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OPEN FILE REPORT SERIES

EASTERN GOLDFIELDS FIELD EXCURSION

FIELD GUIDE

C.R.M. Butt, R.E. Smith, M. Dell, R.R. Anand, M.J. Lintern, D.J. Gray, J. Vinar, A.P.J. Bristow, H.M. Churchward, Z.S. Varga and J.E. Wildman

CRC LEME OPEN FILE REPORT 109

June 2001

(CRC LEME Restricted Report 4R/
CSIRO Division of Exploration and Mining Report 253R, 1996.
2nd Impression 2001.)

CRC

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CRC LEME is an unincorporated joint venture between The Australian National University, University of Canberra, Australian Geological Survey Organisation and CSIRO Exploration and Mining
Headquarters: CRC LEME c/o CSIRO Exploration and Mining, Private Bag No 5, PO Wembley, Western Australia, 6913.

RESEARCH ARISING FROM CSIRO/AMIRA YILGARN REGOLITH GEOCHEMISTRY PROJECTS 1987-1996

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" 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 commenced with 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 (1991-1993). 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.

Most reports related to the above research projects were published as CRC LEME Open File Reports Series (Nos 1-74), with an index (Report 75), by June 1999. Publication now continues with release of reports from further projects.

P252: Geochemical exploration for platinum group elements in weathered terrain. Leader: Dr C.R.M. Butt.
This project was designed to gather information on the geochemical behaviour of the platinum group elements under weathering conditions using both laboratory and field studies, to determine their dispersion in the regolith and to apply this to concepts for use in exploration. The research was commenced in 1988 by CSIRO Exploration Geoscience and the University of Wales (Cardiff). The Final Report was completed in December 1992. It was supported by 9 companies.

P409: Geochemical exploration in areas of transported overburden, Yilgarn Craton and environs, WA.
Leaders: Drs C.R.M. Butt and R.E. Smith.
About 50% or more of prospective terrain in the Yilgarn is obscured by substantial thicknesses of transported overburden that varies in age from Permian to Recent. Some of this cover has undergone substantial weathering. Exploration problems in these covered areas were the focus of Project 409. The research was commenced in June 1993 by CSIRO Exploration and Mining but was subsequently incorporated into the activities of CRC LEME in July 1995 and was concluded in July 1996. It was supported by 22 companies.

Although the confidentiality periods of Projects P252 and P409 expired in 1994 and 1998, respectively, the reports have not been released previously. CRC LEME acknowledges the Australian Mineral Industries Research Association and CSIRO Division of Exploration and Mining for authority 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 109) is a second impression (second printing) of CSIRO, Division of Exploration and Mining Restricted Report 253R, first issued in 1996, which formed part of the CSIRO/AMIRA Project P409.

Copies of this publication can be obtained from:
The Publication Officer, c/- CRC LEME, CSIRO Exploration and Mining, Private Bag 5, Wembley, WA 6913, Australia. Information on other publications in this series may be obtained from the above or from http://leme.anu.edu.au/
Cataloguing-in-Publication:

Eastern Goldfields Field Excursion Field Guide.
ISBN 0 643 06731 0
1. Gold - Western Australia
I. Butt, C.R.M. II. Title
CRC LEME Open File Report 109.
ISSN 1329-4768

CONTENTS

INTRODUCTION

AMIRA Project 409, *Geochemical exploration in areas of transported overburden, Yilgarn Craton and environs*, has, as its principal objective, the development of geochemical exploration methods for areas having a substantial cover of surficial sediments, through investigations of the processes of geochemical dispersion from concealed mineralization. An important aspect of the project is to translate research findings into practical outcomes. Field excursions have a significant role in this process, for they permit geologists and geochemists from the research group and the supporting companies to examine key sites together. This interaction promotes a much freer exchange of ideas than is possible during, for example, the formal atmosphere of seminars. The project has several important research sites and districts across the Yilgarn Craton. It is impractical to visit all of these in one excursion. The excursion in August 1995 examined sites in the Murchison and adjacent areas, including Mt Gibson, Mt Magnet, Baxter and Fender, having a variety of different types of transported overburden. Each is characterized by the development of red-brown hardpan in the surface horizons but, except at Mt Gibson, pedogenic carbonates are rare or absent. This second excursion is to the Eastern Goldfields region and again provides an opportunity to examine a range of different overburden types and offers a comparison between areas having a strong development of pedogenic carbonates, south of the Menzies line, and those having red-brown hardpans, to the north.

The first visit is to the Kanowna Belle gold mine. This has not, in fact, been studied during this project, but it was an important site for AMIRA Project 240A, *Yilgarn Lateritic Environments*. It serves as an excellent introduction to many of the important features of the regolith of the Kalgoorlie region and to the usefulness of surface soil sampling in areas of shallow transported cover, including the use of pedogenic carbonates as sample media. The excursion then visits two areas within which the effectiveness of surface sampling has been investigated where mineralization concealed by deeper sediments, in both cases associated with palaeochannels. Steinway and Greenback have supergene mineralization within and beneath 15-25 m of oxidizing sediments. There is a surface anomaly at Steinway, whereas there is none at Greenback, although mineralization is shallower and has been mined. The anomaly at Steinway is now considered possibly coincidental, a result of natural contamination - a common and potentially misleading feature of the region. Argo and Apollo are concealed beneath reducing lake and channel sediments. Although Au is again concentrated in the calcareous horizons of the soils, there is no surface anomaly. Partial extraction analyses appear to be ineffective in defining anomalies in either the Steinway or Argo-Apollo areas.

On the second day, the excursion visits the Safari prospect at Mt Celia, and Golden Delicious, on or north of the Menzies line. Carbonates are present at both sites, though commonly deeper in the regolith (below 2-5 m) than the pedogenic carbonates further south. Selective sampling of carbonates appears to give a good response at Mt Celia, where the cover is shallow (mostly <10 m) and, for the most part, overlies truncated profiles. At Golden Delicious, about 17 m of sediments overlie residual profiles truncated to approximately the mottled zone. There is no geochemical expression of the mineralization in the sediments, but dispersion along the unconformity gives a widespread anomaly, particularly associated with ferruginous nodules and mottles.

Near Laverton, the South Lancefield, Telegraph and Beasley Creek pits have Permian boulder clays exposed in the walls. These have not been examined for their geochemical response, although some results from the dispersion study at Beasley Creek, carried out during AMIRA Projects 240 (*Laterite Geochemistry*) and 241 (*Weathering Processes*) are given in this guide. The excursion then travels to Bronzewing, to examine sites where essentially complete profiles are preserved, with lateritic residuum close to the surface (Laterite pit) or buried beneath alluvium and colluvium that includes lateritic debris (Central pit). A similar situation is present at North pit, Lawlers, the last stop, where lateritic duricrust is buried by 20 m of sediments.

The authors of the articles in the guide wish to thank Colin Steel and Angelo Vartesi for drafting the diagrams, and Gill Ashton for preparing and compiling the final manuscript. Gill Ashton also assisted with much of the organisation of the excursion. We are also grateful to Kanowna Belle Gold Mines, Newcrest, St Ives Gold Mines, RGC Exploration, Acacia Resources Ltd., Metex Resources Ltd., Great Central Mines and Plutonic Resources for permitting access to their mines and exploration properties.

C R M Butt and R E Smith
Project Leaders

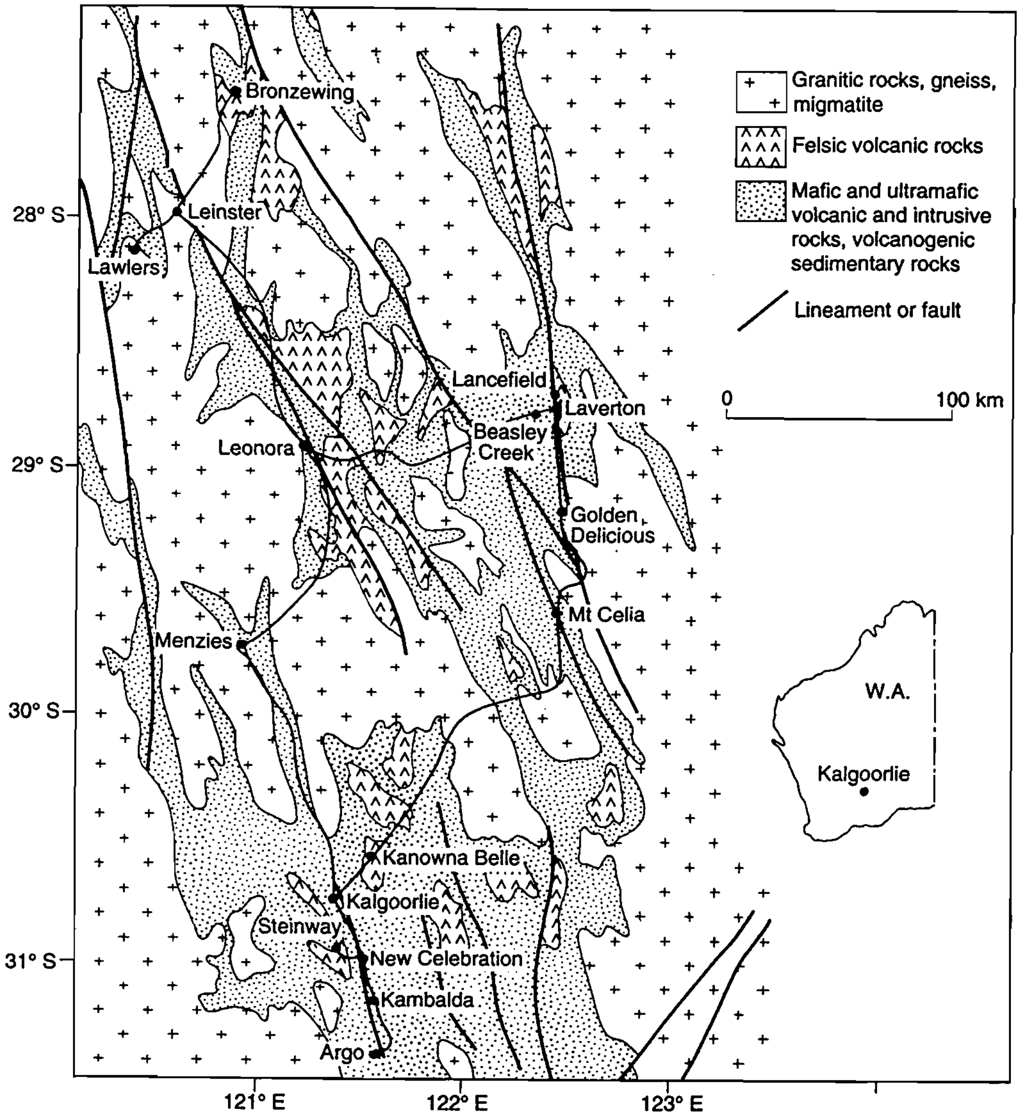

Figure 1: Locations of sites to be visited during the excursion.

KANOWNA DISTRICT

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1. INTRODUCTION

The Kanowna Belle Au deposit, jointly held by Geopeko and Delta Gold N.L., is located some 18 km northeast of Kalgoorlie. The district chosen for study (Figure 1), typical of the Kalgoorlie region, covers an area of some 600 km^2. This account is derived largely from Dell (1992) and Anand *et al.* (1993).

2. REGIONAL AND LOCAL GEOLOGY

The Kanowna district lies on the eastern margin of the Kalgoorlie Terrane within the Eastern Goldfields Province. It forms part of a belt of north-northwest trending metamorphosed ultramafic, mafic, sedimentary and felsic volcanic and intrusives rocks of the Norseman-Wiluna Belt. The Kanowna Belle deposit is contained within a package of northeast trending, south-dipping, predominantly intermediate to felsic, volcanic-derived tuffaceous mass flow units and breccias.

The Kanowna Belle sequence has distinct hanging wall and footwall rock types, generally separated by the Fitzroy Fault. The footwall sequence is mostly a polymictic conglomerate and the hangingwall sequence consists of felsic angular rudites with sporadic pebble-to-boulder beds and mafic flows. The feldspar-phyric to aphyric Kanowna Belle Porphyry, ranging from less than 10 m to 80 m in thickness, appears to intrude along a pre-existing shear zone cut by the Fitzroy fault, which transgresses the porphyry at an acute angle (Thomson and Peachey, 1993).

3. GEOMORPHOLOGY AND DRAINAGE

The Kanowna district forms a broadly undulating terrain between 320 and 420 m above sea level, with isolated belts of low hills and ridges providing local relief. More detailed relief variations are observed near erosion escarpments that result from differential stripping of the laterite regoliths, and within the sand and gypsum dunes bordering the playas. The elevated ridges and hills (areas above 400 m) are generally restricted to the south, southeast and central regions of the study area and give way to gently sloping pediments to the north. Several 10 to 30 km long, shallowly incised drainage systems lead into the playas in the north of the study area. These are prominent on air photos (Figure 2). The breakaways generally occur in the headwaters of these drainage systems or on isolated, low, topographic rises on the boundaries of the sandplains.

4. REGOLITH

4.1 REGOLITH DISTRIBUTION

The area immediately surrounding the Kanowna Belle Au deposit, is characterized by a broadly undulating, variably truncated, lateritic terrain, dominated by both saprolitic to fresh mafic and felsic bedrock, and broad colluvial and alluvial plains. A detailed map for the Kanowna Belle area is shown in Figure 2. Relict regimes, containing lateritic duricrust, lateritic nodules and pisoliths are restricted to small crests that occupy less than 5% of the area. Backslopes are stripped and are characterized by the fragments of ferruginous saprolite, saprolite and ferruginous lithic fragments. This contrasts with the Lawlers orientation districts where complete or near-complete lateritic profiles are preserved on the backslopes.

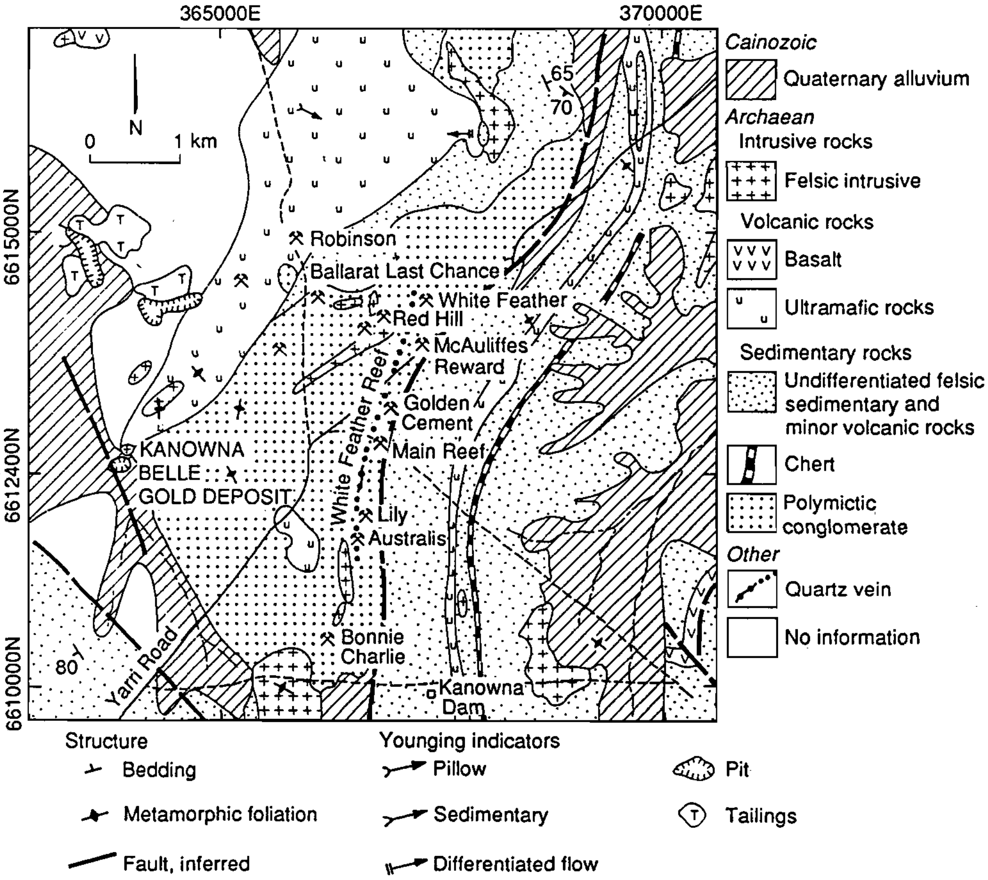

Figure 1: Schematic geology and gold deposit location map of the Kanowna district (after Ross, 1993).

The lateritic duricrust commonly overlies a well developed ferruginous saprolite or mottled zone which, in turn, overlies leached saprolite. This is exposed along the truncated profile of breakaways. Lateritic duricrust is most strongly developed (in terms of thickness) over the mafic and ultramafic units and is weakly developed above the granitoid and felsic lithologies. This difference is due to the amounts of Fe available during the duricrust formation being considerably greater in mafic rocks than in felsic rocks. Replacement of the kaolinite-goethite-rich matrix by carbonate in the lateritic duricrust is common, with the carbonate penetrating to depths of more than 1.5 metres.

In the erosional regimes, deeper units of the regolith and, in places, unweathered bedrock, are exposed. They are dominated by a shallow, residual calcareous soil and a lag of ferruginous lithic fragments, ferruginous granules and vein quartz, with outcrops of ferruginous bedrock and saprolite.

The depositional regimes are the most extensive, occupying 50% of the area. They are mantled by a friable, acid to calcareous, red to orange, sandy clay soil with an abundant lag of black ferruginous granules, and lesser detrital vein quartz, lateritic gravels and lithic fragments. Extensive playa systems are characterized by saline dark to pale brown fine clays and muds and borded by gypsiferous and quartz-rich clayey sands.

5. REGOLITH STRATIGRAPHY

5.1 KANOWNA-BELLE DEPOSIT

The Kanowna-Belle deposit is located within a major northward-flowing drainage basin (Figure 2). The pale orange, calcareous, sandy clay soils form a 20 to 100 cm thick mantle (Figure 3). The carbonates occur as coatings on, and as soft aggregates within, the clay. The 2 to 5m of acid red clays underlying the calcareous soils, show a decreased to non-existent carbonate content within the top 30 cm. Both the calcareous and non-calcareous red clays contain abundant, black, ferruginous granules. The thickness of the acid red clays increases northwards over 1-2 km. A mottled zone occurs at depths generally greater than 2 m. A zone of silicified saprolite, 1m to 8m thick and preferentially developed from the weathering of grits and feldspar porphyry, marks the base of the mottled zone above bleached saprolite. It appears to represent complete silicification of saprolite by the filling of available voids with silica but preservation of primary quartz crystals and bedrock fabrics assist in determining the parent material. Saprolitic clays form a 20-50 m thick weathered mantle above the bedrock. A thin (2 m) mineralized supergene blanket occurs within the lower saprolite (Peachey, 1991).

5.2 REGOLITH STRATIGRAPHY - PALAEOCHANNEL ENVIRONMENTS OF THE NLP9 PIT

The NLP9 Pit was chosen as a site at which to examine the morphological, mineralogical and geochemical characteristics of a weathering profile typical of palaeochannel environments. The pit provided an opportunity to study the characteristics and development of regolith units within the weathering profile and the inter-relationships between units.

The stratigraphic sequence of regolith units within the NLP9 pit is summarized in Figure 4. The uppermost unit consists of 20 to 40 cm of red to brown calcareous soil overlain by a medium to fine polymictic lag comprising abundant ferruginous gravels, vein quartz and lithic fragments. The soils lie above a 1 to 4 m thick horizon of pale orange, calcareous soil. The unit consists of multiple lenses of bedded and graded alluvial deposits that have cut channels in the underlying clays. An acid red clay unit forms a sharp but irregular lower boundary with the overlying calcareous alluvials. The 2 to 5 m thick red clay contains small, magnetic, sub-angular to rounded, black, ferruginous granules, fine, lithic fragments, detrital quartz and vein quartz. The clasts observed within the unit occur as horizontally elongate lenses up to 20 m wide. Root systems penetrate the unit and show an intimate relationship with Fe accumulations. Bleaching and incipient mottles develop within the basal Fe-rich clays and mark the transition into the mottled zone.

RELICT REGIME

R1 Lateritic duricrusts, lateritic pisoliths and nodules, crests and low topographic highs

EROSIONAL REGIME

E1 Lag of hardened mottles and ferruginous saprolite, backslopes

E2 Calcareous clay soils over mottled zone, ferruginous granules, gently sloping terrain

E4 Saprolite, black ferruginous granules and quartz, erosional plains

E6 Bedrock, low hills

E8 Bedrock, high hills

DEPOSITIONAL REGIME

D1a Acid red clay soils with polymictic ferruginous lag within major drainage basins and channels

D1b Acid red clays with common black polymictic ferruginous lag within minor drainage basins and channels

D4 Red clay soils with black ferruginous granules over saprolite, alluvial floors

N

Figure 2: Map showing the surface distribution of regolith-landform units and vegetation, overlay to colour air photograph, 3/8525, 20.3.85 Kanowna Belle Au deposit, Kevron Aerial Surveys, published with permission of North Ltd.

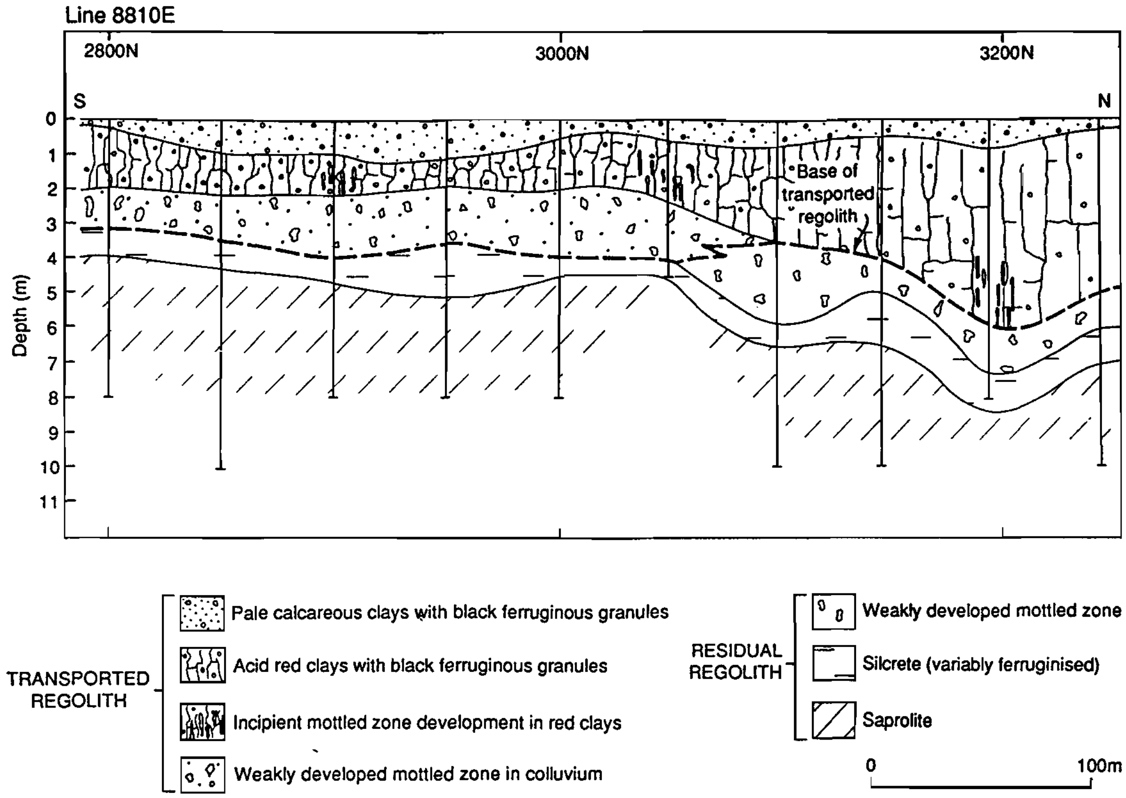

Figure 3: Cross sections showing the regolith stratigraphy for line 8810 mE, overlying the Kanowna Belle Au deposit. (From Anand *et al.*, 1993.)

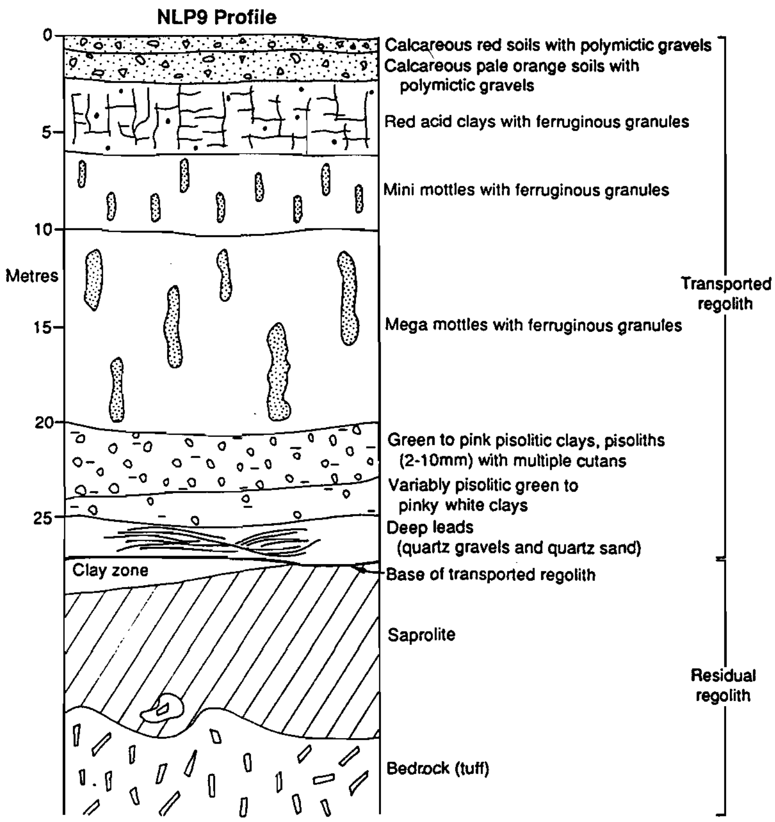

Figure 4: Regolith section through the palaeochannel at NLP 9 pit, Kanowna district. (From Anand *et al.*, 1993.)

The mega-mottled zone is characterized by increased bleaching and development of evenly-spaced irregular, hematite and goethite-rich, 10 to 25 cm long mottles (Figure 4). Mega-mottles are conspicuous within the transported overburden. Two units are recognized within the mottled zone, the mini-mottled (4-8 m thick) and mega-mottled (6-10 m); the boundary between the units is marked by shrinkage cracks within the clays. Magnetic, black, ferruginous granules are abundant throughout. The transition from the mottled zone to the underlying pisolitic clay unit is marked by gradual decrease of mottles until the clays are totally bleached.

The pisolitic clay horizon, 4 to 6 m thick, is characterized by sub-sperhical to spherical pisoliths, with greenish-brown to grey cutans, in a matrix of pale-pink through to grey clays with minor detrital quartz. Pisoliths are typical of the palaeochannel profiles in the Kalgoorlie region. The lowermost unit of the channel sediments consist of medium to coarse grained quartz sands and gravels. These in turn overlie clay-rich saprolite.

Gold mineralization occurs in the basal clay sands and some overlying clay units.

5.3 DEVELOPMENT OF FERRUGINOUS GRANULES

Granules, extracted from the bulk soil samples, are remarkably uniform, occurring as black, hematite-maghemite rich, sub- to well-rounded granules <0.2 to 15 mm in size. Typically the granules have an earthy to sub-metallic lustre and some thin earthy, clay cutans are developed around rare spherical granules.

Petrographic examination of granules indicated that they have formed by a combination of pathways (Figure 5). Textural variations have enabled recognition of the four major granule groups outlined below:

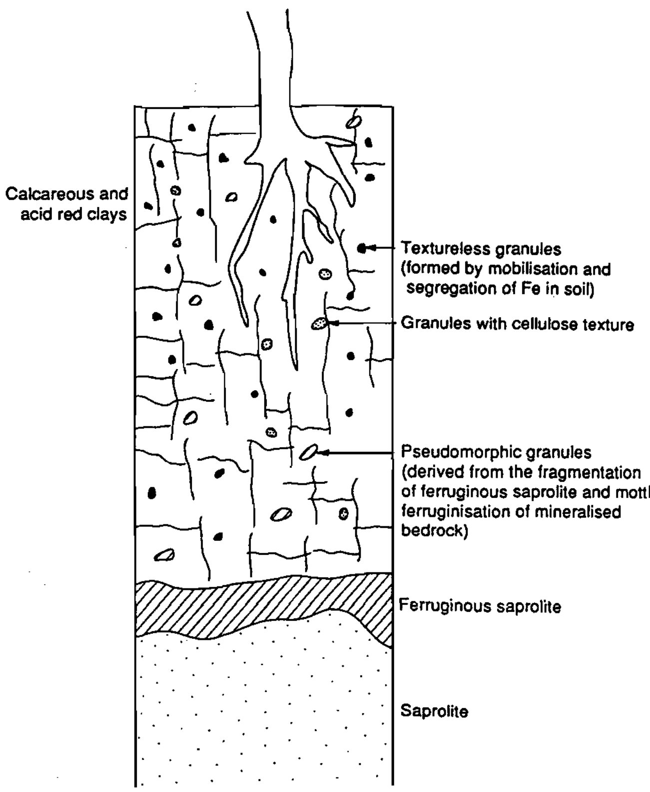

Figure 5: Types of ferruginous granules and their possible origins within the upper part of a regolith profile, Kanowna district. (From Anand *et al.*, 1993.)

(i) Ferruginized clays: these are textureless granules in soil formed by the replacement of clays by hematite along cracks and voids.

(ii) Ferruginized lithic fragments: these granules are identified by preservation of relict rock fabrics and pseudomorphed primary minerals.

(iii) Ferruginized cellulose: these granules are clearly identifiable by the intricate preservation of individual cell walls now totally replaced by hematite. The cellulose fragments may represent vestiges of penetrative root systems, which show a close spatial relationship to areas of granule development within the clays and mottled zones. The cavities generated by root penetration may, upon death of the roots, provide voids within which Fe oxides may be precipitated, with the hematite selectively replacing dead cellulose.

(iv) Concentrically zoned granules: these granules have a cutan developed around a nucleus of the cellulose, quartz, clays and saprolite fragments. Quartz fragments are commonly incorporated into the concentric bands indicating multiple periods of development.

6. REGOLITH-LANDFORM MODEL

Generalized regolith-stratigraphic relationships for the Kanowna district are shown in Figure 6. This figure is based on the district-scale regolith-landform assessment and a detailed study at the Kanowna Belle and NLP9 pits. The regolith-landform relationships and regolith stratigraphies indicate a polyphase, multi-process history. The wide range of regolith units developed within the Kanowna Belle district reflects the highly variable bedrock geology described above.

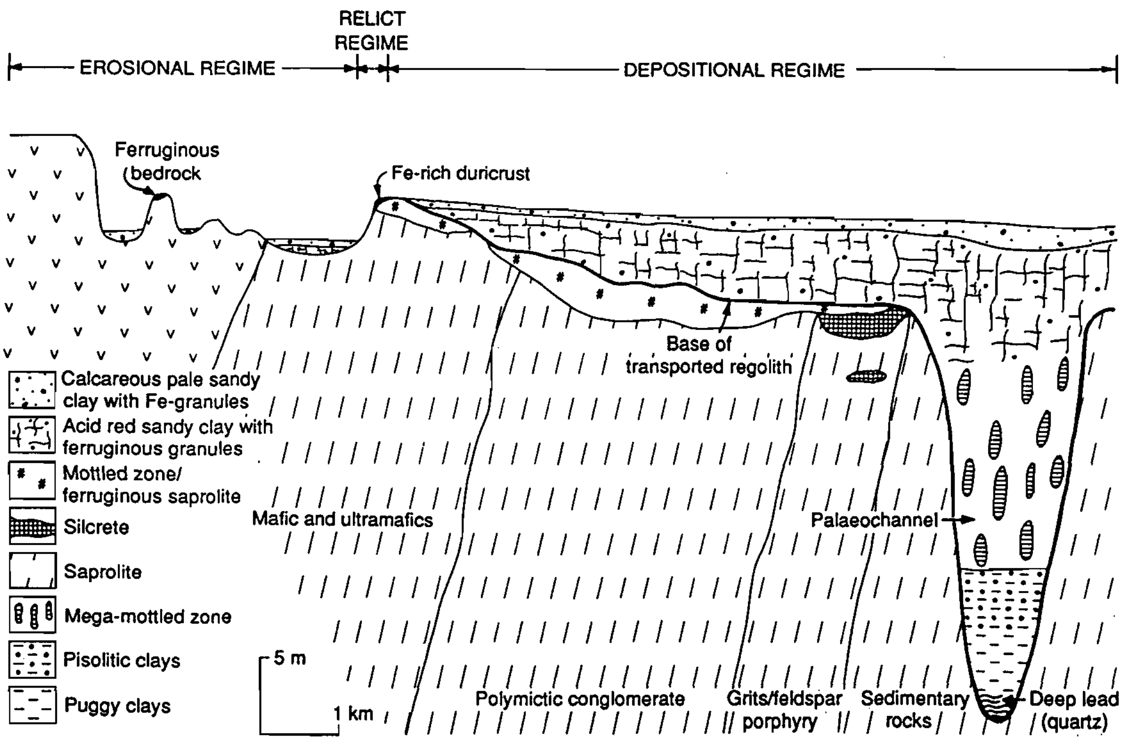

Figure 6: Regolith model of the Kanowna Belle area. (Modified after Anand *et al.*, 1993.)

7. GEOCHEMICAL DISPERSION IN FERRUGINOUS GRANULES AND SOILS - KANOWNA BELLE AND NLP9

Transverses across the Kanowna Belle and NLP9 deposits were sampled. Whole soil samples, comprising calcareous (0-1 m) and acid (2-3 m) red clay soils and black ferruginous granules, separated by wet sieving, were anlaysed for a range of major and trace elements.

The most important feature of the results is the strong concentration of the alkaline earth elements, Ca and Mg, in the top 1 m of the regolith. Mean concentrations of Ca and Mg differ significantly between the top soil (CaO 7.41%, MgO 1.34%) and sub-surface soil (CaO 0.28%, MgO 0.85%). Calcium and Mg contents are very low in the ferruginous granules. They occur predominantly as calcite, gypsum and dolomite with minor quantities in smectite and inter-stratified clay minerals. Calcium is strongly correlated with Mg.

Mineralization is indicated by a multi-element geochemical halo within both the ferruginous granules and the soils (Figures 7 and 8). The granules are anomalous in Au, Sb, As and Ce. High values of Au coincide with the elevated Sb and As. The mean values of As, Sb, Au and Ce in granules collected across the Kanowna Belle orebody are considerably elevated relative to granules collected away from the known mineralization .

Gold is most concentrated in soil samples with the average surface soil expression (90 ppb) consistently 10-20 ppb above the concentrations obtained from the ferruginous granules extracted from the same soils. Gold concentrations in the top metre range from 17 to 232 ppb and are commonly in excess of 60 ppb. There is a considerable decrease in Au abundances in the soil samples collected from 2 to 3 m. The observed peak Au concentrations within the surface calcareous soils conform well with the sub-surface position of the major ore shoots. This observation is consistent with previous findings in the Southern Yilgarn Craton, in which a close correlation has been identified between Au and pedogenic carbonates (Lintern and Butt, 1993).

In the traverses across Kanowna Belle, the near surface (0-1m) ferruginous granules mimic the bulk soil pattern for Au (Figure 8). Gold concentrations in ferruginous granules range from 2 to 147 ppb. The granules separated from the 2-3 m soil sample contain lesser amounts of Au. A high 75 ppb peak for Au in the granules separated from an acid red clay (2-3 m depth) is observed at 3200N, 8810E. However, the peak may be due to particulate gold.

Arsenic and Sb are notably enriched in the granules in the area above and surrounding the orebody, with respective concentrations on average of 4 and 7 times greater than those in the bulk soils. Mean concentrations of As and Sb are similar for the ferruginous granules separated from the top soil (As 241 ppm, Sb 38 ppm) and sub-surface soil (As 292 ppm, Sb 43 ppm). These abundances are significantly greater than known background levels (As <40 ppm, Sb <1 ppm, Table 10) and are associated with Au mineralization. Cerium is present in significant concentrations both in soil and in the ferruginous granules and is strongly correlated with Ca. It ranges from 7 to 37 ppm in soils and 17 to 38 ppm in ferruginous granules.

Over the palaeochannels, gold is concentrated significantly within the calcareous soils (Figure 9), and the mega-mottled (250 ppb) zone and is present in very low abundances in other regolith units. The processes of enrichment of Au in mega-mottles and calcareous soils are not fully understood. The processes may involve chemical transport of dissolved Au deep in the regolith by diffusion, capillarity, evapotranspiration, cycling by deep-rooted plants, and accumulation in the soil evaporite horizon.

