrolytic Zinc Co. Such anomalies were largely responsible for discovery of mineralisation at Bottle Creek. Sampling limits are shown in yellow and detailed study areas, at Emu and VB-Boags, discussed in this report, are in black. The As anomaly is more coherent and extensive than that of Au. Both are largely restricted to residual-erosional areas (e.g., Emu) and absent in areas of colluvium-alluvium (e.g., VB-Boags). For contour values, see Appendix 11.



## **DEDICATION**

This report is dedicated to the memory of our friend and colleague, John Innes, who took part in the CSIRO-AMIRA Program, Exploration for Concealed Gold Deposits, Yilgarn Block from 1987-1990. He worked at Bottle Creek during 1989-1990 and died in July 1993, after a long illness.



## **PREFACE AND EXECUTIVE SUMMARY**

The CSIRO - AMIRA Programme "Exploration for Concealed Gold Deposits, Yilgarn Block, Western Australia" has, as its overall aim, the development of improved geological, geochemical and geophysical methods for mineral exploration that will facilitate the location of blind, concealed or deeply weathered Au deposits.

Two of the projects within the programme (AMIRA P240A, Yilgarn Lateritic Environments and P241A, Dispersion Processes) have collaborated for integrated studies at selected orientation sites. One of these is an integrated regolith study at the Bottle Creek Gold Mine, near Leonora, in the Mt. Ida Greenstone Belt. This report describes the results of a mineralogical, petrographic and geochemical study of the gossan, soil and lag, carried out for both Projects P240A and P241A, using samples that were collected both prior to and after mining. The site is very close to the Menzies Line but has a surficial environment typical of the hard-pan and mulga areas to the north. It covers a complex geomorphic environment, including residual, residual-erosional, erosional and several varieties of depositional regime. Significant outcomes were:-

- The best indicator elements for Au at Bottle Creek are  $As > Sb > Au > Pb$
- The phyllic halo is shown by  $K$  and  $Rb > Na$  (and  $Ba$ )
- Sampling of laterite and its derived lag in residual and residual-erosional areas produces broad anomalies
- Lag sampling of depositional areas produces small, sporadic anomalies
- The success of lag sampling of depositional areas is critically dependant on thin cover and on bioturbation of the cover - drilling these areas is recommended, with sampling initially directed at buried lateritic residuum where present
- Planning of a geochemical program and interpretation of results need to take into account regolith-landform relationships.

The Bottle Creek orientation study has taken longer than originally planned, due to the unfortunate illness of one of the Project staff and a Ph.D., study which was terminated within its first year. Work on regolith relationships continued with contract staff being added to the small team. The geochemical and some of the petrological work, presented here, commenced in the 1992 academic year and incorporated a B.Sc., Honours study by the junior author. Thus, aspects of the project did not have quite the continuity they may have had.

R.E. Smith  
Project Leader, P240A (Yilgarn Lateritic Environments)

C.R.M. Butt  
Project Leader, P241A (Dispersion Processes)

October, 1993.



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## 1 ABSTRACT

The tectonically-related mineralisation at Bottle Creek is a chalcophile, pathfinder-rich Au-Ag deposit. Gossans contain anomalous Ag, As, Au, Cu, Pb, Sb and Zn. The mineralised zone at Bottle Creek strikes for 5 km and traverses a complex geomorphic environment consisting of residual lateritic duricrust, partly covered by colluvium, parts where the duricrust has been partly or wholly stripped to saprolite, areas where laterite and stripped profiles are buried beneath sheet-flood colluvium-alluvium and numerous, more recent drainage channels, now filled with fluvial gravels. Most profiles have been hardpanised to a varying extent. The study area lies in an arid area of mulga scrub, very close to, but north of, the Menzies Line.

Within the broad catchments, regolith-landform relationships have been integrated with both the original exploration data and with CSIRO orientation geochemistry to test the effectiveness of surficial sampling in residual, erosional and depositional areas. The two study areas, Emu and VB-Boags, lie in contrasting residual-erosional and depositional regimes respectively. In the former area, geochemical sampling of laterite and lag gives broad indications of mineralisation typical of lateritic areas. Indications from the latter are very dependent on localised thinning of the cover, on mechanical dispersion and on bioturbation carrying ferruginised saprolite and hardened, ferruginous mottles to the surface.

The best indicator elements are  $As > Sb > Au > Pb$ . The width of the As anomaly is 1200 m, that of Pb is 400 m. A phyllic halo surrounds the Emu mineralisation and this is detectable mineralogically as remnant muscovite in the lag by both XRD and petrography and geochemically as a K halo with minor Na and Ba. At VB-Boags, the phyllic halo is very much reduced in size and patchy, as are halos in As, Sb, Au and Pb. A sediment-filled fluvial channel, between VB and Boags, has truncated all geochemical anomalies.

A very brief investigation indicated that the coarse soil fraction would be as effective as the lag; the choice between these sampling media would be one of cost and convenience.

Regolith-landform mapping provides an essential basis for planning geochemical prospecting. In the residual-erosional lateritic terrain, surrounding the Emu Pit, wide-spaced (up to 1 km) lag sampling on a triangular grid, using As, Sb, Au and Pb as indicator elements will delineate the mineralised zone. In thinly-covered depositional regimes (for example VB-Boags), lag may be used at a much reduced sample spacing (e.g., 50-100 m) but there are significant attendant risks, in that success is very dependant on the cover being thin. Thin cover may, in part, be due to induration of the weathered mineralisation which tends to form positive features in the palaeotopography.

## 2 INTRODUCTION

The Bottle Creek Au deposit (Figure 1) was discovered by magnetic lag geochemistry, which revealed a distinctive multi-element (As, Sb, Au) anomaly. Prior to mining, the area surrounding the mineralised zone was sampled in detail by both Norgold and by CSIRO. Mining has left two large pits, at VB and Boags, and a test pit, at Emu, providing good exposure of the regolith in depositional and residual terrain; this pit exposure makes Bottle Creek a valuable orientation area.

### 2.1 Location, access, climate and vegetation

The Bottle Creek Gold Deposits, held by Norgold Limited, are located 210 km NW of Kalgoorlie at 120°27'E, 29°10'S. Access is by a gravel road and, within the mining and exploration tenements, along grid lines and fences.

The area has an arid climate with a recorded average annual rainfall of 180-190 mm from convectional summer storms, much of which falls between January and April. Rainfall variability is very high; some heavy falls are due to cyclone-related rain-bearing depressions. Spring (September to November) is the driest season. Summers are hot to very hot; winters are cool and frosts are common.

The vegetation is dominated by mulga (*Acacia aneura*) (Figures 2A and B) and by various types of poverty bush and turpentine (*Eremophila* spp.). On the major depositional surfaces there are *mulga* shrub communities with tall shrubs on the steeper slopes and breakaways. Thickets of eucalypts grow on erosional tracts with scattered trees on the sandy, gravelly soils of long, gentle slopes. Isolated kurrajong trees (*Brachychiton* sp.) occur on a variety of land surfaces (Churchward *et al.*, 1992).

### 2.2 Exploration history

There has been exploration for copper-nickel sulphide deposits along the Mt. Ida Lineament (Figure 1) and adjacent areas by several companies in the late 1960's and early 1970's without success. Since then, until 1983, virtually no exploration was recorded within the area.

The Bottle Creek deposits (Legge *et al.*, 1990) were 'greenfield' discoveries, although the old mining site at Copperfield is well known. Although it lacks outcrop, this area was considered prospective (Barnes, 1985) because a major structural dislocation or shear, sub-parallel to the Ida Lineament, may be projected through the area. The Ida Lineament marks a major tectonic discontinuity in the greenstone belt stratigraphy and associated Reidel shears could be sites for Au mineralisation. Gold occurs at Pianto's Find, south of Bottle Creek, in a highly deformed, carbonated, phyllic-altered and silicified, carbonaceous shale, rich in pathfinder elements (As, Bi, Cu, Pb, Sb, W).

Initial regional sampling by Electrolytic Zinc Co., showed that mullock dumps at Copperfield are anomalous in Au, As, Cu and W; these indicator elements were reflected in magnetic lag (due to small amounts of maghemite) collected around these sites, with enhanced abundances of As, Zn and Pb, due to adsorption by goethite. Deformed porphyries appeared to be spatially related with the majority of the workings. BLEG analysis of stream sediment samples showed anomalous Au; magnetic, Fe-rich soil nodules, sampled at a density of 1/km<sup>2</sup>, were anomalous in Au, As and W. There may be some lithological control over the Cu distribution. Attempts were made to normalise the pathfinder elements against Fe and Mn - improvements were marginal.



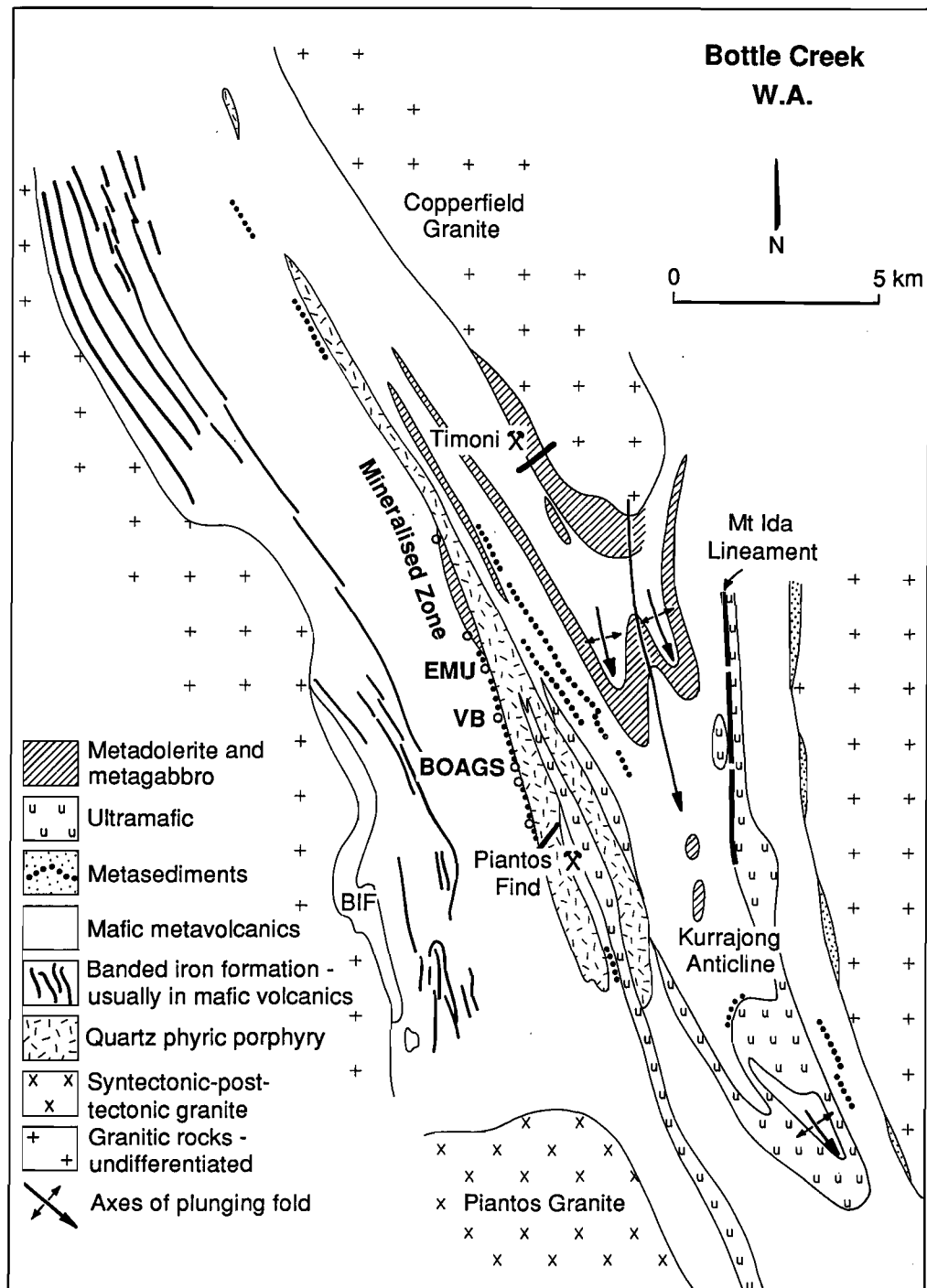


Figure 1. Geology and structure of the environs of the Bottle Creek study area, after Legge *et al.*, (1990).

An area around Bottle Creek was selected for reconnaissance stream sediment sampling (5 kg, <180 µm, BLEG) and magnetic lag sampling on a 1 km triangular grid in 1984. The lag survey (Exploration Phase 1) revealed a 10 km long As anomaly with some non-coincident Au anomalies around Bottle Creek (see frontispiece). Ferruginous gossans, up to 10 m wide, rich in As, Sb, Bi, Pb and Au, were found on the main geochemical trend. More detailed lag geochemistry and gossan sampling (Exploration Phase 2) was followed by shallow RAB drilling, RC drilling and diamond drilling; resources were outlined at Emu, Boags and VB (for detail see Section 7).

A geochemical orientation study in 1987 (Monti, 1987) compared magnetic lag and three soil fractions to determine the best pathfinder elements and analytical techniques. Surface sampling was not able to 'see through' the transported overburden at the main VB ore zone. The best indicator elements were Au, As and Sb (least sensitive). Base metals were generally ineffective, except Pb in the coarse fraction at some locations. Nickel, Cr, W, Mo and Bi were not useful in delineating the ore zone. All four sampling media detected the Au anomaly over VB east; the coarsest and finest soil fractions proved the most useful. At Emu, only the Fe oxide and coarse fractions delineated the mineralisation. The coarse soil fraction is most effective where mineralisation is disseminated or is from a gossanous horizon, even if the surficial material is only partially residual.

In the immediate environs of the deposit, mafic volcanics, with interflow sediments, are locally intruded by quartz-eye porphyries. The host to the mineralisation is said to be a steeply-dipping, sheared, sulphidic, black shale (Legge *et al.*, 1990) of exhalative origin. The surrounding rocks show extensive potassic alteration, silicification and carbonation. Minor pyrrhotite, magnetite and pyrite in adjacent rocks has caused a related but non-coincident magnetic anomaly. Weathering penetrates to 100 m. The micro-fine nature of the Au and extensive alluvial cover over the gossans had precluded previous discovery by panning and loaming.

Mining commenced in October 1987 and the first Au was poured in December 1987. The reported production (Clark, 1990) was 66,000 oz Au at 2.25 g/t and 229,031 oz Ag at 7.82 g/t. A total of 908,273 tonnes of ore was mined from VB-Boags in the period November 1987 to November 1989. Although outlining of the pit at Emu was commenced, operations there were subsequently suspended.

### **2.3 CSIRO work program**

Research by CSIRO at Bottle Creek comprises studies of the unweathered rocks of the ore environment (Binns, 1988), the mineralogy and geochemistry of gossans (Taylor, 1989), preliminary regolith studies (van der Heyde, 1988), petrography of ferruginous nodules and lags (Davy, unpublished), regolith landform relationships (Churchward *et al.*, 1992) and some ground waters (Gray, 1992). This report covers aspects of the geochemistry of gossan, soil and lag. A total of 490 surface and near surface samples had been collected previously by J. Perdrix, D. van der Heyde, J. Innes and R. Davey over the period 1984 to 1988 and several distinct anomalies were revealed. The earlier sampling was not sufficiently even to allow satisfactory contouring to define the anomalies accurately. To provide contourable data around VB-Boags and Emu, an additional 100 samples of lag were collected by R. Wills in 1992, as part of an honours project with Curtin University of Technology (Wills, 1992).

Work by Binns (1988), prior to initiation of the CSIRO-AMIRA Yilgarn Programme, on fresh drill core from the Emu deposit, indicated a complex alteration history about narrow zones of deformation. Alteration of tholeiitic lithologies has produced a biotite-garnet schist and a banded, mafic rock of hornblende and biotite, called 'zebra rock'. The geochemistry of these rocks was considerably altered during pervasive phyllic carbonate alteration which occurred prior to or during ductile deformation, together with introduction of sulphide. Argillic and silicic alteration of



porphyry was followed by brittle deformation and quartz-pyrite veining, which formed an horizon of massive pyrite. Graphitic horizons here could have been interflow carbonaceous sediments or a product of this alteration. Static, prograde metamorphism to amphibolite facies was followed by retrograde alteration along fractures and shears. The timing of Au and Ag mineralisation has yet to be determined accurately but they seem to have been introduced during or after the sulphides. The biotite schists have been likened to those carrying Au mineralisation at Davyhurst (Hellsten *et al.*, 1990; Douglas *et al.*, 1993) but, unlike Bottle Creek, the latter all have, characteristically, extremely low pathfinder element concentrations.

Investigation of surface and subsurface gossans from Emu, Boags and VB by Taylor (1989) indicated that they are composed largely of quartz, muscovite, kaolinite, goethite and hematite with minor talc, rutile, tourmaline and Mn oxides. Secondary As- and Pb-rich minerals of the jarosite and alunite groups are common in gossans and wall rocks respectively. The gossans were derived from a protore of pyrite with minor tetrahedrite, sphalerite, arsenopyrite, marcasite and magnetite in a gangue of kaolinite, muscovite, quartz, chlorite, siderite, dolomite and calcite. The gossans are anomalous in Ag, As, Au, Cu, Pb, Sb and Zn, although there is a marked depletion at the surface. Mercury, Te and Tl are also anomalous but current analytical techniques were not regarded as sufficiently sensitive for them to be useful. The significance of concentrations of Mn, Ti, B and Ba have still to be fully explained. Gold distribution in the gossan was found to be patchy. Taylor compared the volatile element composition of the Bottle Creek gossans with those developed on VMS deposits elsewhere in the Yilgarn Block (Smith *et al.*, 1983). Except for As and Sb, they are significantly lesser and he concluded that these gossans may not be of classic VMS origin.

### 3 GEOLOGY AND MINERALOGY

#### 3.1 Regional geology

The Bottle Creek Au deposits are located at the northwestern tip of the Mt. Ida Greenstone Belt (Figure 1), which is the most westerly greenstone sequence of the Kalgoorlie sub-province of the Western Australian Shield (Griffin, 1990). The Mt. Ida Greenstone Belt comprises a north-northwest striking, eastward dipping succession, surrounded by variably deformed adamellite rocks (Kriewaldt, 1970). Facings suggest that the succession is youngest to the east (Figure 3B). The western part of the belt is marked by a laterally extensive sequence of banded iron formations, interspersed with coarse-grained mafic rocks. The remainder of the belt is dominated by high-magnesian basalts and intercalated interflow metasediments (black shales and cherts). To the north, a prominent meta-tholeiite unit in the centre of the belt changes along strike to intensely sheared and brecciated black shales and felsic porphyries to the south (Figure 1B). This is informally referred to as the Emu Complex, or Emu Formation, and hosts the mineralisation. Meta-komatiites are intercalated with high magnesian metabasalts in the eastern portion of the belt.