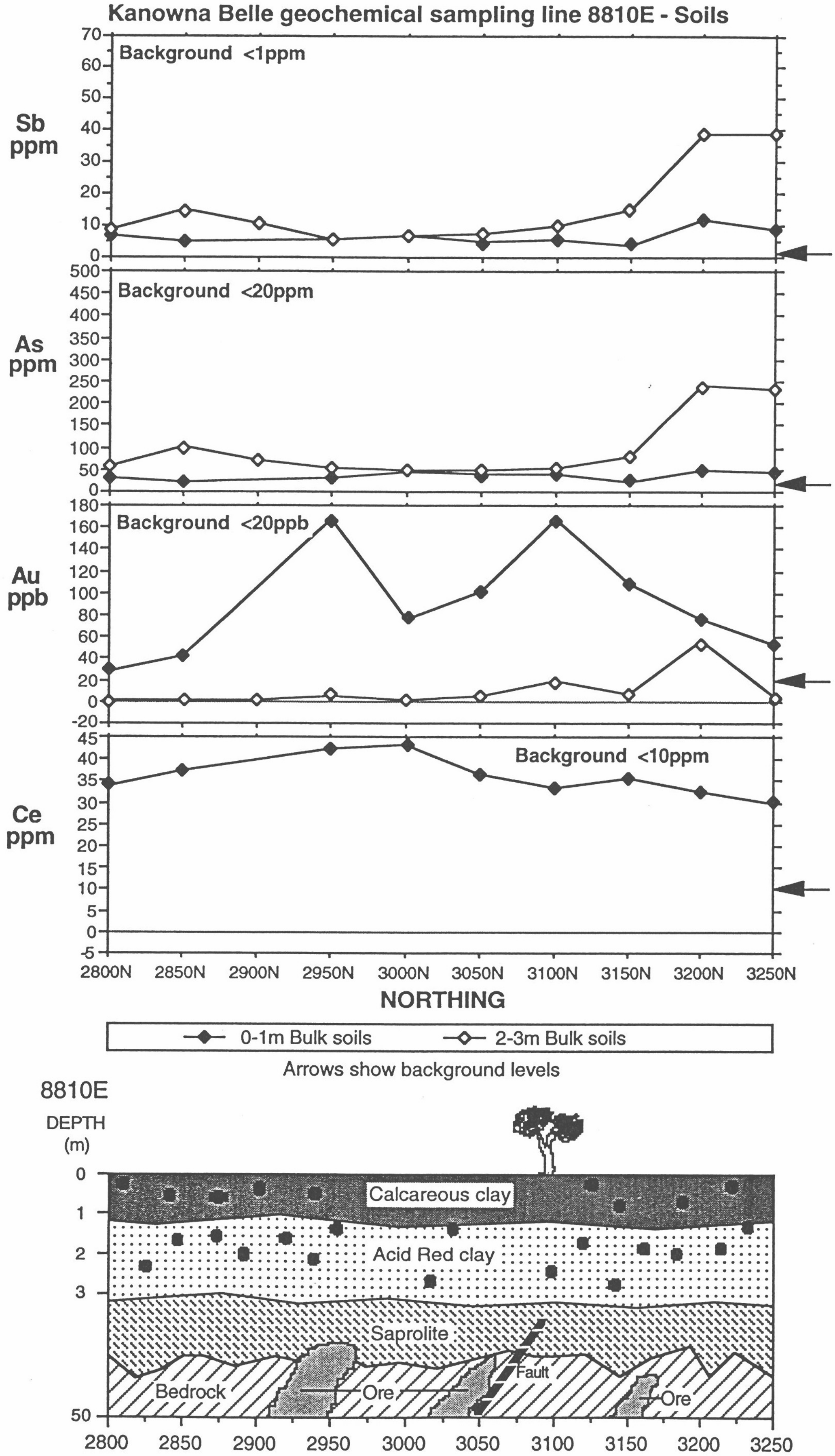

Figure 7: Traverse along line 8810 mE showing the distribution of Sb, As, Au and Ce in soils, Kanowna Belle Au deposit. (From Anand *et al.*, 1993)

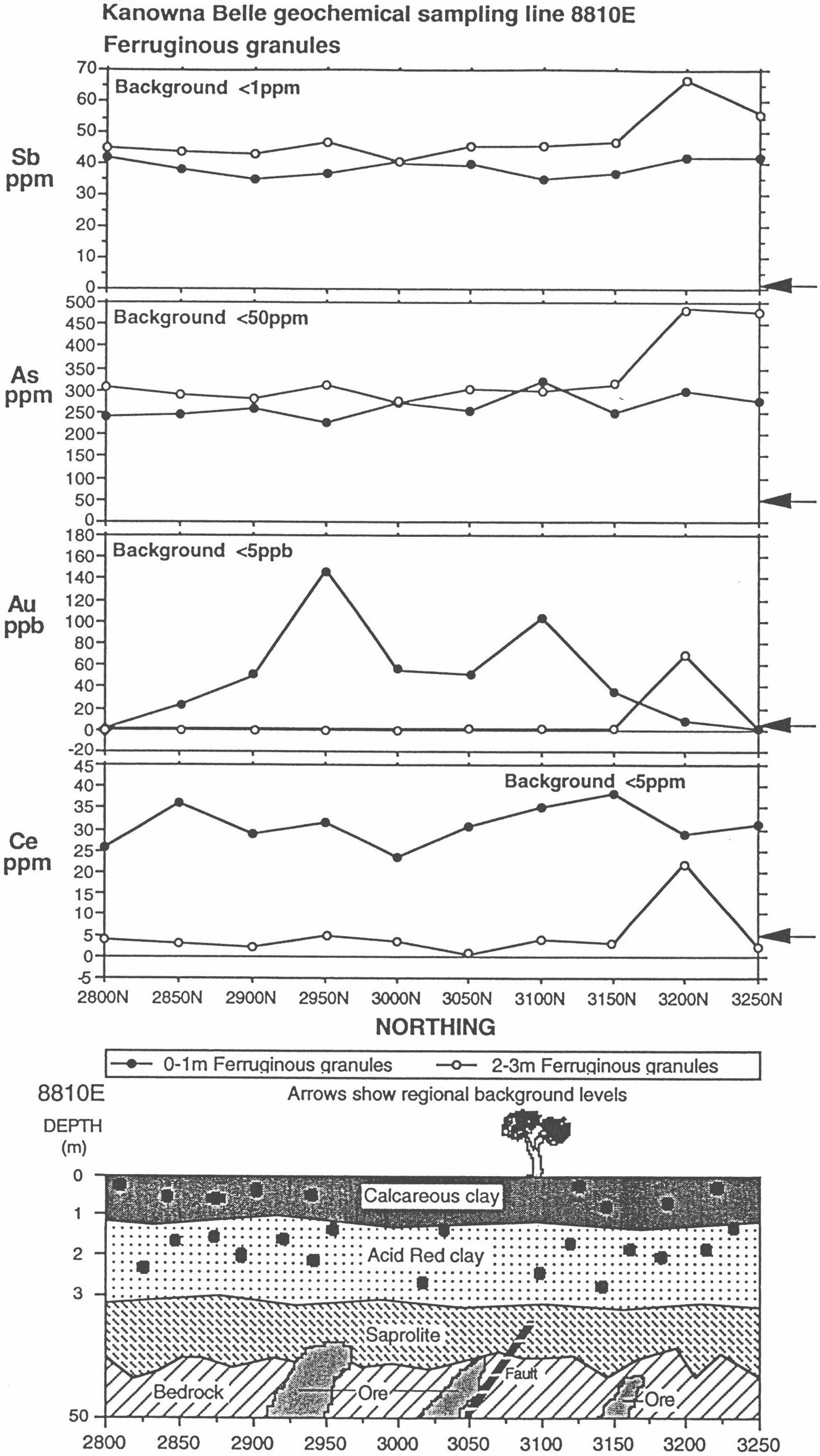

Figure 8: Traverse along line 8810 mE showing the distribution of Sb, As, Au and Ce in ferruginous granules, Kanowna Belle Au deposit. (From Anand *et al.*, 1993.)

Cerium, W, Zr, Mn, Ti and Co are concentrated within quartz-rich deep leads present at the base of the profile, overlying residual saprolite. These elements are contained in heavy minerals (zircon, scheelite) which were concentrated by the alluvial processes in the bed load of the deep lead systems.

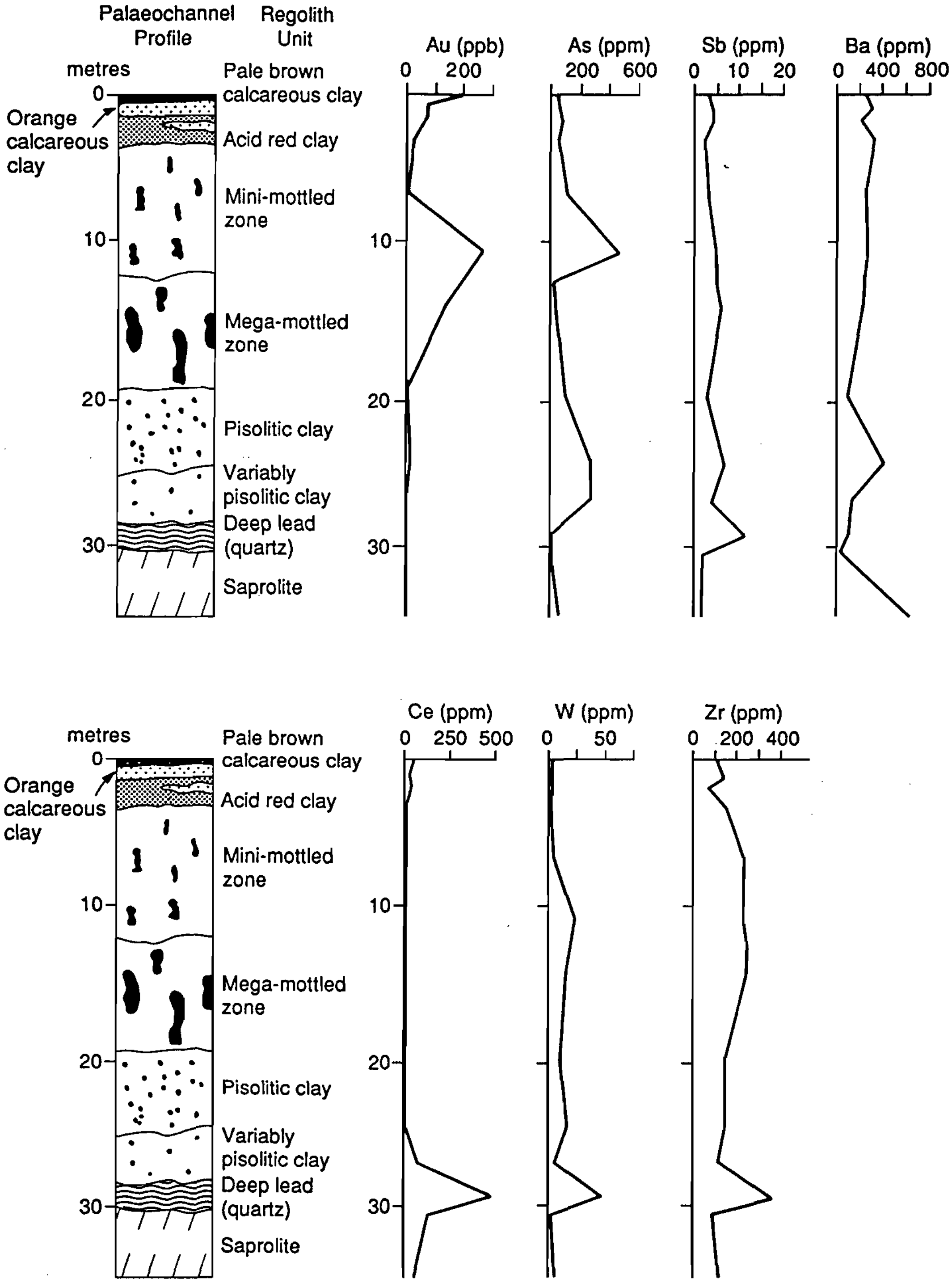

Figure 9: Geochemical variations within the regolith units of the NLP 9 Pit, Kanowna. (From Anand *et al.*, 1993.)

8. IMPLICATIONS FOR EXPLORATION

The red clays forming the top 2 to 6 m of the regolith overlying the Kanowna Belle deposit are transported. These red clays are underlain by residual saprolite which is up to 50 m thick, with the deepest development overlying the Fitzroy Fault. Ferruginous granules commonly occur in the soils and are formed by a combination of pathways. The soils show anomalous Au with weak As and Sb. By contrast, the ferruginous granules in the red clays are markedly anomalous in As, Sb and Au (relative to appropriate backgrounds) and the multi-element anomaly is broader and stronger (forming a larger target) in ferruginous granules than shown by soil geochemistry. Below this surface expression, there is a depleted or leached zone to depths of 50 m. The research shows that the Kanowna Belle deposit, concealed beneath 50 m of barren saprolite, has a significant multi-element surface geochemical expression.

The results from this study have substantial potential for application in the extensive deep saprolitic erosional and depositional regimes of the Kalgoorlie region. A geochemical dispersion model is shown in Figure 10.

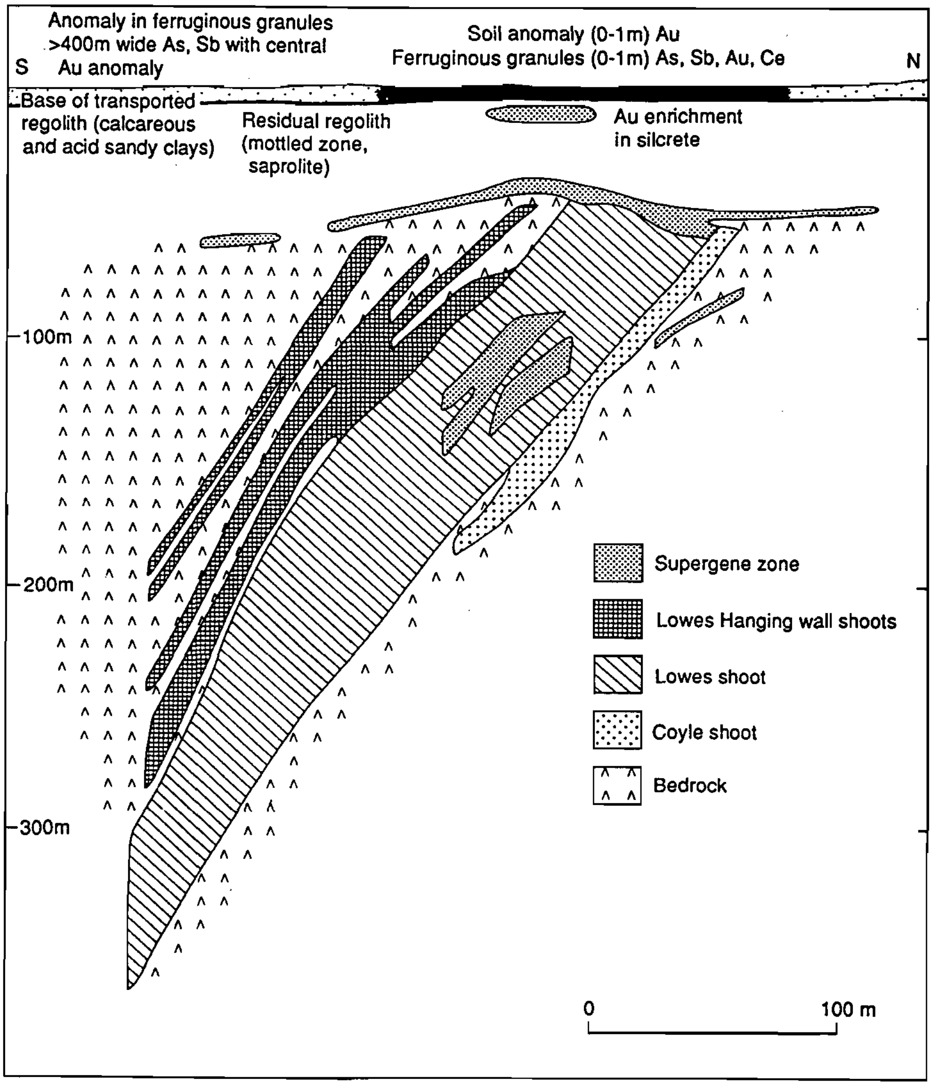

Figure 10: Geochemical dispersion model of the Kanowna Belle orientation area. (From Anand *et al.*, 1993.)

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THE STEINWAY GOLD PROSPECT, WESTERN AUSTRALIA

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1. GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

Steinway is one of a series of Au prospects located within several hundred metres of each other, about 25 km south of Kalgoorlie and 15 km west of the New Celebration Mine. The area encompassing and immediately surrounding Steinway forms a flat-lying, depositional plain (Figure 1) with higher areas rarely rising more than five metres above it. To the south is an erosional area (mafic saprolite) which includes the Penfold Au deposit. To the west is a depositional area which includes the Greenback palaeochannel Au deposit. Drainage is to a playa, White Lake, about 10 km to the north. Present-day shallow ephemeral channels cross the study area and generally flow in a northerly direction; such channels separate the Steinway and Penfold soil anomalies from each other (Figure 2). Vegetation is salmon gum open woodland with an understorey dominated by bluebush.

The regolith consists of the following units:

0-2 m: calcareous, clay-rich red soil, with abundant ferruginous granules;

2-5 m: non-calcareous clay containing large amounts of ferruginous granules;

5-15 m: clay containing zones of Fe-rich material such as hardened mottles;

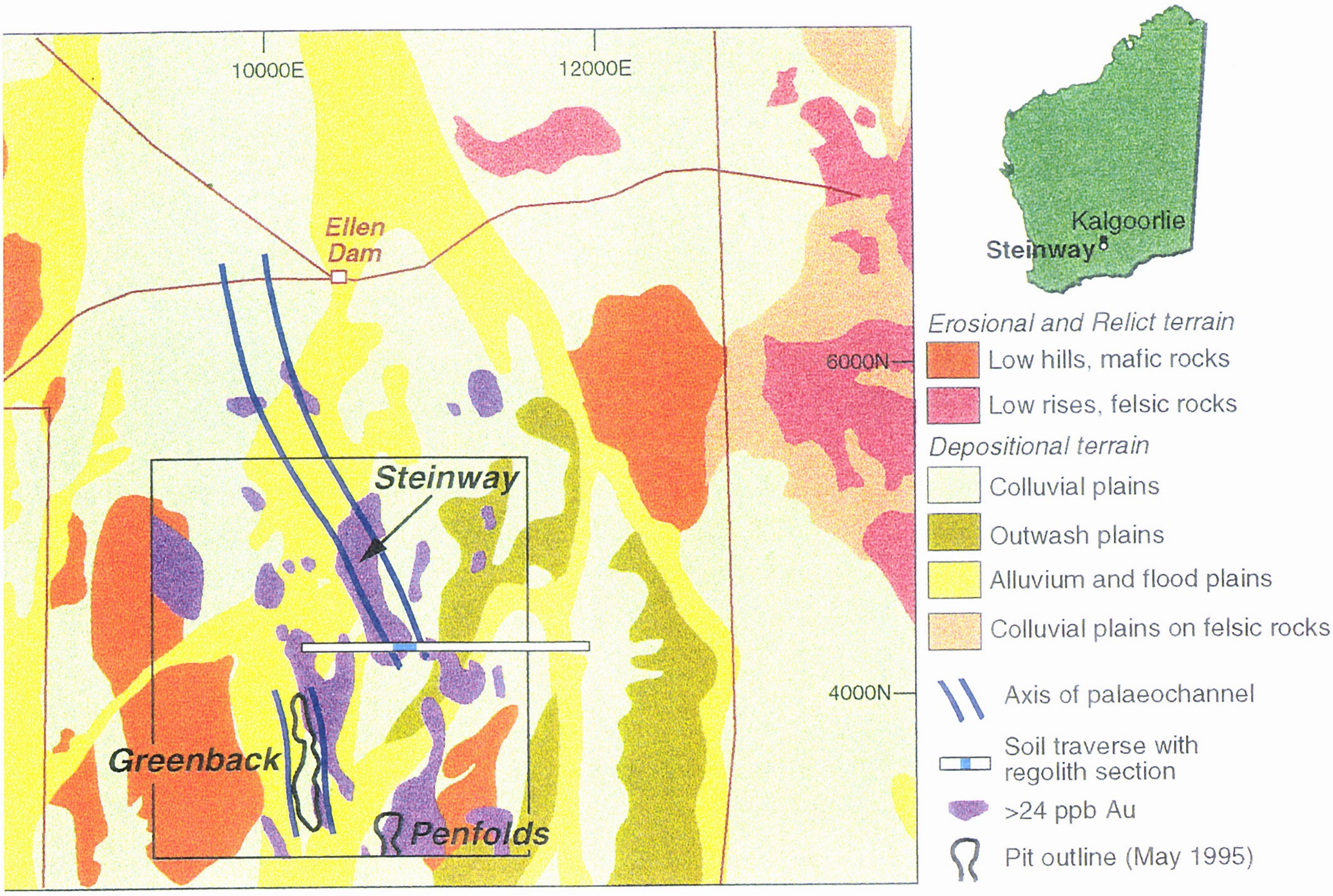
25-30 m: variably silty to sandy clay with lenses of coarser sand-rich material; a sandy horizon usually marks the lowest part of the channel, and mica-rich clays the beginning of the saprolite

30-50 m: saprolite, clay-rich towards the top;

50 m+: fresh rock.

Saprolite derived from weathered andesitic rocks dominates the upper part of the residual zone. The bedrock consists of mafic andesites with trachytes, porphyritic tuff and black shales (Figure 3).

There are two types of mineralization at Steinway: (i) supergene mineralization located below a palaeochannel system and (ii) primary mineralization associated with quartz stockwork veining within mafic andesites/amphibolites (M. Spivey and M. Miller, Newcrest Mining Ltd, written communication, late 1994). The andesites and amphibolites consist of microporphyritic amphibolites dominated by hornblende, ubiquitous biotite, and lesser amounts of feldspar and garnet. Strongly altered areas generally display silicification, carbonate alteration, tourmaline quartz veining and disseminated pyrite.



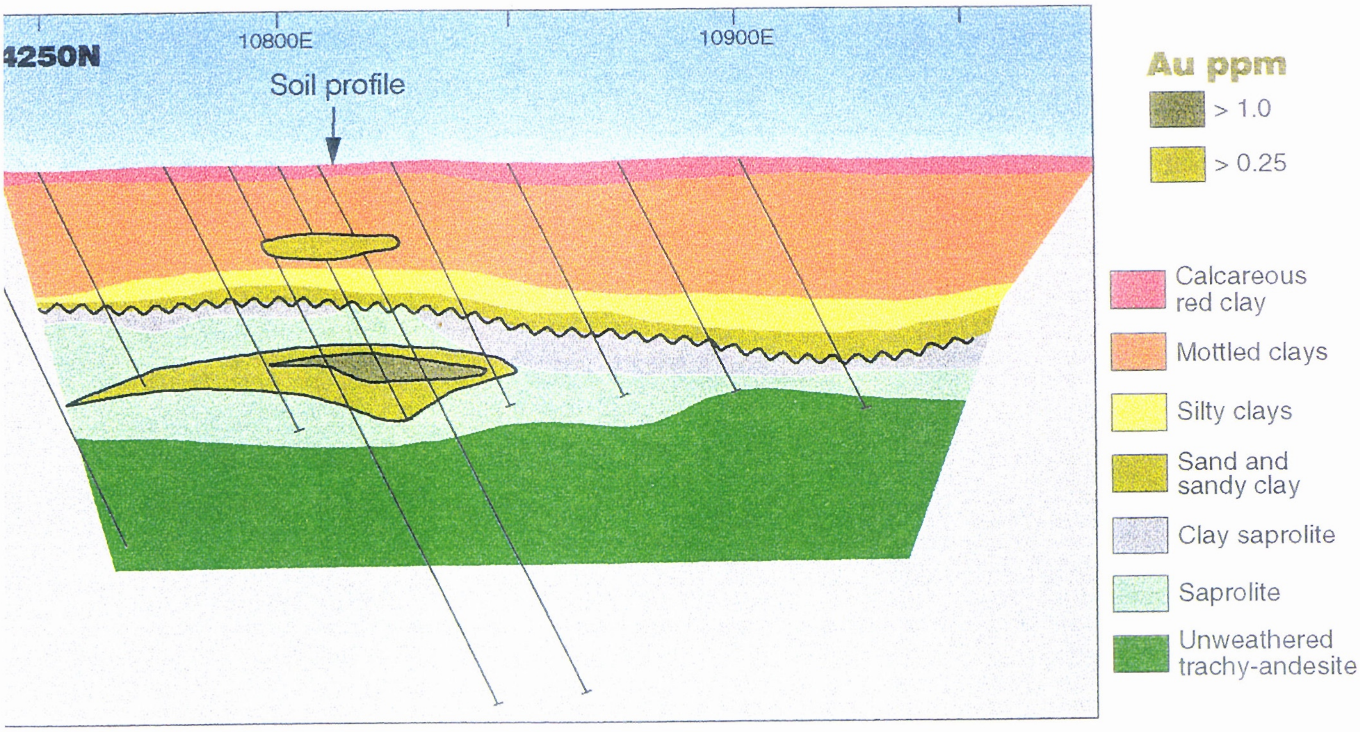


Figure 1: Regolith map (a) and stratigraphy (b) of the Steinway area showing the location of the soil anomalies, palaeochannels, and sampling points (after Gardiner, 1993 and company data).

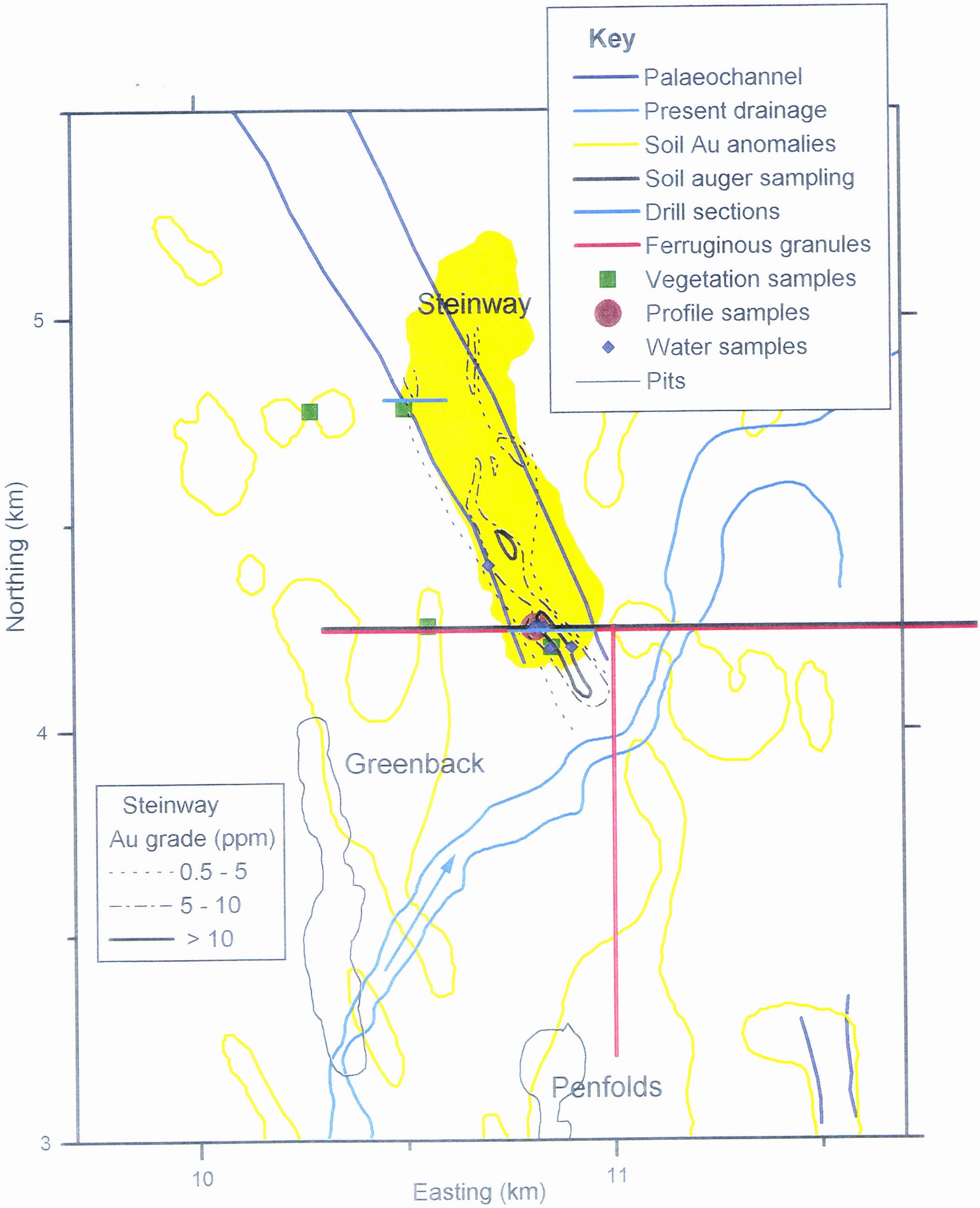


Figure 2: Plan of Au soil anomalies from auger survey showing sampling points including water, palaeochannel and surficial drainage lines (after Gardiner, 1993), with outlines of the Greenback and Penfolds pits also shown.

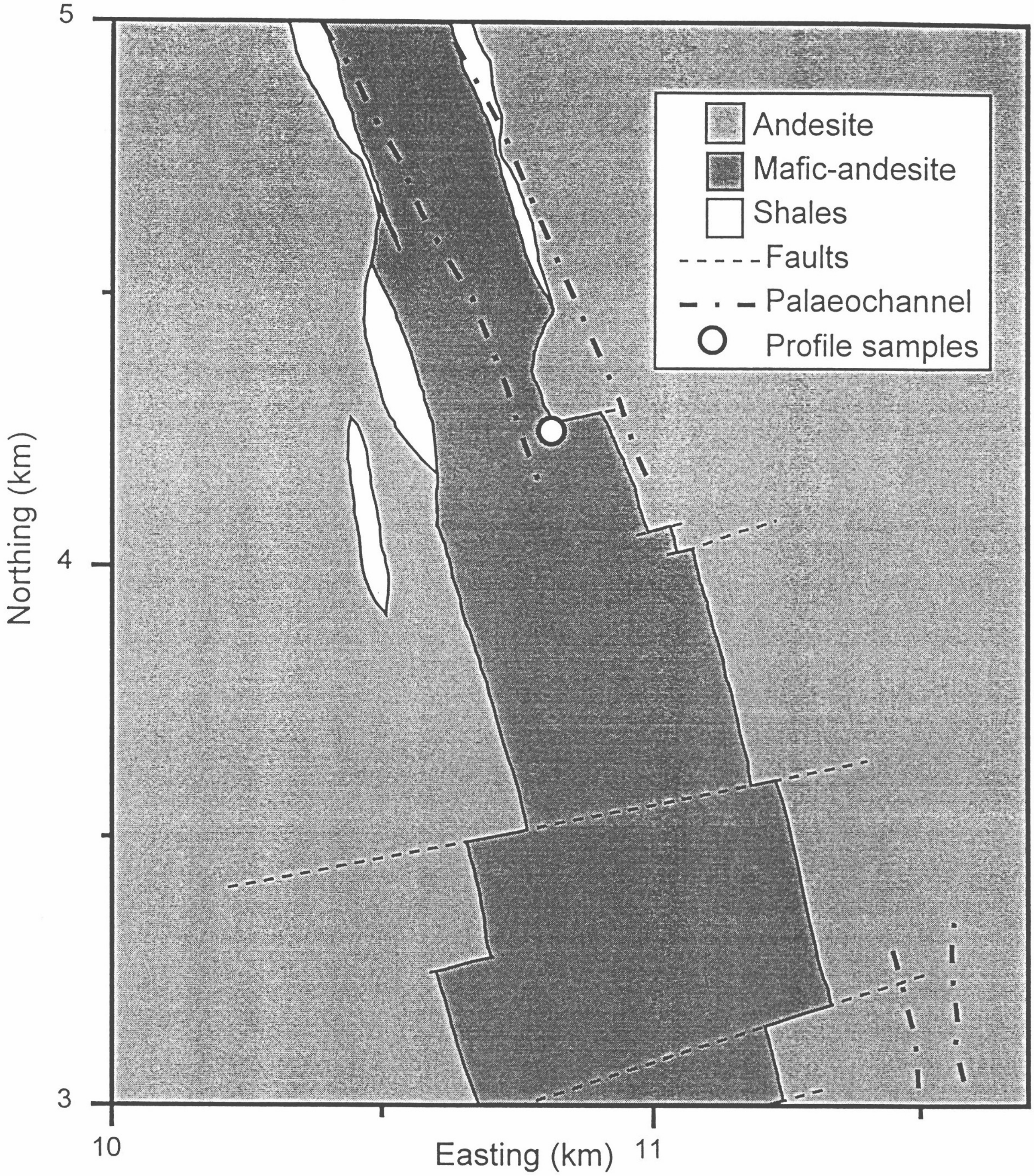


Figure 3: Plan of geology showing palaeochannel (from data supplied by Newcrest Mining Ltd) and soil profile location.

2. SOIL GEOCHEMISTRY

2.1 SOIL PROFILE

The soil profile (10818E, 4250N; Figure 2) is located above mineralization, close to the sites with the most Au-rich soils. Gold concentration gradually increases with depth (Figure 4), whereas Ca and Mg sharply increase then decrease; Fe concentration, in response to dilution from the alkaline earths, decreases sharply from the surface and then gradually increases with increasing depth. Although Au and Ca concentrations are probably related in the upper horizons, the relationship is not as strong as that found elsewhere (*e.g.*, Lintern, 1989; Lintern and Scott, 1990; Lintern and Butt, 1991, 1992). Gold content may be related to the Fe in the lower part of the profile (below 0.5 m). Augering is considered an effective sampling technique at Steinway, since Au concentrations in the top metre are still anomalous (mean 200 ppb), even though concentrations are higher still in the second metre.

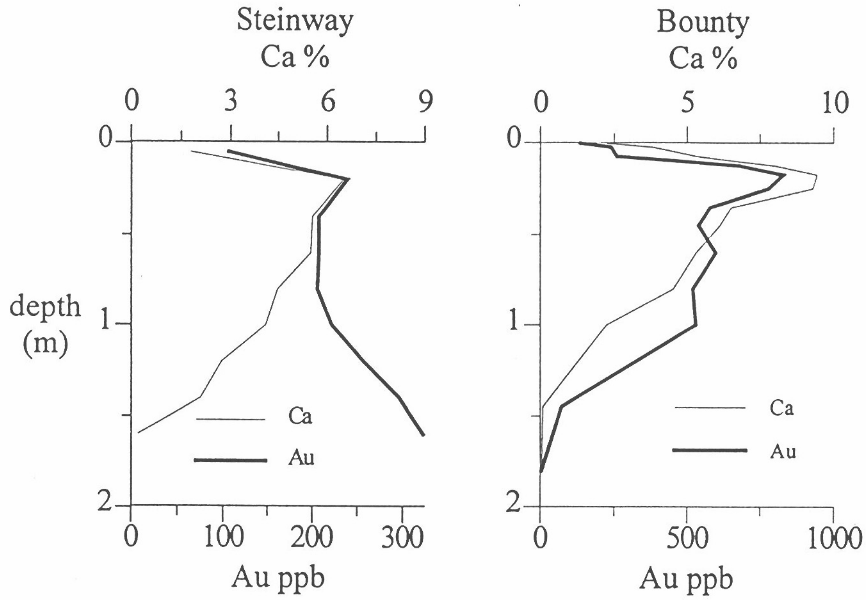


Figure 4: Gold and Ca results for the soil profile at Steinway (10810E 4250N) and a typical soil profile from the Bounty Au deposit at Mt Hope (Lintern, 1989).

The moisture content of the soil (measured as weight loss after heating at 70°C for one week) increases with depth and is approximately correlated with Au content (Figure 5). This is also observed at Zuleika (Lintern and Butt, 1992) and Argo (Lintern and Gray, 1995). The significance of this association is not known, although it may be an indication of the mobility of Au in the soil environment. Partial extraction experiments (see below) indicate that the amount and proportion of water soluble Au <u>decreases</u> with increasing depth *i.e.* where soil moisture is greatest.

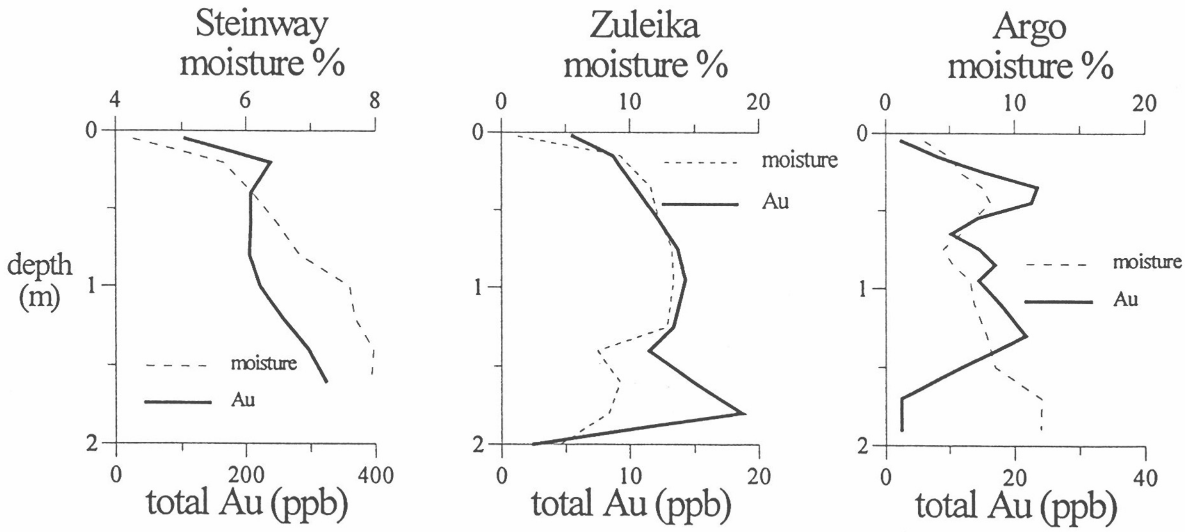


Figure 5: Gold and moisture results for the soil profile at Steinway and typical soil profiles from Zuleika (Lintern and Butt, 1992) and Argo (Lintern and Gray, 1995).

Sequential extraction (water, iodide, cyanide) of unpulverized soils (taken at approximately 0.2 m intervals down to 1.7 m) from the soil profile indicates that the proportion of water soluble Au in the profile decreases with depth (Figure 6), whereas total Au actually increases with depth (Figure 7). The most soluble Au (20% of total) is found at the surface where the total Au concentration is 106 ppb. The mean proportion of iodide soluble Au is approximately 80% of the total Au. Cyanide removes almost all of the remaining Au.

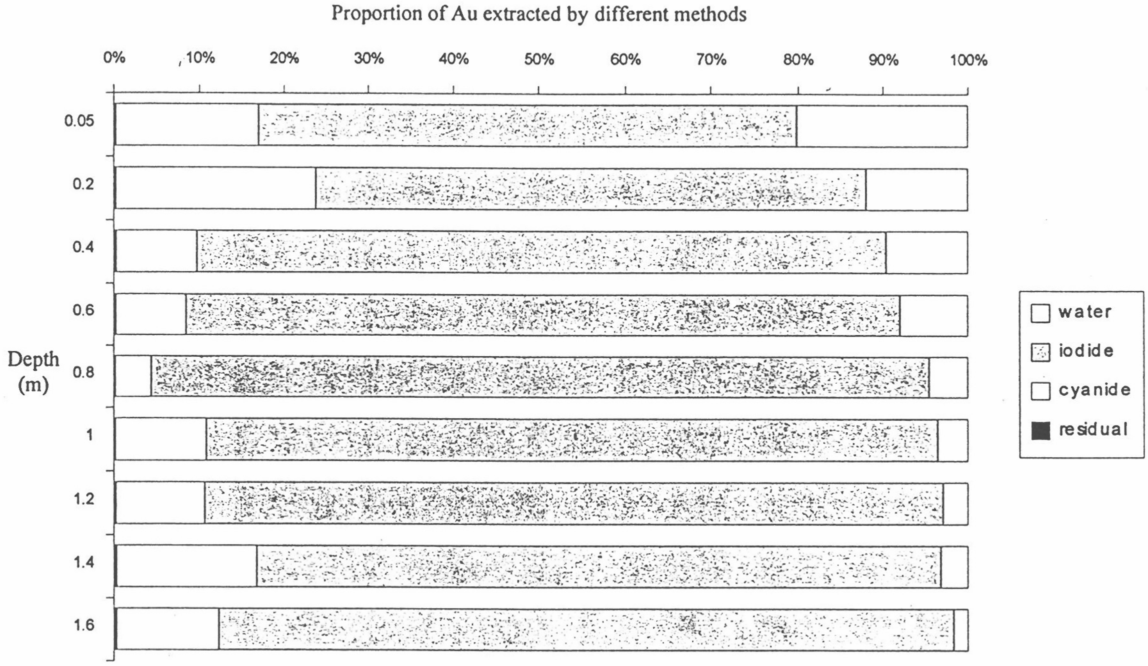


Figure 6: Sequential extraction of Au from the soil profile at Steinway. Results expressed as proportion of total Au.

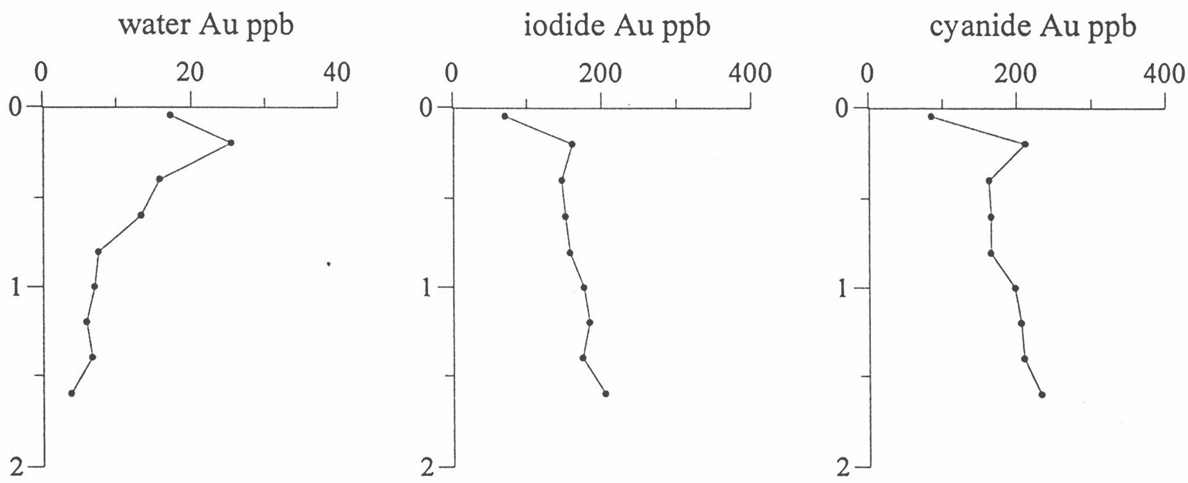


Figure 7: Sequential extraction of Au from the soil profile at Steinway. The cyanide-extractable Au data includes Au extracted by iodide.

The concentration of water soluble Au in the soil profile appears to be strongly related to organic C content (Figure 8). However, this is not observed at the Bounty Au deposit, where water soluble Au is related to total Au and Ca.

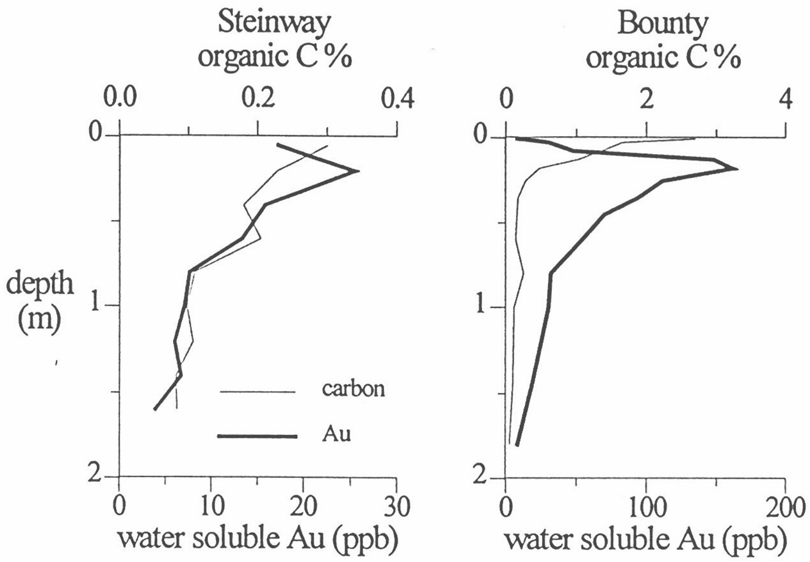


Figure 8: Water soluble Au and organic C results for the soil profile at Steinway and a typical soil profile from the Bounty deposit.

2.2 TOPSOIL (0 - 0.1 M)

The highest Au concentration in topsoil (93 ppb) occurs over mineralization and is significantly higher than background (approximately 20 ppb, Figure 9). Topsoil maxima appear to define slightly better the location of mineralization than that obtained by augering (Section 2.3), which is displaced slightly to the east (Figure 9); however, the contrast is no better.

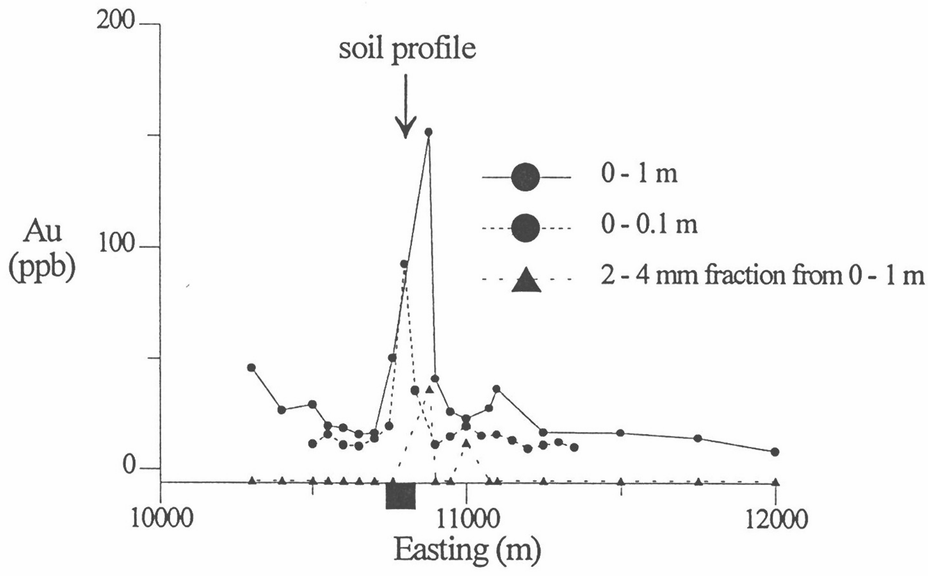


Figure 9: Au concentrations for 0 - 0.1 m, 0 - 1 m and 2 - 4 mm size fraction (separated from 0 - 1 m material) for 4250N at Steinway. Hatched area locates mineralization.

2.3 SOIL (0 - 1 M)

The distribution of Au in the 0 - 1 m composite samples on 4250N appears to be related to the underlying mineralization; the anomaly is particularly strong over Steinway (150 ppb) although there are subsidiary peaks above mineralization at about 11000E (35 ppb) and Greenback (10300E, 45 ppb), against a background of < 20 ppb (Figure 9). The anomaly (> 24 ppb) over Steinway is over 150 m wide (3 samples; Figure 10) in the east-west direction and (according to previous Newcrest data in Gardiner, 1993) stretches over 1 km to the NW, following the direction of the palaeochannel. The coarse fractions (> 710 µm < 2 mm) sieved from the bulk soils have lower Au contents, but are still anomalous; these principally consist of ferruginous granules, quartz float and (over Penfold) ferruginous saprolite.

Partial extractions of auger samples by water, iodide and cyanide produce anomalies coincident with that produced from total Au analysis, and thus give no additional information than total Au analyses (Figure 10).

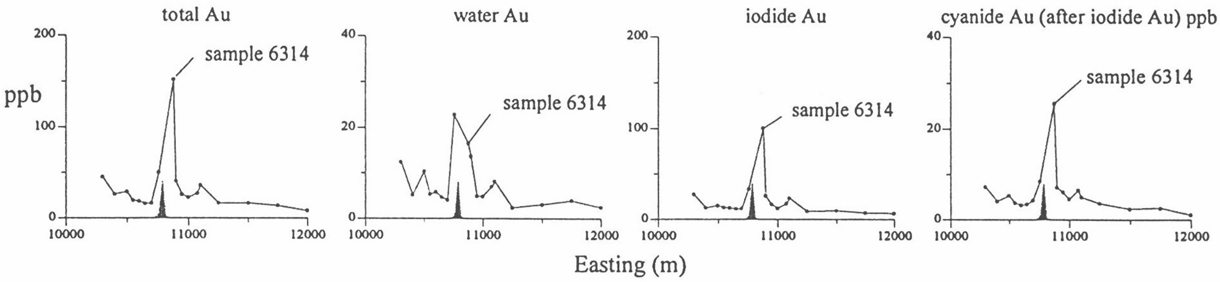


Figure 10: Total, water, iodide and cyanide soluble Au for the auger traverse at Steinway. The cyanide results are for the Au left after the iodide extraction. The shaded area below the plots is the location of mineralization at Steinway.

The plot of water extractable Au versus total Au indicates that the sample with the greatest total Au (sample 6314, 152 ppb) has the lowest proportion of water soluble Au (11%), compared with all the other samples (mean 27%). The proportion of each type of soluble Au is approximately the same for all other samples from the traverse (Figure 11). The unusually low water soluble Au for sample 6314 may be due to:

(i) a high proportion of Au in coarse material, and/or

(ii) an association between Au and another phase, *e.g.* Fe oxides (see profile results),

leading to poor water (but not iodide) extraction of Au. Earlier studies have shown that Au associated with Ca dissolves comparatively readily with water.

Analyses of elements other than Au on the bulk soil and coarse fraction (> 710 µm < 2 mm), indicates that there are relatively high concentrations of Fe coincident with and adjacent to the Steinway soil Au anomaly. Chromium, As, Sc, and Sb appear to be related to the Fe concentration; the distributions of REE, Zn, Co and, possibly, Ni are similar to that of Mn.

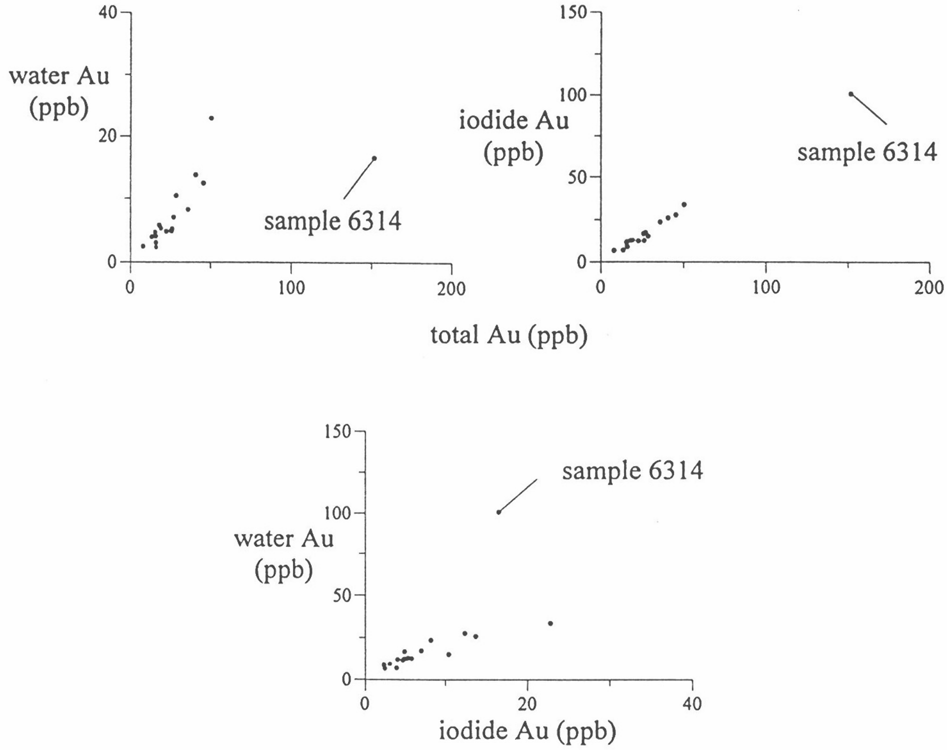


Figure 11: Water soluble versus iodide versus total Au for the Steinway traverse.

2.4 FERRUGINOUS GRANULES

In order to investigate the distribution of the Au in more detail, samples from 0.2 m (09-2040) and 1.6 m (09-2046) from the soil profile were wet-sieved to produce 4 sub-samples (A = > 710 µm, B = 710 - 250 µm, C = 250 - 53 µm and D = < 53 µm), and analysed for Au and other elements (Figure 12). The highest Au concentration is in the coarse fraction (>710 µm) at 1.6 m (A-1.6 m, 450 ppb). This sub-sample represents 10.6% of the total weight of the entire sample from this depth and has 17% of the total mass of Au; most of the Au (80%) is found in the <53 µm fraction. Sample A-1.6 m is also enriched in As, Cr, Eu, Fe, La, Sb, Sc, Sm, Th and W. The distribution of Au and Ce is similar for each size fraction at 1.6 m (Figure 12).

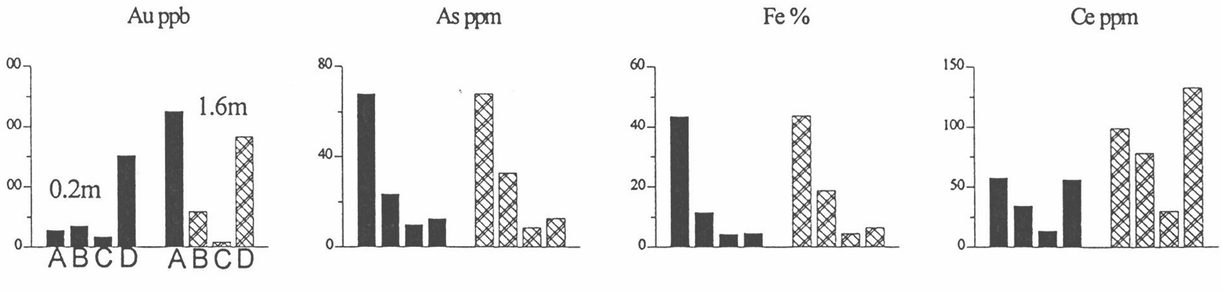


Figure 12: The distribution of Au, As, Fe and Ce from 4 size fractions (A = > 710 µm, B = 710 - 250 µm, C = 250 - 53 µm and D = < 53 µm) within two horizons (0.2 m, 1.6 m).

A detailed study of the petrology of the ferruginous granules indicates that lithic fabrics (after primary silicates) are present. This points to the allochthonous nature of this material; although it does not exclude post-depositional modification, including the addition of Au.

3. GEOCHEMISTRY OF CHANNEL SEDIMENTS

Gold concentrations in ferruginous material separated from 6 samples of transported material collected from 6 to 20 m depth do not exceed 20 ppb and are thus much lower than surficial samples. The sample with the most Au (17 ppb) also has the highest Fe, Ba, Ce, Cr, Eu, La, Lu, Mn, Ni, Pb, Sb, Sc, Sm, Th, U and Yb; these elements are probably concentrated within Fe and/or Mn oxides rather than being specifically related to Au.

Data from Gardiner (1993) for selected samples from the regolith indicate:

(i) that Lu and Yb have relatively high concentrations in saprolite and bedrock samples containing medium (0.1 to 1 ppm) to high (>1 ppm) concentrations of Au (Figure 13);

(ii) multi-element concentrations for hole ST-1 (10808E/4250N) suggest there is a surface enrichment (0 - 5 m) of Au, Ca, K, Mg, Mn, S, Cl, Cs, Cu, Pb, Rb, Sr, Zn and REE, compared with the sub-surface (5 - 10 m);

(iii) that Fe content appears to influence the concentration of several elements, including As, Ni, Sb, Sc and V;

(iv) palaeochannel sediments are enriched in Al, Br, Cr, Hf, Th and Zr with respect to the saprolite and basement;

(v) a S-rich unit at about 15 m shows elevated total Au concentrations (up to 85 ppb) relative to adjacent sediments (< 20 ppb). Gardiner (1993) suggests that the patchy distribution of this unit diminishes its suitability as a sample medium;

(vi) the ratios of As/Fe and Cr/Fe from drill hole ST-1 also indicate that there may be at least two distinct types of sediments that make up the transported overburden. The boundary between the two types appears to be close to 15 m below the surface.

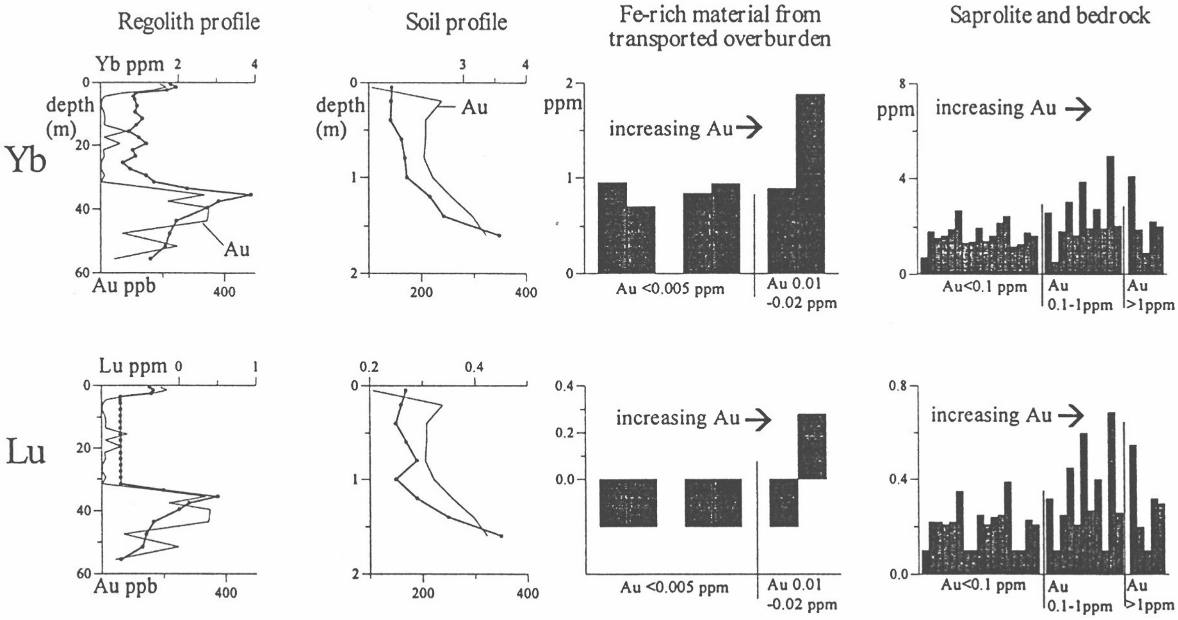


Figure 13: Distribution of Yb and Lu in relation to the concentration of Au in surficial, transported material and saprolite/bedrock. Results for Lu shown < 0 ppm are below detection.

4. BIOGEOCHEMISTRY

Gardiner (1993) suggests that Au contents of vegetation (eucalyptus leaves, bark, twigs, mull or bluebush) does not indicate the presence of mineralization (Table 1). In depositional areas, the maximum concentrations of Au for bluebush and mull at Steinway are lower than those found at the Zuleika Sands Au deposit (about 50 km north west of Kalgoorlie), where up to 7.9 ppb (bluebush) and 5.8 ppb (mull) was reported (Lintern and Butt, 1992); maximum Au concentration in eucalyptus leaves was similar at Zuleika (0.6 ppb) but much lower (0.1 ppb) at Panglo Au deposit (Lintern and Scott, 1990). For erosional areas, the maximum reported Au values for vegetation at the Bounty Au deposit (about 200 km south west of Kalgoorlie; Lintern, 1989), Zuleika and Panglo are an order of magnitude greater than at Steinway.

Table 1: Au analyses (in ppb) of dried vegetation (from Gardiner, 1993).

Sample Type	Over mineralization	Over background
Eucalyptus leaves	0.8 <0.5	<0.5 <0.5
Eucalyptus bark	<0.5 <0.5	<0.5 <0.5
Eucalyptus twigs	1.1 1.1	1.2 0.5
Mull	3.8 4.4	4.1 <0.5
Maireana (*Kochia*) (bluebush)	0.9 1.7	1.8 1.7

5. GROUNDWATER

The sample locations are shown in Figure 2, with all samples from the mineralized area. Groundwaters varied from moderately (pH 5.8) to highly (pH 3.4) acid. The total dissolved solids (TDS), a measure of groundwater salinity, were calculated from the major element contents. Nine other sites with saline groundwater were used for comparison: Wollubar, Golden Hope, Baseline, Panglo and Mulgarrie are all mineralized areas in the Kalgoorlie region (Gray, 1990, 1992b, 1993b); Yalanbee is a non-mineralized site 70 km east of Perth; (west Yilgarn); and Granny Smith, Mt. Gibson and Boags are Au deposits in the central Yilgarn area (Gray, 1991, 1992a, 1993a). Wollubar, Baseline, Panglo and Yalanbee are acid groundwater systems, whereas the other sites have mainly neutral groundwater. A generalized description of the hydrogeochemistry of the Yilgarn Craton is given in Butt et al. (1993).

The Steinway groundwaters are appreciably saline (up to 2½ times sea water) and acid (Figure 14) and, as expected, have similar chemistry to Wollubar, Baseline and Panglo. They are enriched in Al and Si, the transition metals Mn, Fe, Co, Ni, Cu and Zn, Y and the REE, Pb and (in the most acid groundwater) U. These enrichments will commonly occur where acid groundwaters contact mafic rocks (Gray, 1990), as is demonstrated by the fact that these acid groundwaters are undersaturated with respect to the corresponding secondary minerals, and therefore may not have any direct exploration significance, aside from indicating mafic lithologies. The Cr concentrations are below detection for the Steinway groundwaters, consistent with previous observations that Cr is only enriched in groundwaters contacting ultramafic lithologies.

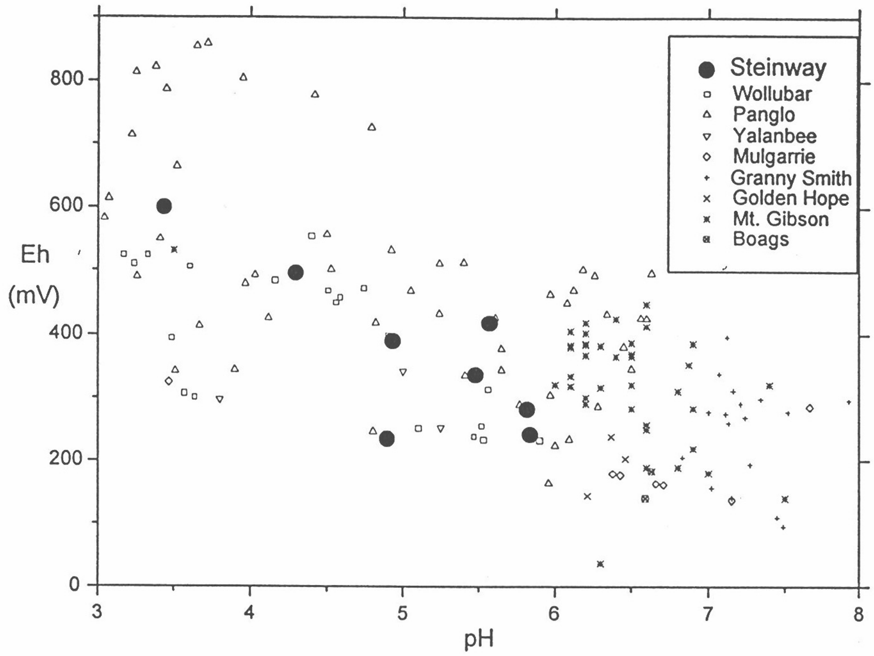


Figure 14: Eh vs. pH for groundwaters from Steinway and other sites.

Chalcophile elements that are enriched in neutral groundwaters in contact with weathering sulphides (e.g., Ga, Mo, W, Ag, Sb and Tl) have very low concentrations in the Steinway groundwaters, as expected. Iodine, however, has a high concentration in these groundwaters, as is also observed in other mineralized sites in the Yilgarn Craton.

In neutral groundwaters, the most likely mechanism for the dissolution of Au is as the thiosulphate complex, whereas in acid saline groundwater, such as at Steinway, Au halide (chloride or iodide) is expected to be important (Gray et al., 1992). High redox potentials (Eh) are required for the dissolution of Au as Au halide, and all but one of the Steinway samples are insufficiently oxidising for significant Au dissolution (Figure 15). The one highly oxidising groundwater contains 0.8 ppb Au, which is very anomalous, whereas the other samples all have low Au contents (< 0.03 ppb). However, groundwater Eh is very sensitive to a number of factors (e.g., Fe and Mn contents and the degree of equilibration with atmospheric O_2, and could vary significantly over time. Under favourable conditions, therefore, dissolved Au concentration throughout the Steinway mineralized area could be high.

The spatial distribution of the elemental abundances in groundwater show that Be, B, Si, I, transition elements, Y and the REE appear to be enriched on line 4250N, but this would need to be substantiated by further sampling.

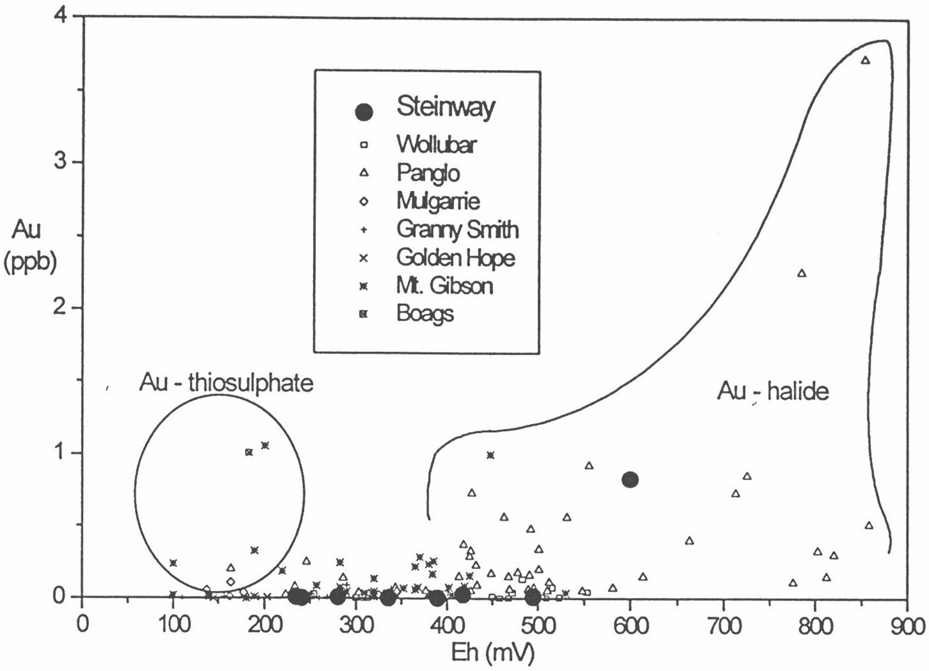


Figure 15: Au vs. Eh for groundwaters from Steinway and other sites, with fields of Au dissolution marked.

6. DISCUSSION

Of all palaeochannel sites investigated, Steinway is unusual in two respects:

(i) it has the highest Au concentrations found in the soil;

(ii) the highest Au contents almost directly overlie the underlying mineralization.

The origin of the Au enrichment at Steinway is of prime importance to exploration in the Kalgoorlie studies. There are two hypotheses:

1. The soil anomaly is derived from the underlying mineralization. The Steinway soil anomaly defined by the 24 ppb contour approximately overlies the boundaries of the sand base of the palaeochannel. This suggests that the channel itself may be playing a role in the formation of the anomaly, and/or that the channel position has been influenced by the geology. In this study, the distribution and tenor of Au mineralization has only been determined for two sections and so its relationship to the channel over a broader area is not established. Furthermore, the presence of other mineralization in the area, and its spatial relationship with the other soil anomalies, needs to be investigated. Evidence from the nearby Greenback deposit 500 m to the west, suggests that there is no anomaly directly over palaeochannel mineralization.

2. The soil anomaly is not derived from the underlying mineralization. Evidence has been presented for the possible origin of Au from up slope, and includes:

    (i) the presence of ferruginous lithorelics containing high Au concentrations (from samples 09-2040, 09-2046); the presence of Au within these lithorelics is strong evidence for at least some of the Au being of exotic origin.

(ii) the association of Au with Fe, rather than Ca in the lower part of the soil profile; the negative correlation with Ca implies that the Au is not behaving in the same way as that in erosional areas, where the correlation is very high. Profiles at Zuleika also indicate that the association between Au and Ca is not as strong in depositional areas. Indeed, the Au/Ca relationship at Steinway is similar to that at the Mulline Au deposit, approximately 130 km NW of Kalgoorlie (Lintern and Butt, 1991), where there appears to be an association between Au and Ca near the surface and between Au and Fe in the lower part of the soil profile (Figure 16); however, Mulline is in a relict landscape regime.

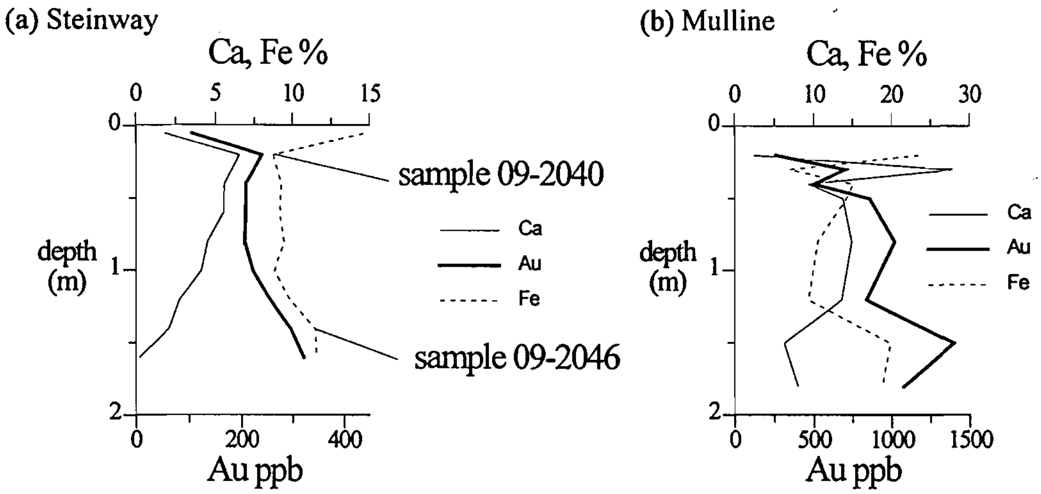


Figure 16: Concentration of Ca, Fe and Au in profiles from a) Steinway (this study) and b) Mulline (Lintern and Butt, 1991)

(iii) the sample with the highest total Au concentration in the 0 - 1 m composite sample has the most insoluble Au when extracted with water. The form of Au has not been determined from these extractions, but experiments conducted on samples from other sites show that water soluble Au is often proportional to total Au when the soil is carbonate-rich. This is the case at Steinway, except for this sample closest to mineralization, where presumably the Au is associated more with Fe (in ferruginous granules) rather than Ca.

If the second hypothesis is true (i.e. Au in the soil is NOT derived from underlying mineralization) then a possible mechanism for the formation of the anomaly is as follows: Au has been transported from up slope within ferruginous granules, now at 1-2 m below the present land surface, which represent a buried lag. The granules have undergone some post-depositional weathering, remobilizing some of the Au, which is now associated with the pedogenic carbonate. A possible up slope source is the Penfold deposit, 1 km to the south. It is now separated from Steinway by recent drainage, but this post-dates deposition of the buried ferruginous granules.

Further detailed sampling of the ferruginous granules in the area is being undertaken to provide further evidence to confirm that the soil anomaly is un-related to the underlying mineralization.

7. SUMMARY

1. Gold is found to be correlated with Ca in the top 0.5 m (of 2 m) of the soil profile.

2. The highest Au concentrations in the 0 - 0.1 m (93 ppb) and the 0 - 1 m samples (150 ppb) are located above mineralization.

3. Water- and iodide-soluble Au (partial extractions) are also anomalous over mineralization, though they give no additional exploration information than total Au alone.

4. The 0 - 1 m sample with the highest total Au has a relatively low proportion of water extractable Au.

5. High Au concentrations are found in ferruginous granules over mineralization.

6. Vegetation does not define the location of the mineralization.

7. Where groundwaters are sufficiently oxidising, Au is soluble, presumably as a Au halide complex.

8. Groundwaters at Steinway are similar to those throughout the Kalgoorlie region, in that they are acidic and saline and enriched in REE and base metals.

9. Steinway groundwaters show particularly high values of Mn, Co, Ni and Cu.

10. More study is required to assess whether the Steinway soil anomaly is fortuitous.

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GREENBACK GOLD DEPOSIT

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The Greenback deposit is located about 25 km SW of Kalgoorlie and 16 km W of the New Celebration mine. It lies adjacent to a regional contact between mafic-ultramafic rocks of the Saddle Hills Belt and overlying intermediate to felsic volcanic and sedimentary rocks assigned to the Black Flag Group (Figure 1). Most of the area is deeply weathered, with a cover of clay-rich transported overburden.

Folding has produced a NNW-trending, N-plunging syncline (the Kurrawang syncline), the western limb of which abuts the Zuleika Shear Zone. The Penfold deposit, south east of Greenback, has a primary sulphide resource, with Au mineralization hosted by a fine-grained amphibolite dominated by biotite and feldspar. Silica, carbonate, quartz veining and fine-grained disseminated pyrite are the principal alteration minerals. The Greenback deposit has similar alteration at depths of about 120 m which, in places, hosts primary sulphides.