The regional foliation is subparallel to the bedding. Immediately east of Bottle Creek, in the Mt. Ida-Copperfield area, the greenstones are folded into a tight, south-plunging anticline with the Copperfield granite in its core. The eastern margin of the belt, the Mt. Ida lineament, shown by a strong zone of regional aeromagnetic contrast, is regarded as a major crustal suture.

#### 3.2 Local geology and mineralisation

The Bottle Creek Au deposits are hosted by what initially appeared to be silicified, sulphidic, black shales in biotite-altered mafic metavolcanics, which are part of a high-magnesian metabasalt sequence. In areas of greater mineralisation, the metavolcanics and the ore zone itself have been intruded by quartz-feldspar porphyry, which is now a quartz-sericite schist. The mineralised zone has been affected by strong potassic and carbonate metasomatism and silicification.

Legge *et al.* (1987) considered the Emu formation to be a volcanic-related, auriferous, exhalative horizon of sulphidic, graphitic shales, chert and felsite which now contains massive pyrite and pyrrhotite. They concluded that Au concentration took place during a period of strong deformation and intrusion by quartz-feldspar porphyry. The mineralisation is within a 50 m wide shear zone, hosted by a 10 m wide sulphidic and graphitic black chert-shale horizon adjacent to a felsic quartz porphyry. The cherty nature is due to silica introduced by ore fluids. The Emu formation and its associated porphyry are traceable along strike for 26 km. The relationship between felsic porphyries and Au mineralisation is discussed by Perring *et al.*, (1990a, b). Weathering of the sulphides has resulted in a discontinuous and sporadically outcropping line of gossans along the 26 km strike. Shearing was focused along, and adjacent to, the sediment horizon, which is more ductile than the surrounding, altered high-magnesium basalts, which allowed the intrusion of the porphyry and the ore fluids. Graphite, within the sediment, acted as a chemical trap, reducing the fluids and causing precipitation of metals from solution (Legge *et al.*, 1990; Monti, 1988).

Binns (1988) suggested that the shale horizon, within the Emu Formation, is not an interflow sediment, but part of a zone of strong deformation and alteration in a basaltic sequence. Accordingly, it may be a previously unrecognised style of mineralisation in the greenstone sequences of the Yilgarn Block. Binns suggested that the porphyries had intruded a boundary between low Ti tholeiite<sup>1</sup> and high Ti tholeiite, now biotite-garnet 'schists'. Later, phyllic carbonate alteration occurred prior to or during a phase of ductile deformation. There was considerable removal of Na, introduction of K and of sulphide. Zones of argillic and siliceous alteration in the porphyry are responsible for the exhalative sedimentary appearance. Brittle deformation occurred before low amphibolite metamorphism.

The mineralised zones dip steeply and, in places, have been warped and cross faulted. They have undergone intense, ductile deformation followed by later, brittle deformation (Binns, 1988). There are two types of mineralisation; one within the main mineralised zone and the other, a stockwork ore, within the adjacent porphyries and altered volcanics.

Bodies of massive pyrite and pyrrhotite, up to 6 m wide, occur in the Emu formation. Sulphide minerals, Ag-bearing tetrahedrite, sphalerite, pyrrhotite, arsenical pyrite and chalcopyrite occur with micron sized Au grains and electrum (Legge *et al.*, 1990). The Au is fine to very fine grained (8 to 60  $\mu\text{m}$ ), most being less than 10  $\mu\text{m}$ . The expected Au recovery was 92%. Gold occurs within and on the surface of limonite (61%), in liberated form (35%), within and on the surface of quartz (2%) and in a Ni-Fe-Sb-sulphate-beudantite mixture (2%). Micron size Ag-rich Au and a species of Ag-bearing tetrahedrite are intimately associated with pyrite in the fresh ore zones. Sphalerite, pyrrhotite, arsenical pyrite, arsenopyrite and chalcopyrite have been recognised. Silver occurs in a variety of minerals generally enclosed within quartz grains. These are, in descending frequency, haloargyrite (mainly AgCl, AgI and AgBr), beudantite ( $\text{PbFe}_3(\text{SO}_4)(\text{AsO}_4)(\text{OH})_6$ ), argentojarosite ( $\text{AgFe}_3(\text{SO}_4)_2(\text{OH})_6$ ), arcanthite ( $\text{Ag}_2\text{S}$ ), toconalite (Hg-Ag iodide) and argentiferous sphalerite. The grain size of Ag minerals is also very small.

#### 4 GEOMORPHOLOGY AND REGOLITH

A framework of landforms and regolith stratigraphy was established by Chuchward *et al.*, (1992) for the area surrounding the Bottle Creek Au deposits, as a basis for this geochemical study. First, a regolith-landform map (1:10,000 scale) was produced for the upper Bottle Creek catchment, then the regolith was mapped over an area of approximately 450  $\text{km}^2$  surrounding the detailed study, at a

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<sup>1</sup>Now 'zebra rock' which shows irregular interlayering of darker green bands, rich in hornblende, and paler brownish bands, containing biotite.

reconnaissance scale, to test the findings of the detailed investigation and a 1:25,000 map was produced of this reconnaissance.

Several well-defined regolith units were identified as related, directly or indirectly, to a deeply weathered mantle and to its modification by landform processes. These regolith materials were either horizons of a deep profile, developed by *in situ* weathering of basement rock, or of transported debris, derived from this profile by erosion. The nature of the regolith stratigraphy is strongly related to its landform, so a framework of landform regimes provides a useful guide to the regolith. Thus, units of relatively stable, deeply weathered tracts were recognised as relics of a once more extensive land surface that had been fragmented by fluvial action and replaced by erosional and depositional regimes.

At Bottle Creek, the ancient, deeply weathered land surfaces are expressed by varieties of the (upper) ferruginous horizon of the regolith (the residual regimes), along with the mottled zone, saprolite and saprock, where erosion has been more severe. Several transported regolith types, of colluvial and alluvial origin, occur in both erosional and depositional regimes.

#### **4.1 Ferruginous horizon**

The ferruginous horizon comprises various types of lateritic residuum, the more common being duricrusts with abundant lateritic pisoliths, generally with yellow-brown cutans, set in a brown to red-brown clayey matrix. At depth, this material merges with mottled clays. Large, hard, irregular to lenticular, Fe-rich duricrust bodies occur in the upper part of the regolith, which contrast with the surrounding brittle, pisolitic, lateritic residuum. The Fe-rich duricrust bodies have a dark red matrix and dark brown to black nodules, some of which are magnetic. Ferruginous saprolite, vermiform duricrust and fragmentary duricrust are diffusely mottled and brown to pale brown, some with vermiform voids. Goethite-rich pods, with box-work fabrics, occur in the upper regolith. These gossan-like bodies occur close to a carbonaceous, previously pyritic zone in the underlying greenstones.

#### **4.2 Residual regimes**

The residual regimes at Bottle Creek form extensive, gently undulating tracts on the divide between the Raeside and Ballard drainages. An example of this may be seen around the Emu test pit (Figure 4B and 5B). Most crests are slightly stripped<sup>2</sup>, exposing an array of upper regolith ferruginous materials, predominantly ferruginous saprolite but also pisoliths and pieces of Fe-rich duricrust, clay and sand. These contribute to the colluvial mantle that extends down slope from the crest, covering the lateritic residuum; the latter forms the most extensive substratum of the residual regime. On the mid- and upper slopes, colluvium is <1 m thick but, beneath the lower slopes and drainages, the colluvium can be 4 m thick. The lag composition varies with position in the landscape. Coarse fragments of ferruginous saprolite dominate on the crests. Where there is subcropping lateritic residuum, yellow-brown cutan-coated pisoliths occur. Down slope from these crests, the dominant lag is of dark brown to black granules, with little quartz or lithic material. The soils are acidic and form a fine, sandy loam-colluvium, containing granules of similar composition to the lag. Hardpans appear at a depth of 1 m and continue to 3-8 m depth.

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<sup>2</sup>The term 'residual regime' is, a misnomer in that minor erosion has taken place to expose them. However, the extent of stripping, due to a combination of position in the landscape and hardness of the substrate, has been relatively slight.



**FIGURE 2**  
**VEGETATION ON TRANSPORTED AND EROSIONAL REGIMES**



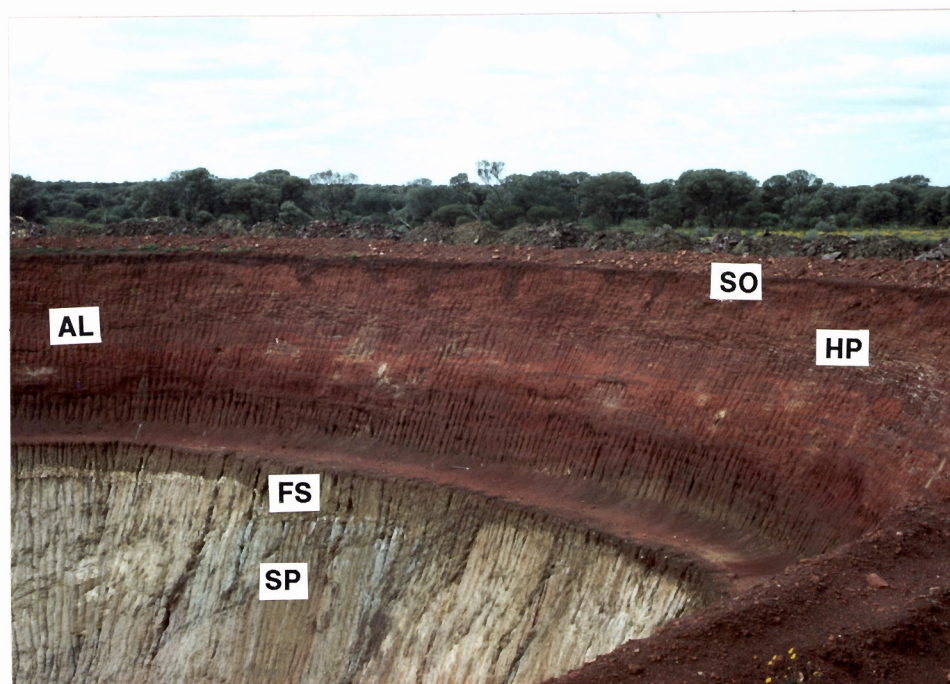
A. Mulga vegetation with sparse eucalypts on low-gradient colluvial slopes covered with prolific winter flora on a deep soil. North of Emu (17600 mN).



B. Small mulga and sparse vegetation developed on a very thin soil. This is underlain by ferruginous saprolite of an erosional regime.



**FIGURE 3**  
**THE REGOLITH AT VB-BOAGS**



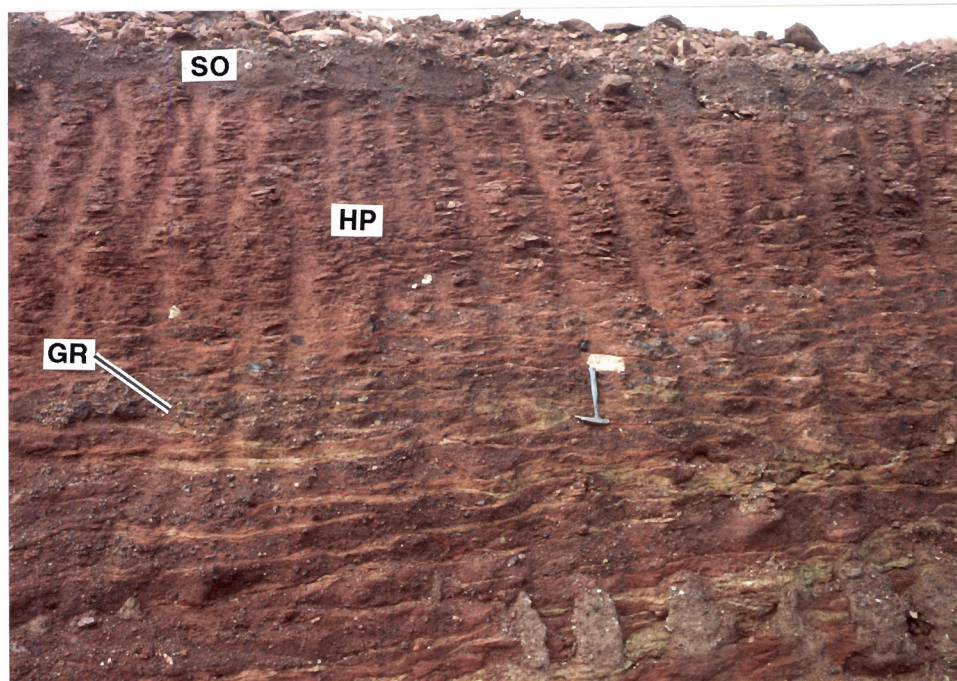
A. Saprolite of Archaean rocks (SP) is overlain in turn by ferruginous saprolite (FS), thick alluvium (AL), hardpanized alluvium (HP) and a thin, stony soil (SO). Alluvial plain at the south end of VB Pit.



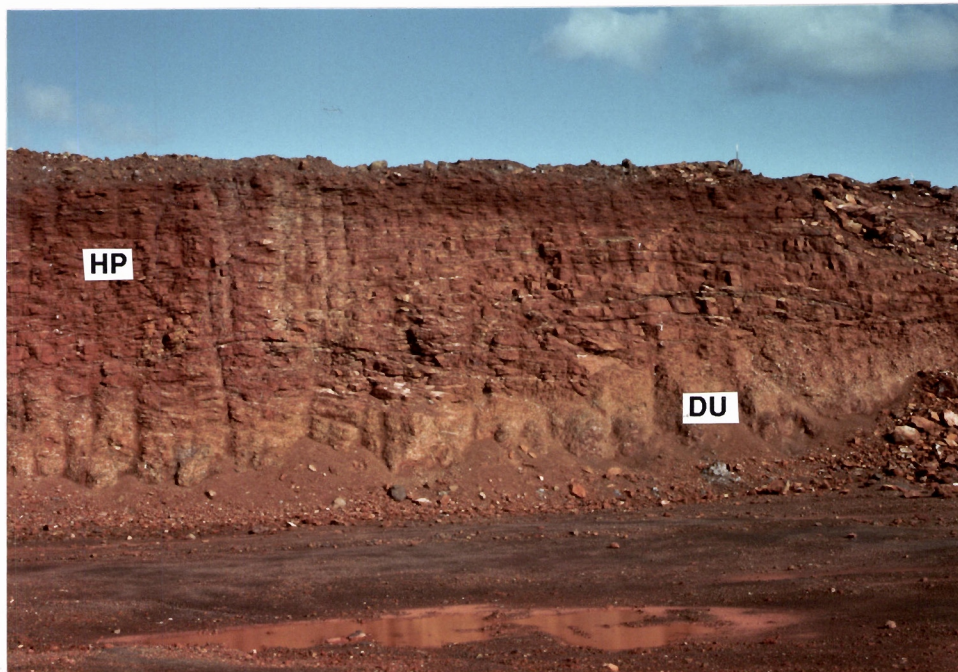
B. Pillows in slightly mottled kaolinitic saprolite of tholeiitic metabasalt. The sequence locally youngs to the left (east). The saprolite is overlain by road debris. Access ramp into Boags Pit.



**FIGURE 4**  
**TRANSPORTED AND RESIDUAL REGOLITH**



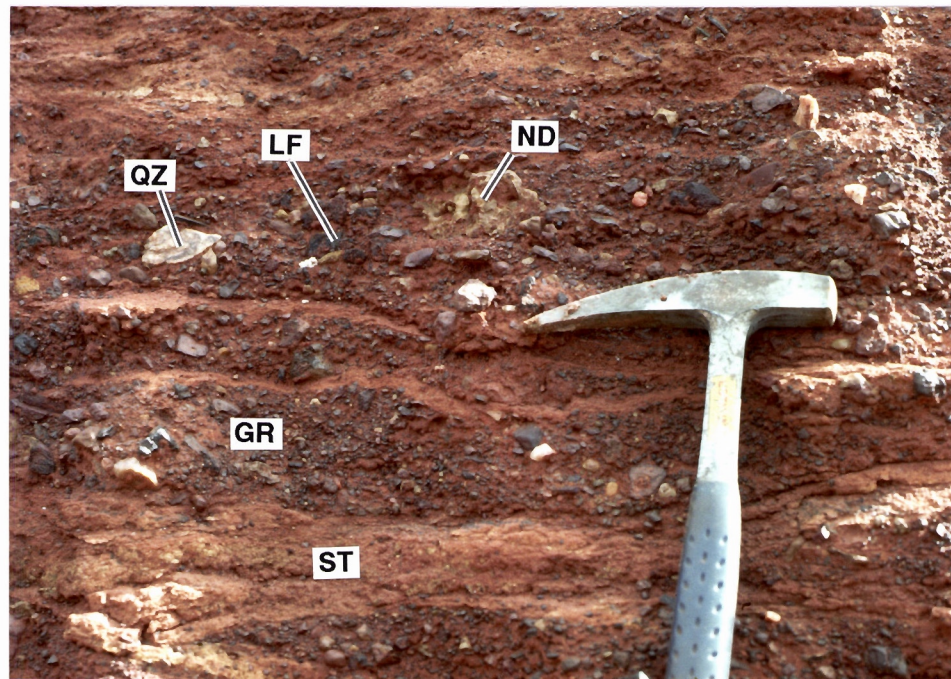
A. Transported regolith. Fluvial gravel lenses (GR) in alluvium of fluvial channel. The upper 800 mm has been hardpanized (HP) and is overlain by a thin, stony soil (SO). North end of Boags Pit.



B. Residual lateritic duricrust (DU). The top 1-2 m of a yellow-brown, pisolitic lateritic duricrust has been extensively hardpanized (HP). Emu Test Pit.



**FIGURE 5**  
**DETAILS OF TRANSPORTED AND RESIDUAL REGOLITH**



A. Detail of a transported regolith. A coarse gravel (GR) and fine silt (ST) with fluvial structures and polymictic nature (ferruginous lithorelics (LF), vein quartz (QZ) and lateritic nodules (ND)) in alluvium of fluvial channel. North end of Boags Pit.



B. Detail of residual lateritic duricrust. Yellow-brown nodules and pisoliths of Fe oxides, coated with goethite-stained kaolinite, cut by hardpanned partings (HP). Emu Test Pit.



**FIGURE 6**  
**LAG COVERING TRANSPORTED AND ERODED REGOLITH**



A. A fine-grained, polymictic lag of ferruginous nodules, lithorelics and minor clasts of vein quartz largely masks a red-brown acidic soil covering a plain of hardpanized alluvium. East of Boags Pit.