Gold mineralization at Greenback occurs within and beneath flat-lying, gently undulating sediments in a north-trending palaeochannel (Figure 2). The stratigraphy at the deposit has the following units:

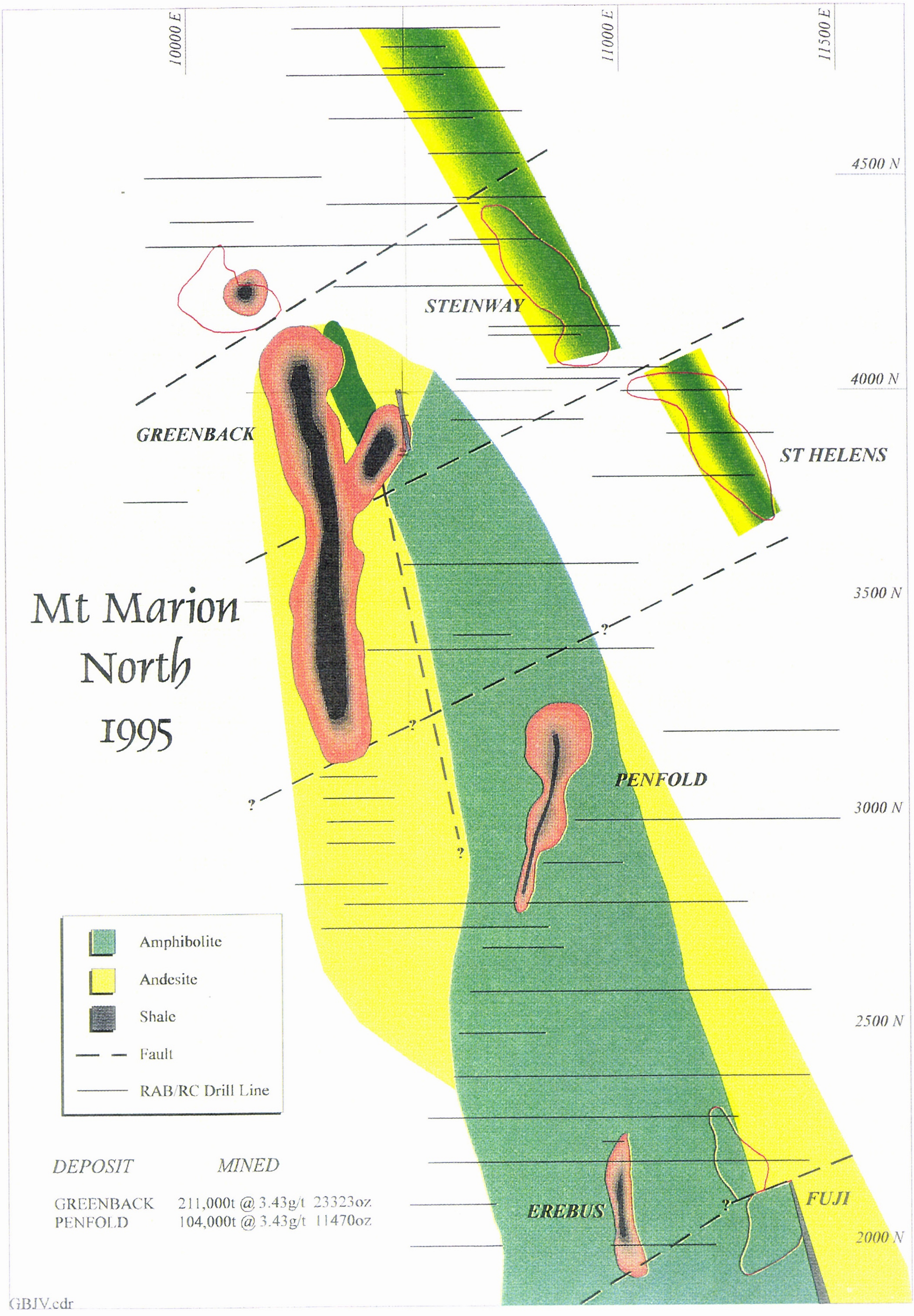
Unit	Thickness (m)
Calcareous topsoil	1
Red, non calcareous, mottled and pisolitic clay	20
Pale coloured, puggy, lacustrine clay	2-3
Pale grey-light brown quartz-rich sandy clay (Base of palaeochannel)	to 5
Yellow-brown clay saprolite	15
Interbedded ultramafic and micaceous andesitic bedrock, with quartz-chlorite-biotite shears and narrow amphibolites	

There are three styles of mineralization:

1. An upper, flat-lying supergene zone within ferruginous mottled and pisolitic clays of the palaeochannel.

2. A middle supergene zone within the basal sandy clays of the paleochannel and the upper saprolite.

3. A lower primary zone. This is east-dipping, discontinuous and best developed along the andesite-amphibolite contact. Strong silica-carbonate-chlorite(?)-biotite alteration is developed, with pyrite mineralization (to 80%) present *in situ* and remobilized along fracture planes.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STEINWAY
GREENBACK
ST HELENS
Mt Marion North 1995
PENFOLD
EREBUS
FUJI
Amphibolite
Andesite
Shale
Fault
RAB/RC Drill Line
DEPOSIT
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GREENBACK 211,000t @ 3.43g/t 23323oz
PENFOLD 104,000t @ 3.43g/t 11470oz
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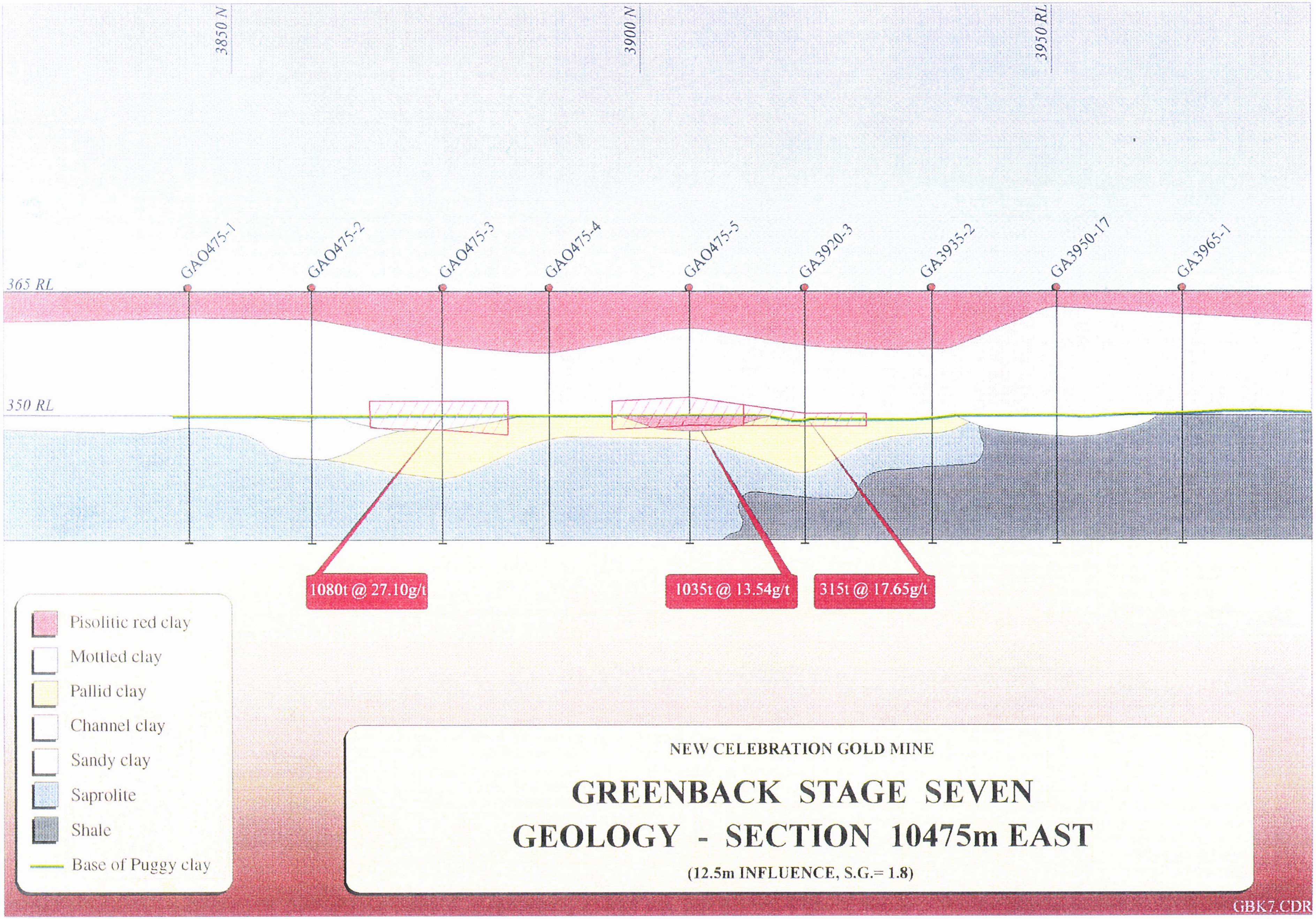
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GA3920-3
GA3935-2
GA3950-17
GA3965-1
365 RL
350 RL
1080t @ 27.10g/t
1035t @ 13.54g/t
315t @ 17.65g/t
Pisolitic red clay
Mottled clay
Pallid clay
Channel clay
Sandy clay
Saprolite
Shale
Base of Puggy clay
NEW CELEBRATION GOLD MINE
GREENBACK STAGE SEVEN
GEOLOGY - SECTION 10475m EAST
(12.5m INFLUENCE, S.G.= 1.8)
GBK7.CDR

THE ARGO GOLD DEPOSIT, WESTERN AUSTRALIA

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CRC for Landscape Evolution and Mineral Exploration, c/- CSIRO Exploration and Mining

1. GEOLOGICAL AND GEOMORPHOLOGICAL DESCRIPTION

Argo is a large Au deposit[1] located 25 km south of Kambalda. The landscape is typical of the floodplains bordering the salt lake regions to the south and east of the Kalgoorlie area. Vegetation is sparse and is composed of eucalypt open woodland with occasional *Casuarina*, *Eremophila*, bluebush and other small shrubs. A broad colluvial plain with occasional clay pans drains the entire study area to the south-west towards Lake Lefroy, located about 2 km to the west. Large areas are draped with aeolian dunes.

The regolith consists of:

(i) 0-0.2 m thin sand-rich topsoil (possibly aeolian);

(ii) 0.2-2 m calcareous clay-rich red soil. Carbonate occurs as coatings of clays, coatings on partially weathered lithorelics (principally basalt), and as cutans on nodules. A narrow, dark, manganiferous horizon occurs at about 1.5 m;

(iii) 2-7 m hard red and grey clays with variable ferruginous mottling to 7 m, containing zones of indurated ferruginous and siliceous material.

Below 7 m, the regolith is variable, depending on location. In the central and northern parts of the study area, the regolith below 5 - 10 m mainly consists of clay-rich saprolite. In the southern part of the study area, the thickness of the transported material increases and consists of puggy lacustrine clays with lenses and horizons of spongolite and lignite. Palaeotopography (Woolrich, 1994) indicates that the transported material lies unconformably on the southern and eastern flanks of a valley. A palaeochannel, with up to 70 m of transported sediments, is located at the base of the valley and is orientated approximately east-west (Figure 1). The underlying geology of the study area consists of high-Mg basalts with minor interflow sediments, and well-differentiated dolerite (Figure 2).

Mineralization is confined to bedrock, saprolite and at the unconformity with the transported material, where it appears to follow the palaeosurface downslope. Patchy but spectacular grades of mineralization (with carbonate alteration) occur in the saprolite, associated with favourable contacts (possibly Fe-rich) between basalts and dolerites (B. Watchhorn, WMC, pers. comm., 1994). The St Ives processing plant is located about 3 km to the north east and is a potential source of contamination of Au.

[1] approximately 1 Mt at 3.5g/t (B. Watchhorn, Western Mining Corporation Ltd (WMC), personal communication, May 1996).

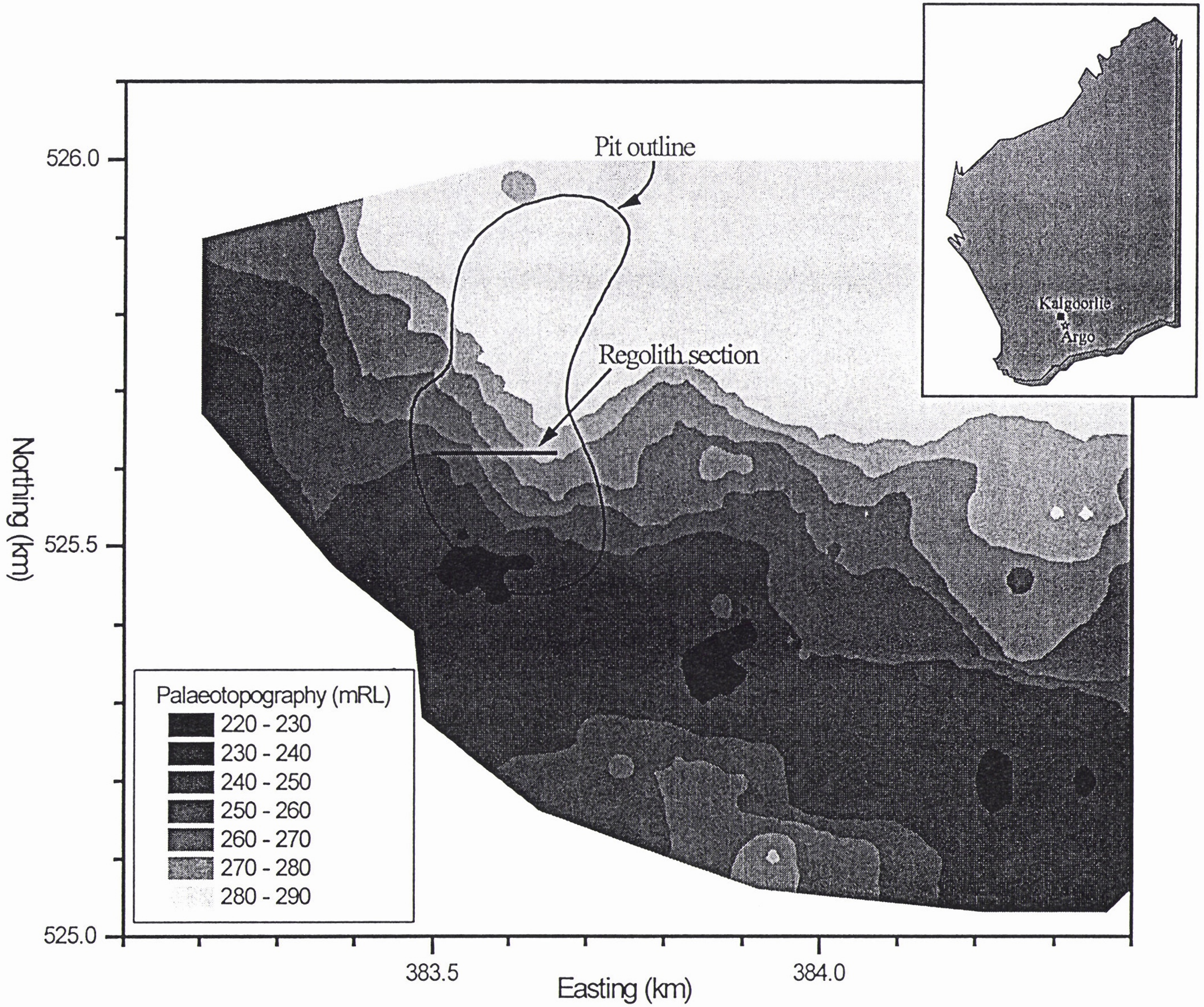


Figure 1: Plan of Argo area showing palaeotopography, Argo pit and regolith section (after Woolrich, 1994), with location diagram.

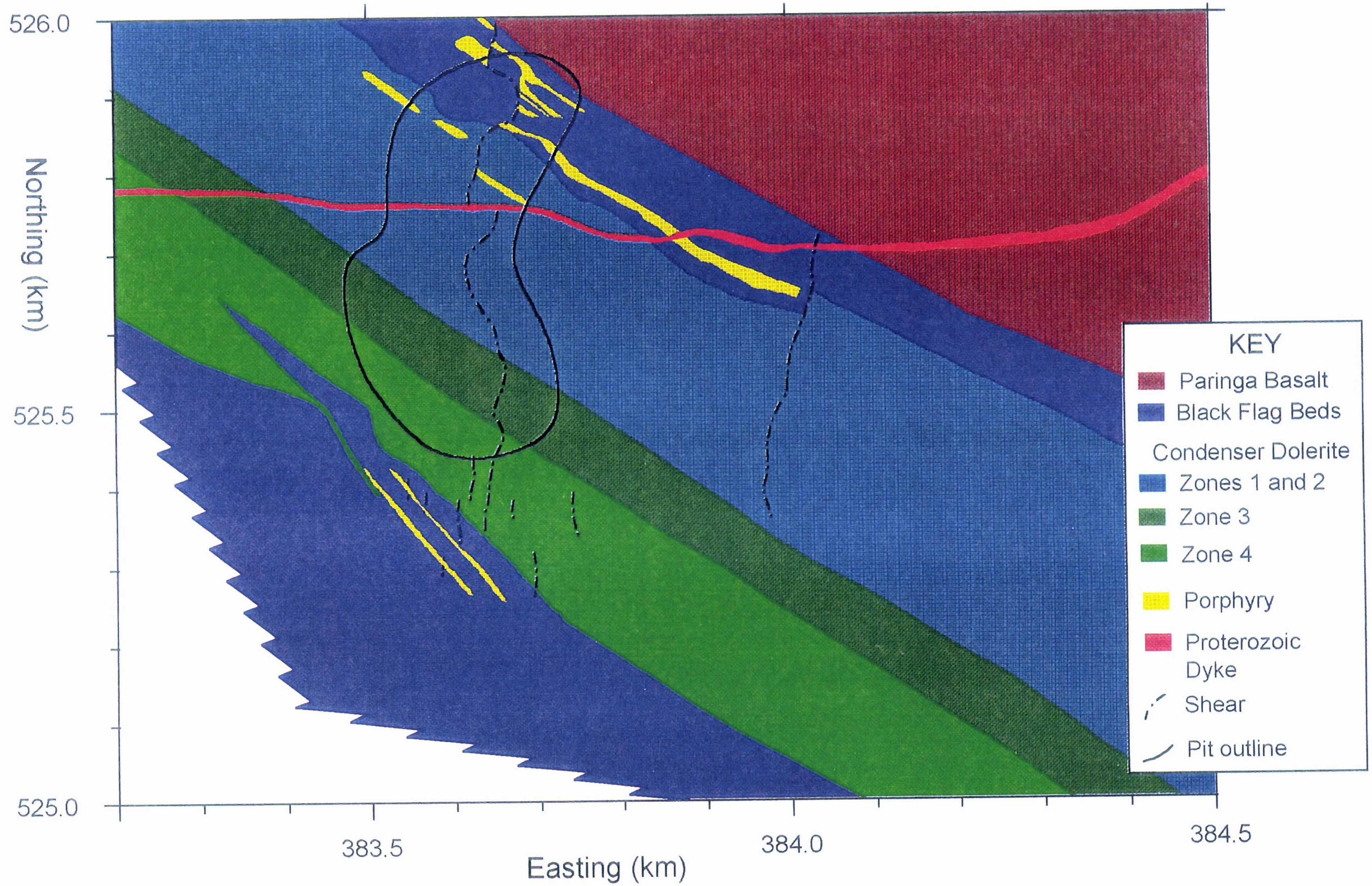


Figure 2: Plan of Argo Au deposit showing geology (modified from Western Mining Corporation plans).

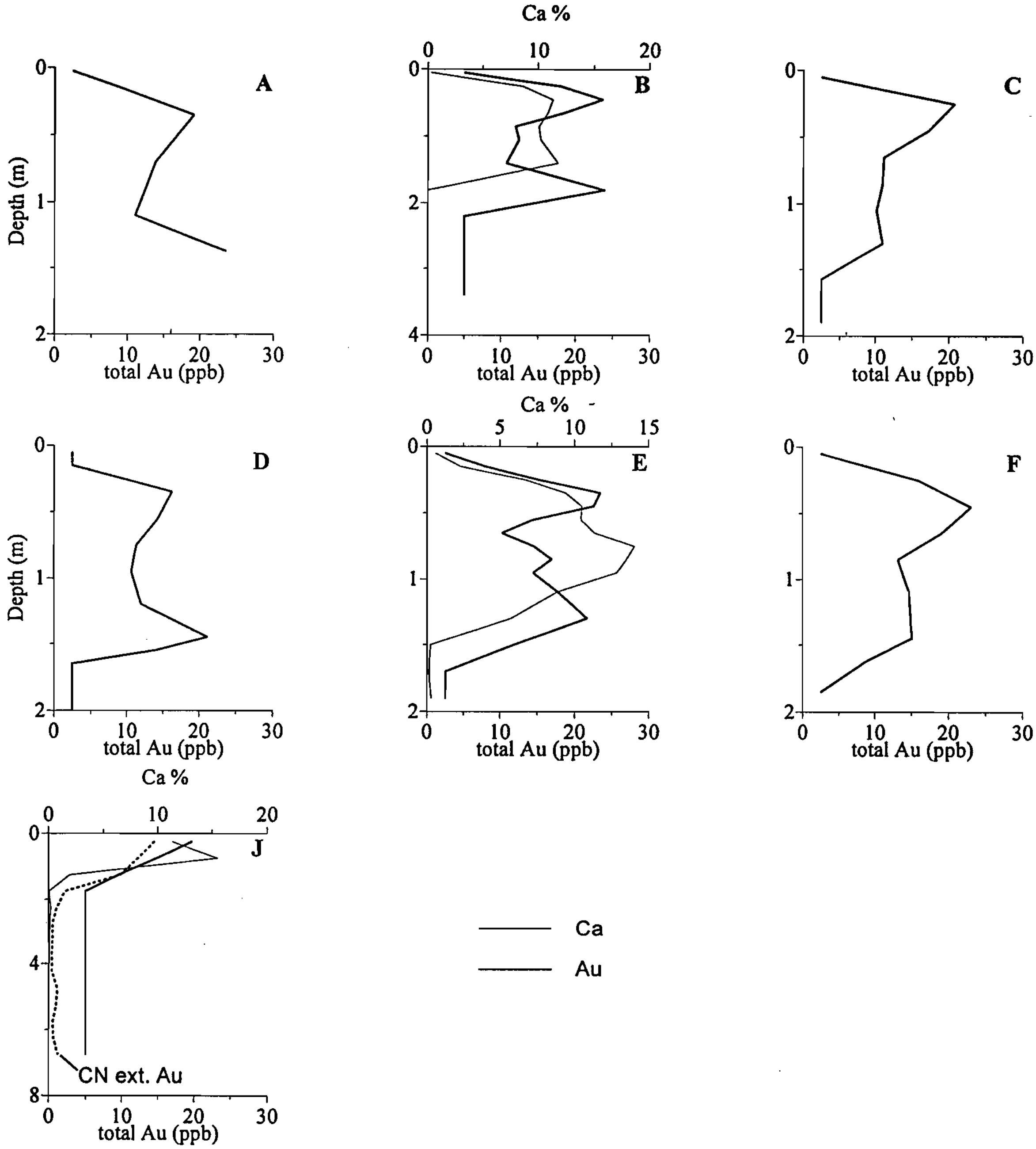


Figure 3: Au and Ca data for soil profiles at Argo.

2. SOIL GEOCHEMISTRY

2.1 PROFILES

Seven soil profiles were sampled in detail (Figure 3). These included six profiles (A to F) that were sampled at 0.1 - 0.2 m intervals and one profile (J) sampled at 0.5 m intervals from the southern end of the then pit wall, prior to expansion of the pit. Profiles were situated over mineralization (*e.g.*, E and J) and in background areas (*e.g.*, B). The total Au results indicate an association with Ca, with both elements largely confined to within 2 m of the surface (Figure 3). Gold concentrations are low (mean < 10 ppb) with two maxima (0.3 m to 0.5 m and 1.3 to 1.8 m) in each profile. The relationship between Au and Ca is not as strong as that found in profiles at other sites (*e.g.*, Panglo, Bounty and Zuleika; Lintern, 1989; Lintern and Scott, 1990; Lintern and Butt, 1991, 1992); nevertheless, augering the top metre is still an effective compromise sampling technique to locate Au in the soil profile. Importantly, however, there are no significant differences in the distribution characteristics or total Au content between either the mineralized or background areas. However, further studies are being undertaken to extend 0-1 m sampling further east and west to see if these values are anomalous in a regional context.

The highest Mn content (1M HCl extractable) is observed in the lower part of the profile (Figure 4), where the clays are stained dark brown to black. Several elements, including Au, As, Co, Mo, Sb, W and REE (Ce, Eu, La, Lu, Sm and Yb), also have maxima in this horizon, reflecting the commonly observed scavenging characteristics of Mn oxides and of amorphous forms of Fe, which commonly correlate with Mn (ongoing research within P409). This Mn-rich horizon is widespread throughout the Argo area.

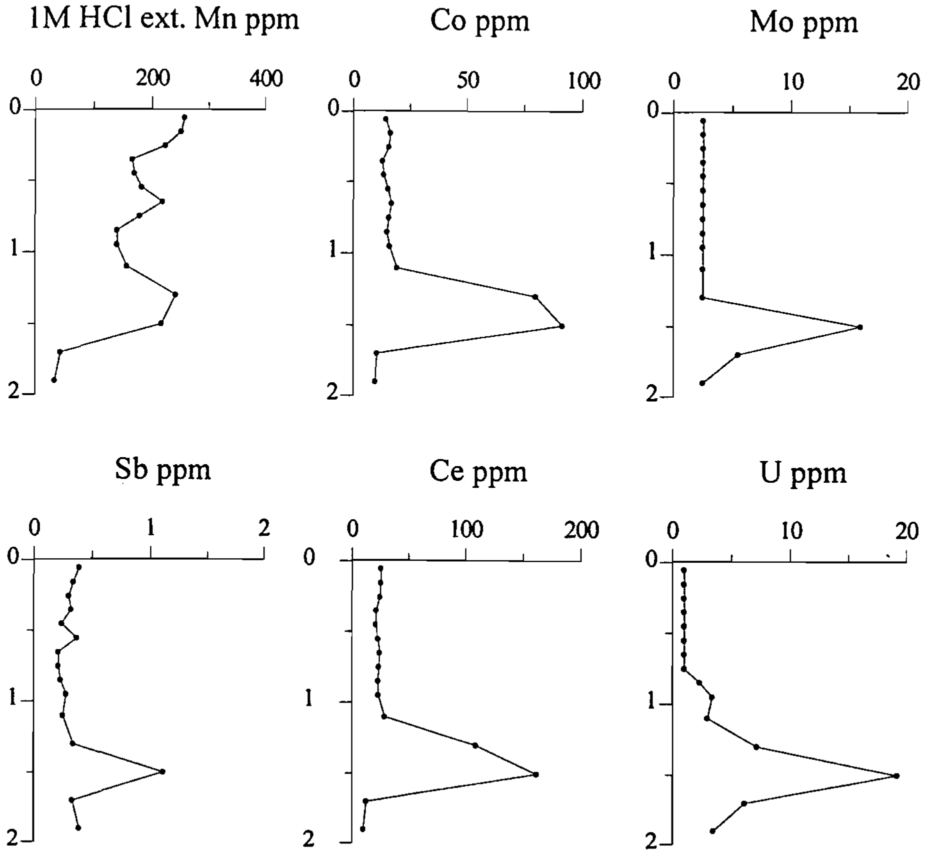


Figure 4: Multi-element geochemistry for Profile E at Argo.

2.2 COMPOSITE SOIL SAMPLES

Surficial samples (0 - 1 m, 1 - 2 m) from 526030N, 525800, 525600 and 525380N were collected by augering and a selection analysed for Au and other elements. The distribution of Au does not to appear to be related to the underlying mineralization (Figure 5) and concentrations are generally low (Table 1).

Table 1: Summary statistics for total Au (ppb) for 0 - 1 m samples taken from 4 traverses at Argo.

Traverse	Mean Au	Maximum Au
526030N	11	15
525800N	8	24
525600N	5	8
525380N	9	17

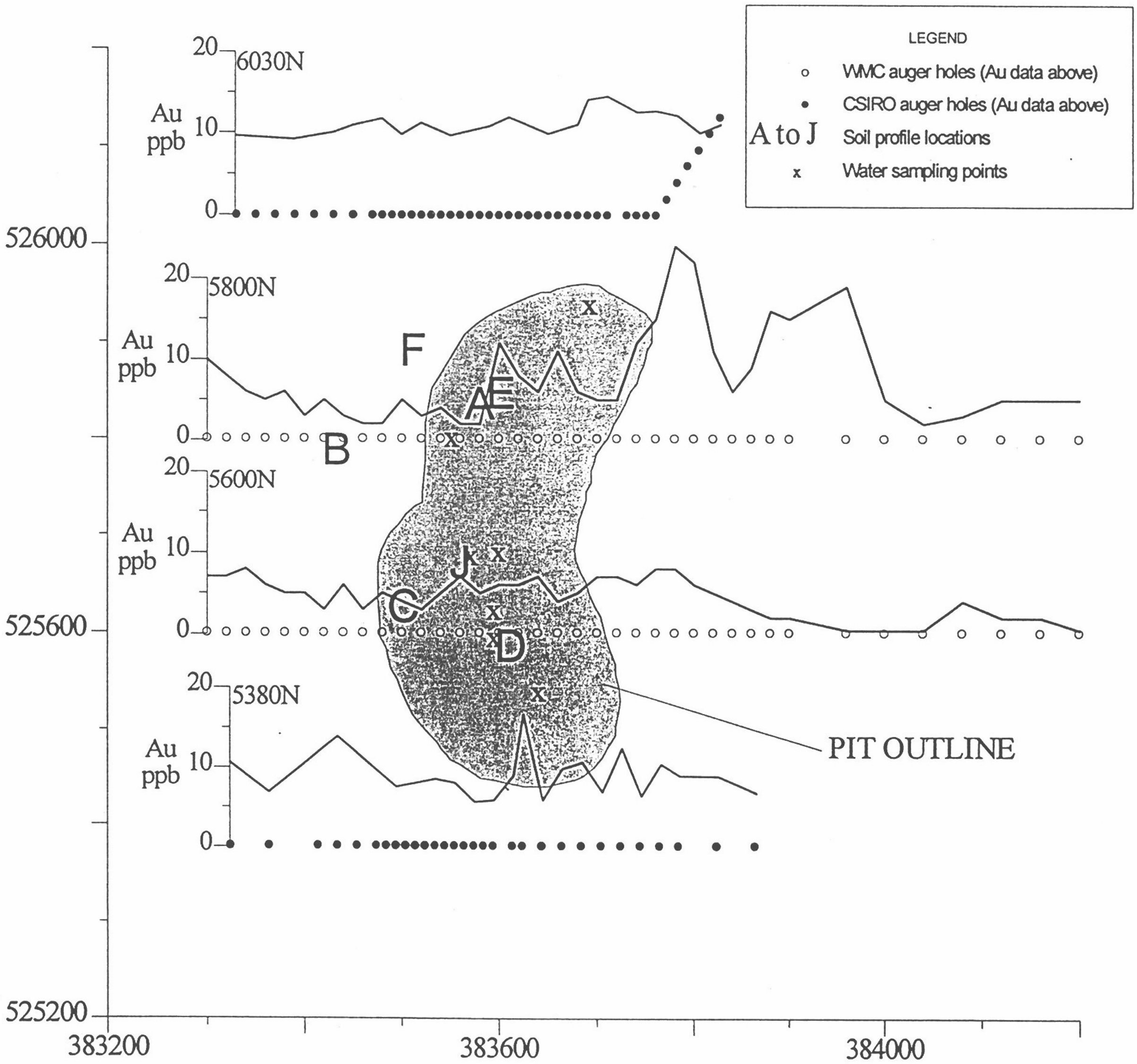


Figure 5: Total Au contents for soil traverses. Locations of soil, water and profile sampling points shown. Outline of pit is shaded. Data for 525800N and 525600N supplied by WMC Ltd.

Calcium is evenly distributed on 525380N and 526030N, with higher concentrations at 1-2 m (9%) than 0- 1 m (5%). Magnesium concentrations tend to increase towards the eastern portions of both traverses, and also have higher concentrations at 1-2 m. Normalization of Au with respect to Ca and Mg does not produce any significant trends. Similarly, the partial extraction of Au from 0-1 m samples (525380N) by water, iodide and cyanide did not produce any significant correlations with underlying mineralization (Figure 6). However, further studies are being undertaken to extend the 0 - 1 m sampling further east and west to determine whether these values are anomalous in a regional context.

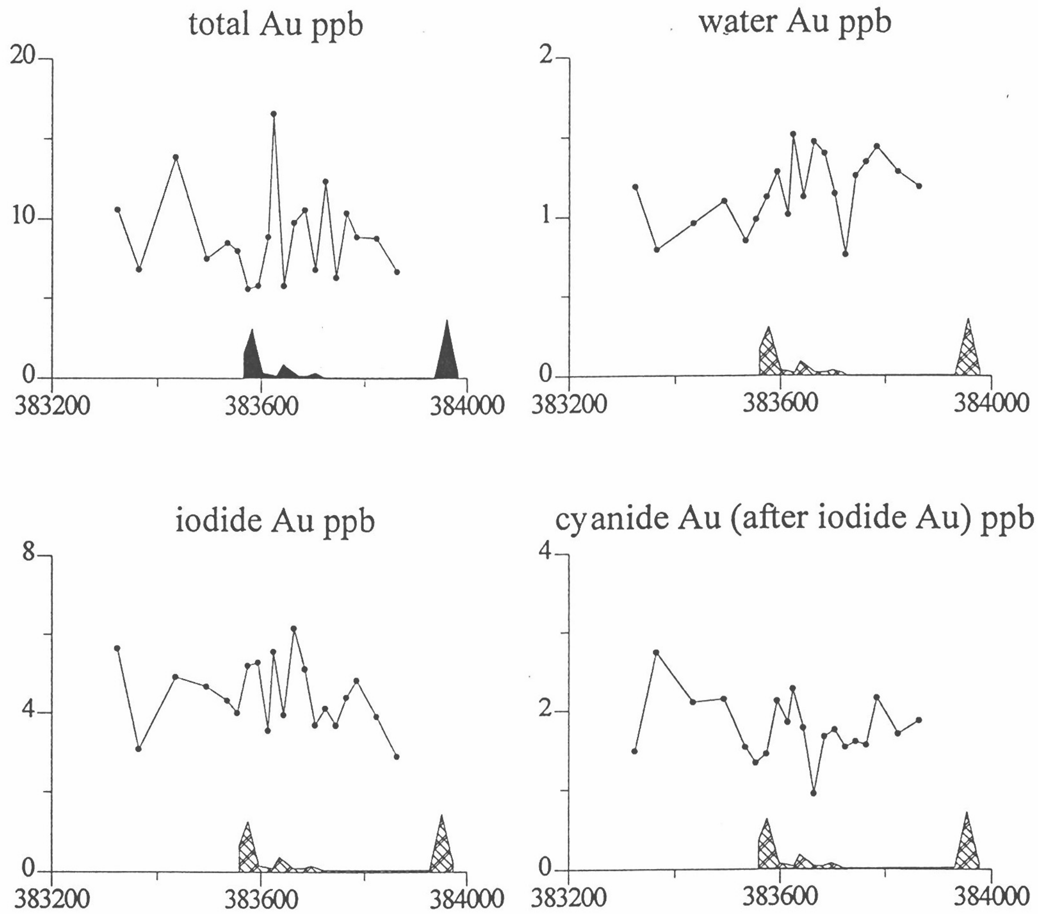


Figure 6: Total, water, iodide and cyanide soluble Au for 0 - 1 m samples on 5380N at Argo. The cyanide results are for Au left after iodide extraction. The hatched area locates mineralization.

3. REGOLITH GEOCHEMISTRY

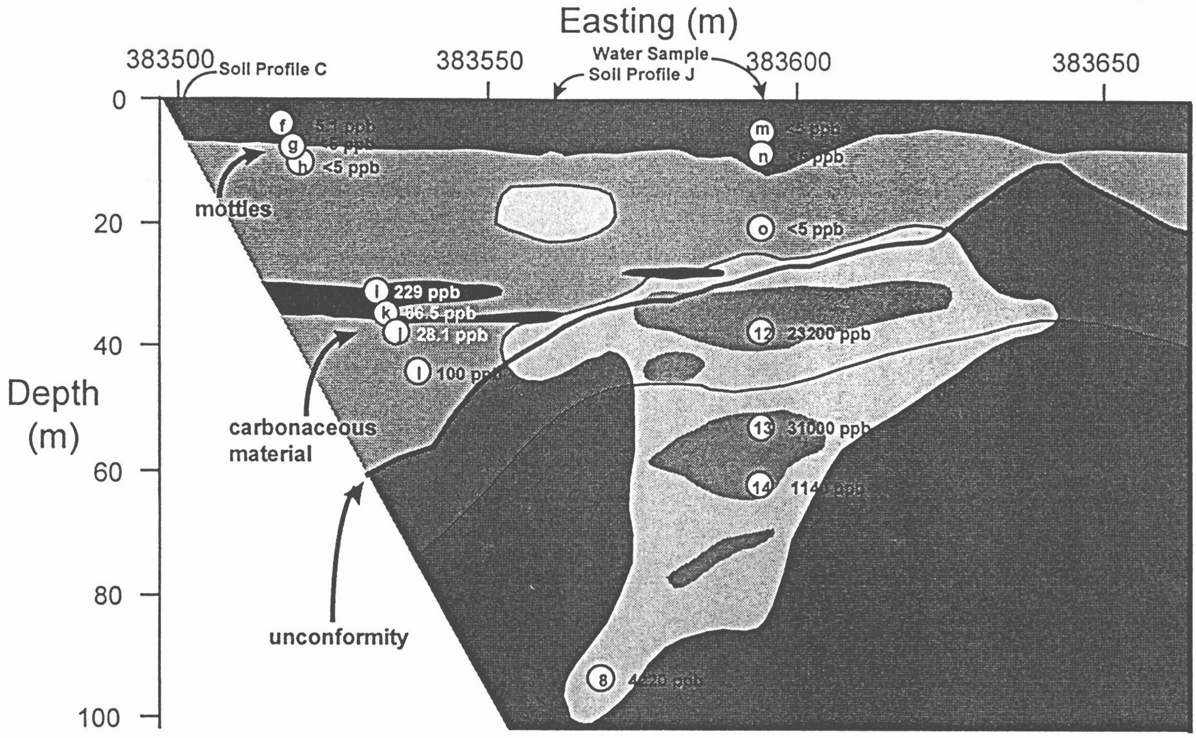
3.1 MATERIAL SEPARATED FROM TRANSPORTED OVERBURDEN

A selection of ferruginous and lignitic samples were separated from the transported overburden e.g. section 525620N (Figure 7) and analyzed for Au and other selected elements. Results indicated that:

(i) samples from transported overburden located directly above mineralization did not contain any detectable Au;

(ii) some samples laterally adjacent to mineralization contained several tens of ppb Au;

(iii) samples from the reducing environment containing carbonaceous material (including samples from background areas) had the highest Au content (maximum over 200 ppb; Figure 8). These samples also had relatively high Na, Br, Hf, La, Pb, Sm, Ta, U, Zn and Zr contents. Like Mn and Fe oxides, carbonaceous material is a well known scavenger of trace elements.



Calcareous red-brown sandy clay with Ca-rich nodules becoming non-calcaerous with depth. Indurated siliceous hardpan often present at base of horizon.

Puggy lacustrine clays of various colours (yellow, red and/or grey). In areas with deeper cover, lenses of lignite and/or spongolite present. Towards southern end of study area, quartz sands and gravels present mark base of horizon.

Spongolite

Saprolitic clays with some partially weathered rock.

Fresh rock/saprock dominated by dolerite.