B. A coarse lag of ferruginous saprolite lithorelics lies on the low gradient colluvial slopes, shed from an erosional regime, north of Emu. Pisoliths and nodules dominate lag of residual regimes.

### 4.3 Erosional regimes

The landforms and the regolith types in the erosional regimes are more complex and reflect previous and active geomorphic processes. Deeper units of the weathered mantle, as well as country rock, are exposed (Figure 2B). The regolith is dominated by a shallow, generally calcareous soil, and a lag of lithic fragments; there are outcrops of vein quartz and goethitic Fe-segregations. Pediments below low breakaways form gentle slopes which are mantled by acidic red earths, developed on colluvium, blanketed by a lag (Figure 6B) of coarse, ferruginous saprolite, lithic fragments and quartz.

### 4.4 Depositional regimes

The most extensive depositional tracts (Figure 2A) are mantled by friable alluvial clay deposited by sheet flooding, on which acidic red earths have developed. The lag is dark brown to black (Figure 6A) and consists of granules of mixed origin, with medium (20-40 mm) lithic and ferruginous saprolite fragments, and minor, characteristic quartz clasts. This alluvium overlies saprolite and saprock (Figure 3A) at a depth of 1.0-1.5 m but, in places, it mantles pockets of pisolitic, lateritic residuum or coarse, fluvial deposits in palaeochannels (Figures 4A and 5A). Some of the depositional tracts have been further modified by erosion, resulting in landforms and regoliths similar to those in other erosional regimes.

### 4.5 Regolith evolution and a framework for geochemical dispersion

The topographic relationships and regolith stratigraphies reveal a complex history (Churchward *et al.*, 1992). Many of the regolith types have a distinctive pattern. The residual regimes, which have had a relatively stable geomorphic history, are dominated by intense, *in situ* weathering. Some of this regolith has been transported and deposited by local colluviation. In contrast, depositional regimes have received fluvial detritus, ranging from highly weathered to relatively fresh, which is of diverse, and commonly distant, origin. Prior to deposition, some areas have been subjected to widespread, though incomplete, stripping of the pre-existing regolith. The regolith in erosional regimes is, in detail, complex, with exposure of a variety of variably weathered lithologies.

VB-Boags and Emu lie in depositional and residual-erosional regimes respectively. However, VB-Boags was formerly in an erosional regime and, later, in a depositional regime. It lies on the edge of an alluvial plain, where the cover is largely thin. Unlike the drainage 3 km to the east, where erosion has stripped the profile to saprolite and fresh rock, erosion at VB-Boags was less severe, so that remnants of the ferruginous saprolite, mottled zone and basal laterite are preserved. These have been subsequently buried under an alluvial plain. At Emu, the regolith is thick and well-developed to the south but, to the north, it thins, where the relief is greater, and the profile has been stripped to expose porphyry saprock and gossan. Understanding this geomorphic framework is essential to appreciate geochemical dispersion and it provides a basis for sampling strategies in this complex terrain of weathered residual and transported materials.

## 5 STUDY METHODS

### 5.1 CSIRO lag sampling

Samples were collected (Wills, 1992) around the Emu and VB-Boags mine sites to supplement the existing sample grid to a distance of 800 m from the mineralised horizon. Care was taken in selecting undisturbed and uncontaminated sample sites, where the ground had not been disturbed by mining operations, drilling and vehicle tracks. Where lag was scarce, or where the sample site was

disturbed or contaminated, the area of search was extended up to 5 m along the sample line and up to 10 m across the line (along strike). Particularly coarse lag (>40 mm) and quartz clasts, which would bias the sample, were avoided. The lag was swept from the surface into a plastic dustpan, with a nylon-bristled brush, from several (minimum of 5) randomly selected locations, within the chosen sampling area, until 1500-2000 g had been collected. The lag sample inevitably contained some organic litter, soil and sand, which were later removed manually and by sieving.

## 5.2 Preparation of lag

All lag samples were washed with tap water on a 500  $\mu\text{m}$  plastic sieve to remove dust and organic debris was removed manually; the samples were dried at  $<40^{\circ}\text{C}$ . Large quartz fragments were discarded. A small, representative sub-sample was selected by hand for reference and later petrographic examination; the remainder was jaw crushed to a nominal  $<10$  mm. A 100-130 g aliquot was riffle split from the jaw-crushed material and pulped to a nominal  $<75$   $\mu\text{m}$  in a case-hardened steel mill (Robertson and Crabb, 1988), using a double clean with sand and an alcohol wipe of the mill components between samples.

## 5.3 XRD mineralogy

*Qualitative Analysis.* Samples were examined by XRD at Floreat Park using a Philips PW1050 diffractometer, fitted with a graphite crystal diffracted beam monochromator.  $\text{CuK}\alpha$  radiation was used for both qualitative and semiquantitative analysis. Each sample was scanned over the range  $3-65^{\circ} 2\theta$  at a speed of  $1^{\circ} 2\theta/\text{min}$  and data were collected at  $0.02^{\circ} 2\theta$  intervals. Mineralogical compositions were determined by comparison with JCPDS files and laboratory standards.

*Semi-quantitative analysis.* Mineral abundances were estimated using the height above background of a selected XRD peak for each mineral (Table 1). The measured peaks were chosen so as to avoid overlap by peaks of other minerals. It must be emphasised that these results are approximate and are influenced by the degree of crystallinity, mass absorption of the sample, mineral orientation and abundance. Because of the wide variation in Fe contents, the results were corrected for mass absorption by the method of Brindley (1980). The data are in arbitrary units, which give an approximate comparison of the relative abundances of *particular* minerals *between* samples; they do not indicate the relative abundances of the different minerals in each sample.

TABLE 1  
DIFFRACTION PEAKS USED FOR  
SEMI-QUANTITATIVE MINERALOGY

| Mineral   | Diffraction peak (hkl) | d-Spacing ( $\text{\AA}$ ) |
|-----------|------------------------|----------------------------|
| Quartz    | 101                    | 3.34                       |
| Hematite  | 110                    | 2.51                       |
| Goethite  | 110                    | 4.18                       |
| Maghemite | 220                    | 2.95                       |
| Kaolinite | 001                    | 7.10                       |
| Calcite   | 002                    | 3.03                       |

XRF analysis of the major elements (Appendices 1 and 2), together with the XRD charts, were used to quantify the mineralogy. The method has been outlined by Wills (1992). Trace amounts of maghemite, Ti minerals and smectites appear in some of the samples but these have not been considered in the calculations.



#### 5.4 Geochemical analysis (Electrolytic Zinc Co.)

During the Phase 1 and 2 sampling a total of 173 and 134 magnetic lag samples respectively were collected and analysed as follows:-

| PHASE 1 |                        |           |
|---------|------------------------|-----------|
| Element | Method                 | Detection |
| Au      | Fire Assay - C rod AAS | 1 ppb     |
| As      | Vapour hydride - AAS   | 1 ppm     |

| PHASE 2 |   |           |
|---------|---|-----------|
| Element | Method                                    | Detection |
| As      | XRF                                       | 2 ppm     |
| Au      | Fire Assay - C rod AAS                    | 1 ppb     |
| Cr      | HNO <sub>3</sub> /HClO <sub>3</sub> - AAS | 1 ppm     |
| Cu      | HNO <sub>3</sub> /HClO <sub>3</sub> - AAS | 1 ppm     |
| Fe      | HNO <sub>3</sub> /HClO <sub>3</sub> - AAS | 0.1%      |
| Mo      | XRF                                       | 2 ppm     |
| Ni      | HNO <sub>3</sub> /HClO <sub>3</sub> - AAS | 1 ppm     |
| Pb      | HNO <sub>3</sub> /HClO <sub>3</sub> - AAS | 1 ppm     |
| Sb      | XRF                                       | 3 ppm     |
| V       | HNO <sub>3</sub> /HClO <sub>3</sub> - AAS | 1 ppm     |
| W       | Colourimetric                             | 0.5 ppm   |
| Zn      | HNO <sub>3</sub> /HClO <sub>3</sub> - AAS | 1 ppm     |

No details are available on the sample preparation methods used.

#### 5.5 Geochemical analysis (CSIRO)

The samples (06-1600 to 06-1703), collected by Wills (1992) were analysed as follows:-

- A. Neutron activation analysis on 30 g aliquots by Becquerel Laboratories Pty. Ltd.: As, Au, Co, Cr, Mo, Sb, W.
- B. X-Ray fluorescence on pressed powders, using a Philips PW1220C by the methods of Norrish and Chappell (1977) and Hart (1989), with Fe determined for matrix correction by CSIRO: Ba, Bi, Cu, Ga, Ge, Mn, Nb, Ni, Pb, Se, V, Zn, Zr.
- C. X-Ray fluorescence on fused discs (0.7 g sample and 6.4 g Li borate) using a Philips PW1480 instrument by the method of Norrish and Hutton (1969) by CSIRO: Si, Al, Fe, Mg, Ca, Na, K, Ti.

Earlier sampling of laterite, colluvium and lag, prior to 1992 (samples 06-0047 to 06-1653), were analysed by XRF pressed powder as in B above. Major elements (Si, Al, Fe, Ti) were determined by ICP-OES after a Na-peroxide fusion and nitric acid uptake. Manganese, Cr and V were also determined from this solution. ICP-OES after a HNO<sub>3</sub>-HCL-HClO<sub>4</sub>-HF digest was used to determine Mg, Ca, K, Mn, Ba and Be. Gold was determined by HNO<sub>3</sub>-HCl digest and C-rod AAS.

The geochemical data for the lag, comprising 8 major and 21 trace elements, are tabulated in Appendices 1 and 2, displayed graphically in Appendix 6 and are shown as frequency distribution plots in Appendix 3. Statistics are given in Appendix 5.

# BOTTLE CREEK

## Gossan Sample Locations

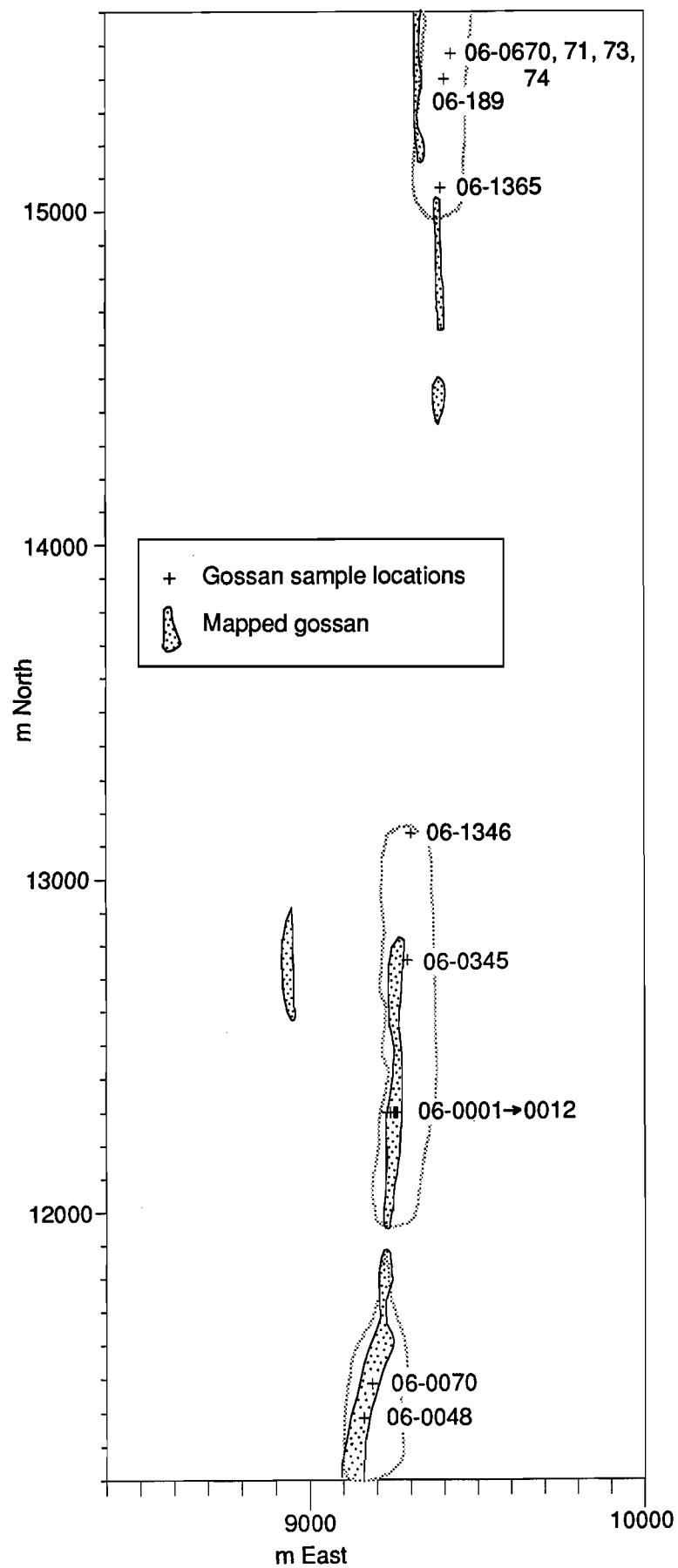


Figure 7. Locations of gossan samples. Pits (from N to S: Emu, VB, Boags) shown in outline.

## 5.6 Sequencing and standards

The samples were analysed in random order and in-house weathered rock standards (Iag STD 9) were introduced into the analytical batches at a ratio of 1:10 to 1:15, to monitor both accuracy and precision. The results were satisfactory in terms of both accuracy and precision.

## 5.7 Data presentation

The distribution of the two dimensional sampling was sufficient to allow data contouring. The data for each study area were gridded on a 40 x 40 mesh, using a moving weighted least squares method (weighting exponent 2.0), utilising the nearest eight points. The weighted values were used to compute a first order polynomial for each grid node. This method was chosen as it

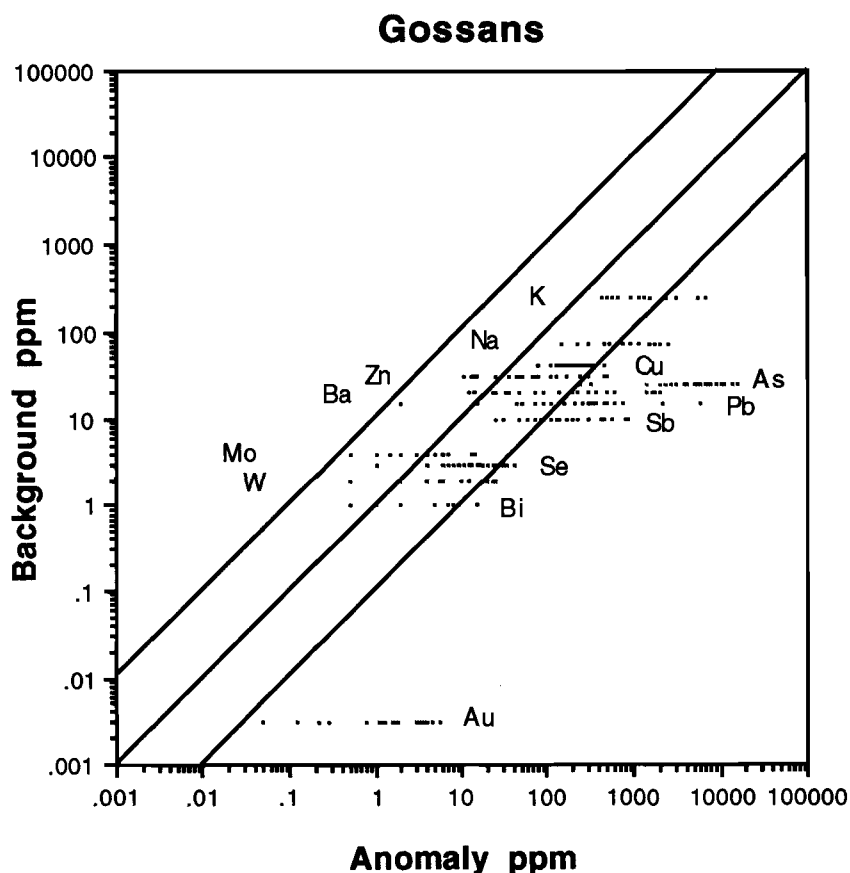


Figure 8a. Log-log plot of gossan geochemistry showing relationships of element distributions to background, as established in Section 8.4.1.

closely honours the control points. However, difficulty was encountered with highly variable and skewed As and Au data which, in the untransformed form, produced anomalies that were larger than implied by the point data. Log(10) transforms were applied to these skew elements and the data translated during contouring. This produced a much more accurate result. No pre-contouring transformations were necessary for the other elements.

Contours were smoothed using four filtering passes. Contour intervals were chosen to display the data with the best sensitivity but with minimum clutter; it was necessary to specify contour intervals such as 1, 2, 5, 10, 20, 50, 100 ..... for highly skewed elements (Au and As), but more

linear intervals were used for the remainder. Thresholds are shown in a heavier line and negative and positive features have been marked (Appendix 6) to assist interpretation<sup>3</sup>.

## 5.8 Petrography

Polished sections were prepared from pieces of the coarse lag. The polished sections were examined using both normally reflected and oblique illumination.

## 6 GOSSAN SAMPLING

A suite of 23 gossan samples (Appendix 8) was collected from eight localities in the environs of Emu, Boags and VB (Figure 7) during the course of the project, in addition to those collected by

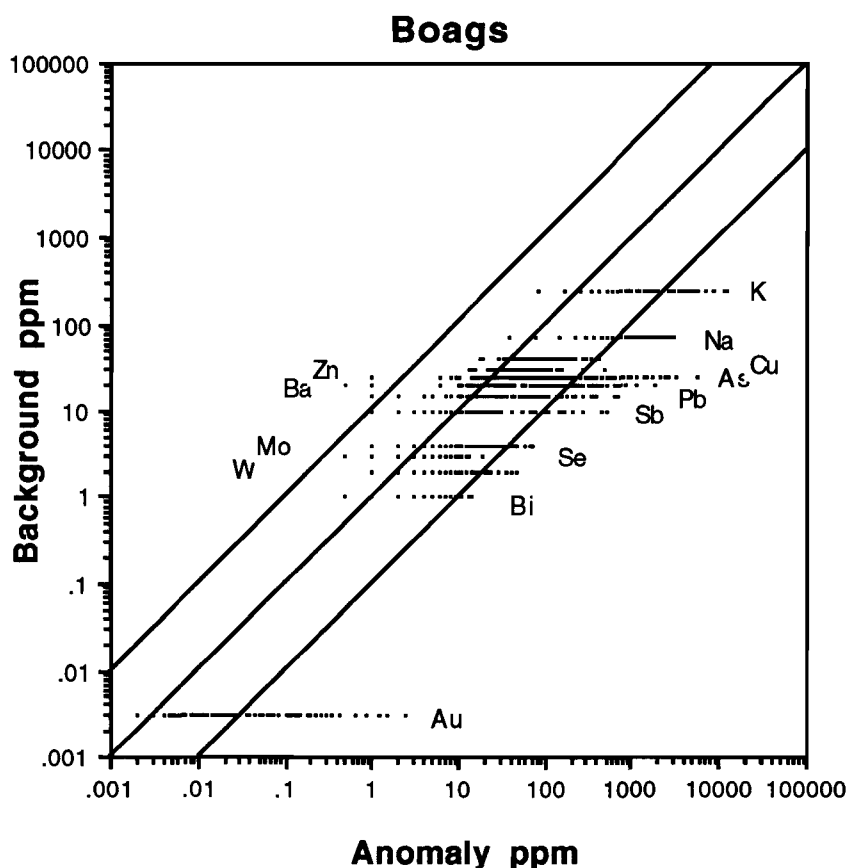


Figure 8b. Log-log plot of lag geochemistry from VB-Boags showing relationships of element distributions to background, as established in Section 8.4.1.

<sup>3</sup> Assessment and interpretation of a contoured product must be made with care, as with all mathematically smoothed geochemical data. A set of random numbers may be contoured and will produce a pattern. If the data are truly random, data points generally should not have a consistent relationship to their neighbours. In addition, there are three inherent sources of error; analytical error, sampling error and error in location. All contribute to 'noise' in the contoured product, which may also contain artifacts introduced by the gridding and contouring process. It is difficult to determine at what point the data cease to be random and become 'real', without applying spatial statistics, which is beyond the scope of this report. Empirically, a contoured product, which shows consistent and geologically explicable trends, is less likely to be derived from random data; 'spotty' results are far more likely to have had a significant random content. A whole range of products between these two extremes may be expected.



Taylor (1989). Taylor found anomalous concentrations of Ag, As, Au, Cu, Pb, Sb and Zn in the gossan. Though Ba, K and Na were analysed, for most, and elevated Ba was recorded, the roles of Na, K and Ba in a primary halo were not clearly recognised.

The gossans (Figure 8A) show a range of anomaly strengths in relation to background<sup>4</sup>; Au (x 3000), As (x 700), Pb, K, Na (x 300), Sb, Ba (x 100), Bi (x 20), Cu, Se, W (x 10) and Mo (x 4). The composition of gossans is notoriously inhomogeneous. The chief value of gossans is in identifying the mineralised lithology and as a source of enriched material that becomes incorporated and dispersed in the soil and lag. The process of dispersion improves the anomaly homogeneity. Thus, the ranges of the anomalous elements and their maxima in the lag may be compared to those of the gossan, to determine if each anomalous element has survived the transition. Log-log plots of geochemical backgrounds and the ranges of each element may be compared for the gossans (Figure 8A) with those in the lag at VB-Boags (Figure 8B) and Emu

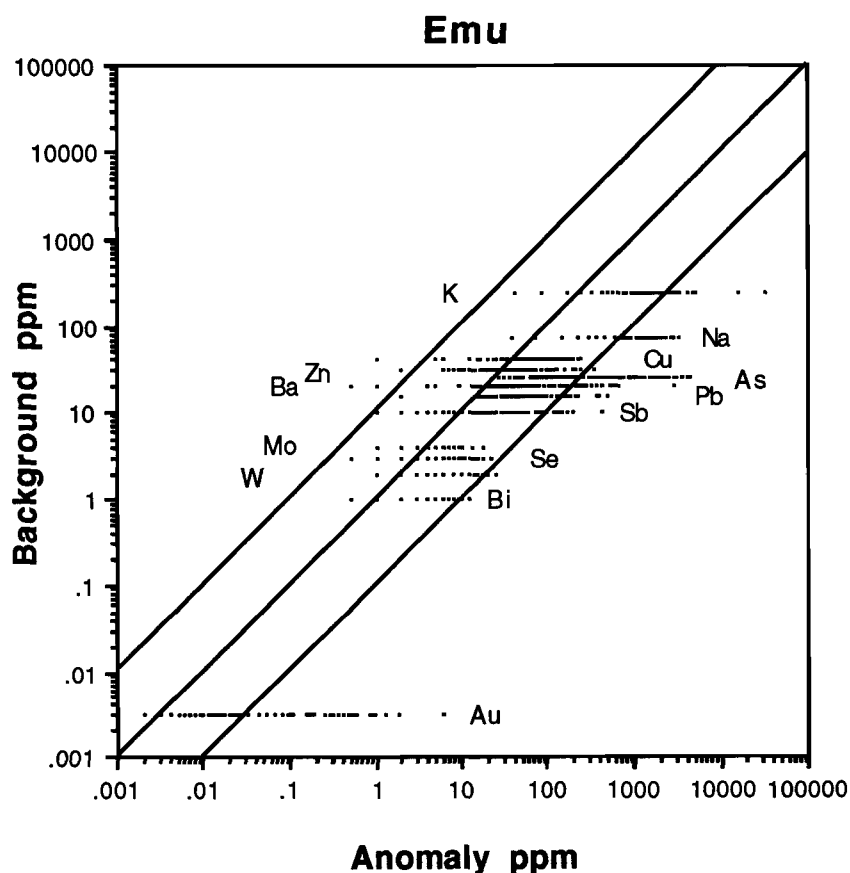


Figure 8c. Log-log plot of lag geochemistry from Emu showing relationships of element distributions to background, as established in Section 8.4.1.

(Figure 8C). Arsenic is significantly depleted (x 0.1) on passing from gossan to lag; a few other elements, notably Cu, Pb, Sb and Se, show minor depletions (x 0.5-0.3). Thus, a particularly wide, probably hydromorphic, dispersion of As in the ferruginous surficial materials may be expected.

Reference samples of some of the analysed gossans were physically examined (06-0048, 06-0070, 06-0189, 06-1346, 06-1365). None of these had a detectable magnetic (maghemite)

<sup>4</sup>As discussed in section 8.4.1

component; use of magnetic soil and lag fractions may, therefore, discard the small, though very important, gossanous component and would rely on secondary hydromorphic dispersion of target and pathfinder elements within the laterite. Although the anomalous abundances would be lesser, the target may be larger. Analysis of all the material (magnetic and non-magnetic) would be advisable.

## **7 LAG SAMPLING (Electrolytic Zinc Co.)**

After initial BLEG stream sediment sampling had been completed by Electrolytic Zinc Co., Ltd., 172 magnetic lag samples were collected over a large area of about 190 km<sup>2</sup>, extending from north-west of Sharman Well to Pianto's Find, on a 1 km triangular grid (Phase 1; Barnes, 1985). A hand magnet, with switchable flux, was used and the magnetic fraction was collected after the sample had been brushed from the surface onto a 2000 µm screen. Only about 10% of the ferruginous lag tends to be magnetic. The procedure was said to be tedious (5-60 mins) and not very effective in wet conditions. Sampling was difficult, in places, due to scarcity of suitable material. Stream channels were avoided where possible. The samples were analysed for Au, As, Pt, Cr, Fe and W. The Au and As data (Appendix 14) were digitised from existing plans. All repeat analyses from the same locality were averaged (arithmetic mean). The As and Au data has been assessed as populations (Appendix 10) and as contoured plots (Appendix 11; see also Frontispiece).

A later, more detailed sampling of 134 magnetic lag samples, also on a triangular grid (0.5 km) was completed (Phase 2) covering the smaller but highly anomalous south-east part of the Phase 1 area. This information (Appendix 15) was also digitized from plans and has been similarly assessed as populations (Appendix 12) and as contoured plots (Appendix 13). A fairly full chalcophile and lithophile multi-element suite (Au, As, Sb, Zn, Pb, Cu, W, Ni, Mo, Cr, V, Fe) was determined. The Phase 1 and Phase 2 data, as supplied from Company records, have been assessed as part of, and included with, the CSIRO/AMIRA Gold Programme.

### **7.1 Initial 'Phase 1' geochemistry**

Backgrounds and thresholds for As (25, 60 ppm) and Au (5, 20 ppb) respectively were established empirically, by inspection of quantile-quantile plots, and the thresholds were included on the contoured plots. A 17 km long, slightly curved zone of anomalous As (Appendix 11; see Frontispiece) is apparent in the eastern part of the area; this is particularly well demonstrated by the 100 ppm contour, suggesting that the threshold was set slightly low. The As anomaly is restricted to areas covered by lateritic residuum and low gradient colluvial slopes. The As anomaly is truncated by the hardpan-underlain alluvial plains and alluvium-filled drainages. There is a small, parallel anomaly to the east, largely in an erosional area. The main anomaly appears to continue south, though displaced to the east, towards Pianto's Find, also in a residual-erosional area.

The Au anomalies are patchy (see Frontispiece) and are only coincident with As at Emu, where the regolith is residual. If a lower threshold is selected (10 ppb), the Au distribution remains patchy. Arsenic is a better indicator element in this environment. Neither Au nor As anomalies project into the depositional area occupied by VB-Boags. There are only weak As and Au anomalies in the Copperfield area.

### **7.2 Follow-up 'Phase 2' geochemistry**

Backgrounds and thresholds were established for Au (2, 10 ppb), As (60, 150 ppm), Sb (8, 15 ppm), Pb (35, 50 ppm), Zn (55, 100 ppm), Cu (35, 45 ppm), Mo (4, 6 ppm), W (1, 3 ppm)

respectively by inspection of quantile-quantile plots. The thresholds have been included on the contoured plots (Appendix 13). The strong As anomaly of Phase 1 was confirmed by Phase 2 anomalies in As and Sb and, to a limited extent, by Pb and Au. The first three elements accurately locate the mineralized horizon at Emu but not at VB-Boags. Distributions in Cu, Mo and W were unhelpful.

The regular, triangular grid, used by the Phases 1 and 2 sampling, has produced very useful and countourable data. The marginal improvement in resolution, in moving from Phase 1 sampling (1 km) to Phase 2 (0.5 km), has produced very similar results, although the additional pathfinders (Sb and Pb) serve to confirm the anomalies. Perhaps this may have been achieved more economically by expanding the analytical suite of the Phase 1 sampling of those areas that were anomalous in As, rather than embarking on expensive additional sample collection. Follow-up work of this kind requires a change in resolution of an order of magnitude (to 0.2-0.05 km) to successfully define drill targets and to take advantage of locally thin alluvial/colluvial cover in the depositional areas (see below).

## **8 LAG SAMPLING (CSIRO)**

### **8.1 Mineralogy**

The mineralogy of the lag on two traverses across Boags and Emu was investigated. These consisted of 17 samples across Boags, from traverse 11400 mN, and 8 samples across Emu, from traverse 15400 mN. X-ray diffraction analyses and major element geochemistry were used to determine semi-quantitative estimates of the mineralogy. The amount of Al substitution in goethite and hematite was also estimated. The samples were also analysed by infra-red spectroradiometer (see Wills, 1992) to explore the potential of high spectral resolution remote sensing for quantitative detection of mineralogy.

Variations in lag mineralogy across the two areas are compared in Figure 9. The lag of depositional tracts (VB-Boags) contains more quartz and less kaolinite than that of residual/erosional areas (Emu). Although hematite dominates the Fe oxide mineralogy, goethite is slightly more abundant over mineralisation, displacing some kaolinite. The increased Fe oxide content probably reflects the Fe-rich (sulphidic) nature of the mineralised zone. Although there is muscovite in the lag of both areas, the muscovite content at Emu is greater by an order of magnitude. Binns (1988) reported 4-15% K<sub>2</sub>O in the porphyry from Emu and suggested that major alteration had occurred after porphyry intrusion. This included the introduction of potassium, possibly as muscovite (phyllitic alteration). Muscovite was not sufficiently abundant to be detected in the lag by infra-red spectroradiometry (Wills, 1992).

### **8.2 Petrography**

The most significant result from the mineralogical investigation is the association of muscovite with mineralisation. Polished sections from reference lag samples from the traverse along 15400 mN at Emu, which had the strongest muscovite anomaly (Appendix 6), show that lag preserves fabrics not readily visible in other near-surface materials (e.g., saprolite). Two samples, from close to the pit, contained significant quantities of granular quartz, particularly well-formed K mica (Figure 10A, B) and preserved quartz 'eyes'. Mica is visible by hand-lens examination of the cut surface of lag fragments (Figure 10A). In others, alternating layers of quartzose and pseudomorphed argillaceous material suggest either a graded argillaceous metasediment or the 'zebra rock' of Binns (1988). Linear mica flakes (Figure 10B) and equant, subhedral hematite pseudomorphs after magnetite and/or sulphide (Figures 10C, and D) are set in massive to

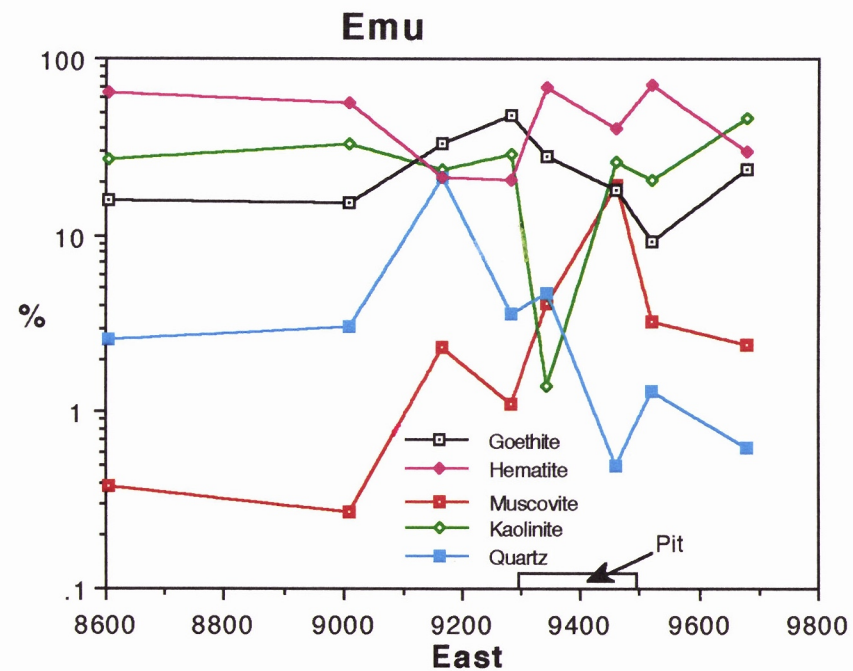
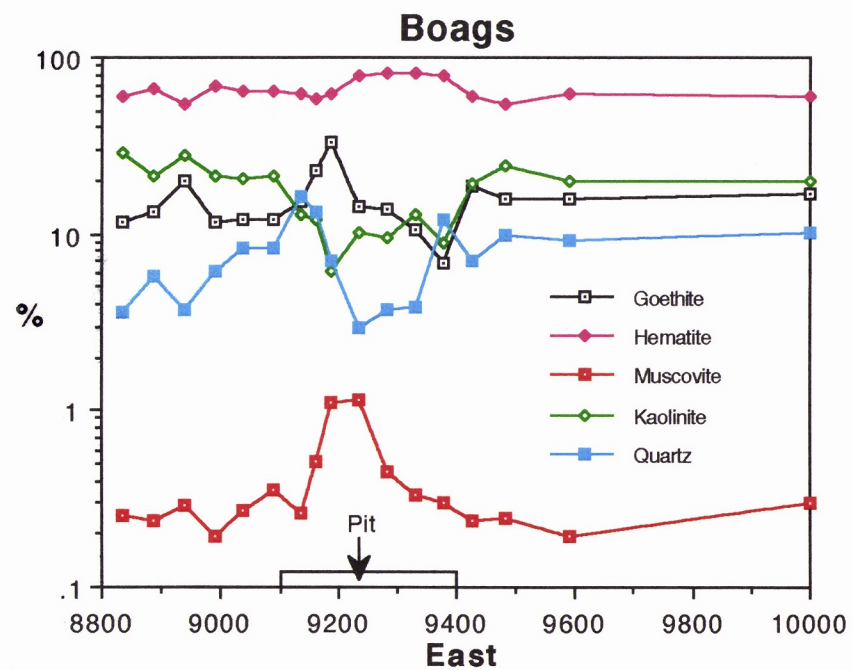


Figure 9. Semi-quantitative mineralogical traverses across VB-Boags and Emu. Note the very strong muscovite anomaly related to the phyllic halo.