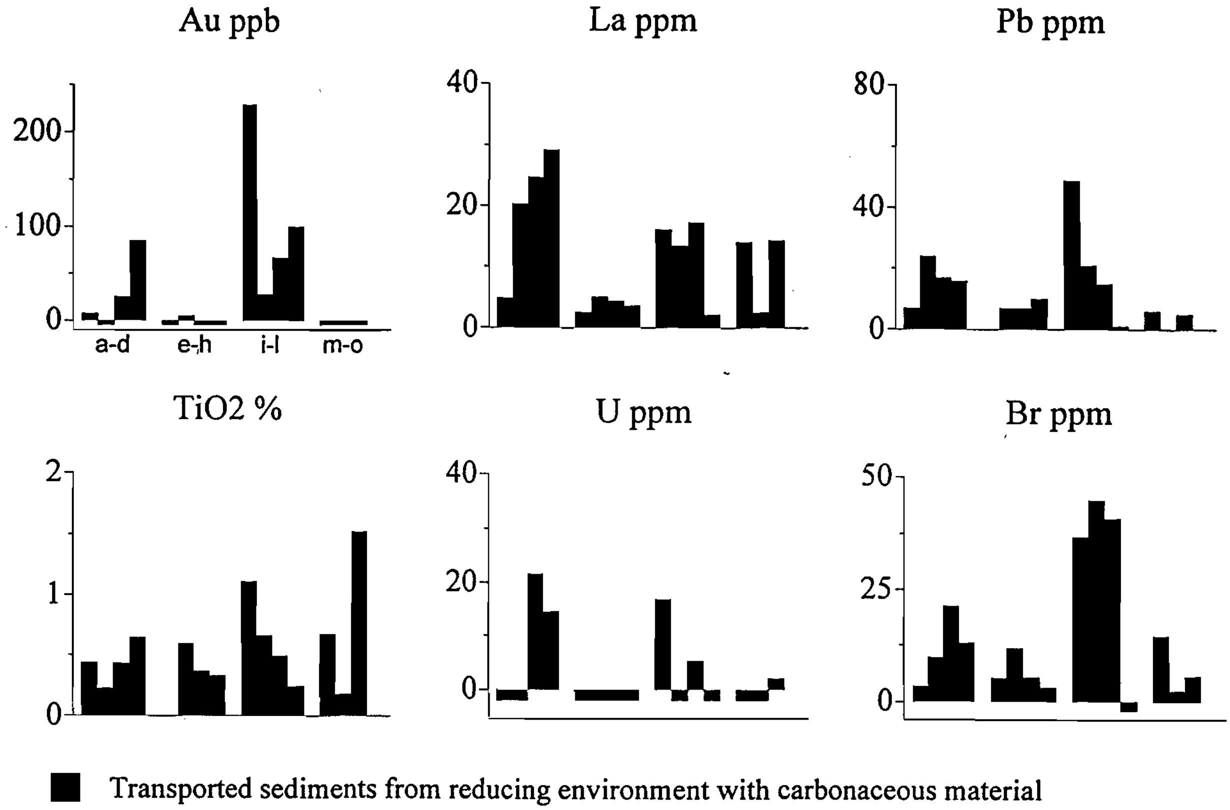
Lignite

Moderately mineralized (Au 1-10 ppm)

Strongly mineralized (Au >10 ppm)

Sample points

Figure 7: Regolith stratigraphy, Au mineralization and Au concentrations for selected samples from 525620N at Argo.



Sample	Depth (m)	Location	Description
a	9	Distant from mineralization	ferruginous - siliceous mottles
b	23	Distant from mineralization	pisoliths
c	26	Distant from mineralization	lignitic
d	25	Distant from mineralization	reduced clays with lignite
e	3	Above+adjacent to mineralization	ferruginous - siliceous mottles
f	6	Above+adjacent to mineralization	ferruginous - siliceous mottles (see section)
g	8	Above+adjacent to mineralization	ferruginous - siliceous mottles (see section)
h	12	Above+adjacent to mineralization	ferruginous - siliceous mottles (see section)
i	37	Adjacent to mineralization	lignitic (see section)
j	40	Adjacent to mineralization	lignitic (see section)
k	39	Adjacent to mineralization	reduced clays with lignite (see section)
l	51	Adjacent to mineralization	pisoliths (see section)
m	5	Above mineralization	ferruginous siliceous mottles (see section)
n	8	Above mineralization	ferruginous - siliceous mottles (see section)
o	21	Above mineralization	Perkolilli shale (clay) (see section)

Figure 8: Selected elemental abundances in grab samples from transported overburden at Argo.

3.2 SAPROLITE AND BEDROCK

Fourteen samples of saprolite and bedrock were analysed for Au and other elements. Most samples with high concentrations of Au (> 5 ppm) were significantly richer in W, relative to Au-poorer samples (Figure 9). In comparison, W concentrations in transported material were generally below detection (Figure 9).

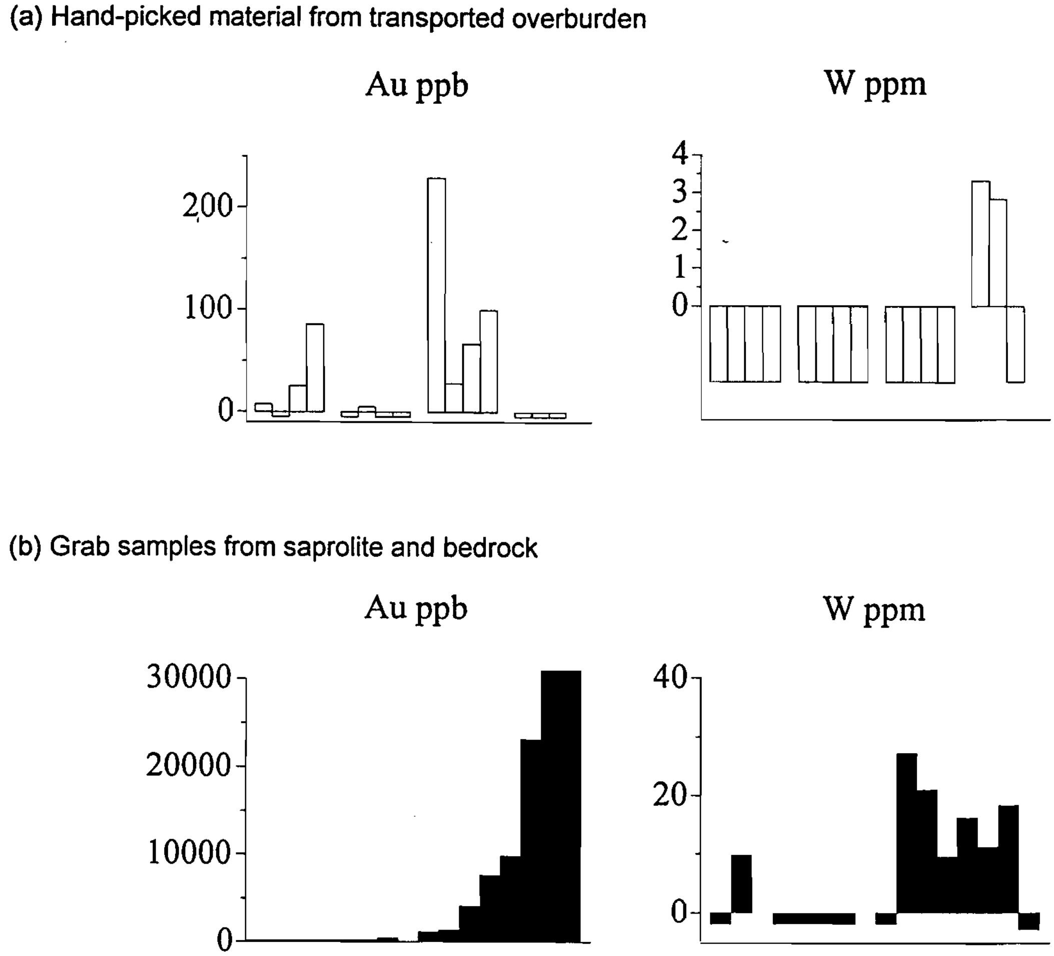


Figure 9: Gold and W abundances for grab samples from (a) transported overburden and (b) saprolite and bedrock at Argo. See Figure 8 for explanation of samples for transported overburden. Samples for saprolite and bedrock are ranked by Au concentration.

4. VEGETATION

The Au contents of *Eucalyptus* leaves, *Eremophila* whole plant or mull do not appear to indicate the presence of mineralization (Table 2). The concentrations of Au are lower than those found in comparable sites at Zuleika where up to 0.6 ppb in *Eucalyptus* and 5.8 ppb in mull was reported (Lintern and Butt, 1992). The maximum Au concentration for *Eucalyptus* and *Eremophila* over the palaeochannel mineralization at Panglo (Lintern and Scott, 1990) was 0.1 and 1.4 ppb, respectively. Maximum reported Au concentrations in vegetation from erosional and relict areas at Bounty (Lintern, 1989), and erosional areas at Zuleika and Panglo, are an order of magnitude greater than these data.

Table 2: Results of Au analyses (in ppb) of dried vegetation.

Sample Type	Over mineralization	Over background
Eucalyptus leaves	<0.5	<0.5
	<0.5	<0.5
	<0.5	<0.5
Eremophila whole plant	<0.5	<0.5
	<0.5	<0.5
	0.5	0.5
Mull	1.9	1.6
	2.3	2.2
	4.9	3.4

5. GROUNDWATER

Groundwaters at Argo are highly saline, with a major increase in salinity with depth (i.e., about 5-8% TDS for shallow samples, 9-12% for intermediate samples and 19-26% for deep samples, as compared with 3.5% for sea water). The major element abundances suggest that waters have been evaporated within a salt lake environment (with varying, later, degrees of mixing with fresher waters), i.e. groundwaters are:

(i) saturated with respect to gypsum, with the most saline approaching halite saturation - as a consequence of precipitation of these minerals, Na and Ca concentrations are lower than expected for the measured salinity;

(ii) enriched in Mg and SO_4, which remain in solution when other salts precipitate. Gypsum precipitation has little effect on dissolved SO_4 concentration, because of the proportionally lower Ca concentration.

In addition, groundwaters at Argo are depleted in K. This is commonly observed in groundwaters throughout the Yilgarn Craton and is particularly marked in the Kalgoorlie region, and may be due to adsorption of K by smectites, or precipitation of alunite (Gray, 1990).

Groundwaters vary from slightly acid (pH 4.5-5.5) for deep groundwaters to highly acid (pH 3.5-4) for shallow samples (Figure 10) and have similar elemental abundances to other sites in the Kalgoorlie region. Thus, they are enriched in Al and Si, the transition metals (Mn, Fe, Co, Ni, Cu and Zn), Y and REE, Pb and (weakly) U. These enrichments commonly occur where acid groundwaters contact mafic rocks (Gray, 1990), as is demonstrated by the fact that these acid groundwaters are undersaturated with respect to the corresponding secondary minerals, and therefore may not have any direct exploration significance, aside from indicating mafic lithologies. The Cr concentrations are below detection for the Argo groundwaters, consistent with previous observations that Cr is only enriched in groundwaters in contact with ultramafic lithologies.

Chalcophile elements that are enriched in neutral groundwaters in contact with weathering sulphides (e.g., Ga, Mo, W, Ag, Sb and Tl) have very low concentrations at Argo, as expected. Iodine, however, has a high concentration in these groundwaters, as observed in other mineralized sites in the Yilgarn Craton.

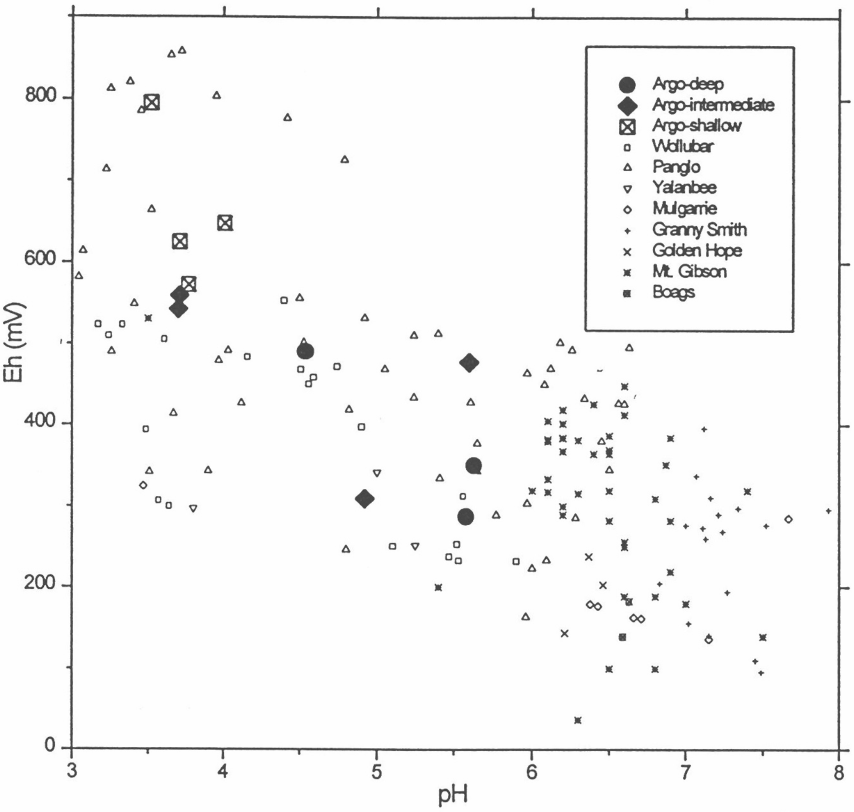


Figure 10: Eh vs. pH for groundwaters from Argo and other sites.

In neutral groundwaters, the most likely mechanism for the dissolution of Au is as the thiosulphate complex, whereas in acid saline groundwaters such as at Argo, Au halide (chloride and/or iodide) are expected to be important (Gray et al., 1992). High redox potentials (Eh) are required for dissolution as Au halide; all shallow and most intermediate Argo groundwaters are sufficiently oxidising for significant Au dissolution by the mechanism (Figure 11). Despite this, the Argo groundwaters tend to have low to moderate Au concentrations and, in most instances, are undersaturated with respect to Au metal. This suggests that the Au in the regolith is less accessible to the groundwater than at other sites, such as Panglo; this is possibly due to differing mineralogy (e.g., larger Ag-poor Au grains), or to obstructions to flow (e.g., compact clay impeding groundwater), leading to preferential flow in fractures avoiding most of the Au.

Groundwater enrichments in Co, Ni, Mo and Au appear to be associated with mineralization, similar to those observed at other sites (Butt et al., 1993). However, this observation would be considerably strengthened by a more extensive database of samples at this site.

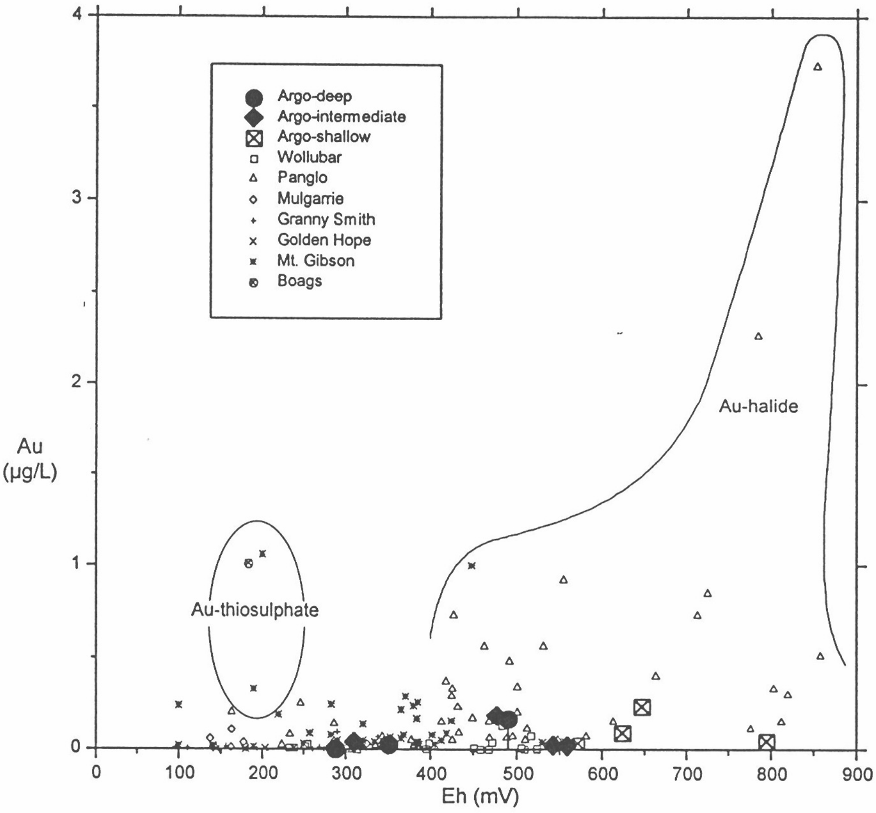


Figure 11: Au vs. Eh for groundwaters from Argo and other sites, with fields of Au dissolution marked.

6. DISCUSSION

The Argo deposit has no detectable surface geochemical expression in total or extractable Au or in other elements. If Au has been upwardly dispersed into the soil from the underlying mineralization, then it might be expected that this component would be more soluble. If so, then partial extractions of the soil using water and iodide might yield higher proportions of soluble Au compared with total Au. The absence of such a response implies either (i) that no such dispersion is occurring, or (ii) that further re-mobilization and homogenization of Au within the landscape obscures any response that may develop. A possible consequence of the latter is the production of a broad, low order, Au-in-soil anomaly which may be detected with longer sampling traverses. Such traverses are currently being investigated.

If groundwater was involved in the production of Au anomalies at the surface, then it would be expected that significant concentrations of Au in groundwater would be a pre-requisite. However, as with other soil profiles lying directly over mineralization, very little Au was detected in Profile J (Figure 3), despite the presence of relatively high concentrations of Au (0.24 ppb) in groundwater only 14 m away. This indicates that there is either:

(i) a very poor hydrological connection between the two sampling sites, and/or

(ii) there are low concentrations of suitable scavenging materials present such as Fe or Mn oxides and unsuitable conditions to allow the build-up of Au concentrations.

It appears that while groundwater is playing a role in the dispersion of Au at Argo, any related effects on the surficial environment are, at best, obscured by factors detailed above i.e. re-mobilization and homogenization within the landscape.

Gold in soil at Argo is largely confined to the calcareous horizon, which is generally restricted to the top 2 m. Augering thus remains an effective sampling procedure. Although these data do not directly indicate mineralization, the procedure should not necessarily be abandoned for a first pass evaluation of depositional regimes because in a few areas *e.g.*, the Steinway Au deposit 25 km south of Kalgoorlie, and the Baseline deposit 30 km to the north of Kalgoorlie, it appears that surficial anomalies have been found that have led to the discovery of underlying Au deposits. However, while research at Steinway is still on-going, there is some evidence to suggest that the surficial anomaly is of a detrital nature and therefore coincidental to the underlying mineralization. Conversely, the lack of a surficial anomaly should not be taken as evidence of the absence of mineralization at depth.

The association between Au and pedogenic carbonate in the soil profile is well established. However, at Argo, the association does not appear to be as strong, i.e. to be highly correlated, as that found in relict and erosional areas (Figure 3). There are several possible explanations for this, including:

(i) the soils are poorly drained; Ca and Au maybe re-mobilized and re-deposited at different rates e.g., during sudden influxes of floodwater;

(ii) the accumulation of Au and other elements in the Mn-rich horizon distorts the Au-Ca association. Gold in this horizon is less water soluble than in adjacent calcareous horizons;

(iii) the paucity of vegetation may allow soils to remain wetter longer than areas where there is a greater biomass and therefore greater evapotranspiration;

(iv) detrital Au lower in the soil profile may be coarser-sized and less mobile than the Au associated with the Ca higher in the profile; the Mn-rich horizon may be such an old soil surface containing detrital Au.

7. SUMMARY

1. Soil Au concentrations are generally low (mean <10 ppb) with higher concentrations (>20 ppb) located 200 m from mineralization.

2. Total, water- and iodide-soluble Au concentrations are not anomalous over mineralization.

3. Gold is associated with Ca in the top 1 to 2 m of the soil profile throughout the study area.

4. Tungsten, in a variety of sample media (samples from the transported overburden, saprolite, bedrock) appears to be a pathfinder for gold mineralization.

5. Carbonaceous material appears to scavenge Au and is a useful sample medium in the transported overburden.

6. Gold in *Eucalyptus*, *Eremophila* or mull does not locate mineralization.

7. Gold is present in groundwaters within mineralized areas.

8. Groundwaters are acid and saline, and dissolved Au is expected to occur as the Au halide (chloride or iodide) complex.

9. Even where groundwaters are highly oxidising, dissolved Au is low - moderate, suggesting poor accessibility of Au in the solid.

10. Groundwaters at Argo are similar to those throughout the Kalgoorlie region, in that they are acidic and enriched in REE and base metals.

11. Groundwaters associated with mineralization have higher concentrations of Co, Ni, Mo and Au, which is similar to observations at other analogous sites.

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SAFARI PROSPECT - MT CELIA

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1. INTRODUCTION

The Safari prospect, 200 km north-north-east of Kalgoorlie, is a greenfields Au discovery made by Pancontinental Mining Ltd (now Goldfields Exploration Pty Ltd) in their Keith Kilkenny projects. CSIRO research at this site is based on interpretation of satellite imagery, logging, sampling and analysis of existing drill spoil at the site, and of RAB samples drilled by Pancontinental Mining Ltd. and CSIRO specifically for this research.

2. GEOLOGY AND MINERALISATION

The Safari prospect was discovered in 1988 following a regional BLEG survey and subsequent power auger sampling on a 250 m x 50 m grid. Drilling, to date, indicates a resource of 1.08 million tonnes @ 3.3 g/t Au.

The prospect lies within the southern extension of the Laverton Tectonic Zone, a major, north-south trending corridor of complex structural deformation, bounded to the west and east by weakly deformed rocks of the Murrin-Margaret and Merolia sectors respectively. The greenstone assemblage in the vicinity of the deposit comprises a wide variety of volcanic and volcaniclastic rocks (komatiite and komatiitic basalt, basalt, andesite, dacite and rhyolite) and minor BIF, chert and argillite. These rocks are heterogeneously deformed, and generally strike north-north-west, and have a near-vertical to west-south-west dipping tectonic foliation and a sub-horizontal to down dip mineral lineation. Plutons of porphyritic syenite and coarse, equi-granular granodiorite and ademellite intrude the greenstones. Supracrustal rocks, adjacent to the larger of these plutons have been metamorphosed to the amphibolite facies. Elsewhere, the rocks are at the lower greenschist facies.

The greenstone assemblage is dissected by a number of brittle, ductile shears, including the Kangaroo and Mt Hornet faults, which appear to separate distinctly different greenstone domains. The shears parallel the gross north-north-westerly striking lithological layering of the volcanic pile and are considered to be strike-slip, reactivated, high-angle thrust faults.

Mineralisation is hosted by andesite to dacite metavolcanic rocks, now largely represented by quartz-chlorite-sericite $\pm$ carbonate schists, bounded to the east and west by talcose schists and serpentinised komatiite. Gold is primarily associated with quartz veins within an anastomosing shear (Kholer, 1996).

Analysis of a number of intersections of primary Au mineralisation showed Pb as the only element directly associated with Au. Correlation with grade is not particularly good, although a high Au assay generally corresponds to a high Pb assay. Zinc was enriched in one of the intersections, suggesting more than one mineralising event. Arsenic, S and W are generally enriched in the mineralised zone but are not specifically related to the Au grade.

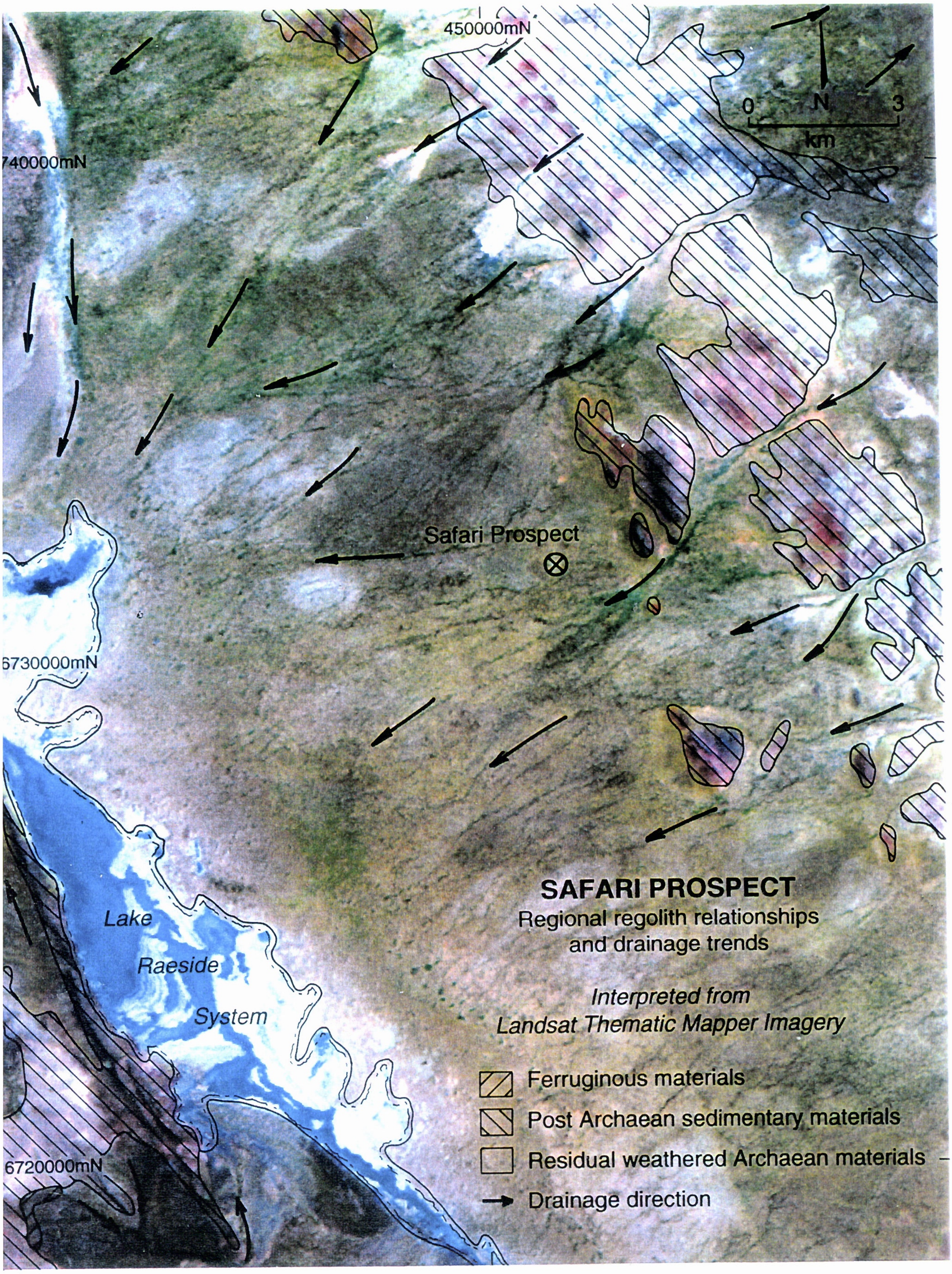

Figure 1: Landsat TM Bands 742(RGB) with regional interpretation of key regolith relationships.

3. REGIONAL REGOLITH RELATIONSHIPS

Safari is situated on a broad, sandy, colluvial plain approximately 9 km north-east of the margin of Lake Raeside and 3 km south west of the nearest exposed Archaean.

The vegetation is a medium to dense woodland of *Acacia* spp. and *Eucalyptus* spp., the former being the slightly more common. The climate is arid with an average annual rainfall of 200-250 mm. Rainfall throughout the year is variable and results from frontal systems from the west and south-west in winter and from patchy, convectional storms and cyclone related depressions in summer (Hall *et al.*, 1994).

Regional features of the surface regolith have been interpreted from Landsat Thematic Mapper colour composite imagery, using bands 7, 4 and 2 in red, green and blue (Figure 1) and band ratios 5/7 4/7 4/2 (RGB) with limited field checking. The map subdivides the region into 3 units, each warranting a different approach to regolith geochemistry. Drainage trends were highlighted to indicate the current direction of transport of eroded materials.

Residual weathered Archaean materials
This unit represents the surface expression of outcropping or subcropping saprolite or saprock, (and in places truncated or incipient mottled zones), and soils developed from them. These materials may have been exposed by erosion of a pre-existing weathered profile, or may represent the most weathered form of the parent material.

Post Archaean sedimentary materials
This dominates the region and surficial materials represent the uppermost part of a sedimentary sequence that may be highly variable in genesis, composition and thickness. They include alluvial, colluvial and aeolian sediments and vary from one to many tens of metres thick. They are derived from erosion of fresh and weathered Archaean rocks and the reworking of post Archaean sediments, either locally or from many kilometres away. The sediments themselves may have been subject to extensive post depositional modification by chemical and physical weathering.

Ferruginous materials
This unit depicts the occurrence of highly ferruginous materials that may be developed in weathered Archaean bedrock or younger sediments that have been subject to extreme weathering and/or induration by Fe oxides.

4. REGOLITH STRATIGRAPHY

4.1 TOPOGRAPHY AND PALAEOTOPOGRAPHY

Two hundred and four RAB and RC drill holes were logged specifically for regolith related features in the area surrounding Safari. The collar RL for each drill hole was calculated from level surveying referenced to a digital elevation model provided by Goldfields Exploration and then the RL of the Archaean palaeosurface calculated from logging. The present land surface around Safari forms a broad valley sloping gently south-west (Figure 2). The palaeosurface is much steeper and variable than the present land surface. The most prominent features of the palaeosurface are a palaeohigh at around 6732000 mN 451100 mE, where the palaeosurface meets the present land surface, and the valley draining west in the northern part of the area.

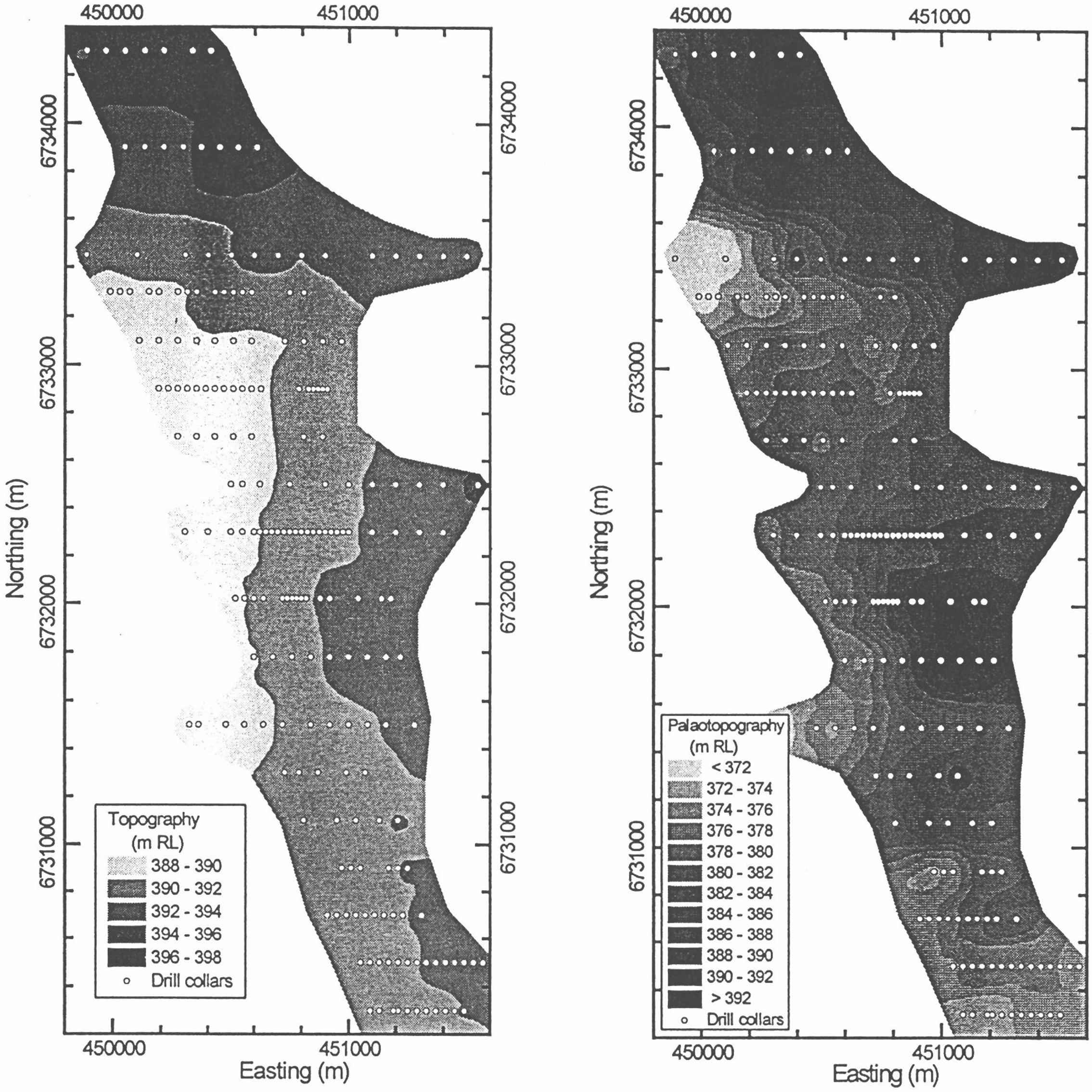

Figure 2: Surface topography and palaeotopography in the area surrounding Safari.

4.2 TRANSPORTED OVERBURDEN

The study area is completely blanketed by transported overburden except for a small area around 6732000 mN 451100 mE where weathered Archaean rocks subcrop. The thickness and composition of the transported overburden varies, although the material at the surface is uniformly distributed, comprising up to 1 metre of sheetwashed and aeolian sand that tends to be more clay-rich in local drainage depressions. The distribution of various regolith materials across the mineralised zone is summarised in Figure 3.

Including sheetwash, the sediments are generally 5-10 m thick, although up to 20 m infill the palaeovalley in the north. Below the sheetwash, the sediments are polymict with 2 - 20% coarse material, (commonly towards the base), in a matrix of sand, silt and in places clay. Over the majority of the study area, and near to the mineralised zone, the coarse fraction comprises polymict, angular, weakly weathered rock fragments, whereas a mixture of ferruginous pisoliths, nodules and lithorelics infills the palaeovalley in the north. In a few places drilling intersected discontinuous, or narrow, coarse, alluvial sand and gravel at various depths.

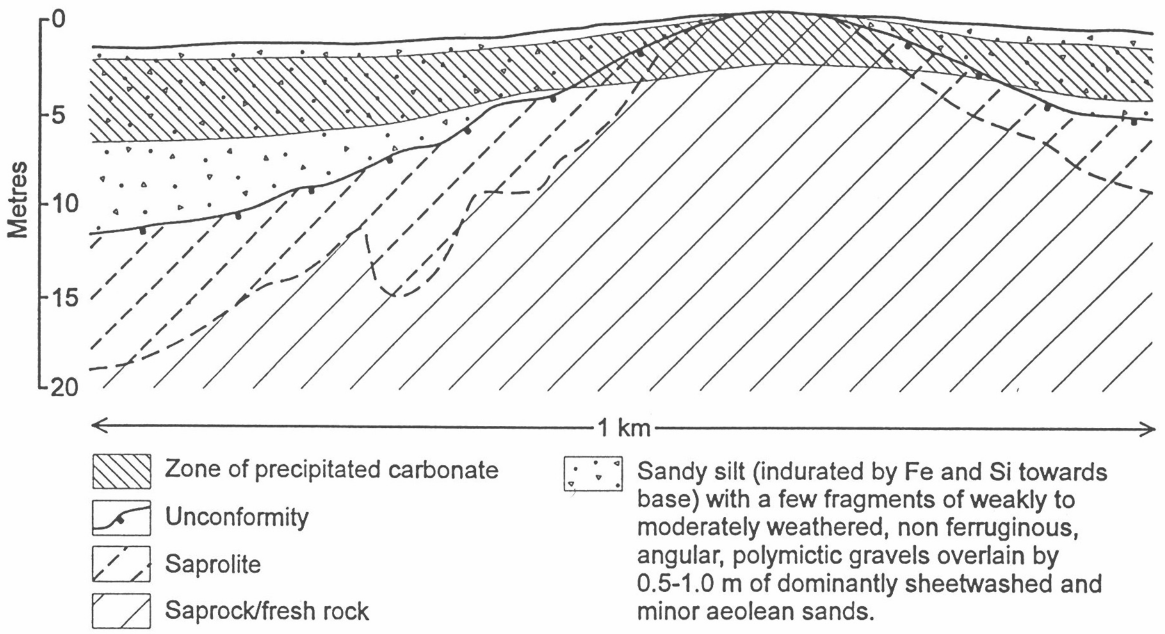

Figure 3: Cross section summarising the key features of the regolith in the vicinity of mineralisation at Safari.

Post-depositional modification of the sediments is widespread, the most significant being intense calcification from approximately 0.5 to as much as 5 m below surface. Drill sumps expose mottles of carbonate (up to tens of mm in diameter) as little as 200 mm below surface. The morphology of the carbonate below 1 metre is uncertain, as it is only seen as drill cuttings. Below the zone of intense calcification, the sediments are commonly moderately to strongly indurated by silica and Fe oxides.

4.3 WEATHERED ARCHAEAN

There are isolated areas in the north where the Archaean has been weathered to deep, highly ferruginous profiles, however the majority is saprolite with a variable clay content, becoming fresh within 10-20 m of the unconformity. There is minor incipient mottling throughout, and the upper few metres are commonly indurated by silica and/or carbonate. Where subcropping, the Archaean is reasonably fresh, but brecciated by carbonate in the upper few metres, with large (up to 100's of millimetres) nodular structures at surface. The processes involved in calcification of the subcropping Archaean are thought to be similar to those affecting the transported material (Figure 3).

5. REGOLITH GEOCHEMISTRY

5.1 SAMPLING AND ANALYSIS

Twenty five RAB holes were drilled under supervision of the authors on section 6732300mN. Conditions at the time of drilling facilitated the collection of high quality samples as the ground was slightly moist, thus minimising hole collapse. A three metre hole was drilled prior to each sampled hole to clean the drilling and sampling apparatus, thus considerably reducing the possibility of cross hole contamination. Samples were collected in half metre intervals and riffle split for analysis. For each hole, all the samples of transported material, and samples from the first two metres of Archaean basement were analysed for Au by INAA. Samples from the top half metre of each hole and all samples from hole SB7 were also analysed by an in-house partial extraction method to give water-, iodide- and cyanide-soluble Au attaining very low detection limits. These methods tested the solubility of Au down hole and the applicability of partial extractions to detect or enhance any surface anomalies.

5.2 GOLD DISTRIBUTION

Hole SB9 intersected quartz veining in the top two metres of saprolite, with a maximum of 1200 ppb Au. This directly overlies primary mineralisation intersected at depth by previous RC drilling. Holes SB6, SB7, SB8 and SB17 are also enriched in Au just below the unconformity, also overlying primary mineralisation at depth. Anomalous Au contents are also present in the carbonate horizon directly overlying deep mineralisation and the enrichment below the unconformity. Lesser Au contents, though still above background, occur in the calcareous horizon along most of the section. Gold contents of the top half metre also give a broad anomaly (over 600 m @ >5 ppb Au), with excellent contrast, peaking directly over mineralisation (Figure 4).

Gold enrichment just below the unconformity at Safari appears to contrast with other sites where Au in this part of the profile is concentrated on either side of the unconformity (eg. Quasar Deposit at Mt Magnet; Robertson *et al.*,1994). Averaging Au contents of the top 1 m of Archaean material gives a very strong anomaly peaking over mineralisation, with a reasonably elevated and noisy background (Figure 5).

The solubility of Au in the regolith on 6732300 mN is shown in Figure 4. Gold in the surface half metre is highly soluble and the relationship between the iodide- and cyanide- soluble components suggests consistent behaviour regardless of proximity to mineralisation. Thus, the partial extractions do not enhance the Au anomaly relative to total (cyanide-soluble) data. In contrast, solubility of Au in regolith varies with depth down hole, reaching a maximum at the unconformity. (Gold is up to 80% iodide-soluble below the unconformity when the reagent is buffered to pH 7.4 - results presented here are for unbuffered extractions).

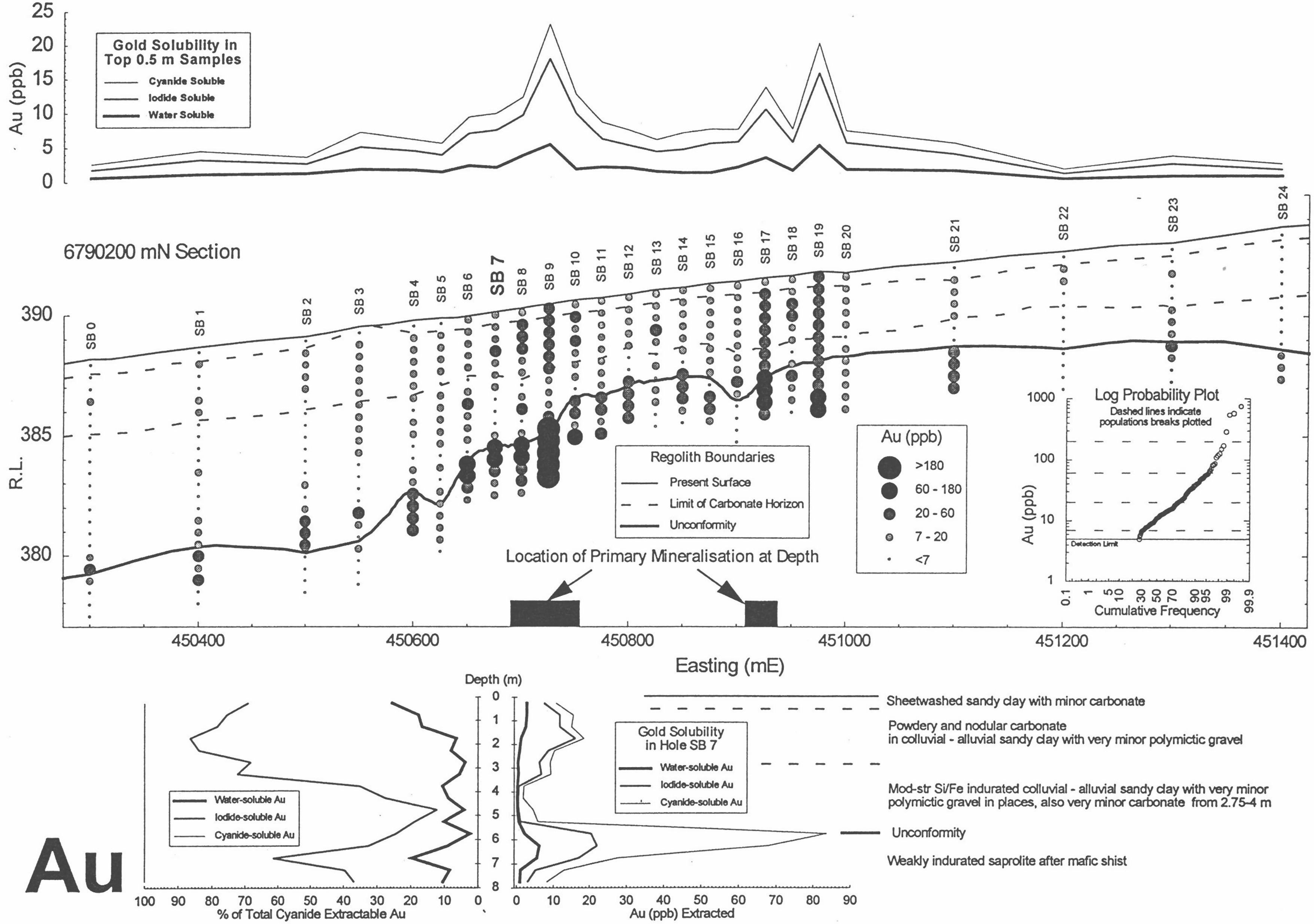

Figure 4: Distribution and solubility of Au in regolith materials

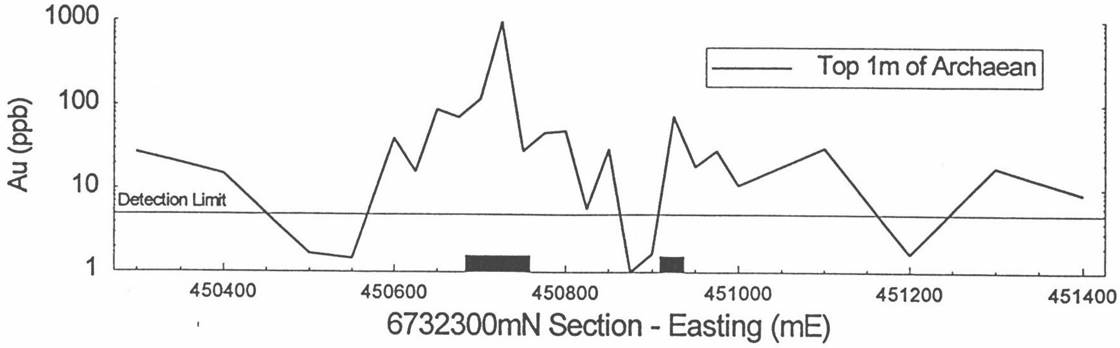

Figure 5: Gold concentration in the first metre of Archaean.

5.3 RELATIONSHIP BETWEEN GOLD AND CALCIUM

Calcium shows strong enrichment from approximately 0.5 m to 3 m below surface (Figure 7) corresponding to the calcareous horizon discussed in section 4.2. Calcium shows less common enrichment in the upper parts of the Archaean corresponding to induration of the saprolite by carbonate.

There is a close, though imperfect association between Au and Ca at Safari (eg. Hole SB7); and a scatterplot of Au against Ca shows no direct correlation in surface or subsurface materials (Figure 7). This suggests that the processes by which Au and Ca were emplaced are similar, but that precipitation of Au is independent of that of carbonate.

The distribution of Ca in the regolith, (and the Au associated with it), at Safari differs from that at other sites where Ca and Au are related (Figure 6). At Bounty and Argo in the Southern Yilgarn, Ca and Au are concentrated in the top metre of the profile (Lintern, 1989; Lintern and Gray, 1995), compared with between 1.5 and 2.5 m at Safari. In comparison with Bounty, Au shows poorer correlation with Ca at Safari and Argo. (There is substantial transported overburden at Argo and none at Bounty).

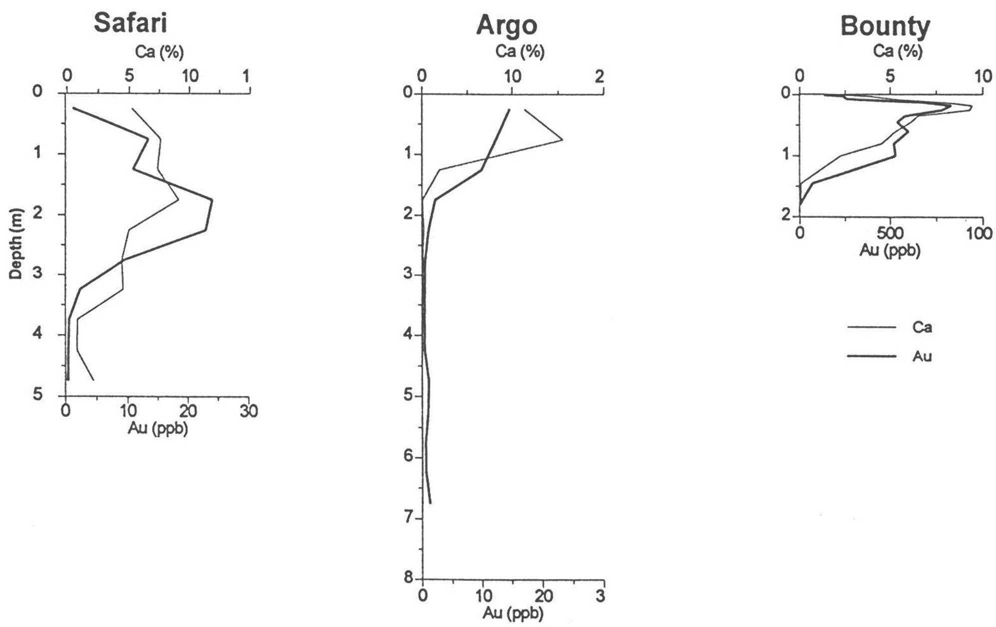

Figure 6: Comparison of Ca and Au distribution with depth at Safari, Argo and Bounty.

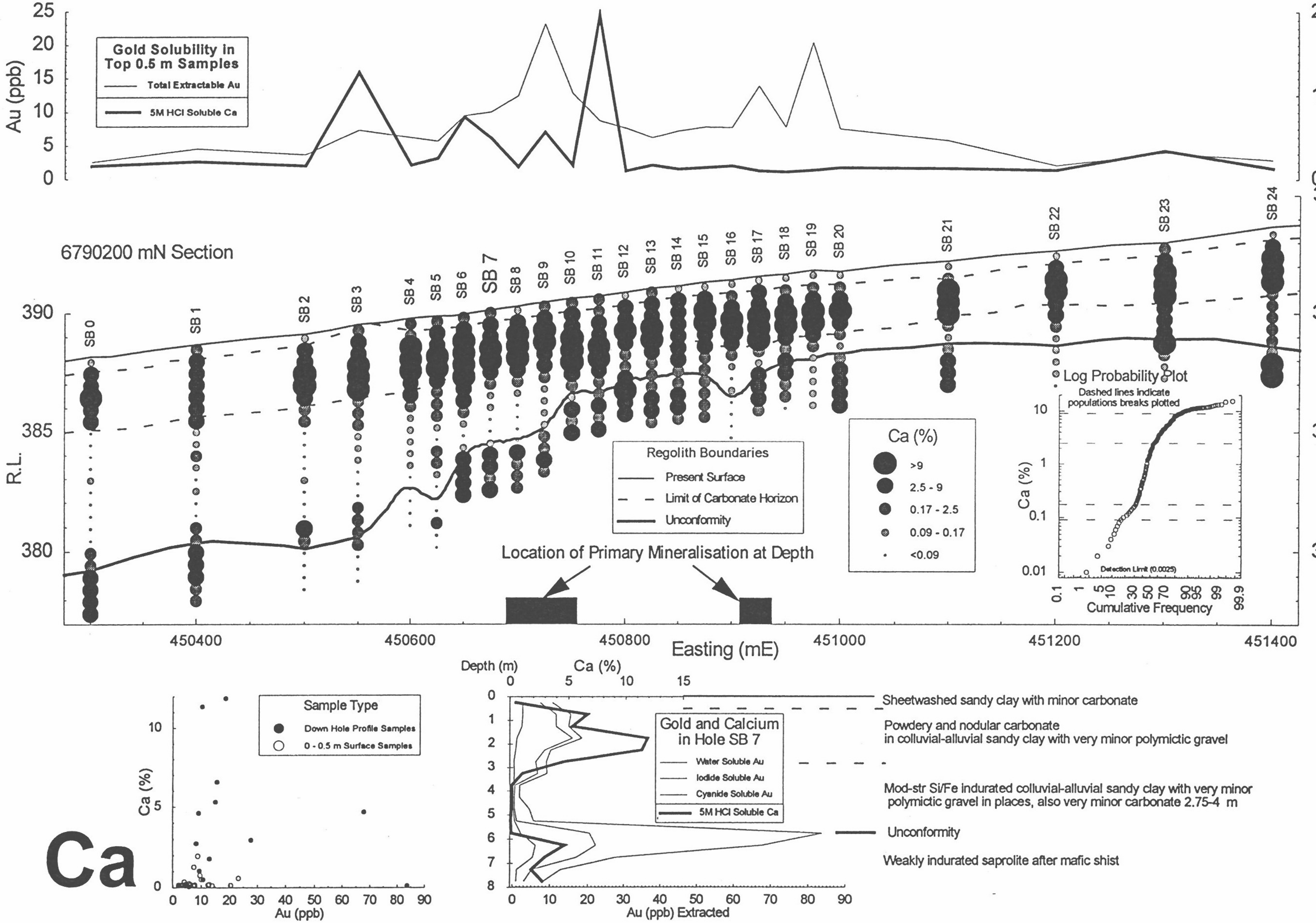

Figure 7: Distribution of Ca in regolith materials and its relationship with Au in samples at surface and down hole.

An examination of optimal sampling depth of the calcareous horizon for generating a Au anomaly, reveals that a sample from anywhere between 0.5 and 2.5 m would provide an optimum broad anomaly with good contrast that accurately locates deeper mineralisation. Anomaly size and contrast would be compromised by sampling outside of this range with this detection limit (Figure 8).

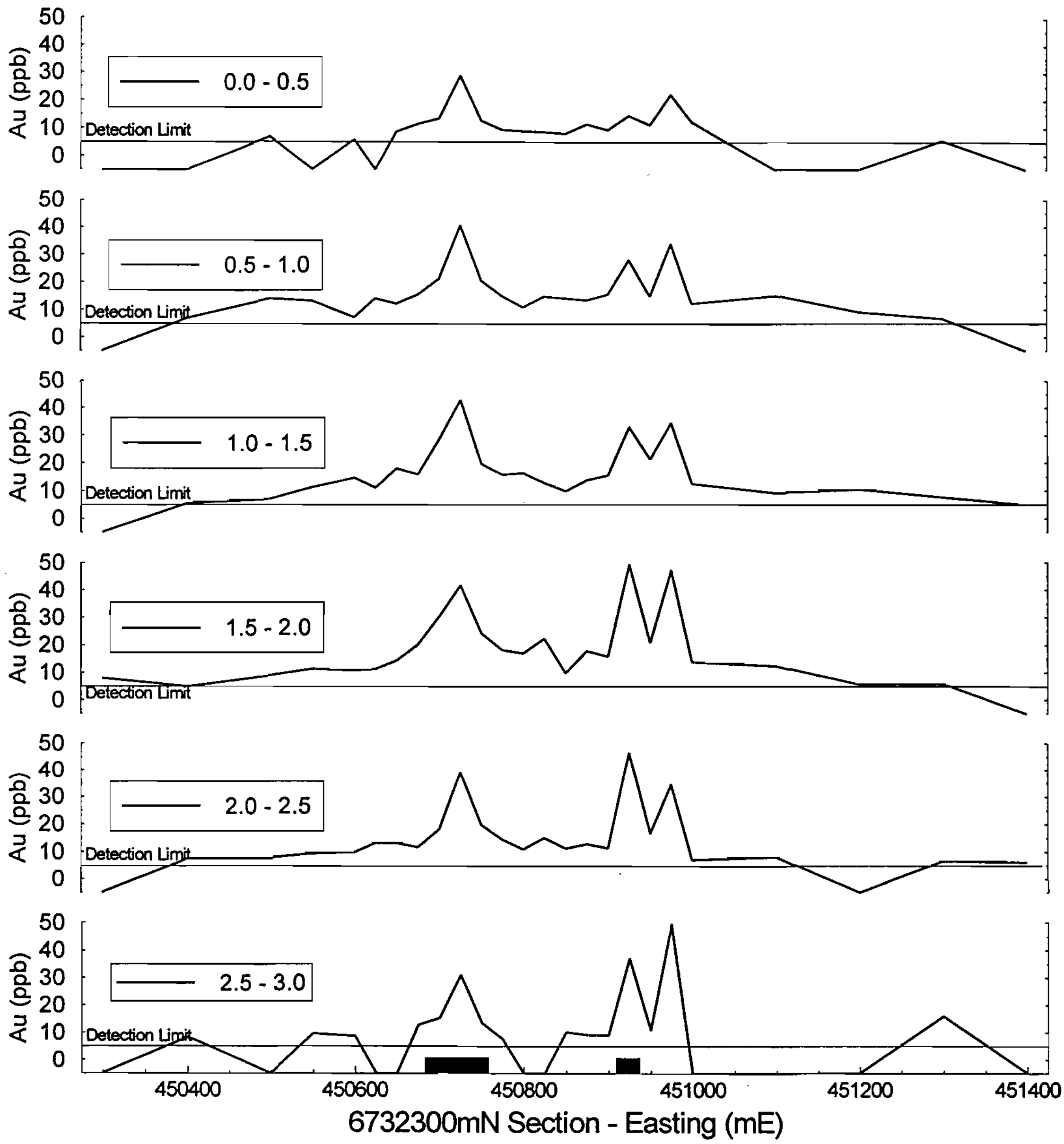

Figure 8: Examination of the effect of sample depth on anomaly definition. Shaded area indicates the position of mineralisation at depth.

Preferential selection and analysis of highly calcareous fragments on sections 6732020 mN and 6732500 mN from two to three metres below surface appeared not to increase anomaly contrast across mineralisation and, despite the absolute concentrations of Au being higher, the Au/Ca ratio is consistently lower in these selective samples when compared with results for bulk samples from the same interval. Similar results have been recorded for carbonates in the Southern Yilgarn at Bounty and Mulline (Lintern, 1989; Lintern and Butt, 1991).

6. SUMMARY AND CONCLUSIONS

Evidence for dispersion of Au into transported overburden at Safari is very strong and can be summarised as follows:

- There is a strong spatial correlation between the location of primary mineralisation at depth and (i) Au enrichments just below the unconformity, (ii) in the carbonate horizon in the transported overburden and, (iii) at the surface.

- The soluble nature of Au in the near-surface and at the unconformity, and its coincidental association with zones of carbonate precipitation, suggest that Au precipitation is associated with evaporation in the near surface.

Characteristics of Au distribution in the regolith directly relevant to exploration are:

- When targeting Au enrichment associated with the calcareous horizon at Safari, samples from between 0.5 to 2.5 m below surface provide the broadest anomalies with the greatest contrast overlying buried mineralisation. Sampling outside this range in the transported overburden is less effective.

- Selecting carbonate-rich fragments appears not to enhance the Au anomalies in calcareous profiles.

- The strong vertical association of Au in the transported overburden with Au in the underlying Archaean suggests that Au was not mobilised a significant distance laterally *in the plane of this section.* Thus, peak Au concentrations in the calcareous horizon, at this site, could be used to target drilling for deeper mineralisation.

- Sampling the top 1 m of the Archaean gives a very strong anomaly directly overlying mineralisation, but the background is high and variable; thus, careful selection of thresholds would be necessary to outline broad anomalies found by initial wide-spaced sampling.

7. ACKNOWLEDGEMENTS

The authors would like to thank the staff of Goldfields Exploration Ltd, (including the former Pancontinental Mining Ltd), particularly Ernst Kholer, Matthew Longworth, Bob Howard and Peter Cleary for their assistance and support throughout the research. Ian Robertson is acknowledged for extensive advice in the preparation of this guide. Dale Longman, Kim Lim, John Crabb, Ray Bilz, Sheryl Derriman and Gill Ashton are also thanked for their technical assistance throughout the research. The staff of CRC AMET, particularly Tim Munday and Lisa Worrall are thanked for their helpful discussion and technological assistance.

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GOLDEN DELICIOUS DEPOSIT

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1. INTRODUCTION

Golden Delicious, 50 km south of Laverton, is one of several greenfields Au discoveries made by Acacia Resources Ltd. (formerly Billiton Australia) in their Sunrise Dam tenement holdings (Figure 1). CSIRO research at this site is based on interpretation of satellite imagery, logging of existing drill spoil preserved at the site, and on logging, sampling, and analysis of RAB samples provided by Acacia Resources Ltd. specifically for this research.

2. GEOLOGY AND MINERALISATION

Golden Delicious is situated in the Archaean Norseman - Wiluna belt of the Yilgarn Craton, in the southern part of the Laverton Tectonic Zone. This zone is characterised by major N - S and NNW trending shear zones and associated faults. The region comprises variously folded, faulted and metamorphosed Archaean greenstone sequences surrounded by granite (Figure 1). The major Archaean lithological units include, ultramafic and mafic volcanics, felsic volcanics and volcaniclastics, banded iron formations, layered gabroic sills and intrusive sheets of granite (Keserue-Ponte 1995).

The total resource is 6.1 million tonnes grading 1.3 g/t Au (0.6 g/t cut), including a higher grade northern zone of 2.4 Mt at 1.8 g/t Au (1 g/t cut), (Acacia Resources Ltd., 1995). Gold mineralisation is hosted by a suite of granitoids (Grove, 1996), which intrude intermediate to mafic volcanic and volcaniclastic 'greenschist' host rocks (Figure 2), including intermediate trachy-andesitic to mafic volcanics, minor interbedded volcaniclastics and rare BIFs. Mineralisation in the greenschist is poor, being localised in narrow shears, and adjacent to the granitoid contacts.

The granitoids can be broadly subdivided into two intrusive suites:

1. A monzonite-syenite suite. The monzonite is the dominant lithology and is a fine to medium grained dark rock with a typical medium grained texture. Syenitic rock types are typically medium to coarse grained, with perthitic feldspar phenocrysts up to 20mm. Intrusive relationships and gradational contacts indicate the monzonite and syenite were co-magmatic, and formed as a result of the same intrusive event. The monzonite-syenite shows extensive propylitic alteration.

2. Granite. This is typically fine to medium grained and, where relatively unaltered, is a grey to light pink colour. Most contacts between monzonite-syenite and the granite are strongly sheared and the intrusive relationships are not understood. Studies by Acacia Resources Limited indicate that the granite and the monzonite-syenite lie on differing fraction trends and are the product of separate intrusive events.

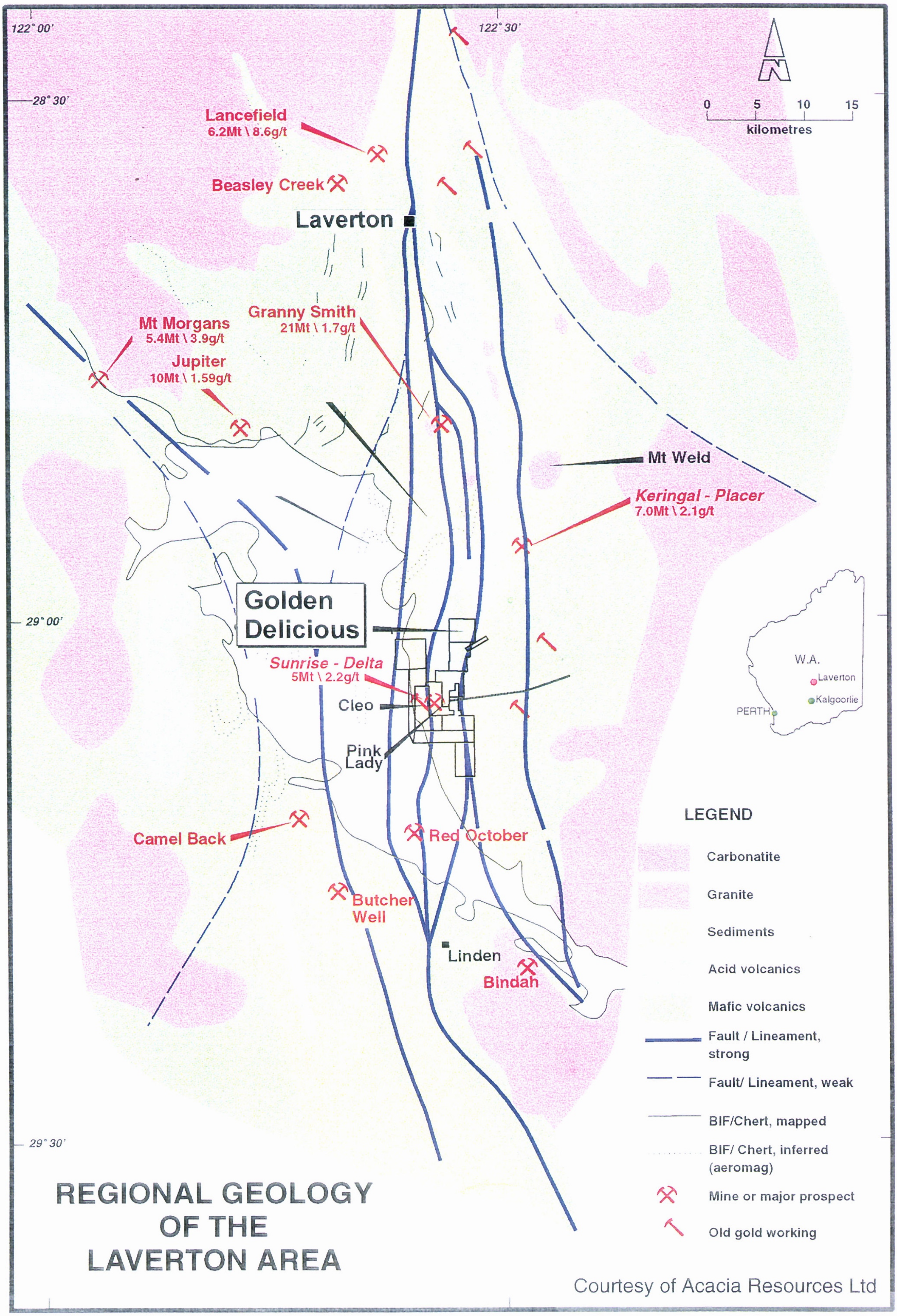


Figure 1: Regional geology of the Laverton area showing Golden Delicious and other gold occurrences in the area, (courtesy Acacia Resources Ltd.).

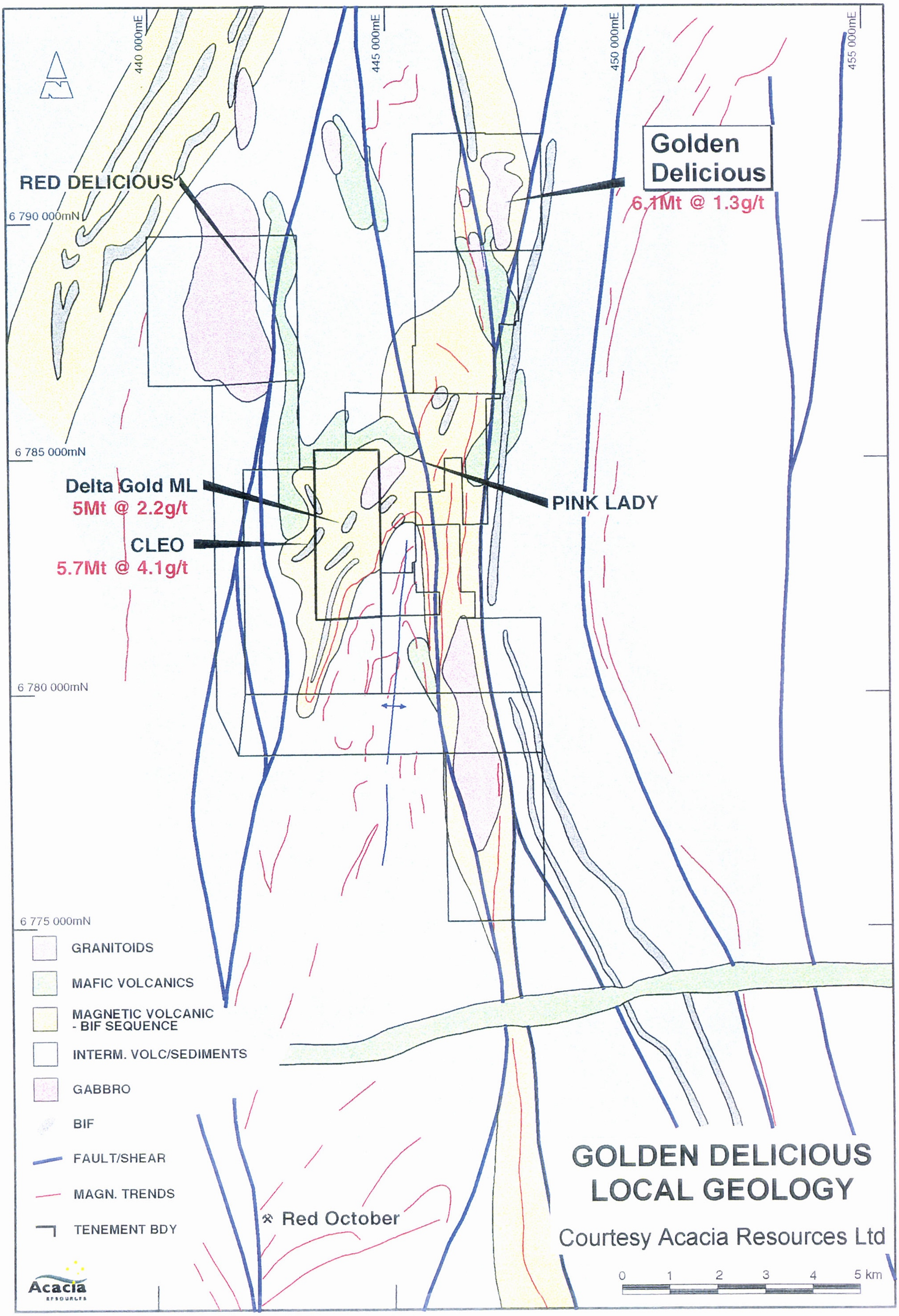


Figure 2: Local geology of the area surrounding Golden Delicious, (courtesy Acacia Resources Ltd.).

3. REGIONAL REGOLITH RELATIONSHIPS

Golden Delicious is situated on a broad colluvial plain approximately 5 km east of the margin of Lake Carey and 5 km north east of the nearest exposed Archaean.

Vegetation in the area surrounding the deposit comprises sparse to dense *Acacia* spp. woodland with an understory of smaller shrubs of *Acacia*, *Eremophila*, and *Cassia* spp. The present climate is arid, with an average annual rainfall of between 200 and 250 mm. Rainfall throughout the year is highly variable and results from frontal systems from the west and south west in the winter months and from patchy convectional storms and cyclone related depressions in summer (Hall *et al*, 1994).

Regional features of the surface regolith have been interpreted from Landsat Thematic Mapper colour composite imagery, using bands 7, 4 and 2 in red, green and blue (Figure 3) and band ratios $^5/_7$ $^4/_7$ $^4/_2$ (RGB) with limited field checking. The map subdivides the region into simple units, each warranting a different approach to regolith geochemistry. Drainage trends are highlighted to indicate the current direction of transport of eroded materials.

Residual weathered Archaean materials
This unit represents the surface expression of outcropping or subcropping saprolite or saprock, (and occasionally truncated or incipient mottled zones), and soils developed from them. These may have been exposed by erosion of a pre-existing weathered profile, or may represent the most weathered form of the parent material.

Post Archaean sedimentary materials
This is the dominant subdivision of the region and the surficial materials represent the uppermost part of a sedimentary sequence that may be highly variable in genesis, composition and thickness. They include alluvial, colluvial or aeolian sediments and may be less than one metre to many tens of metres thick. They are derived from erosion of fresh and weathered Archaean or the reworking of younger sediments, either locally or from many kilometres away. The sediments themselves may have been subject to extensive post depositional modification by chemical and physical weathering.

Ferruginous materials
This unit depicts the occurrence of highly ferruginous materials that may be developed in weathered Archaean bedrock or younger sediments that have been subject to extreme weathering and/or induration by Fe oxides.

4. REGOLITH STRATIGRAPHY

4.1 TOPOGRAPHY

One hundred and forty two RAB, RC, and air core drill holes were logged specifically for regolith-related features in the area surrounding Golden Delicious. Surface RL for each drill hole was estimated from topographic plans provided by Acacia Resources and then the RL of the palaeosurface (top of weathered Archaean) calculated from logging. The present land surface is very gently sloping (maximum 4 m across the study area) towards the north west (Figure 4); the palaeosurface also slopes to the north west, but the gradient is much steeper, (maximum 20 m) and more variable.

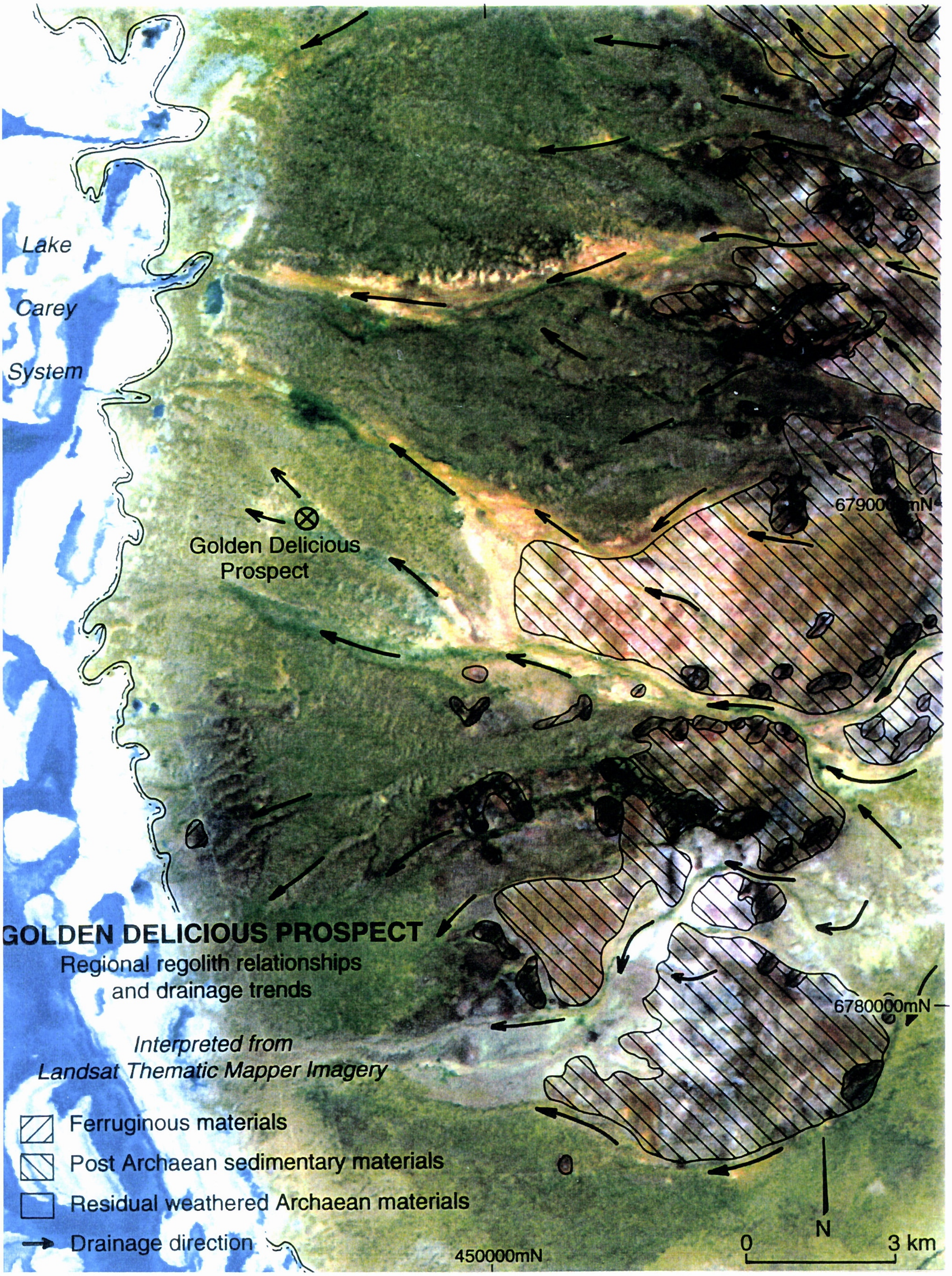


Figure 3: Landsat TM Bands 742(RGB) with regional interpretation of key regolith relationships.