## FIGURE 10

### SEMIMICRO- AND MICRO-FABRICS OF LAG FROM EMU AREA

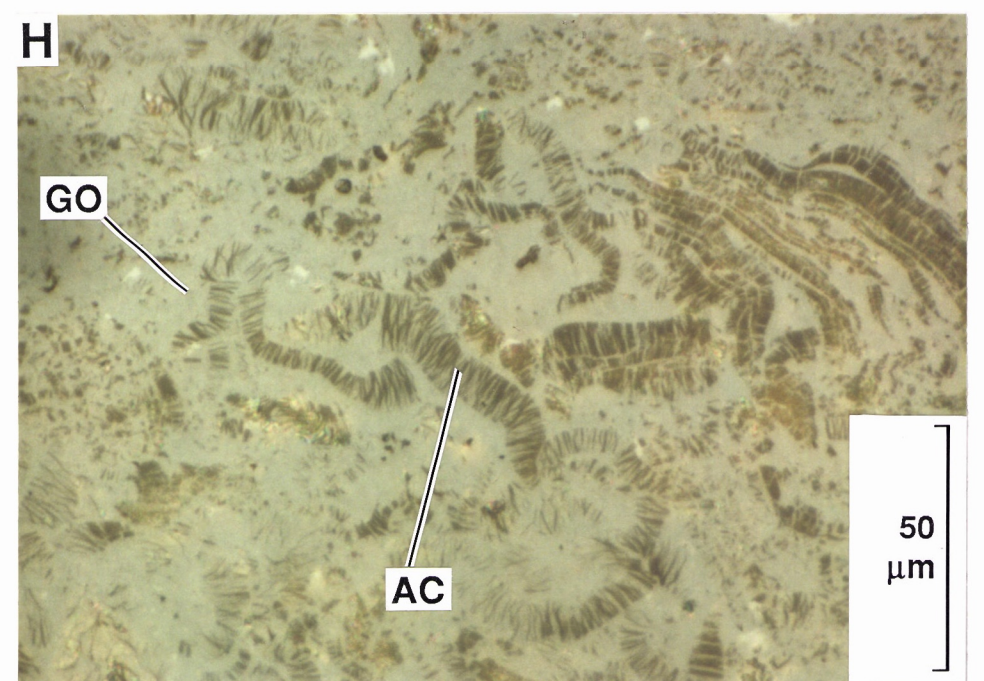
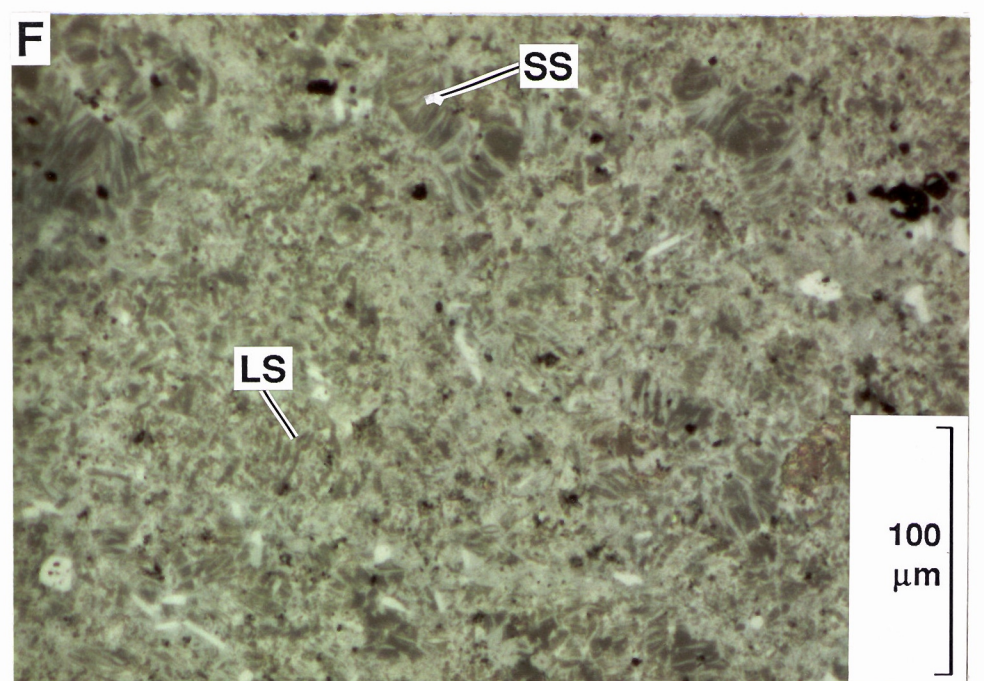
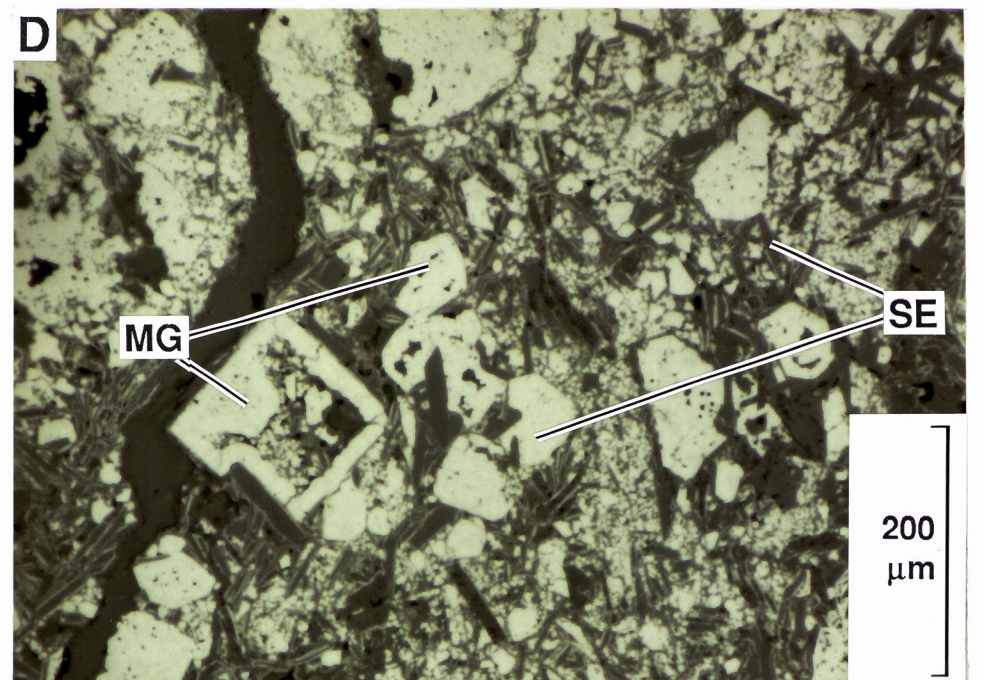
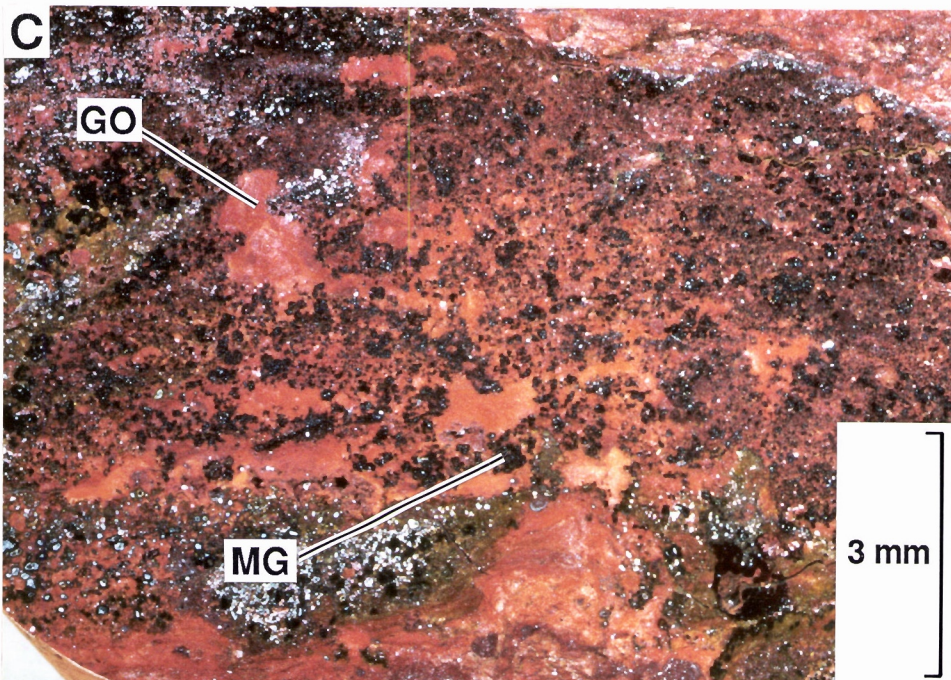
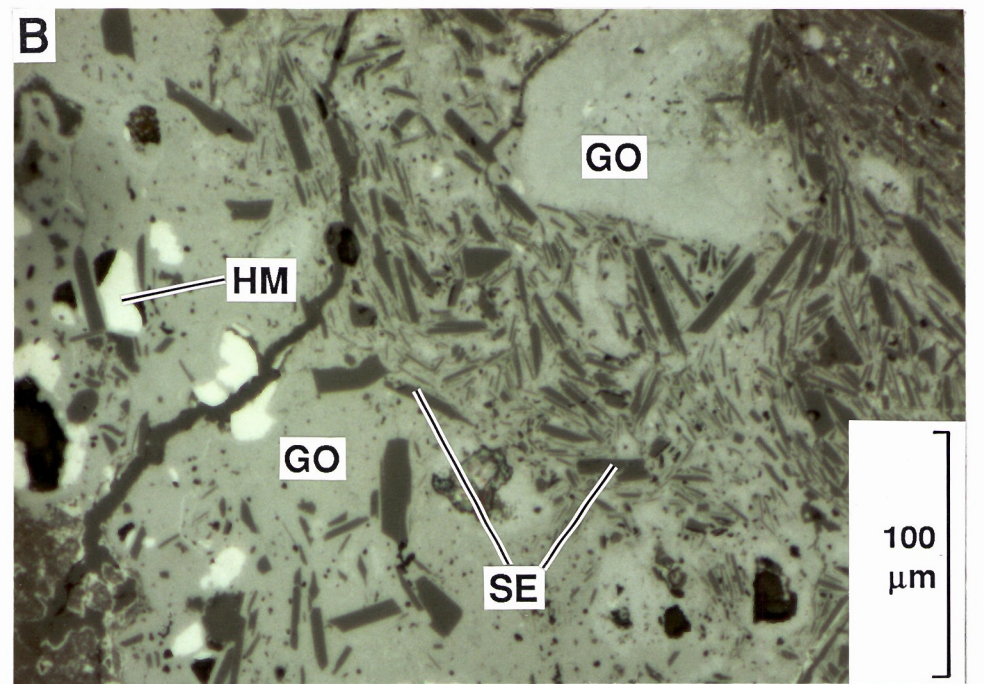
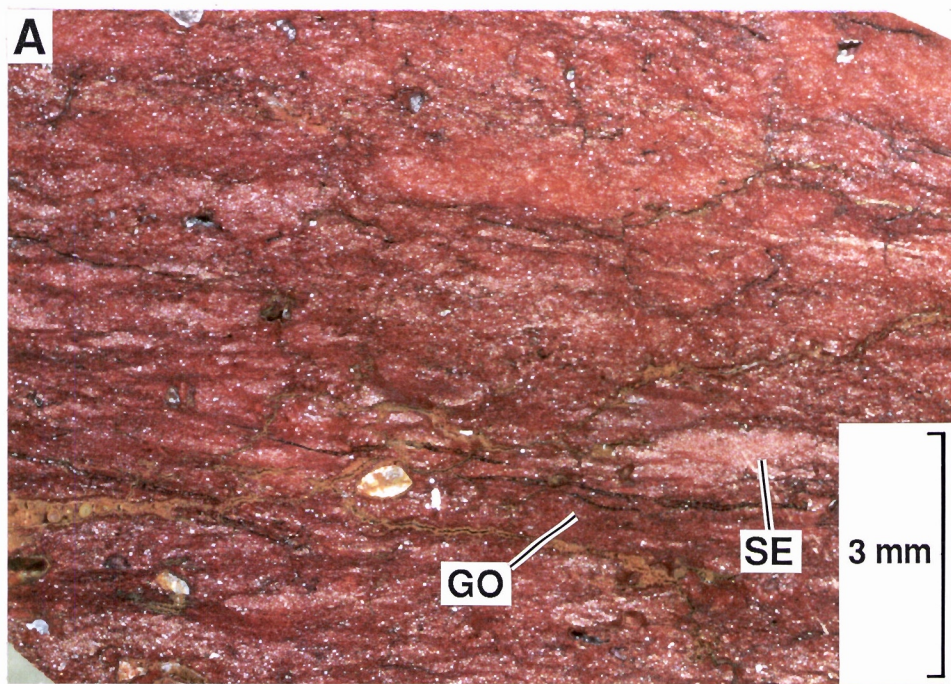
#### *Phyllic Halo*

- A.** Lithorelic lag specimen from the eastern edge of the Emu Pit. Patches of glistening sericite (SE) are set in red-grown goethite (GO). The original banded rock fabric remains. Ferruginised saprolite. Compare Figure 10B. Specimen 06-0190. Co-ordinates 9460 mE 15400 mN. Close-up photograph of polished surface.
- B.** Crisp flakes of sericite (SE) are set in grey goethite (GO) with equant grains of hematite (HM). Compare Figure 10A. Specimen 06-0190. Co-ordinates 9460 mE 15400 mN. Photomicrograph in normally reflected light.
- C.** Lithorelic lag specimen from the eastern edge of the Emu Pit. Goethite pseudomorphs after magnetite (MG), are set in red-brown goethite (GO). Ferruginised saprolite. Compare Figure 10D. Specimen 06-0190. Co-ordinates 9460 mE 15400 mN. Close-up photograph of polished surface.
- D.** Euhedral to subhedral goethite pseudomorphs after magnetite (MG) and possibly some pyrite, surrounded by finer-grained, similar pseudomorphs and remnants of sericite (SE). Compare Figure 10C. Specimen 06-0190. Co-ordinates 9460 mE 15400 mN. Photomicrograph in normally reflected light.

#### *Mafic Host Rock*

- E.** Ferruginised lithorelic from 800 m west of Emu Pit. Small islands of yellow-brown goethite (GO) are cracked and permeated by secondary brown goethite (GT). Compare Figure 10F. Specimen 06-1624. Co-ordinates 8600 mE, 15400 mN. Close-up photograph of polished surface.
- F.** Typical fingerprint fabric of a mafic saprolite, now faithfully pseudomorphed by goethite. It consists largely of pseudomorphs after wavy layer silicates (LS), largely kaolinite, though some have been recrystallised into stumpy stacks (SS) - neoformed accordion structures. Compare Figure 10E. Specimen 06-1624. Co-ordinates 8600 mE, 15400 mN. Photomicrograph in normally reflected light.
- G.** A pedogenically recrystallised fabric of yellowish-brown goethite. Compare Figure 10H. Specimen 06-1624. Co-ordinates 8600 mE, 15400 mN. Close-up photograph of polished surface.
- H.** Relics of well-developed accordion structures (AC) of pedogenically recrystallised kaolinite, set in grey goethite (GO). Compare Figure 10G. Specimen 06-1624. Co-ordinates 8600 mE, 15400 mN. Photomicrograph in normally reflected light.







spongy goethite. Although some of the hematite pseudomorphs are martite, which still preserves the internal trellis structure of pre-existing magnetite, others show massive or internal brush structures. Traces of As were found by SEM examination in the hematite pseudomorphs and in the surrounding goethite.

Lag samples collected more distant from the pit show pseudomorphic fingerprint fabrics typical of saprolitic clays derived from mafic rocks (Figures 10E and F). In places these clays (largely kaolinite) have been recrystallised into complex accordion structures (Figures 10G and H) prior to partial pseudomorphic replacement and encasement in goethite. A few lozenge-shaped crystals of hematite are scattered in the goethite. Later recrystallisation of goethite to hematite has left dehydration cracks and 'cauliflower' structures. Dissolution of the goethite matrix has left numerous channelways and irregular voids, most of which are still open but some of which have been infilled or lined by later goethite; some of the goethite infillings have a cusped form. A few fragments still retain partial rims of ferruginous clay (details in Appendix 7).

### **8.3 Thickness of overburden**

The veneer of hardpanized alluvium and soil is quite thin, in places, at Boags. A traverse down the eastern pit wall showed that it is 0.5-0.2 m thick along the northern access ramp, thins to a mere 0.2-0.1 m of unconsolidated soil over much of its length, in which there is abundant calcrete, and thickens at the southern end to 1-2 m. This is confirmed by photo-interpretation which shows that a low rise of greenstone saprock or saprolite was present in what is now the centre of the Boags pit. Colluvial-alluvial cover was thicker in the area now occupied by the VB pit.

It seems that sporadic silicification, associated with mineralisation, has indurated the ore horizon in places and the rocks in its close vicinity, making them more resistant to weathering and erosion. They seem to have formed positive palaeotopographic features during the erosive phase and were covered by a very thin cover of unconsolidated soil during subsequent sheet alluvial deposition.

The thickness of cover in the depositional areas is very variable, varying from a few metres to nil. Presentation of data as a single profile across such an area is unlikely to be representative. A surface geochemical response to underlying mineralisation in covered areas is unlikely and any response will be related to places where the cover is locally very thin. Samples were collected over the whole area, so as to properly represent this landscape inhomogeneity.

### **8.4 Geochemistry**

The outcropping gossans are anomalous in Au, As, Ba, Bi, Cu, Pb, Sb and Zn; Ag is also anomalous in subsurface gossans (Taylor; 1992). The trace element geochemistry of the lag (derived from lateritic and colluvial material) has been investigated to determine if these pathfinder elements persist in more widespread media. Contour maps are provided for both study areas (Appendix 6) with maps of the regolith-landforms and underlying geology. These should be referred to in the following discussion.

#### **8.4.1 Geochemical backgrounds and thresholds**

Values for geochemical background and threshold were determined empirically by examination of quantile-quantile plots of the combined laterite, lag and colluvium data on a regional basis. These were compared with the AGE Database and with the contoured plots and the backgrounds and thresholds adjusted as necessary. Backgrounds and thresholds, so determined, are listed in Table 2.

**TABLE 2**  
**BACKGROUNDS AND THRESHOLDS FOR**  
**LATERITE AND LAG FROM EMU AND VB-BOAGS**

| Element/Oxide     | Background | Threshold |
|-------------------|------------|-----------|
| Na <sub>2</sub> O | 0.01%      | 0.05%     |
| K <sub>2</sub> O  | 0.03%      | 0.10%     |
| As                | 25 ppm     | 80 ppm    |
| Au                | 3 ppb      | 20 ppb    |
| Ba                | 20 ppm     | 300 ppm   |
| Bi                | 1 ppm      | 3 ppm     |
| Co                | 10 ppm     | 30 ppm    |
| Cu                | 40 ppm     | 180 ppm   |
| Mn                | 180 ppm    | 400 ppm   |
| Mo                | 2 ppm      | 7 ppm     |
| Pb                | 20 ppm     | 75 ppm    |
| Sb                | 10 ppm     | 50 ppm    |
| Se                | 2 ppm      | 7 ppm     |
| W                 | 2 ppm      | 15 ppm    |
| Zn                | 30 ppm     | 50 ppm    |

#### 8.4.2 *Major and associated trace elements: Si, Al, Fe, Ga*

The major elements reflect the hematite, goethite, quartz and clay mineralogy of the lag. Lag from the Emu and the VB-Boags areas has similar compositions, although the VB-Boags area is more siliceous and there is a greater range of Al at Emu. A ternary plot of dominant Si, Al and Fe contrasts differences between Emu and VB-Boags (Figure 11A and B). In general, most lag samples are highly ferruginous but contain variable quantities of clay and quartz and this is illustrated by grouping near the Fe apex and scatter towards the Si-Al axis. At Boags (Figure 11 A), two trends are apparent, one towards a point on the Si-Al axis, corresponding to the Si:Al ratio of kaolinite, and a more scattered trend towards a more siliceous part of the Si-Al axis. Thus kaolinite is a variable diluent to the Fe oxides in some VB-Boags lag samples and both quartz and kaolinite in others. As ferruginous kaolinite is progressively dissolved from the coatings of fragments, either at the surface or in the shallow part of the duricrust, the Fe content increases but the Al:Si ratio is retained (defined by kaolinite), causing a trend towards the Fe<sub>2</sub>O<sub>3</sub> apex.

There do not appear to be any Al minerals less siliceous than kaolinite present at VB-Boags. The more siliceous lag samples were not restricted to the modern drainages, nor were they restricted to the more recent and less selective sampling; they lay generally in the environs of the mineralisation. Thus, a more siliceous nature does not necessarily reflect a greater quantity of included detrital vein quartz chips; it may, however, reflect material derived from a porphyry source.

At Emu, lag compositions have a greater degree of scatter than at Boags (Figure 11B). Although the trend towards kaolinite is evident, there are a number of samples that lie below and above this line. This indicates the presence of different phases that are more aluminous and more siliceous than kaolinite, respectively. This inference is confirmed by detection of gibbsite by XRD examination. The presence of gibbsite may be linked to local acidic conditions, related to sulphide weathering, that leach Si but retain Al. Gallium is strongly correlated with Al, but not with Fe, at both sites so it is probably contained in clays.

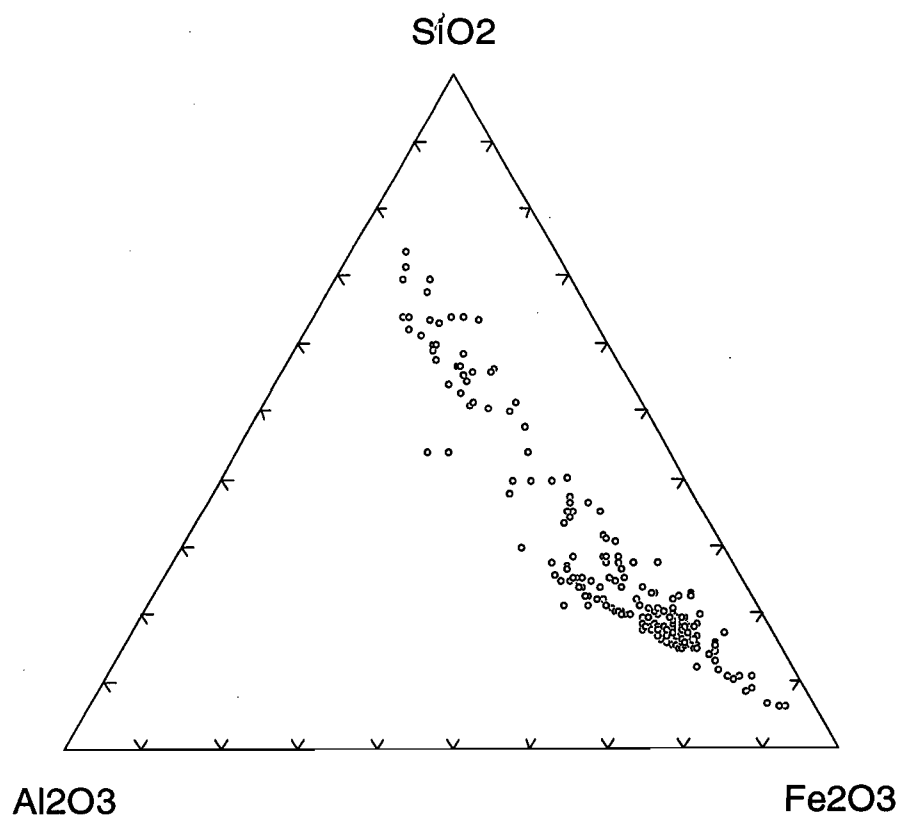


Figure 11a. Ternary Si-Al-Fe diagram of lag data from VB-Boags showing trend from Fe apex towards Si-Al axis, representing variable kaolinite content and a more siliceous trend.

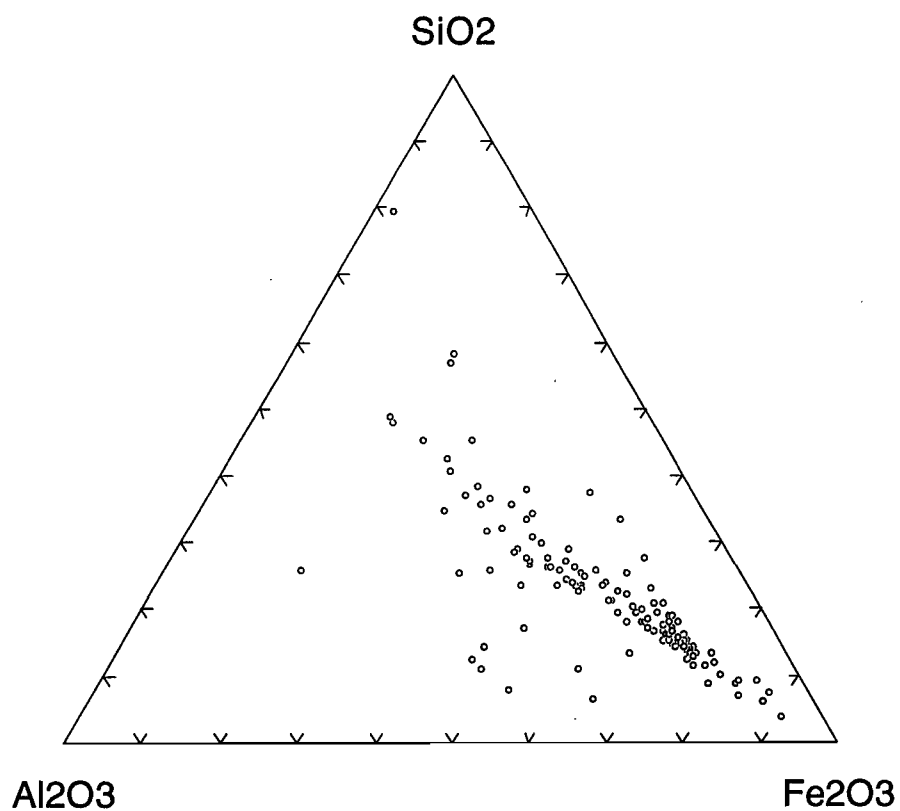


Figure 11b. Ternary Si-Al-Fe diagram of lag and laterite data from Emu showing trend from Fe apex towards Si-Al axis, representing variable kaolinite content and both a more siliceous trend and an aluminous trend, the aluminous trend representing contained gibbsite.

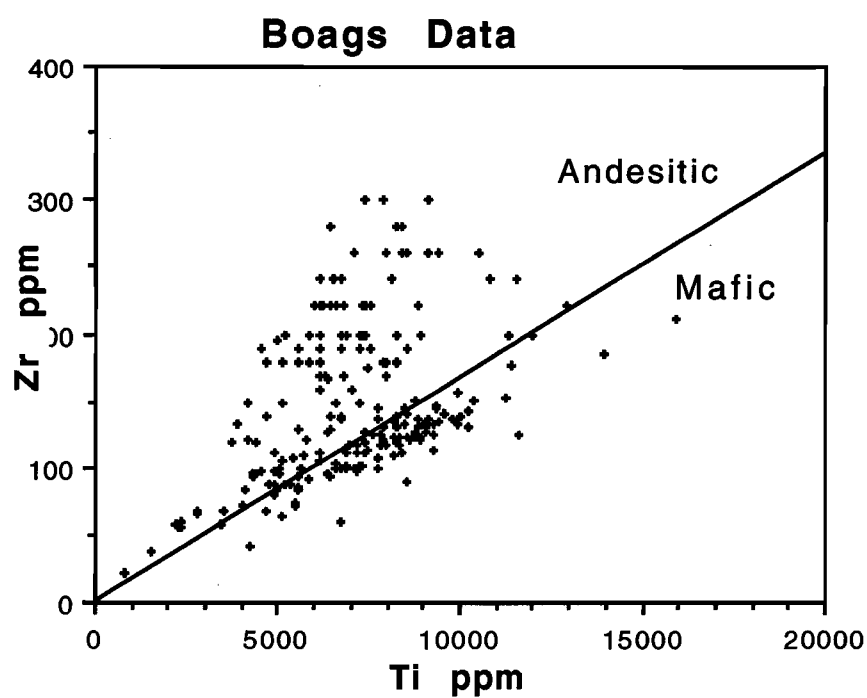


Figure 12a. Ti-Zr scattergram of lag data from VB-Boags showing the 60:1 Ti/Zr ratio dividing the basaltic from the andesitic field (after Hallberg, 1984).

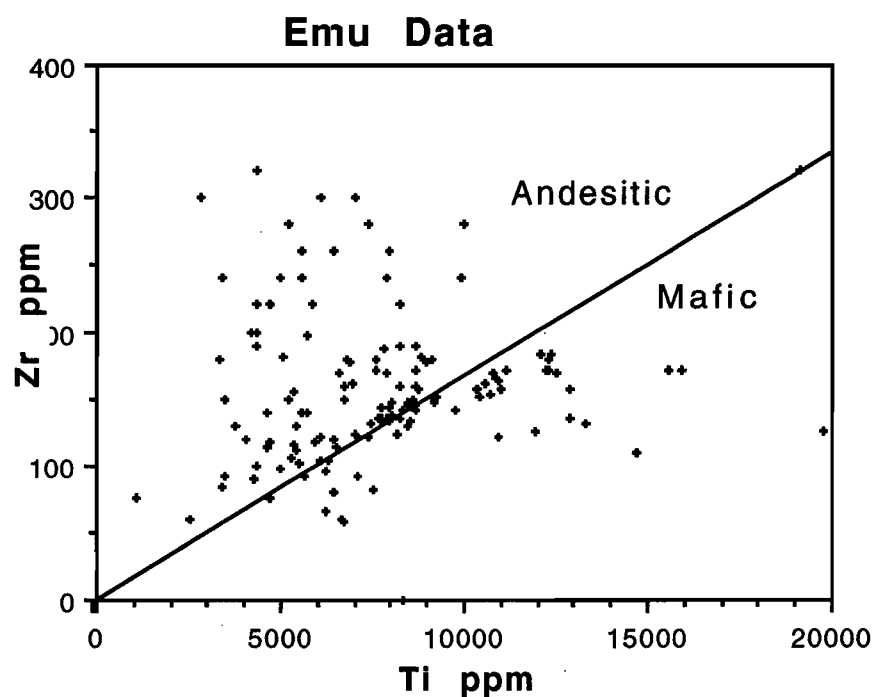


Figure 12b. Ti-Zr scattergram of lag data from Emu showing the 60:1 Ti/Zr ratio dividing the basaltic from the andesitic field (after Hallberg, 1984).



#### **8.4.3 Target elements: Au, Ag**

Gold anomalies of 300-400 ppb in a background of <10 ppb, about 300-400 m across, clearly indicate the mineralisation at both sites (Figure 13A); the anomalies are broader at Emu, due to greater dispersion in the lateritic duricrust. The smaller and more patchy nature of the Au anomalies at VB-Boags is probably due to paucity of lateritic duricrust and variations in thickness of the colluvium-alluvium, which was probably most thin over the centre of the Boags Pit. Most of the Ag data lies below the XRF detection limit (5 ppm); although it has been plotted for completeness, it should be ignored.

#### **8.4.4 Chalcophile pathfinder elements: As, Bi, Cu, Ge, Pb, Sb, Se, Zn**

Most of the residual regime and some of the colluvium at Emu is occupied by a broad As anomaly, with peaks exceeding 2000 ppm, centred over the pit (Figure 13B). The As anomaly is more restricted at VB-Boags, due to the paucity of residual laterite and extensive alluvial cover. The As anomaly clearly marks the locations of the Boags Pit where the cover is known to be thin and the southern end of the VB Pit. The As anomaly between the VB and Boags pits is obscured by the east-flowing drainage. Lead and Sb (Figure 13C) anomalies have similar characteristics to As. Although Pb and Sb maxima at both sites are similar (300-500 ppm), the anomaly is more restricted at Emu, probably due to less dispersion of Pb and Sb in the lateritic residuum.

The Zn peaks are not quite co-incident with As, Pb and Sb but similarly mark the targets. The Zn maximum at Emu is located in a drainage surrounded by calcareous earths. Boags is not depicted by Zn but there is a distinct Zn anomaly at VB. It is possible that a marginal improvement may be achieved by calculating an Fe-controlled Zn residual. At Beasley Creek, Robertson (1990) has showed that Cd (by ICP/MS) shows better anomalies than Zn, in coarse, ferruginous soil clasts, even though its abundance is two orders of magnitude less.

The anomaly in Cu is weak, in few places exceeding the threshold of 180 ppm, although slightly elevated Cu abundances appear to mark the general strike of the mineralised zone. There is no clear anomaly in Bi and Ge, due to much of the data being below detection, and the Se anomaly is indistinct and weak.

#### **8.4.5 Alkaline earth elements: Mg, Ca, Ba**

Patchy distribution of high Ca and Mg at VB-Boags reflects the localised occurrence of pedogenic carbonate in the colluvial-alluvial cover of the alluvial plain. Although the peaks are generally coincident, correlation between these alkaline-earth elements is low, at high Ca abundances, suggesting a variable carbonate composition. Carbonate is patchily developed in the hardpanised materials at Boags but is not present in areas covered by the more recent alluvium-filled drainages.

The distribution of Ba is a little different from that of the other alkaline earth elements. Like Na and K, it may be related to the phyllic alteration halo. There are no Ba anomalies in areas covered by alluvium-filled drainages. Barnes (1985) described Ba anomalies associated with mineralisation in this area. Significant Ba anomalies are associated with phyllic rocks at Beasley Creek in soil, lag and saprolite (Robertson, 1989; 1990; 1991). An alternate interpretation is that Ba reflects weathered feldspars of the porphyries, because Ba is readily reprecipitated after weathering, unlike Na, K and Ca from the same source.

#### **8.4.6 Alkalis: Na, K, Rb**

The phyllic halo is very clearly revealed by lag geochemistry at Emu, where a wide bull's-eye K anomaly (Figure 13D) marks the north end of the pit. At VB-Boags, both pits are similarly indicated but the anomaly is more restricted and of lesser magnitude. Similar anomalies result from Na but the peaks are only in part co-located with K. Although Rb was determined in a

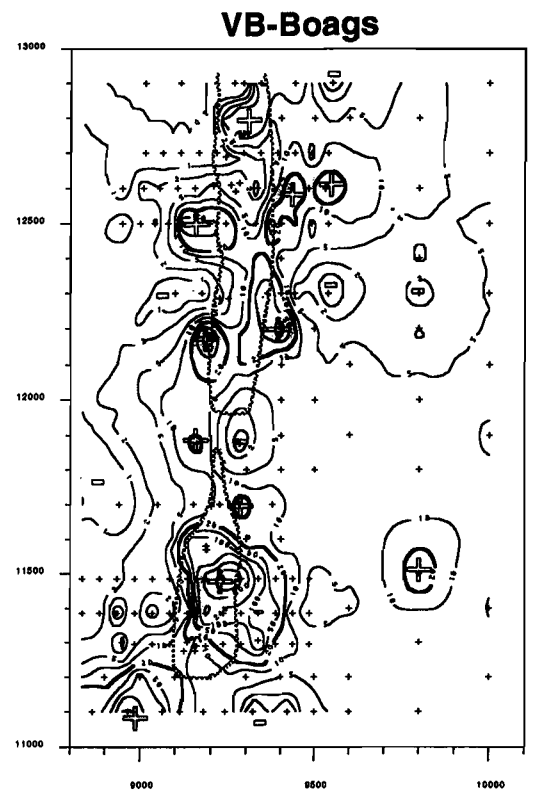
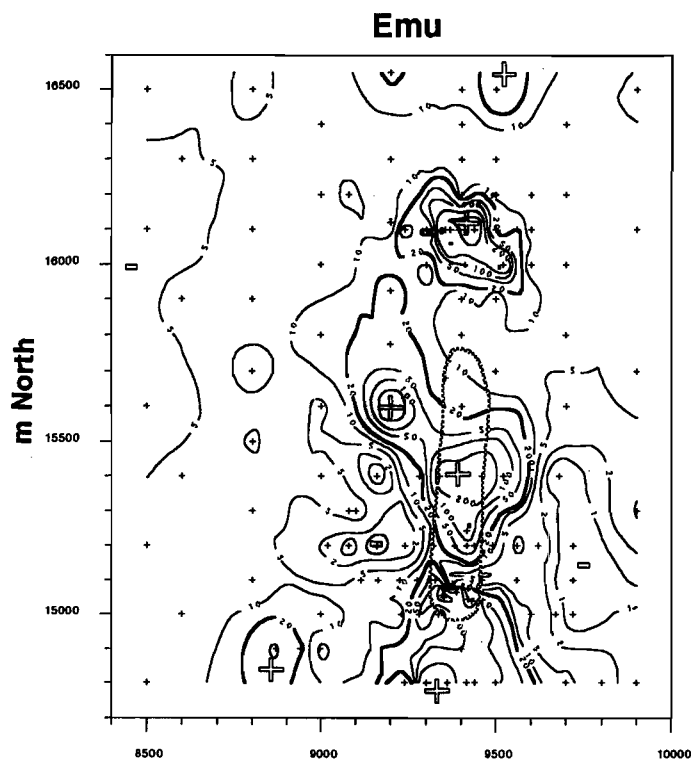


Figure 13A. Gold distributions at Emu and VB-Boags.

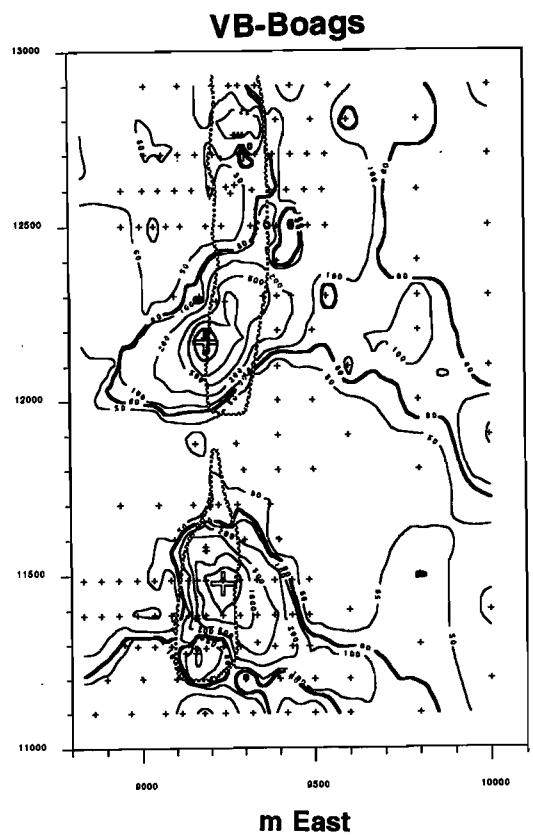
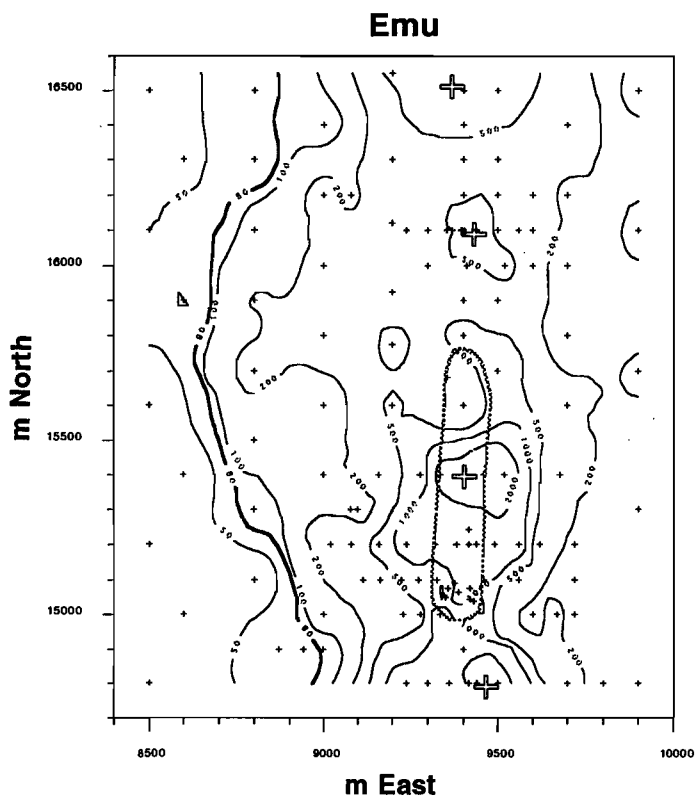


Figure 13B. Arsenic distributions at Emu and VB-Boags.



small number of the samples, its high correlation with K suggests that it would similarly indicate phyllic alteration.