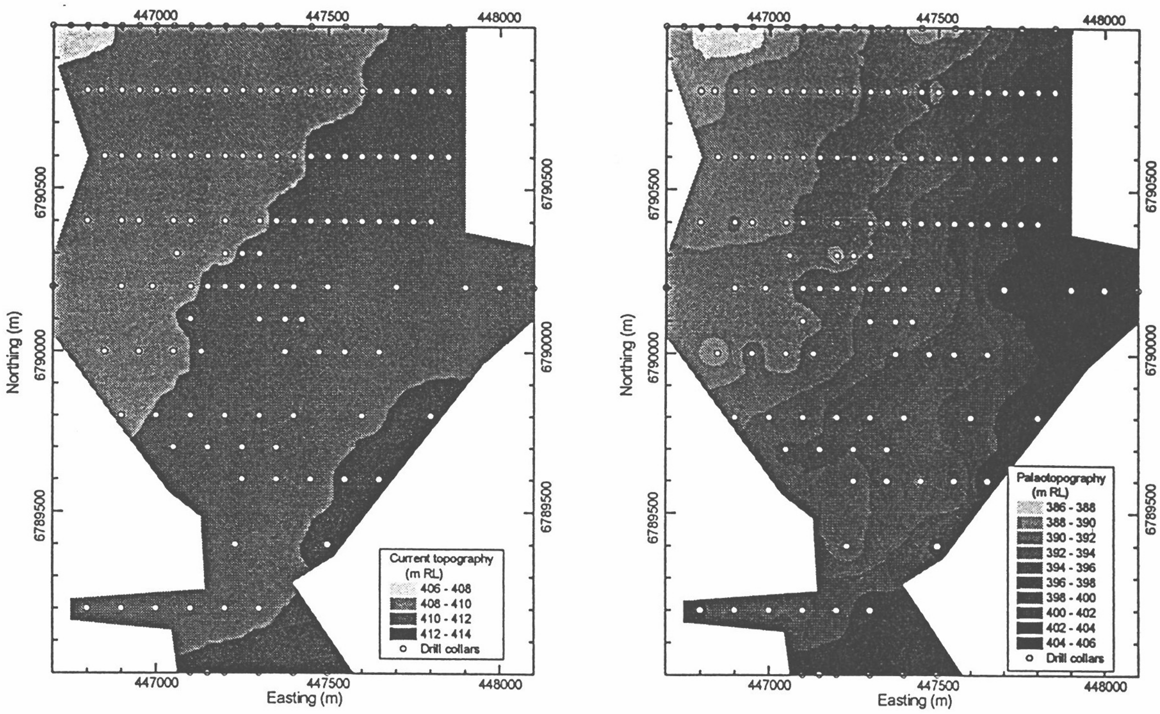


Figure 4: Surface topography and palaeotopography surrounding Golden Delicious.

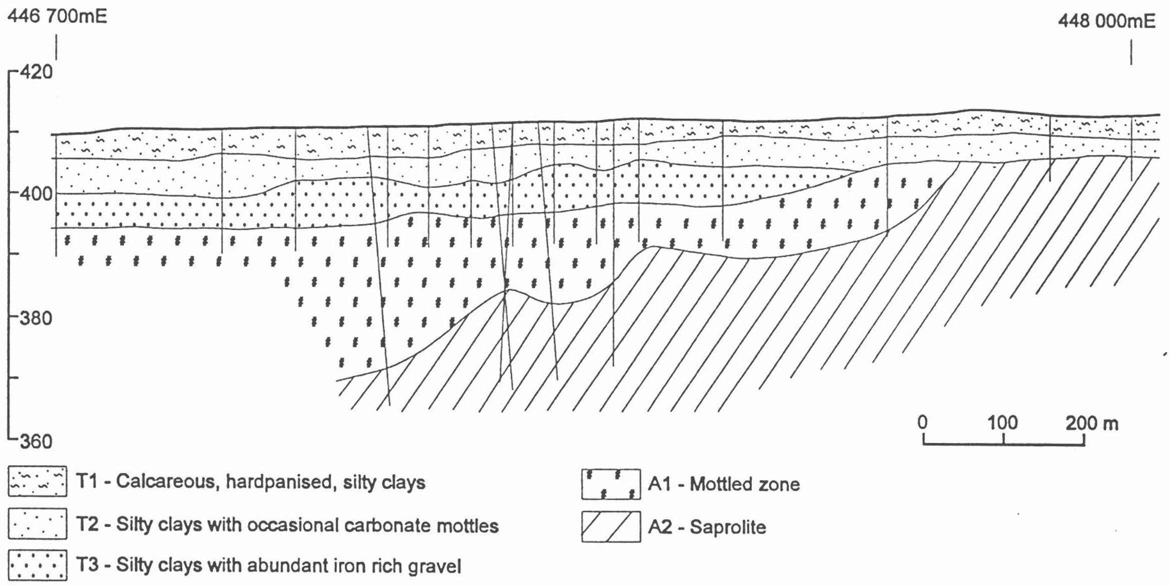


Figure 5: 6790200mN cross section through Golden Delicious showing the distribution of regolith materials.

The distribution of regolith materials at surface and in three dimensions is quite uniform throughout the area surrounding Golden Delicious. Most materials represented by the 6790200mN section (Figure 5) are continuous over the study area, although vary in thickness.

4.2 TRANSPORTED OVERBURDEN

The sediments overlying the weathered Archaean are a poorly sorted, polymict colluvium-alluvium of clay, silt, sand and gravels that, in general, becomes coarser with depth. The sediments have been cemented in parts by various secondary minerals, including silica, carbonates and Fe oxides. Broken and abraded Fe-rich pisoliths, nodules and rock fragments dominate the coarser gravels. The relationship between present and palaeotopography and drainage suggests these gravels are derived from the greenstone uplands 5 - 10 km ESE. Small pockets of ferruginous materials on these uplands (Figure 3) may represent remnants of pre-existing and more widely distributed ferruginous units. The general downward coarsening nature of the sediments supports this hypothesis as it mimics, in reverse order, the distribution of materials found in lateritic profiles.

Three major units within the transported overburden have been identified on the basis of sedimentary features and post-depositional modifications.

T1 - Calcareous, hardpanised, silty clays
This is the uppermost unit of the transported overburden, characterised by fine sediments (< 1 % gravel), which is strongly indurated with silica, carbonate and Fe oxides. Manganese oxides are common as dendritic coatings along partings and fractures. Carbonate occurs extensively as thin (up to 5 mm), laminar, sub-horizontal precipitations along partings and fractures, and as more massive void filling indurations of the fine sediments. The presence of this form of carbonate is diagnostic of the unit.

T2 - Silty clays with occasional carbonate mottles
This is a variable unit dominated by fine sediments, although gravels are more common than in the upper unit. It is less strongly indurated by silica and Fe oxides than T1, and as a result appears more clay rich. Carbonate is present as irregular masses up to 40 mm in diameter, rather than the laminar structures seen in T1.

T3 - Silty clays with abundant iron rich gravel
This unit has abundant Fe-rich gravels that consist dominantly of broken and abraded Fe-rich pisoliths, nodules and ferruginous lithorelics. Maghemite is common in the pisoliths. Quartz and virtually unweathered rock fragments are minor constituents. The upper few metres of this unit, particularly in the NE of the study area, have minor amounts of concretionary goethite seemingly formed (or forming) *in situ*. These lack evidence of transport, have green-yellow cutans, and sometimes incorporate components of the sediment in their internal structure.

The coarse, ferruginous materials are over-represented in drill spoil. Diamond core from this unit has up to 25% coarse material, whereas the drill spoil indicates up to 70%. This is probably because this unit is below the water-table and only weakly consolidated, so that the fine fraction is lost during percussive drilling.

4.3 WEATHERED ARCHAEAN

A1 - Mottled zone
This unit is characterised by large (up to 20 cm diameter) haematite rich mottles developed in clay-rich saprolite. Little primary lithic fabric is preserved in the mottles or the clays except towards the base of the unit, where they are locally present (eg. as kaolinite pseudomorphs of feldspars in a ferruginous groundmass). Accretions or pseudo-mottles of dolomite in places permeate the Fe-poor, kaolinitic clays.

A2 - Saprolite
This unit comprises clay-rich saprolite merging to saprolite with good preservation of primary lithic fabrics. Saprolite is generally present at the base of drilling used in this study (approximately 50 m); the base of weathering is usually at around 70-80 m below surface (indicated from diamond drilling).

5. REGOLITH GEOCHEMISTRY

5.1 GOLD DISTRIBUTION

Gold in transported overburden

The most significant feature of the Au distribution in the transported material is the widespread anomaly in the basal ferruginous gravels of unit T3 (Figure 6). Concentrations up to 107 ppb are distributed 400 m across strike of the mineralisation, offset slightly downslope. Sampling from these few metres provides the greatest target enlargement of any sample medium tested at this site. Shallower sediments generally have much lower Au contents (<5 - 12 ppb) and sampling to the east of the displayed section (at 447800mE, 447900mE, 448000mE) suggests this is the usual background, indicating only that the sediments are derived from a Au-bearing province.

Gold in weathered Archaean

Gold is present in fairly low (though anomalous) concentrations in the upper few metres of the ferruginous mottled zone. Concentrations of 12 - 81 ppb are distributed 300 m across strike of the mineralisation and appear not to be offset, at least within the plane of this section. Below the upper few metres, concentrations decline or remain constant, and increase towards the lower part of the mottled zone. This observation is supported by extensive drilling that indicates that the Au concentration throughout the mineralised zone decrease sharply above 380-385 m RL, which approximates to the basal section of the mottling within the mineralised zone.

There are 2 possible explanations for this distribution:

1. *On this section*, the primary mineralisation is blind and as such does not actually "subcrop" on the palaeosurface.

2. Gold has been leached from the upper part of the mottled zone, and in part reprecipitated elsewhere in the regolith. This apparent depletion of the upper mottled zone is common to the distributions of several elements and is discussed in more detail later.

5.2 DISTRIBUTION OF OTHER ELEMENTS IN THE REGOLITH

5.2.1 Elements associated with Au mineralisation W, Sb, (As)

Tungsten

The distribution of W at Golden Delicious is very similar to that of Au in the saprolite but there is no detectable W in the transported overburden (Figure 7). Tungsten concentrations are high in the primary mineralisation (up to 125 ppm), and there is a gradational reduction in W concentration from lower to upper parts of the weathered Archaean, with the uppermost metre of the mottled zone in all but two samples having less than detection (2 ppm).

Tungsten concentrations in the mottled zone are significantly lower than those in the precursor saprolite. If this is due to W depletion, then the W would have had to have been almost completely dissolved and removed from the system. The known chemistry of W minerals and solubility experiments performed on samples of the saprolite and mottled zone suggest this is highly unlikely. Accordingly, it is concluded that the distribution of W reflects its original distribution in the primary mineralisation prior to weathering.

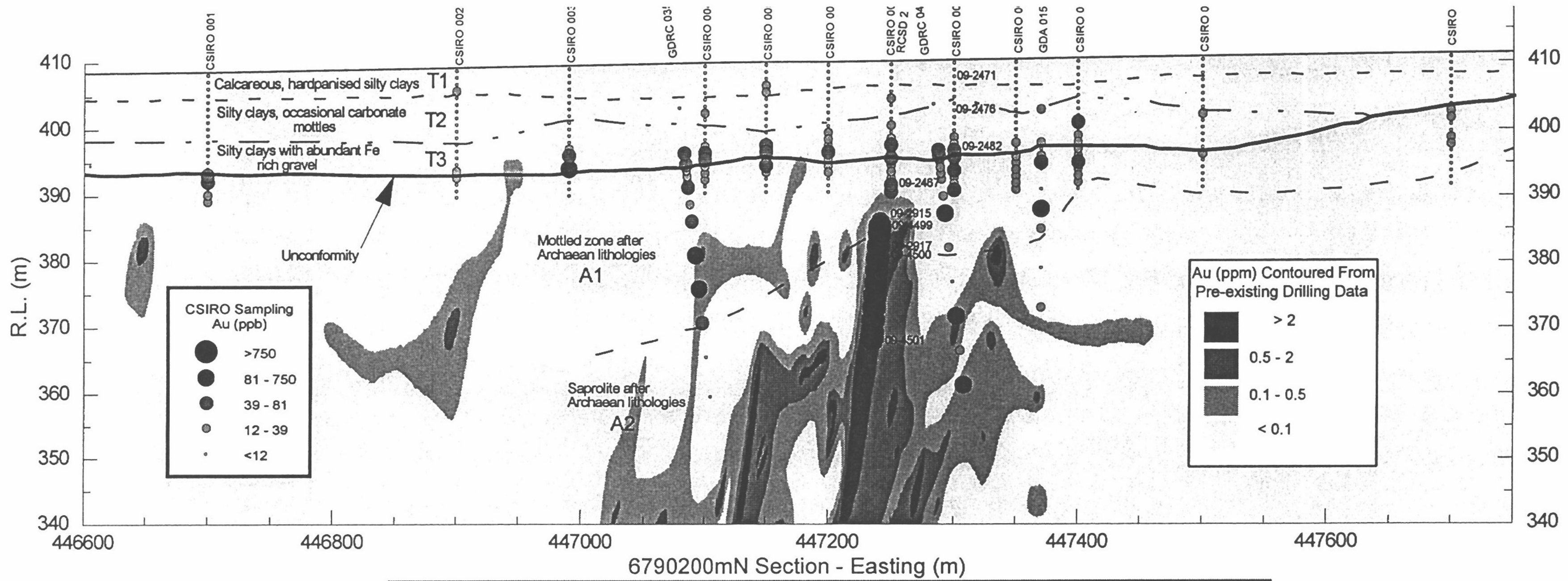
Antimony
Concentrations of Sb in the mineralisation are low (Figure 8) and would not normally be considered anomalous. There is a (statistically) discernible accumulation in the basal gravels of the transported material but this is proportional to Fe and there is no spatial variation in the Sb/Fe ratio in these materials. However, there is a broad anomaly in the Fe normalised data in the upper mottled zone over mineralisation and values tend to increase with depth.

Arsenic
There is no As enrichment in the primary mineralisation and there is an anti-pathetic relationship between As and Au (Figure 9). Arsenic does, however, display a weak anomaly spatially associated with mineralisation (max 41 ppm) in both the basal transported gravels and the upper mottled zone. Like Sb, this enrichment is associated with Fe and there is a strong correlation between As and Fe (Figure 9). Normalising As data with respect to Fe gives no indication of mineralisation and the spatial distribution of As/Fe values is essentially random. The bimodal association of As with Sb is simply a result of the correlation of both elements with Fe.

5.2.2 Major elements: Fe

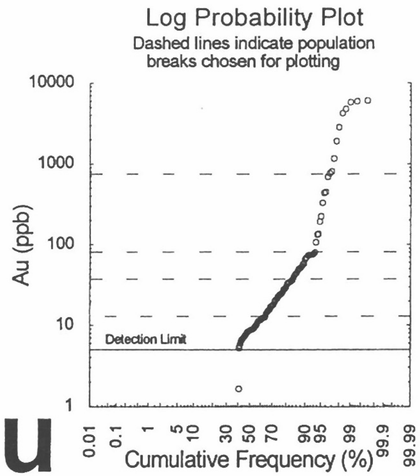
Iron in the regolith is present principally as goethite, haematite and maghemite. The distribution of Fe in the transported material (Figure 10) reflects that of the ferruginous lateritic gravel. Iron is concentrated in the upper few metres of the mottled zone and may, to a small extent control the Au distribution in this material (Figure 11), though this is considered to be insignificant with respect to the bulk samples. The effect of Fe distribution on Au distribution within the mottled zone appears significant and is discussed later in section 5.3.3. The concentration of Fe does, however, control the distribution of As and Sb (section 5.2.1).

The concentrations of Fe are highly variable throughout the entire mottled zone; this can be attributed to the strong fractionation of Fe in this unit and the coarse nature of the individual mottles and their distribution. The more consistent and elevated concentrations in the upper few metres of the mottled zone probably reflect more pervasive ferruginisation, and collapse and compaction of mottles. Elevated concentrations of immobile elements such as Hf in the upper few metres also suggest collapse and relative accumulation of resistant minerals.



Element	Valid N	Mean	Median	Minimum	Maximum	Lower Quartile	Upper Quartile	Std.Dev.	Detection Limit
Au (ppb)	292	235	9	<5	27900	<5	24	1780	5

Au



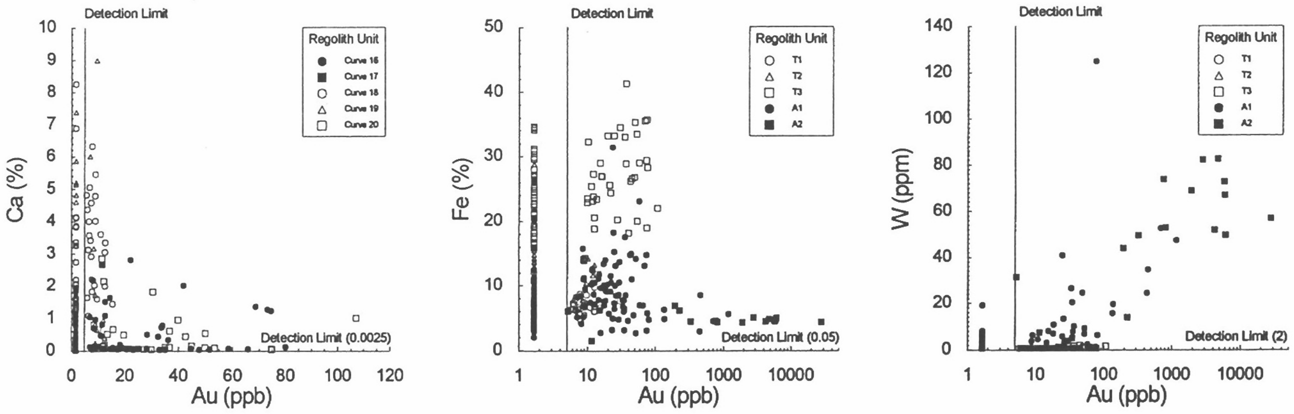
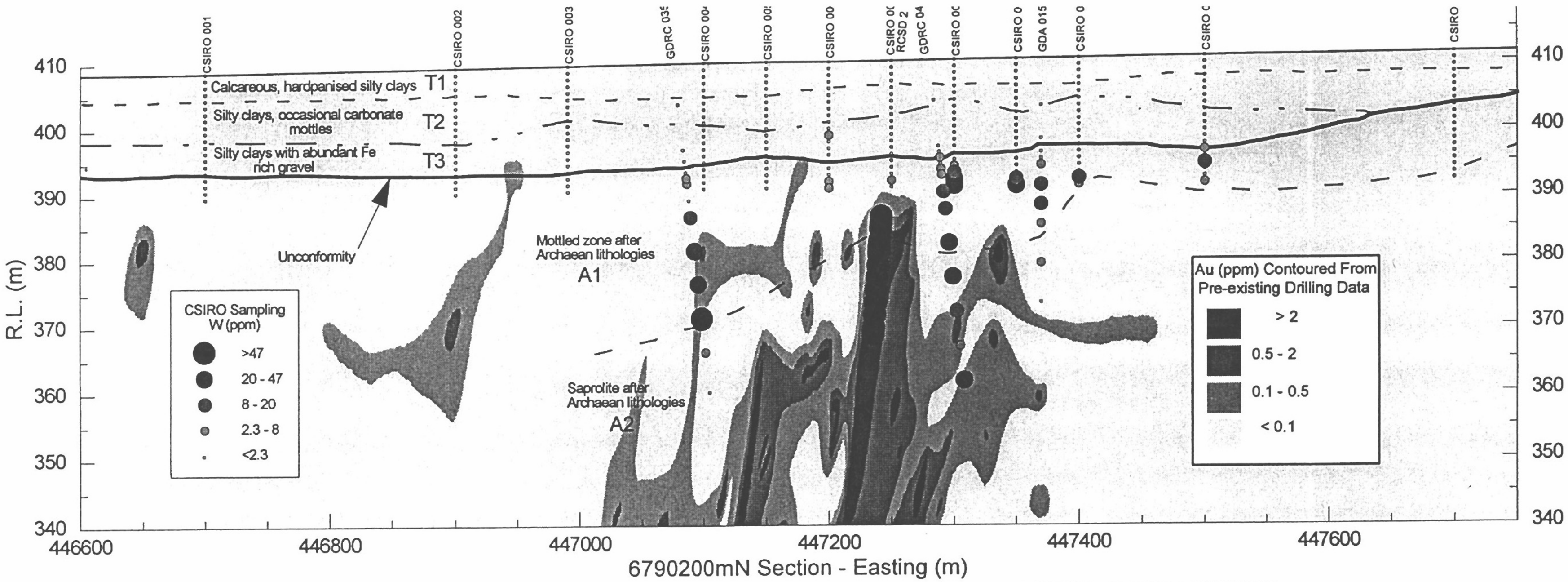
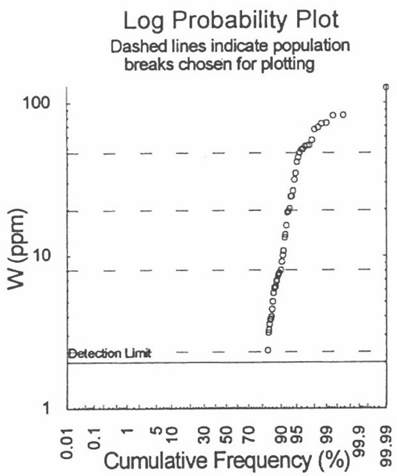


Figure 6: Distribution of Au in the regolith and significant associations with other elements.



Element	Valid N	Mean	Median	Minimum	Maximum	Lower Quartile	Upper Quartile	Std.Dev.	Detection Limit
W (ppm)	292	5.4	<2	<2	125	<2	<2	15	2

W



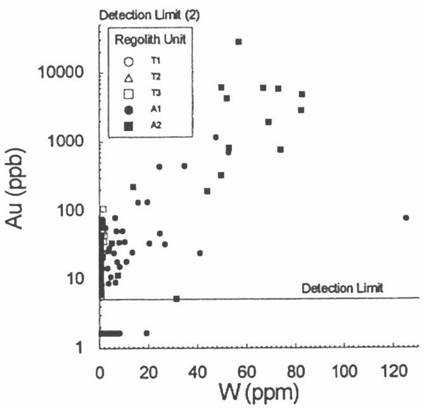
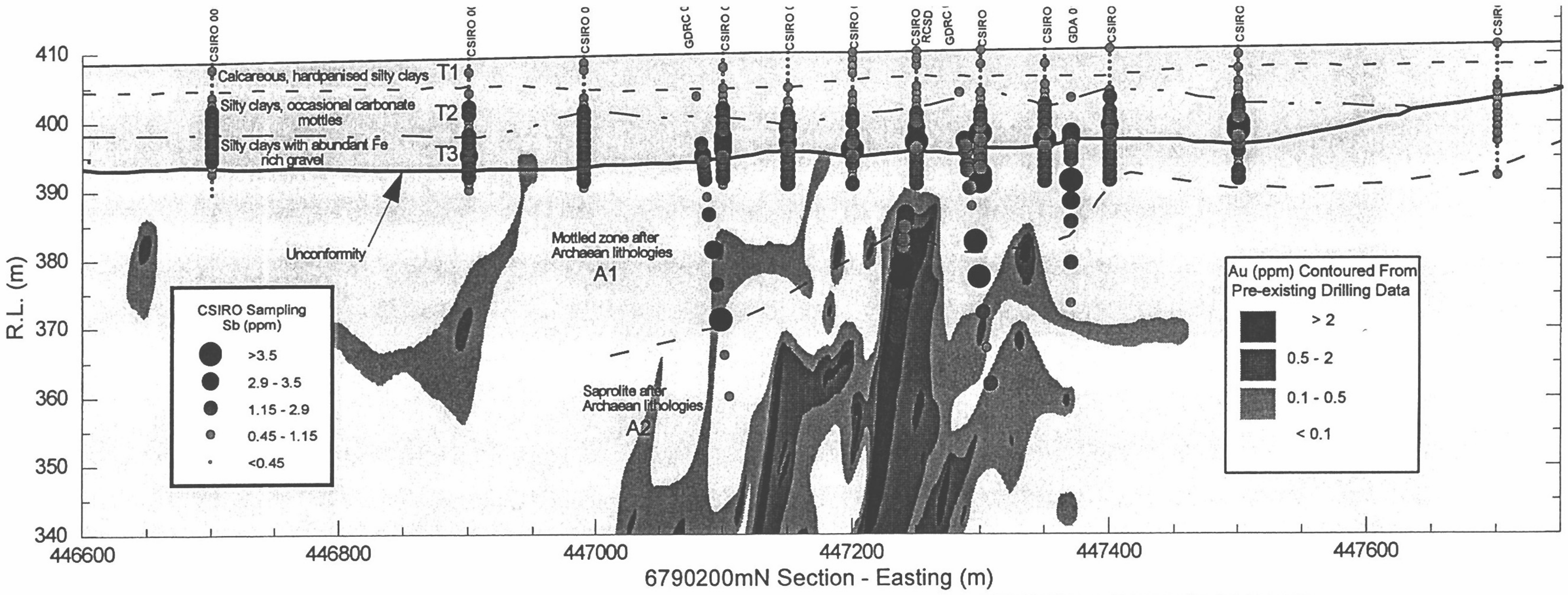


Figure 7: Distribution of W in the regolith and significant associations with other elements.



Element	Valid N	Mean	Median	Minimum	Maximum	Lower Quartile	Upper Quartile	Std.Dev.	Detection Limit
Sb (ppm)	292	1.4	1.2	<0.2	7.9	0.5	2.1	1.1	0.2

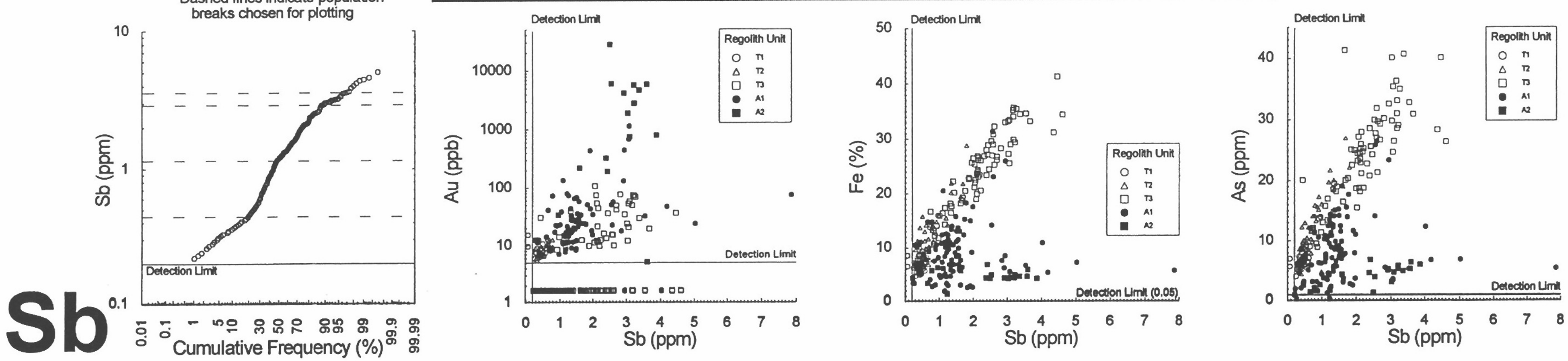
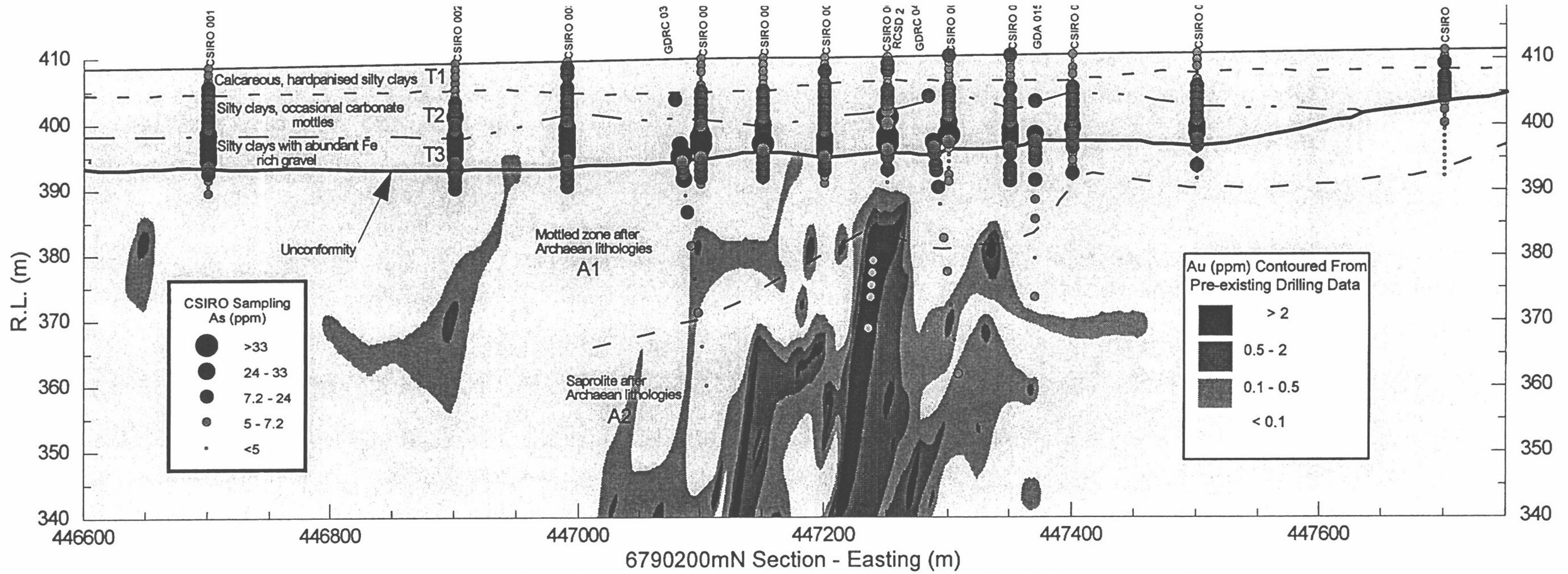
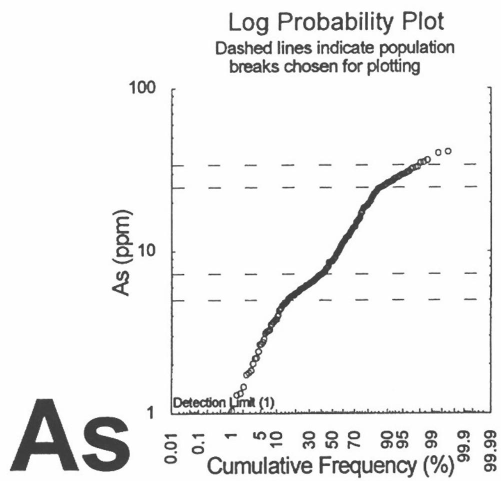


Figure 8: Distribution of Sb in the regolith and significant associations with other elements.



Element	Valid N	Mean	Median	Minimum	Maximum	Lower Quartile	Upper Quartile	Std.Dev.	Detection Limit
As (ppm)	292	12.4	9	<1	41	6	18	9	1



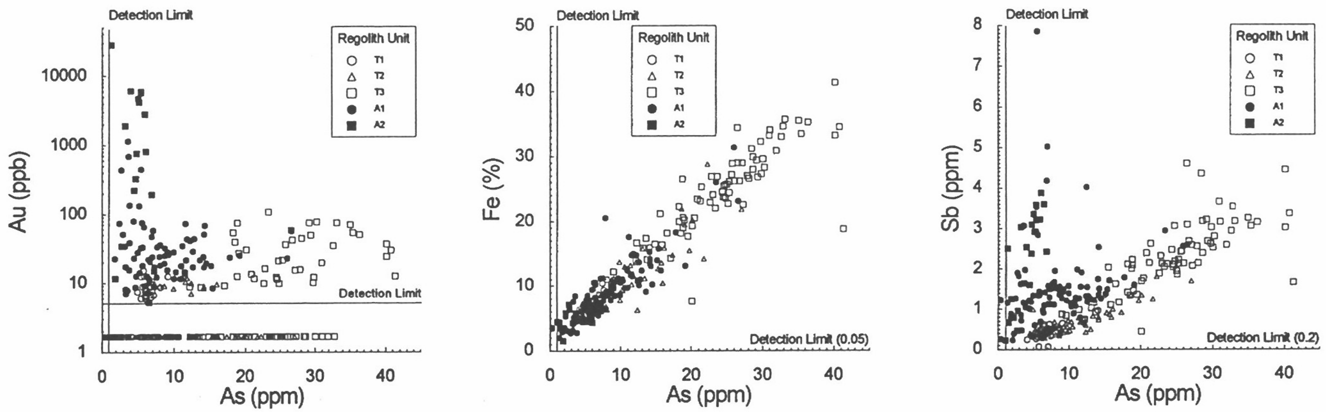
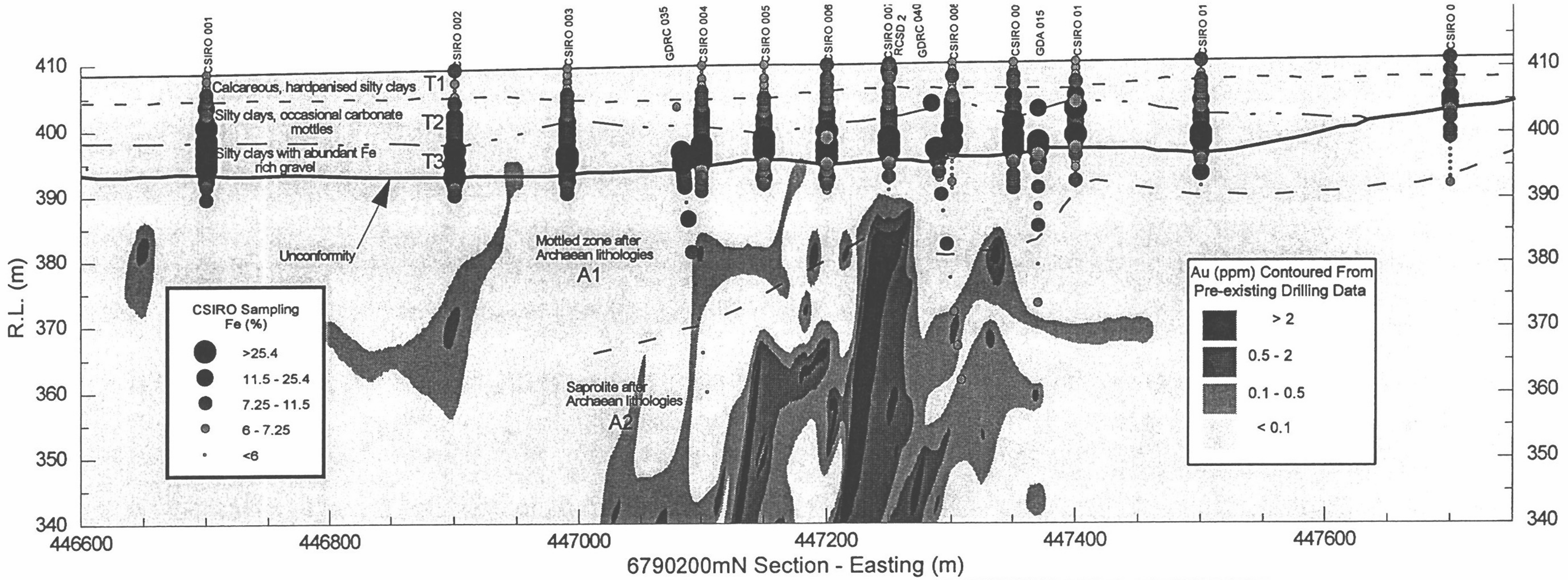


Figure 9: Distribution of As in the regolith and significant associations with other elements



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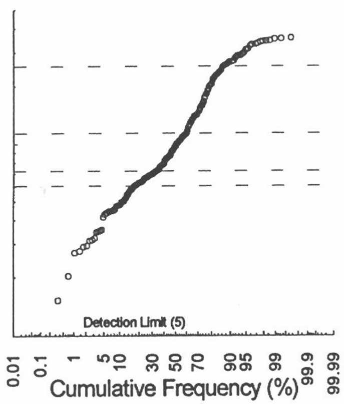
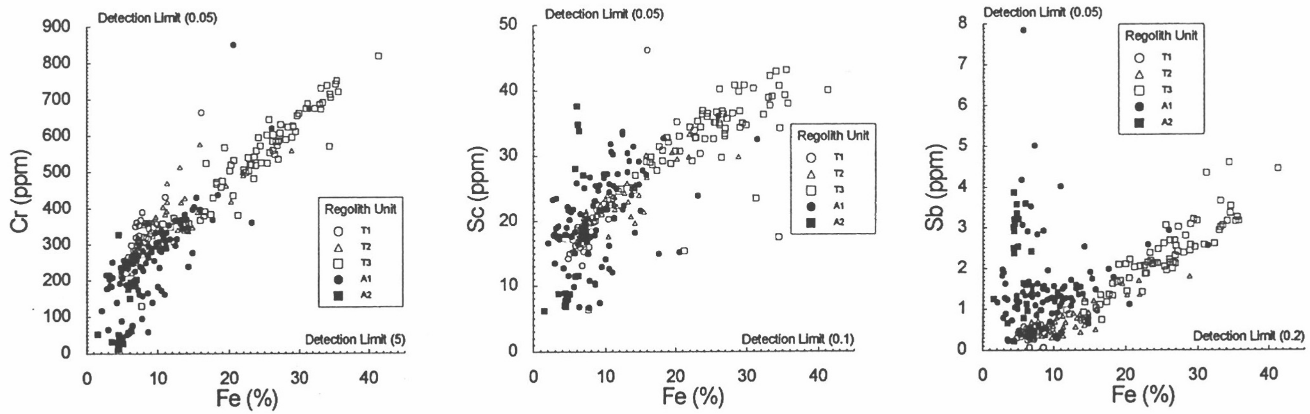
Element	Valid N	Mean	Median	Minimum	Maximum	Lower Quartile	Upper Quartile	Std.Dev.	Detection Limit
Fe (%)	292	13	9.7	1.5	41.3	6.7	17.5	8.6	0.05





Fe

Figure 10: Distribution of Fe in the regolith and significant associations with other elements.