#### **8.4.7     *Stable lithophile elements: Cr, Ti, Zr***

As is usual for these 'stable' elements, there is a considerable random variation at both sites in both Ti and Zr; the Ti/Zr ratio is more helpful. Hallberg (1984) showed that the major groups of both fresh and weathered igneous rocks could be distinguished by their Ti:Zr ratio. Basalt has a Ti:Zr ratio of >60, andesite 12-60 and dacite 4-12. Ultramafic rocks have similar Ti/Zr ratios to basalts but are richer in Cr. Inevitably the fields show some overlap. Robertson (1991) showed that this Ti:Zr relationship for weathered basaltic rocks holds within the saprolite but there was considerable scatter (apparently due to loss of Ti), in the mottled zone and also in the duricrust (where net gain of detrital zircon is possible). Ti-Zr scattergrams for Emu and VB-Boags are shown in Figures 12A and B. There is a large group of data with a Ti:Zr ratio of >60 at VB-Boags but there is considerable scatter in the andesite field (Ti:Zr <60). Although not as distinct, there is a similar trend at Emu. Porphyries, characterised by a very low Ti/Zr ratio (<12) are more abundant at Emu.

Although the peaks in Cr abundance (>1500 ppm) at Emu seem to coincide with mafic rocks and the Cr lows (<500 ppm) with mapped porphyries, the contoured data are not sufficiently distinct to reflect underlying lithologies reliably. There does not appear to be a Cr anomaly associated with the Au deposits (see Barnes, 1985). The distribution of Cr at VB-Boags is more random, in keeping with this depositional environment and there is no indication of the underlying ultramafic rocks in the east.

#### **8.4.8     *Transition elements: Co, Mn, Ni, V***

The Mn and Ni contents at Emu are not linked to either mineralisation or to lithology. However, at VB-Boags, the north-east part of the area, underlain by ultramafic schists, is richer in Mn (>500 ppm) and Ni (>100 ppm) than elsewhere. This may reflect mobility of these elements in the surface environment. The V distribution is similar at both sites to that of Ti, with which it is closely correlated. The distribution of Co is not linked to mineralisation or to lithology.

#### **8.4.9     *Granitoid associated elements: Mo, Nb, W***

There is a significant difference in the range of the Mo and W geochemistry between the two study areas. There is little variation at Emu, probably due to depletion of Mo and W in the laterite zone. Despite isolated peaks, there are no Mo or W anomalies marking the mineralisation. At VB-Boags the range is much greater but the mineralisation at Boags is marked by a depression in Mo and W abundance, again probably due to exposure of highly leached outcrop. There is no relationship between the Mo and W anomalies on the one hand and mineralisation and the lithology on the other. Although the range in Nb abundances are less dissimilar at the two study sites, there is no relationship between Nb anomalies and the mineralisation or lithology. The ranges of Nb and Mo are sufficiently above detection for the data to be real.

### **8.5     Comparisons**

*Emu:* The best pathfinder elements at Emu are As > Sb > Au > Pb. The width of the arsenic anomaly is 1200 m, that of Sb approximately 1000 m, Au 500 m and Pb 400 m. All these anomalies overlie the mineralised horizon and are relatively regular and linear. However, As, Pb and Sb only approximately locate the best Au mineralisation. These four elements could be used effectively in a regional lag exploration program with a sample spacing of 1000 m on a triangular grid, to identify targets for follow up exploration because they directly reflect the mineralisation. The phyllic halo around the mineralisation is shown by anomalies in K > Na > Ba. The K anomaly accurately locates the mineralisation; those of Na and Ba locate only parts. It is suspected that Rb would be as effective as K. Although porphyries are associated with the



mineralisation, intense weathering would destroy the K-feldspar and remove the K. Generally, K survives only in K-micas in the upper saprolite, mottled zone and duricrust. Thus, medium to high resolution, possibly airborne, radiometric surveys may have some potential for locating an exposed phyllic halo. The K abundance in the regolith is not very great so, where it is diluted by other regolith materials, its use may be significantly reduced; where it is concealed by overburden, it would be ineffective.

**VB-Boags:** Arsenic, Au, Pb and Sb are less effective at VB-Boags. Only one sample (9,200E 12,200N) is consistently anomalous at VB and only samples from the central-east portion of Boags are anomalous. These anomalous samples occur where very thin, loose, sheet flood detritus directly overlies the mottled zone, with no intervening hardpanised alluvium. Anomalous clasts were probably dispersed mechanically into the largely exogenous surficial layers by bioturbation (root plucking, insect activity) and illuviation. All remaining laterite is covered by hardpanised alluvium, restricting the anomaly, despite abundant, underlying, ferruginous material. At the northern end of Boags, the anomaly has been truncated by a drainage channel, filled with fluvial sediments derived from the west. All four elements are anomalous immediately south-west of Boags pit, where there is a low hill with outcrops of residual lateritic remnants and ferruginous saprolite. Anomalous K and Ba, derived from the phyllic halo, are preserved in a smaller but similar rise, capped by ferruginous saprolite, which occurred in the area now occupied by the north-central part of the pit (9150 mE; 11550 mN).

Surface geochemical exploration in alluvial plains, using As, Au, Pb and Sb alone, would be very reliant on local thinning of the hardpanised substrate and may fail to detect mineralisation if this substrate is too thick or resistant to bioturbation. Drilling to locate buried geochemical halos in laterite or ferruginous saprolite may, however, be effective. Modified thresholds for Bi (5 ppm), Cu (150 ppm) and Zn (100 ppm) may be used to indicate the mineralisation at VB-Boags. The validity of these Cu and Zn anomalies is uncertain, as their thresholds are low, compared to CSIRO-AGE thresholds. Copper and Zn are more obviously effected by hydromorphic dispersion than Bi. All of these elements may be useful pathfinder elements in the alluvial plains.

The contrasting nature of the geochemical anomalies and the regolith-landforms over Emu and VB-Boags highlight the importance of regolith-landform mapping in planning a geochemical program and in subsequent interpretation. Stable, exposed, lateritic regions must be differentiated from depositional regimes such as alluvial plains for cost effective sampling. In the former (e.g., Emu), wide spaced lag sampling (up to 1 km) on a triangular grid, using As, Au, Ba, Pb, Rb and Sb as indicator elements will delineate mineralisation and its phyllic halo. In depositional regimes, where the hardpanised colluvial substrate is known to be thin, lag can also be used but sample spacing should be reduced to 400 m, or much less, to detect zones of thin cover. Such a strategy would include an appreciable risk of non-detection. It is suspected that success is very dependant on silicification and induration of the mineralised zones, their greater resistance to erosion and *consequent* thin cover. However, deepening of the cover and its hardpanised substrate may well prevent effective surface geochemical prospecting and drilling through this substrate, into the lateritic residuum or ferruginised saprolite would then be necessary.

## 9 SOIL SAMPLING

A small suite of soil samples were collected immediately south of the Boags pit by R. Davy (Figure 14). These carbonate-free soils are red, stony, clay sands, composed of small clay, silt and sandy fractions and a major proportion (>80%) of the ferruginous nodules and lithorelics that are typical of soils over mafic rocks north of the Menzies Line. The ferruginous clasts consist of black glossy goethite nodules, dark brown goethite nodules and angular fragments,

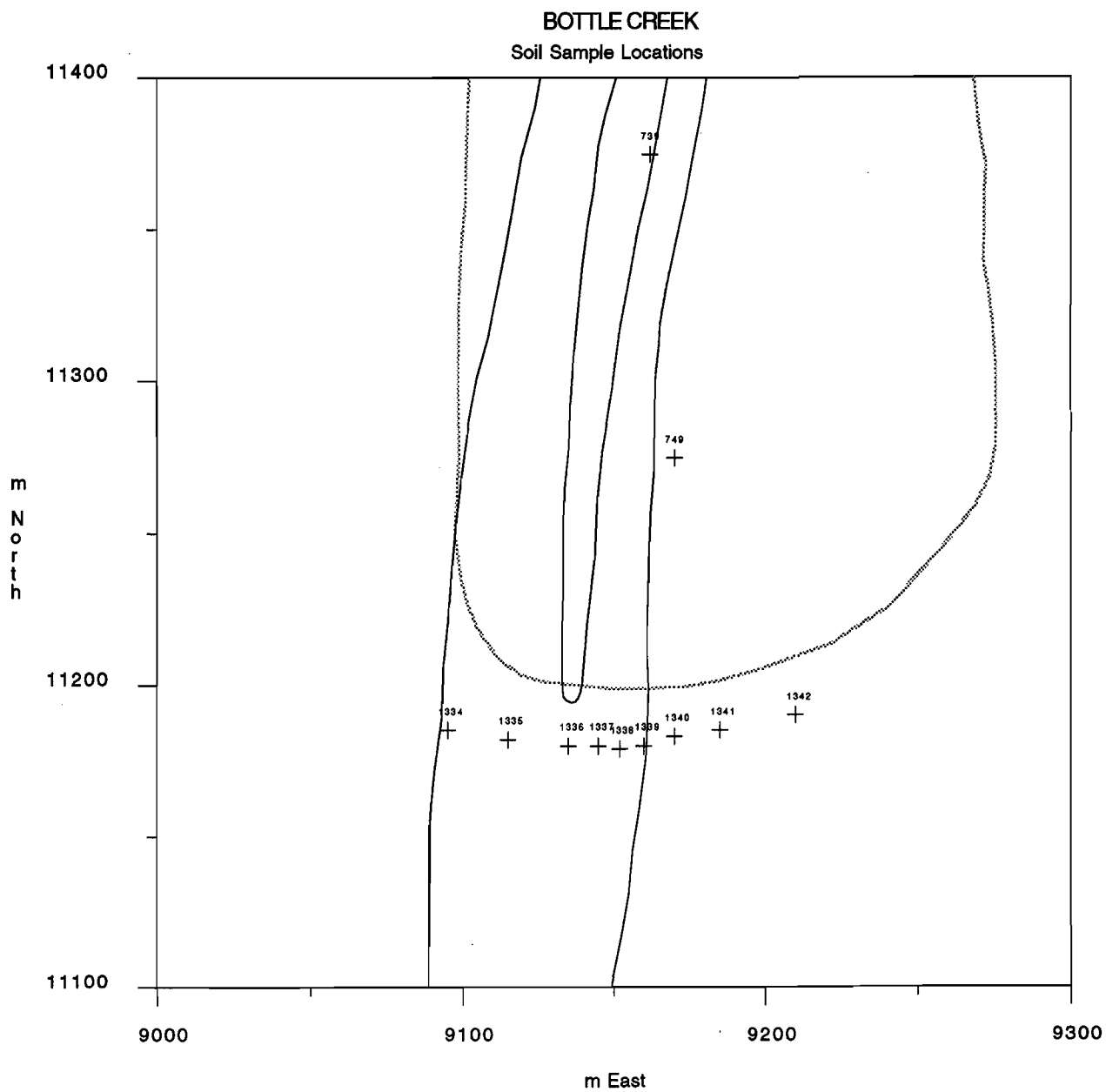


Figure 14. Location of soil samples in relation to the south end of the Boags Pit.

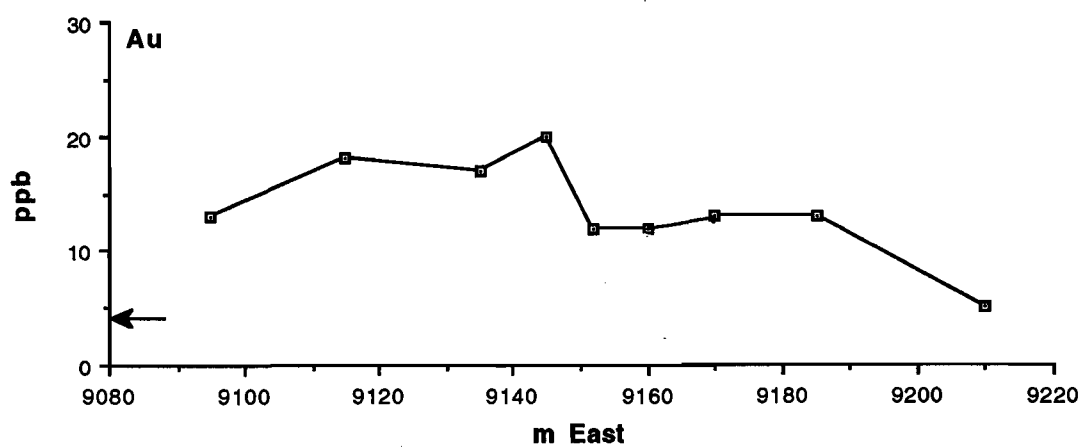
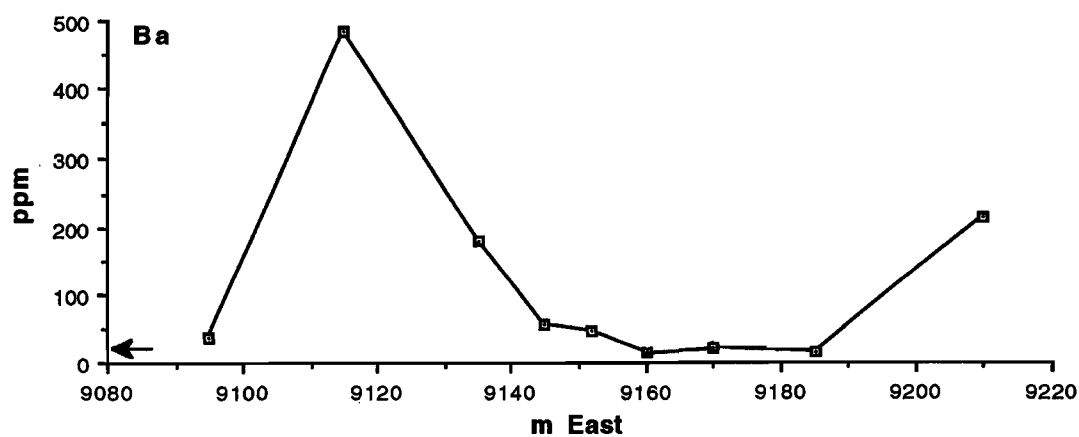
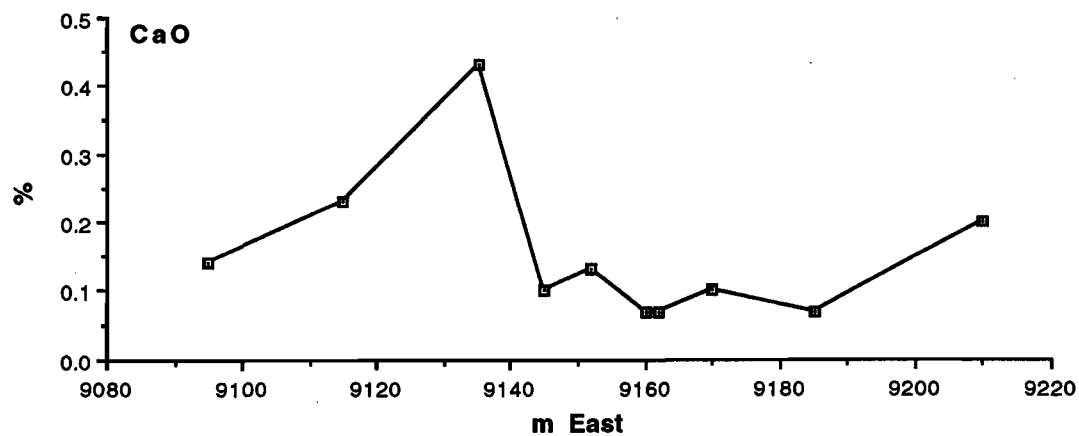


Figure 15. Soil traverse south of Boags Pit. Calcium, Ba and Au.

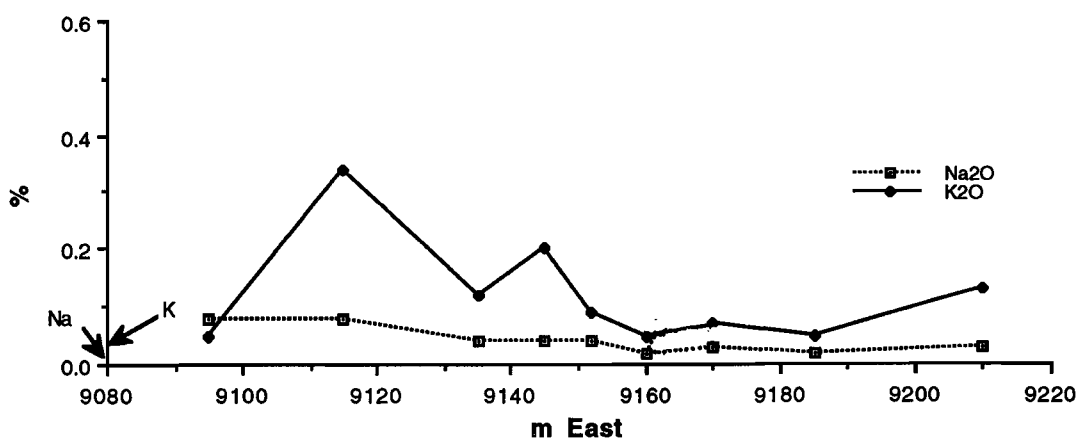
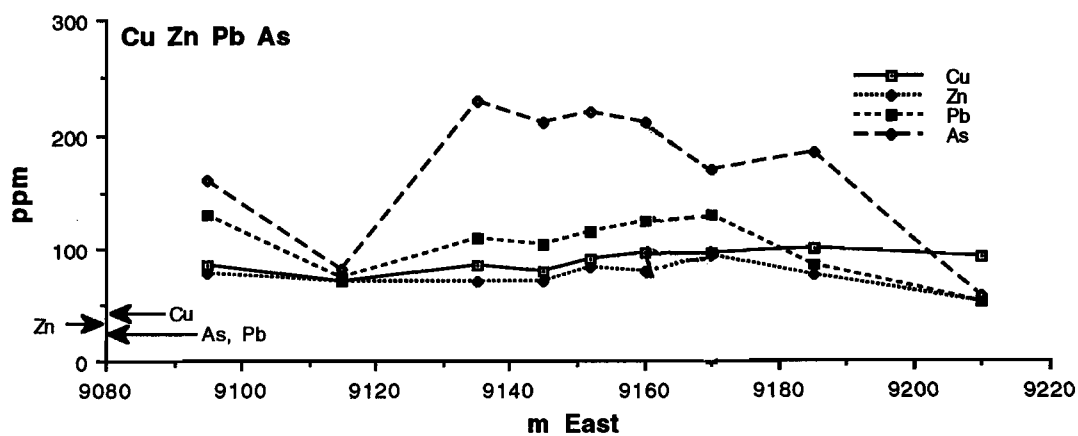
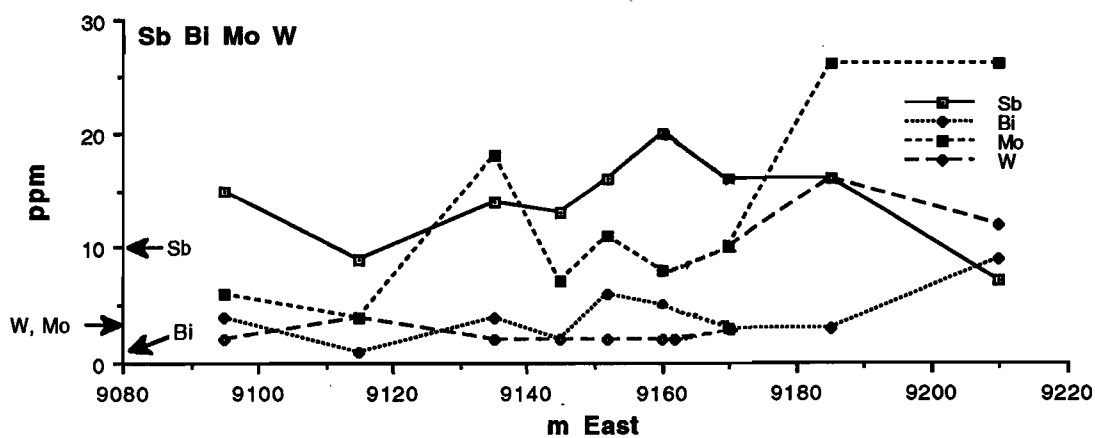


Figure 15 (ctd). Soil traverse south of Boags Pit. Antimony, Bi, Mo, W, Cu, Zn, Pb, As, Na and K.



some of which are magnetic, and brown to yellow-brown, non-magnetic ferruginous clay nodules and fragments. Included with these is a very small quantity of cellular material, probably gossan fragments, *which are non-magnetic*. The fine, sandy fraction consists of hematite-coated angular quartz grains with about 5% of round, polished to frosted aeolian grains. This soil has a very similar composition to that of Beasley Creek (Robertson, 1990). Analyses of these soils are given in Appendix 9. The distribution of samples was not sufficiently wide to extend into background. Since the major part of the soil consists of ferruginous lithorelics, background geochemical abundances used for the lag would be a valid approximation for the soil background; these are shown on the plotted soil traverse (Figure 15). This should be compared to the lag results (Appendix 6).

The geochemistry confirms the non-calcareous nature of the soil (<0.5%). The abundance and distribution of Ba, Au, Sb, Bi, Mo and W reflect those shown by the lag survey.

There are insufficient data to determine the relative efficacy of soil sampling and lag sampling. However, since the soil consists largely of ferruginous nodules and lithorelics, which are the source material for the lag, analysis of pulped whole soil or of the >0.5 mm soil fraction would be as effective as lag sampling. The choice is not one of a better medium but of cost and convenience of collection and preparation. The soil may show slightly less dispersion and so may require a slightly closer sampling grid. Use of a magnetic coarse soil fraction is not recommended as it would probably not include gossanous material.

The high proportion of quartz sand in the silty fraction and a lack of soil carbonate indicates that analysis of the <75 µm fraction would be of doubtful value, based on experience at Beasley Creek (Robertson, 1990) and Lights of Israel (Robertson and Tenhaeff, 1992). As the soil composition and structure is very similar to that of Beasley Creek, it would be expected that use of the <4 µm fraction would be preferable to the <75 µm fraction but inferior to the >500 µm fraction.

## **10 SUMMARY AND CONCLUSIONS**

### **10.1 Gossan**

Gossan sampling, showed anomalous Au > As > Pb, K, Na > Sb, Ba > Bi, Cu, Se, W > Mo with much inhomogeneity. On passing from gossan to lag, most elements showed a slight decrease in geochemical abundance (x 0.5-0.3), although As was significantly depleted (x 0.1) suggesting some hydromorphic dispersion of As, not so apparent in the other elements.

### **10.2 Lag mineralogy and petrography**

The lag at Emu and Boags is dominated by hematite, total Fe and goethite is slightly more abundant in the vicinity of mineralisation, where kaolinite tends to be displaced. Lag of the depositional areas (VB-Boags) contains more quartz and less kaolinite than that of the residual-erosional areas (Emu). Although there is muscovite from the phyllic alteration halo in both areas, the muscovite anomaly over Emu is greater by an order of magnitude.

Remnants of muscovite and pseudomorphs after magnetite and, possibly, sulphides are preserved in the lag at Emu but only very close to the mineralised zone, indicating limited mechanical dispersion of the lag. Lag, derived from mafic lithologies more distant from mineralisation, can be distinguished by fingerprint fabrics, probably after saprolitic kaolinite and/or smectite. Accordion structures, now preserved in goethite, indicate saprolitic and pedogenic recrystallisation of pre-existing kaolinite. Much of these structures have been wholly or partly

replaced by secondary goethite and subsequent partial dissolution has left numerous channelways and voids, infilled or lined with goethite. Due to the polymictic nature of the lag over depositional areas, the lag at VB-Boags was not investigated petrographically.

### 10.3 Lag geochemistry

Lag geochemistry is effective in erosional-residual areas, particularly where the lateritic duricrust subcrops beneath a thin, stony soil. In contrast, the effectiveness of lag geochemistry is severely limited, in depositional areas, by the thickness of the transported veneer and the ability of bioturbation to bring material from the lower layer to the surface. This is made more difficult where the layer of colluvial-alluvial sheet-flood debris has been hardpanised. Sporadically, where the this layer is thin, the lag shows a few indications. Where saprolite is overlain by narrow channels, filled with fluvial gravels, geochemical signals are prevented from becoming incorporated in the lag.

The major element composition (Si, Al, Fe) reflects the mineralogy of the two contrasted environments. There is a trend from the Fe apex, reflecting goethite and hematite, to a point on the Si-Al axis, which corresponds to kaolinite, reflecting variable loss of kaolinite from the outer part (cutan) of lag fragments at both sites. However, the depositional area at VB-Boags is more siliceous than that of the erosional-residual area at Emu, due to quartz enrichment, possibly derived from a porphyry source. Some lag samples from Emu indicate the presence of a more aluminous mineral, subsequently shown to be gibbsite.

Gold anomalies of 300-400 ppb clearly outline the mineralisation at both sites. The anomalies are broad at Emu due to dispersion in the lateritic duricrust; at VB-Boags the Au response is patchy and related to a paucity of lateritic duricrust and to the variable thickness of the transported cover. Anomalies in chalcophile elements (As, Pb and Sb) are broad at Emu but very restricted at VB-Boags, again related to cover thickness. The anomalies in Cu and Se are weak and there are no Bi and Ge anomalies due to their abundances being close to the detection limit. Of particular importance are the anomalies in K, Na and Ba related to the phyllic halo around the mineralisation. These are particularly apparent at Emu.

The best elements are  $As > Sb > Au > Pb$  and show anomaly widths at Emu of 1200, 1000, 500 and 400 m respectively. The phyllic alteration is reflected by  $K > Na > Ba$ . As for Au, these anomalies are small and patchy at VB-Boags. Here, the anomalies occur where thin, loose, sheet flood detritus overlies the mottled zone, with no intervening hardpanised alluvium. Mechanical dispersion into the surficial environment was by bioturbation. All the anomalies have been truncated by a sediment-filled fluvial channel at the northern end of Boags.

A modeled, multivariate representation of the data may be used (Smith *et al.*, 1992), such as a slightly modified CHI-6\*X index ( $As+3.56.Sb+10.Bi+3.Mo+30.Ag+10.W+3.5.Se$ ), given in Figure 16. This is dominated by As. Although it provides a slightly smoothed result, it excludes important elements such as Pb (to which it is very similar) and K. More complex indices could be used with removal of background and each pathfinder element weighted so as to have equal range, similar to that used by Robertson (1991). Such modeled chalcophile indices pre-suppose the type of mineralisation sought and its associated pathfinder elements.

### 10.4 Soil

The soils are red, stony, carbonate-free clay-sands, typical of soils north of the Menzies Line. They are particularly rich (>80%) in Fe-rich lithorelics, some of which are magnetic but most are not. Included with these is a small amount of non-magnetic, cellular, presumably gossanous, material. The sandy fraction consists mainly of hematite-coated, angular grains; only about 5%

EMU

VB Boags

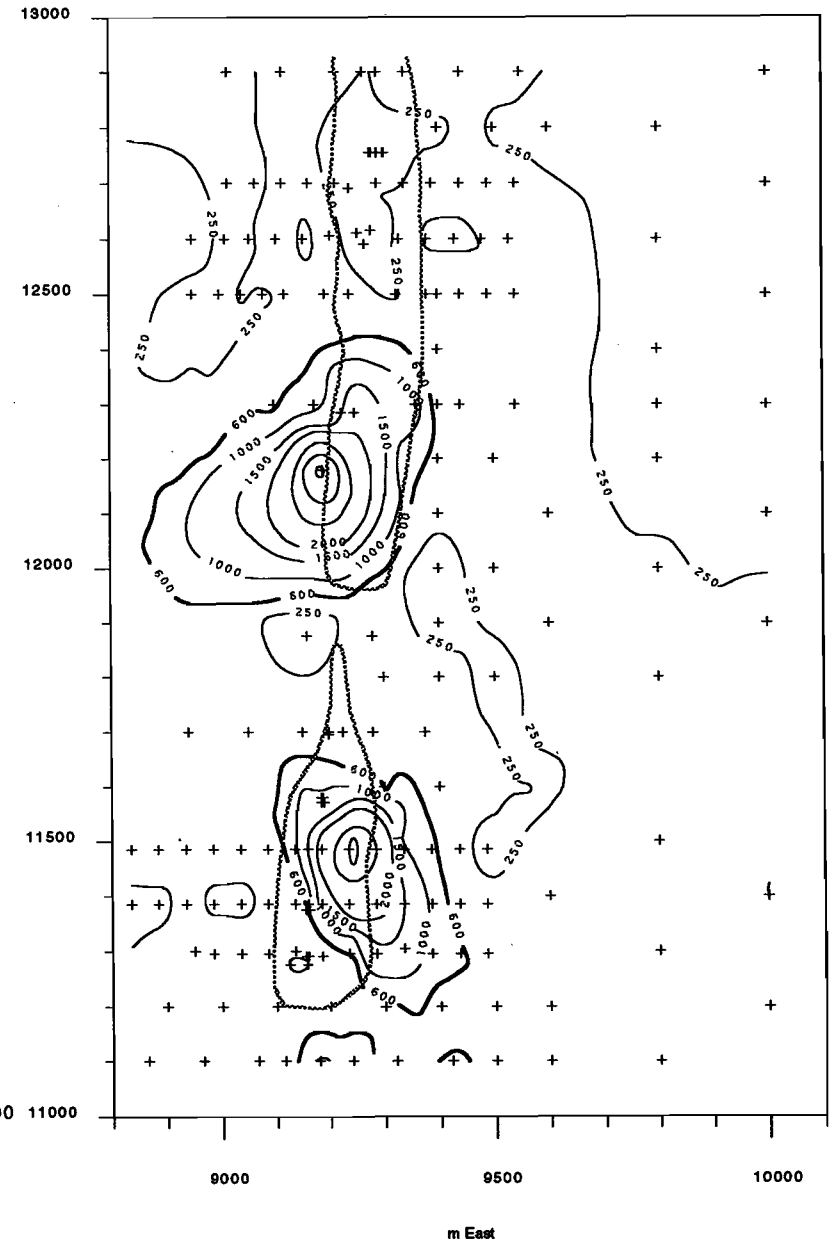
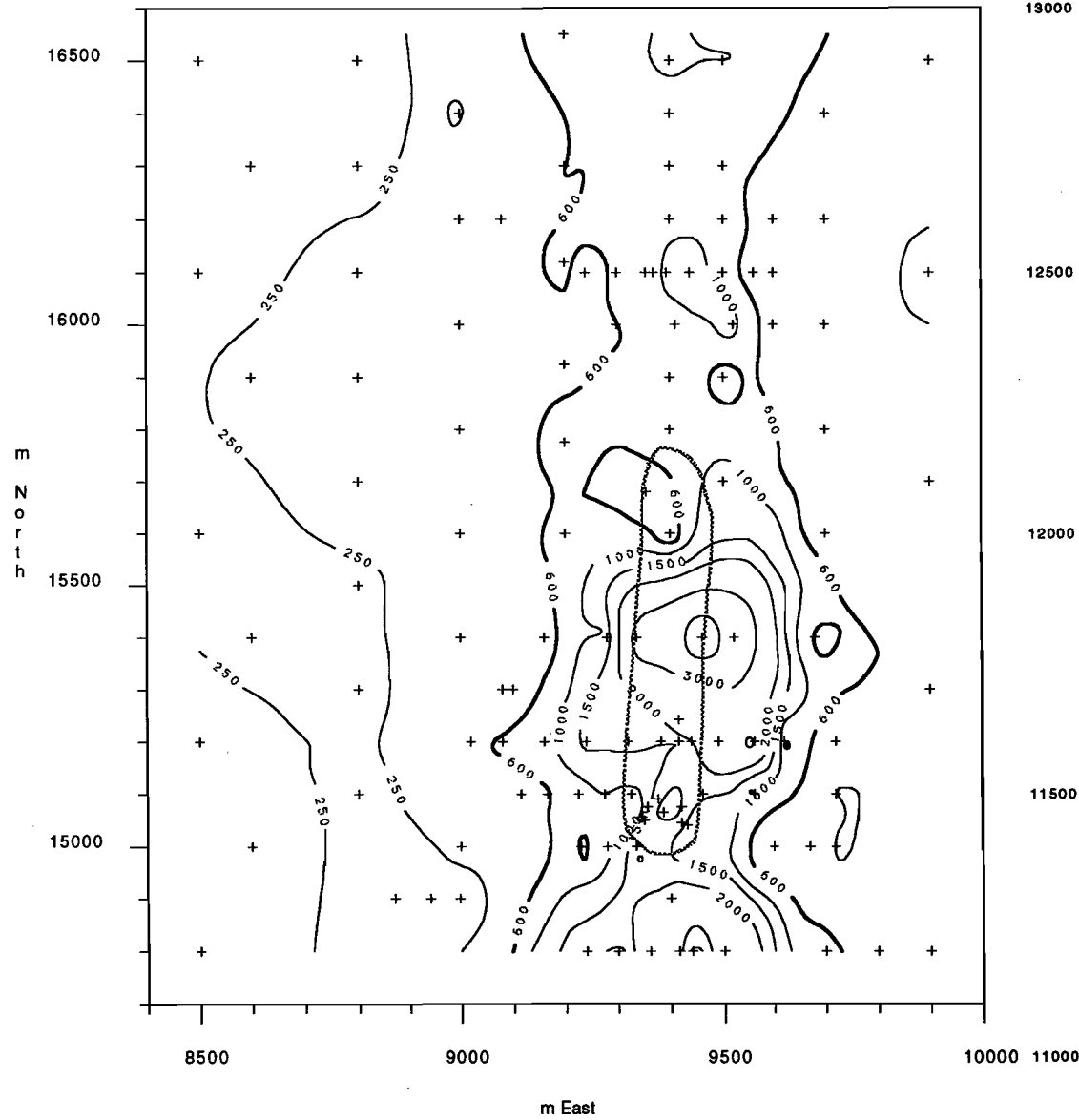


Figure 16. A slightly modified CHI-6\*X index (after Smith *et al.*, 1992) for Emu and VB-Boags.

of these are round, frosted, aeolian grains. The very limited soil sampling, south of VB-Boags, did not extend from the mineralisation into background. The soil geochemistry closely reflects that of the lag, for which it provides the source. Experience in this environment suggests that surficial, coarse-fraction ( $>750\ \mu\text{m}$ ) soil sampling is as effective as lag sampling; the choice being one of cost and convenience.

## 10.5 Strategy

That part of the Phase 1 area that had been geomorphologically mapped has the following regolith-landform composition:-

| Environment        | Regolith                                     | %    |
|--------------------|--|------|
| Residual-erosional | Lateritic residuum and ferruginous saprolite | 10.2 |
| Erosional          | Colluvium                                    | 43.8 |
| Erosional          | Calcareous earth                             | 5.6  |
| Depositional       | Alluvial plain with hardpan                  | 30.3 |
| Depositional       | Drainages with fluvial gravels               | 10.1 |

Almost 60% of the area lies in residual-erosional regimes, in which surficial geochemistry is likely to be successful. Only 10% of this is covered by exposed lateritic residuum, in which anomaly sizes would be enhanced by lateritic dispersion, allowing wide-spaced sampling. The remaining 50% lies in erosional regimes, in which the laterite has been partly or largely stripped and anomaly sizes are likely to be smaller, requiring a closer-spaced sampling.

Over 40% of the area is underlain by depositional regimes, in which surficial geochemistry is unlikely to be reliable and drilling through the cover would be necessary. It is possible that surficial geochemistry could be used along the margins of these areas, relying on bioturbation of the thin cover to carry anomalous material to the surface but this would have attendant risks. Any reliability would depend upon induration of the mineralisation to form positive features in the palaeotopography. If the mineralisation is not indurated or had been subsequently softened during lateritisation, success of this means of prospecting would be considerably reduced. Discovery of mineralisation in thinly covered depositional areas, such as at VB-Boags, is very dependant on chance thinning of the cover and/or on discovery of geochemical anomalies in residual-erosional areas along strike, with subsequent follow-up by drilling of the covered areas. North of the Menzies Line, a consistent strategy of restricting surficial geochemistry to residual-erosional areas and drilling the covered areas is regarded as highly advisable; south of the Menzies Line, sampling of soil carbonates in covered areas may be used for auriferous deposits but not for non-auriferous polymetallic mineralisation.

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