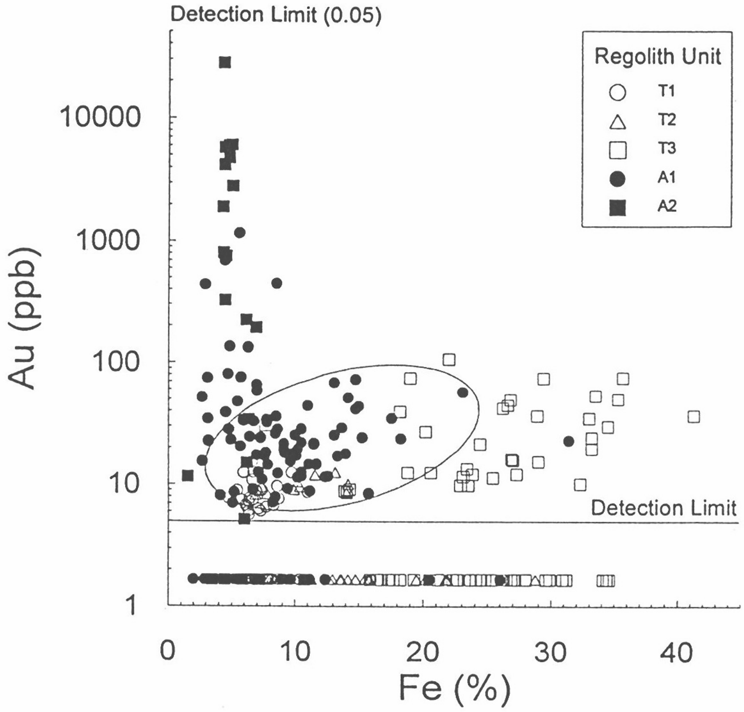


Figure 11: Scatterplot of Fe vs Au with respect to different regolith units, a possible relationship with Au in some of the mottled Archaean material is indicated by the elipse.

5.2.3 Alkaline earth elements: Ca, Mg

Calcium and Mg analyses of a cold 5M HCl digest diluted to 1M HCl after 15 minutes mainly indicate the distribution of calcite and dolomite (Figure 12).

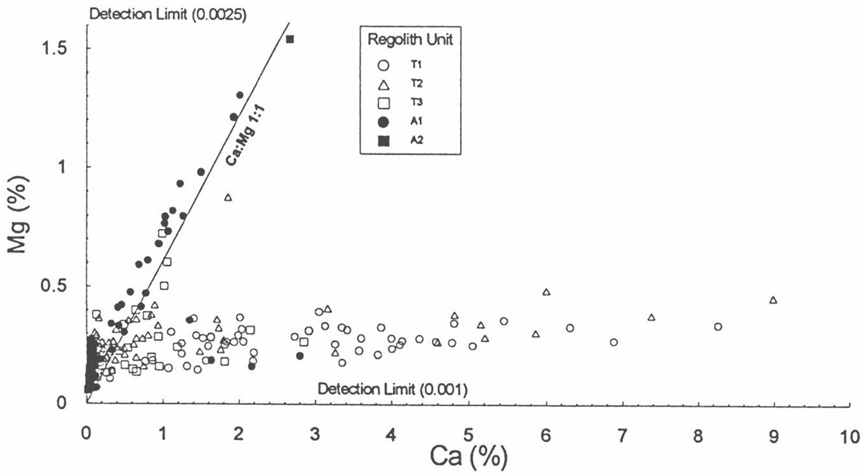


Figure 12: Scatterplot of Ca vs Mg. The 1:1 molar ratio reflects the occurrence of dolomite.

Calcite is restricted to the upper sedimentary unit (T1) and occurs as laminar precipitations or aggregates associated with near-surface hardpanisation. Both calcite and dolomite are present in the carbonate mottling occasionally found in unit T2. Carbonates in the mottled zone are largely dolomite.

In contrast with sites south of the Menzies line, the carbonate in the near-surface at Golden Delicious is not present in its powdery pedogenic form, but as laminar sub-horizontal veins, coatings and mottles. At the detection limits of neutron activation analysis, there is no apparent association of carbonate with Au. Such a relationship may exist at lower detection limits. If not, however, this may suggest the difference in carbonate morphology is significant when selecting carbonate as a sampling medium for Au exploration. Other factors such as depth of transported material and depth and chemistry of the groundwater are also likely to be significant.

5.3 OCCURRENCE OF GOLD IN THE REGOLITH

5.3.1 Introduction

The distribution and solubility of Au in the transported material, mottled zone and saprolite have been examined by size fractionation, Fe fractionation and partial extractions using water, iodide and cyanide reagents in order to clarify the relationship of Au throughout the profile to mineralisation. Sample locations are marked on Figure 6.

5.3.2 Transported overburden

Samples of transported overburden were selected from the upper (T1), middle (T2), and lower (T3) units overlying primary mineralisation. Descriptions of the samples appear in Table 1, and Figure 13 summarises the results of size fraction analysis.

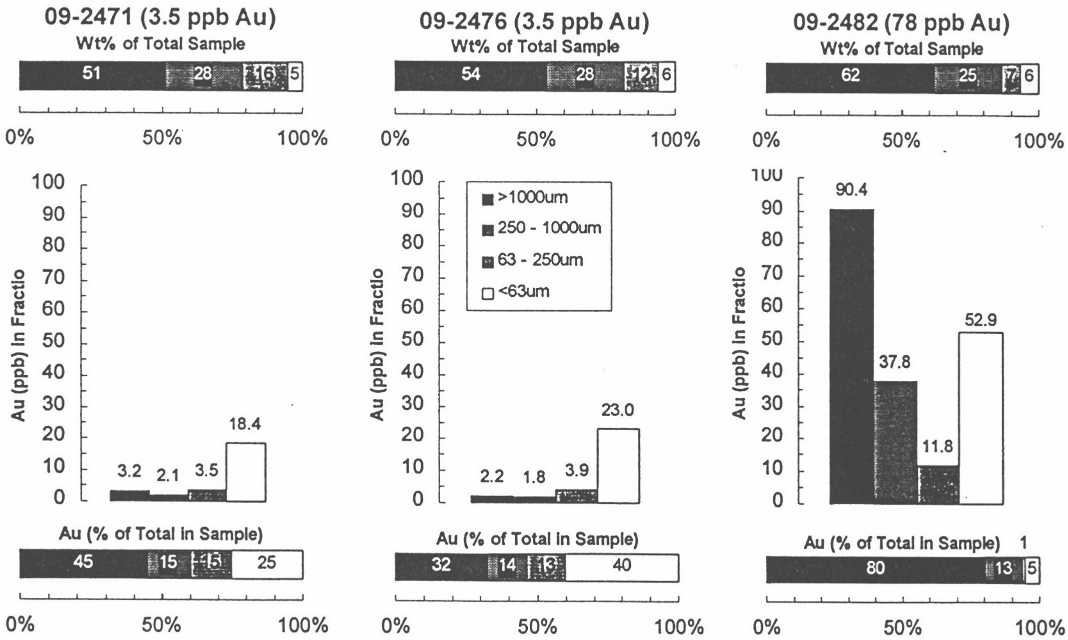


Figure 13: Size fraction analysis (by wet sieving) of transported material. Sample locations are marked on Figure 6: Distribution of Au and important relationships with other elements. (Results >40 times detection).

Table 1 - Descriptions of samples studied from the transported material.

09-2471	Calcified, hardpanised fine sediment, minor Fe-rich gravel. Unit T1.
09-2476	Fe/Si indurated (+/- hardpanisation) fine sediment with ≈20 % Fe rich pisolith dominated polimict gravel. Unit T2.
09-2482	Unconsolidated coarse sediment dominated by Fe rich pisoliths, minor amounts of indurated finer sediments. Unit T3.

All the transported material is to some extent indurated, which compromises the interpretation of the size fraction analysis. Much of the coarser fraction appear to be indurated masses of the finer fractions. This is particularly the case for 09-2471 and 09-2476. The degree of induration decreases with depth:- 09-2471 > 09-2476 > 09-2482.

Samples 09-2471 and 09-2476 exhibit very similar characteristics in terms of physical Au fractionation. Relatively high concentrations of Au are present in the fine fraction although this represents only a small percentage of the total sample weight. The remainder of the Au, in the coarser fractions, may be associated with indurated (though still porous) finer material. Gold is highly soluble in the bulk samples regardless of whether they were pulverised (Figure 14). This suggests that Au is mainly present in a complexed form, rather than as Au metal.

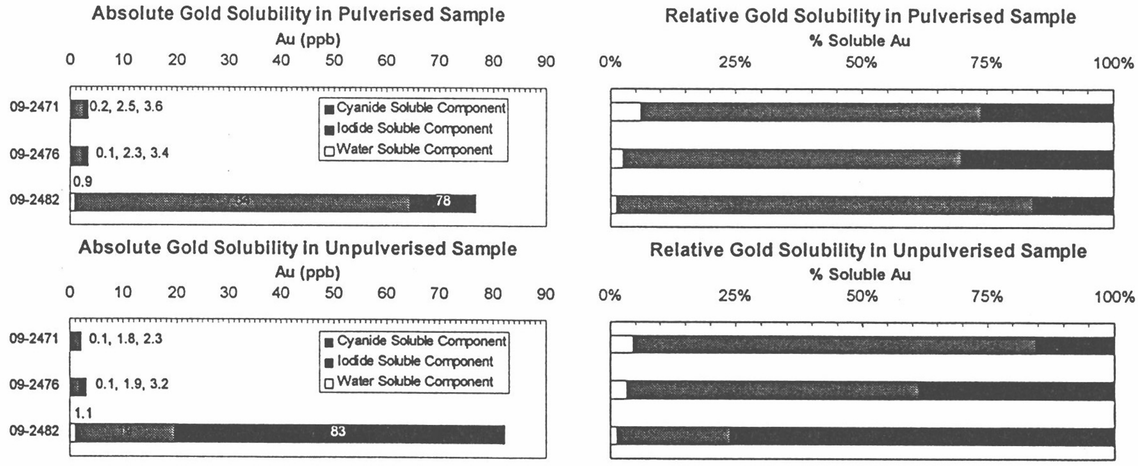


Figure 14: Absolute and Relative Au solubility in pulverised and unpulverised samples of transported materials. Relative solubility is expressed with respect to the cyanide soluble component in each case. Sample locations are marked on Figure 6.

Sample 09-2482 represents the basal few metres of the transported overburden. Size fraction analysis shows that most of the Au in the sample is contained in the coarse fraction (Figure 13), which is dominated by ferruginous lateritic debris. Most of the Au in the bulk sample is dissolved by cyanide whether the sample is pulverised or not. This implies that the Au in the unpulverised sample is accessible to solution and is on surfaces, rather than occluded in the Fe gravel. The proportion of iodide-soluble Au increases from almost 25% to over 80% when the sample is pulverised (Figure 14). The cause is uncertain, but may be due to the presence of an insoluble coating - eg. silica or alumino-silicates that will dissolve in an alkaline cyanide solution but not in the neutral iodide reagent. Alternatively, a kinetic or surface area effect may be responsible.

In summary, there are a number of observations that suggest that Au in the transported material is derived chemically from the underlying mineralisation. These are:

1. The highly soluble and accessible nature of Au in these materials.

2. The spatial distribution of Au in the basal part of the transported material with respect to the location of the primary mineralisation.

3. Gold enrichment in the shallow groundwaters around the mineralisation (section 6) and represents a medium for dispersion into the cover sequence.

5.3.3 Weathered Archaean materials

The objective of this study was to examine changes in the character of Au from the upper through lower mottled zone and into the saprolite. A description of each sample referred to in this discussion is given in Table 2, and their locations are marked on Figure 6.

Table 2 - Descriptions of samples studied from the weathered Archaean materials

09-2467	Upper mottled zone, no primary lithic fabric, strong Fe fractionation.
09-2915	Middle mottled zone, no primary lithic fabric, strong Fe fractionation
09-4499	Middle - lower mottled zone, no primary lithic fabric, strong Fe fractionation.
09-2917	Lower mottled zone, some primary lithic fabric, moderate Fe fractionation
09-4500	Saprolite with incipient mottle development, minor gross Fe fractionation.
09-4501	Saprolite, no gross Fe fractionation.

In the mottled zone, Au contents of ferruginous materials increases with depth (Figure 15). This could be due to depletion of Au from the ferruginous fraction of the upper mottled zone or variations in the primary mineralisation prior to weathering (as discussed in section 5.1).

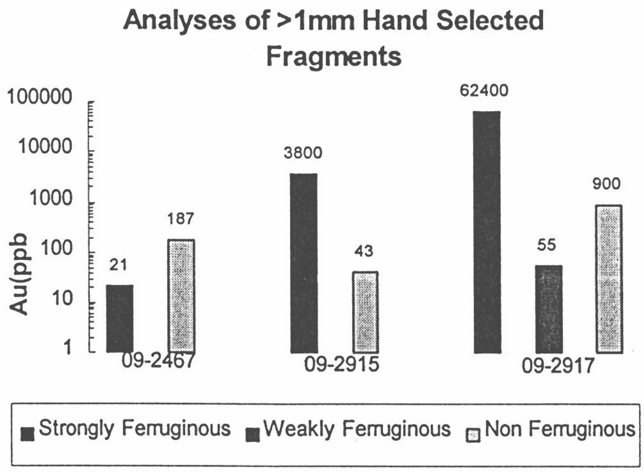


Figure 15: Gold fractionation in ferruginous and non-ferruginous materials from the mottled zone developed in Archaean lithologies.

The solubility of Au in the weathered Archaean is difficult to interpret because of the difference in absolute Au concentrations (Figure 16). Gold has a relatively constant and fairly low (though significant) solubility compared with the transported material. Cyanide-soluble data for pulverised versus unpulverised samples indicate that most of the Au in all of these samples is accessible to solution. (Erroneous results were obtained for water- and iodide- soluble Au in the unpulverised samples of 09-4501, possibly because of its coarseness and very high Au concentration).

A small proportion of the gold is water-soluble, consistent with the observation that groundwaters have anomalous Au content (section 6). These results also suggest that Au is mobile under current conditions and is available for mobilisation into the transported overburden.

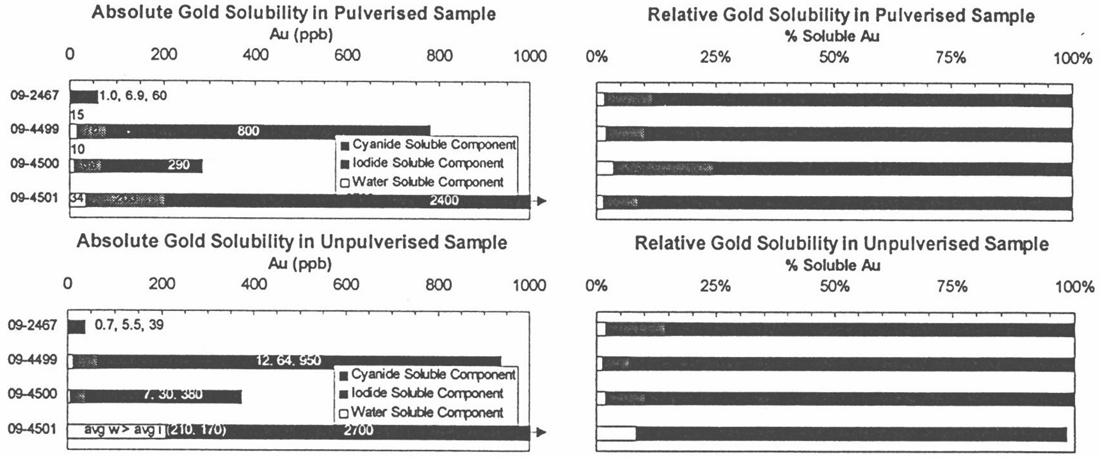


Figure 16: Absolute and Relative Au solubility in pulverised and unpulverised samples of in situ materials. Relative solubility is expressed with respect to the cyanide soluble component in each case. Sample locations are marked on Figure 6.

6. HYDROGEOCHEMISTRY

6.1 INTRODUCTION

The Golden Delicious Au deposit holds considerable interest for hydrogeochemical investigations for a number of reasons:

1. It lies north of the Menzies line, in the eastern Yilgarn.

2. Groundwater is saline to hypersaline. This contrasts with the other sites north of the Menzies line investigated as part of AMIRA Project 409, namely Baxter and Lawlers, which have fresh groundwater, and Granny Smith, which is brackish to saline, permitting comparison of the effect of salinity differences on the chemistry of Au and other elements. It is the first site investigated where saline groundwaters are in contact with the mottled zone of a pre-existing laterite profile.

3. Results can be compared with Granny Smith, which lies in the same region.

4. Groundwater investigations are complementary to other studies conducted by CSIRO at this site.

6.2 SAMPLING AND ANALYSIS

Twenty eight groundwater samples were collected at a variety of depths in late 1994. Major emphasis was placed on the traverse at 6790200N, so as to allow comparison with regolith sampling, with additional samples along the strike of the mineralization, 500 - 700 m S. These samples were analysed for pH, temperature, conductivity and oxidation potential (Eh) during sampling and later analysed for a wide variety of major and trace elements.

The programs PHREEQE (Parkhurst *et al.*, 1980; described in detail in Gray, 1990 and Gray, 1991) and PHRQPITZ (courtesy USGS) were used to calculate the solubility indices (SI) for a number of mineral phases for each water sample. If the SI for a mineral equals zero (empirically from -0.2 to 0.2 for the major elements, with a greater range for other elements), the water is in equilibrium with that particular solid phase, under the conditions specified. Where the SI is less than zero, the solution is under-saturated with respect to the phase, so that, if present, the phase may dissolve. If the SI is greater than zero the solution is over-saturated with respect to this phase and the phase can precipitate. The SI determinations are important in understanding solution processes at a site. They have particular value in determining whether the spatial distribution of an element is correlated with geological phenomena such as lithology or mineralisation, or whether they are related to weathering or environmental effects. Thus, if Ca distribution is controlled by equilibrium with gypsum in all samples, then the spatial distribution of dissolved Ca will reflect SO_4 concentration alone and have no direct exploration significance.

6.3 MAJOR ELEMENTS AND COMPARISONS WITH OTHER SITES

Groundwaters contacting Au-rich material investigated within the Yilgarn can be grouped into particular categories, on the basis of pH, salinity and major element abundances:

1. Northern groundwaters (Baxter and Lawlers: Gray, 1994, 1995): these occur in the northern part of the Yilgarn and margins, and are fresh and neutral, trending more saline in the valley floors.

2. Central groundwaters (Granny Smith, Mt. Gibson, Boags and Golden Delicious: Gray, 1991, 1992a, 1993a): these are neutral and brackish (commonly < 1% TDS) to saline (about 3% TDS), trending to hypersaline (10 - 30% TDS) at the salt lakes, with common increases in salinity with depth.

3. Kalgoorlie groundwaters (Golden Hope, Wollubar, Panglo, Baseline, Mulgarrie, Argo, Steinway: Gray, 1993b, 1990, 1992b, Lintern and Gray, 1995a,b): these are commonly acid (pH 3 - 5) and saline within the top part of the groundwater mass, except where buffered by extremely alkaline materials (*e.g.*, ultramafic rocks), trending to more neutral (pH 5 - 7) and hypersaline at depth and when within a few kilometres of salt lakes.

Groundwaters at Golden Delicious are neutral and saline, similar to those at Granny Smith, Mt Gibson and Boags, consistent with their central Yilgarn location. Golden Delicious is close to Lake Carey and groundwaters have up to 16% TDS, approximately half the salinity of halite saturation. They are relatively enriched in Na and SO_4, and depleted in K, Mg and Cl. These particular major ion ratios match results for Granny Smith, suggesting particular characteristics for groundwater in this region. Various elements that appear to be controlled by mineral equilibration in some or all of the groundwaters are:

Mg:	sepiolite;	Mn:	rhodochrosite ($MnCO_3$);
Ca:	gypsum and/or calcite;	REE:	monazite;
Sr:	celestine;	Sb:	$Sb(OH)_3$;
Ba:	barite;	Bi:	BiOCl;
Si:	amorphous silica and/or sepiolite;	Mo:	$CaMoO_4$.

6.4 GOLD AND INDICATOR ELEMENT HYDROGEOCHEMISTRY

Previous observations suggest that significant Au will dissolve either as the halide (chloride or iodide) complex, under acid, saline and oxidising conditions or as the thiosulphate complex at the weathering interface, where sufficient carbonate is present to buffer sulphide oxidation (Gray, 1988). The Golden Delicious groundwater samples are shallow (commonly about 15 m below surface), saline (to highly saline at depth), and several tens of metres above the weathering front. The more likely mechanism is weak dissolution as Au halide. Compiled data for dissolved Au in groundwaters from the Yilgarn Craton (Figure 17) indicate that the concentrations at Golden Delicious are low to moderate (0.2 ppb). This range is similar to other groundwaters from the central Yilgarn, and contrasts with those in the north, which commonly have very low dissolved Au (< 0.04 ppb), and those in the Kalgoorlie region, which are highly variable, but can contain up to 4 ppb dissolved Au.

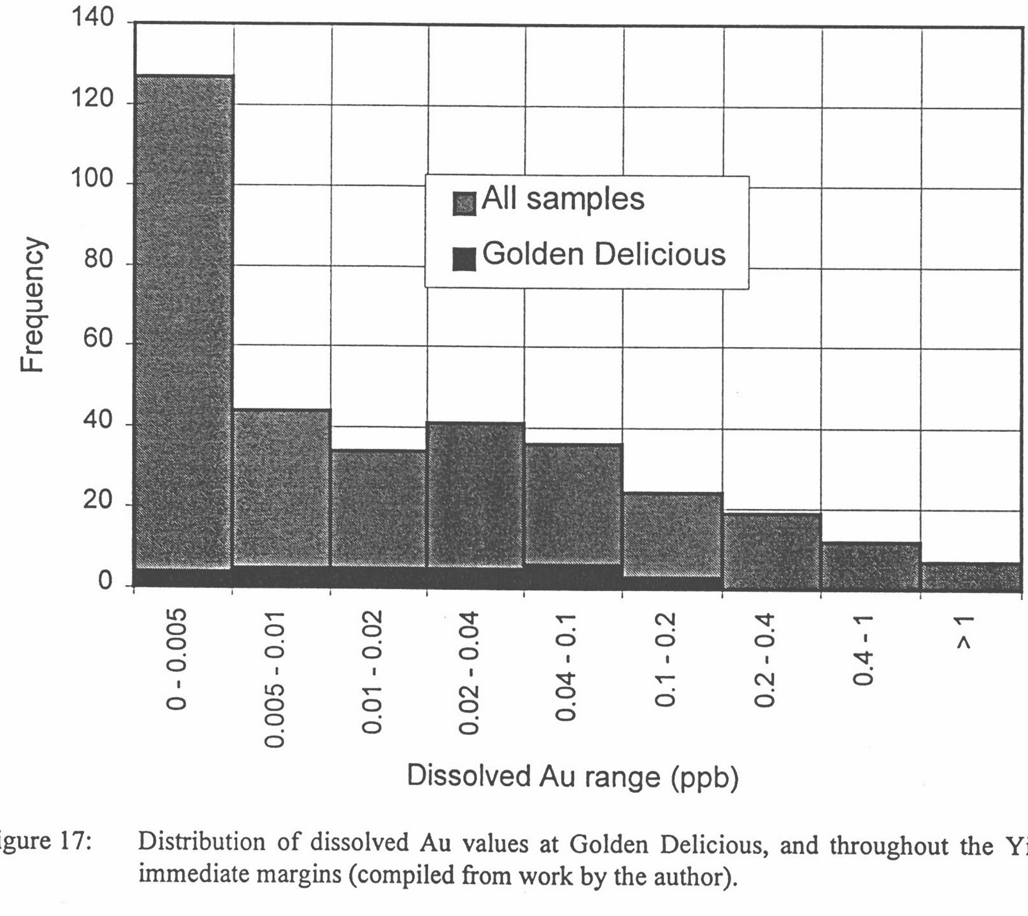


Figure 17: Distribution of dissolved Au values at Golden Delicious, and throughout the Yilgarn and immediate margins (compiled from work by the author).

The distribution of Au strongly reflects the presence of mineralization at this site (Figure 18), even when only the shallow groundwaters are used, indicating that Au has appreciable mobility, and that groundwater Au could be a suitable exploration tool. Other dissolved elements that also appear to correlate with mineralization are I and, possibly Mo, Tl, Pb, Bi (improved correlation if the degree of saturation with solid BiOCl is used rather than dissolved Bi concentration) and U.

This suite of elements is similar to multi-element responses observed in other, neutral, groundwaters contacting Au-rich rock and regolith.

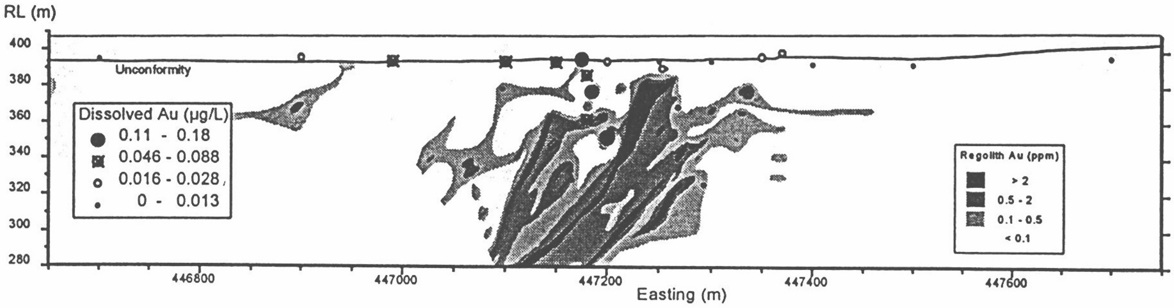


Figure 18: Dissolved Au distribution at Golden Delicious 6790200mN (dots), superimposed on regolith Au contours.

6.5 LITHOLOGICAL EFFECTS ON GROUNDWATER

There appears to be a change in the concentration of Au in groundwater at about 447200E, correlating with the western extent of the granite intrusion. This possible lithological change appears to be reflected in a number of the groundwater parameters: in particular, the eastern, granitic, part of this section shows a strong enrichment in Na (relative to salinity; Figure 19), moderate enrichments in P, Sc and Sn, and possible enrichments in Mn and Cu; whereas the western part of the section possibly has higher Eh and dissolved As. Such lithological effects on groundwaters are common (Butt *et al.*, 1993).

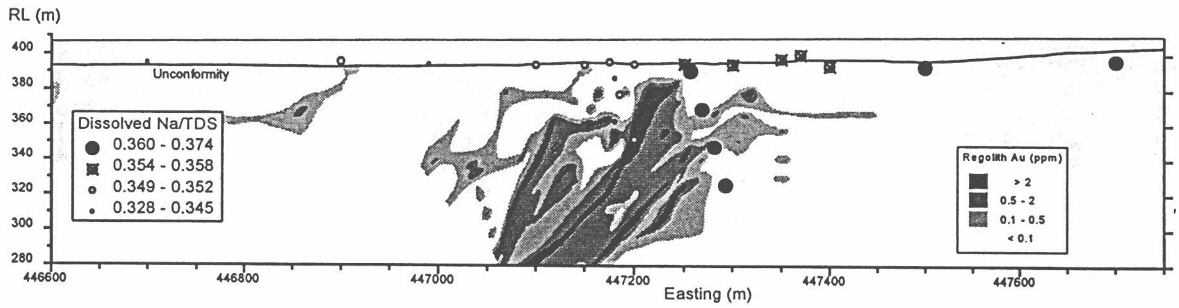


Figure 19: Groundwater Na/TDS distribution at Golden Delicious 6790200mN (dots), superimposed on regolith Au contours.

7. SUMMARY AND CONCLUSIONS

The evidence for geochemical dispersion of Au from mineralisation into the basal unit of the transported material at Golden Delicious is very strong. This can be summarised as follows:

- Highly soluble nature of Au in transported materials.
- Highly accessible nature of the Au in transported materials: i.e. The Au is extractable from transported materials ***without*** pulverising, other than that caused by drilling.
- Spatial distribution of anomalous samples in transported material with respect to underlying mineralisation.
- Existence of shallow, Au-rich groundwater around the mineralisation, suggesting a mechanism for dissolution and precipitation of Au.

Calcareous hardpan in the near-surface overlying mineralisation is not anomalous in Au using the detection limits of neutron activation analysis.

Evidence regarding the apparent depletion of Au and W in the mottled zone is ambiguous. The distribution of Au throughout the mottled zone, its solubility, and the presence of dissolved Au in groundwater suggests that depletion of Au may have occurred. The W distribution also suggests depletion, but solubility experiments do not.

The exploration target size can be enlarged by collection and analysis of different sampling media:

- Ferruginous gravels at the base of the transported overburden - 400 m.
- Ferruginous mottled zone from the top of the Archaean - 300 m.
- Groundwater - 200 m

Fractionation experiments suggest that a restricted but high order anomaly would be expected in ferruginous mottles selected from samples of mottled zone a few metres below the unconformity.

Recommendations for exploration in similar circumstances would be as follows:

1. Determine the regional regolith relationships between transported, *in situ*, and ferruginous materials in the area to be explored.

2. In areas of substantial transported overburden, drill broad-spaced holes (about 1 km spacing) to determine the nature and stratigraphyof regolith materials, and the depth and basic chemistry (pH, Eh, conductivity) of the groundwater.

3. From this information, plan follow up sampling to target specific materials at a scale appropriate for the target size, (e.g. 200 m spaced holes would not miss the anomaly in the basal gravels on the section studied at Golden Delicious, provided profile and material identification was accurate). The groundwater data will aid in the selection of sampling media, by providing information on its ability to mobilise Au throughout the regolith, and therefore give insights into the likelihood of significant Au depletion. Sampling the groundwater may also be advantageous, particularly if it is shallow and its chemistry favours high contrast Au anomalies.

8. ACKNOWLEDGMENTS

The Authors would like to thank staff of Acacia Resources Ltd. And particularly Rick Burg, Gary Snow, Andrew Grove, Jane Ham, and Mike Barker for their invaluable assistance and support throughout the research. Mel Lintern is acknowledged for extensive advice given in the preparation of this guide. Dale Longman, John Crabb, Ray Bilz, Kim Lim, Sheryl Derriman and Gill Ashton are also thanked for their technical support throughout the research.

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LANCEFIELD AND BEASLEY CREEK

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1. INTRODUCTION

Geochemical dispersion in soil, lag and saprolite was studied at the subcropping Beasley Creek Au Mine from 1987-1989, as part of AMIRA Projects 240 and 241. Apart from exposing the weathered and some unweathered basement rocks, mining has left some magnificent exposure of Permian rocks. The geomorphology of the area north-west of Laverton (Robertson and Churchward 1989), surrounding the Au mines at Lancefield, Telegraph and Beasley Creek is shown in Figure 1.

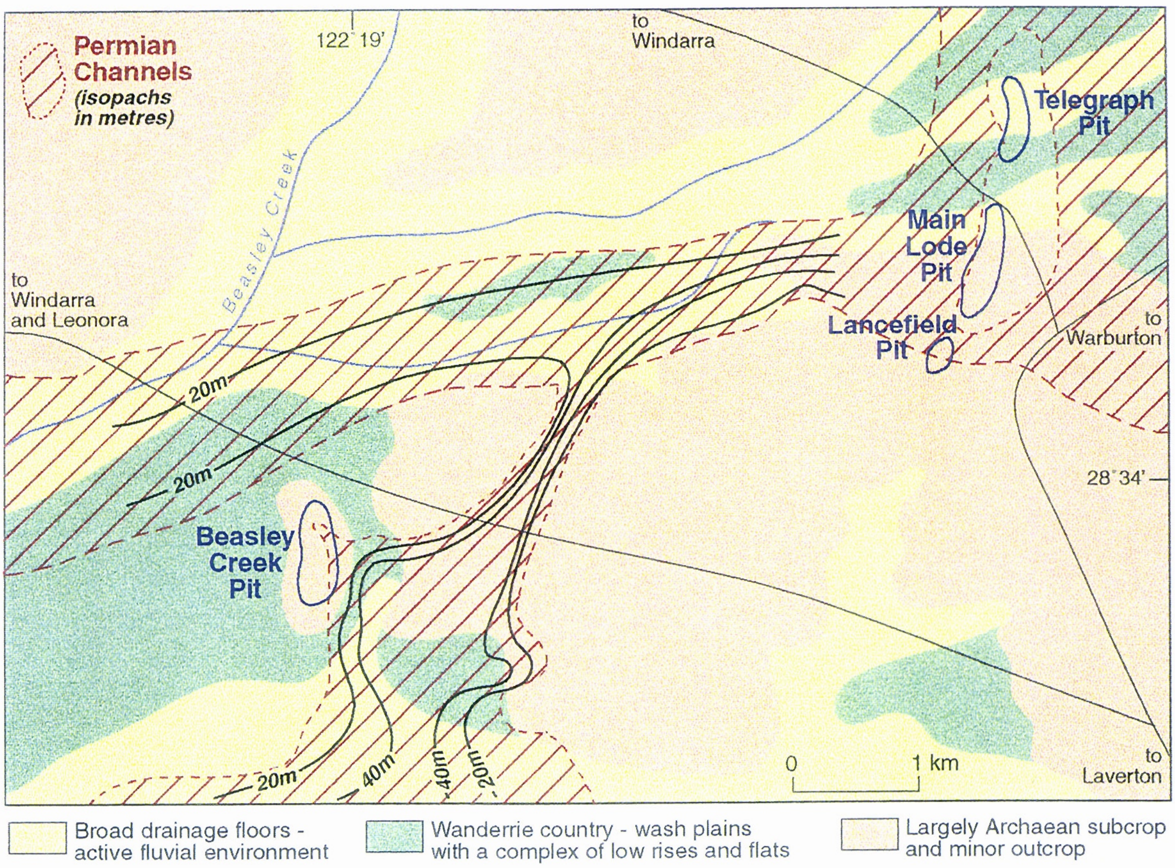

Figure 1: Regional geomorphology of the Beasley Creek and Lancefield mine area, with an overlay showing the Permian fluvioglacial channels as determined by drilling by WMC (Windarra Nickel Project plan 6/4/89). Isopachs are shown in metres.

The climate is semi-arid with hot, dry summers and cool, mild winters with an average rainfall of 225 mmpa. Evaporation exceeds precipitation by an order of magnitude (Gower, 1976). The vegetation is mainly low trees of Mulga (*Acacia aneura*), with an understory of poverty and turpentine bushes (*Eremophila* spp) and various cassia shrubs (*Cassia* spp). Shrubby mulga occurs along drainage floors but the vegetation is more open on sheet flow plains. Here the mulga occurs as dense, arcuate areas, interspersed with clear areas in a pattern referred to as 'wanderrie'.

2. PERMIAN GLACIAL AND FLUVIOGLACIAL DEPOSITS

Outcropping glacial and fluvioglacial deposits at Laverton have been described by Clarke (1919-20), Hobson and Miles (1950) and Gower (1976). These consist of boulder beds containing rounded, smooth boulders and pebbles in a fine-grained, bluish-green clay. Some boulders are large, reaching nearly 3 m in diameter and have been deeply weathered and the matrix has been lateritised in part. Boulder fields overlie presumed Permian and Archaean rocks.

Drilling and mining by WMC Ltd has outlined some extensive channels, over 80 m deep, of Lower Permian sediments (Paterson Formation) which are not readily apparent from surface investigation. Information from a summary map of the Permian by WMC shows two major channels, one following the general strike of the Beasley Creek drainage and another following that of Skull Creek (Figure 1). Some carbonaceous material from the channel at Skull Creek has been dated by palynology, confirming a Permian age, probably just post-glaciation (J. Hronsky, WMC, pers. comm.; April 1996).

Good exposures of the Permian sediments, largely poorly sorted, matrix-supported conglomerates, with some grits and sandstones, are present at Lancefield South, Main Lode, Telegraph and Beasley Creek pits (Figures 3B and 3F). Clasts include various metavolcanics, chert, quartzite, granite, quartz, gneiss and BIF. All have been deeply weathered, after deposition, to clay-rich saprolites in which the rock fabrics are well preserved. Higher in the profile, they pass into 'megamottled' horizons (Figures 3D and 3E) in which the rock fabrics are partly preserved (mottled saprolite and mottled zone). There is a strong tendency for the Permian channels to follow ultramafic lithologies (J. Hronsky, WMC pers. comm.; April 1996).

Although there is good exposure in the pits, the upper part of the profile can be difficult to reach. In places, there can be doubt as to whether parts of the upper, mottled profile is part of a shallow Permian channel, in which the fabric has been destroyed by pedogenic processes, or is residual material. Decision from drill spoil from this zone would be even more difficult. Where the Permian is exposed below the mottled zone, there is little doubt.

3. TELEGRAPH AND LANCEFIELD MINES

3.1 GEOMORPHIC SETTING

The Telegraph Au deposit was completely covered by colluvial deposits (Figure 3F) of a sheet flow plain traversed by active fluvial channels. These shallow, active, meandering, anastomosing channels are incised slightly below the general level of the sheet flow plain. To the north of the fluvial tracts are low hills of quartz-feldspar porphyry and their associated piedmonts; to the south are low hills and slightly undulating tracts on Archaean greenstones and Permian rocks.

The regolith stratigraphy at Telegraph consists predominantly of sheet flow deposits on a previously stripped profile of mottled zone, saprolite and ferruginous saprolite. The colluvium consists of granules and small cobbles of ferruginous saprolite, saprock and quartz in a sandy clay loam matrix. These transported materials are generally less than 1 m thick, with a sharp contact with the saprolite beneath.

Acid red earths and fine, sandy, clay loams mantle the sheet flow deposits and are covered by a thin veneer of granular to cobbly lag of ferruginous saprolite, stained saprock and quartz. There is less lag and the lag is generally finer on the floors of the active, drainage tracts. There is no pedogenic carbonate.

The upper, porous 2-3 m of the regolith has been hardpanized and is characterised by horizontal partings, lined by silica and stained by black manganese minerals. Hardpanisation is present in the soil from 0.5 m and continues through the transported regolith and into weathered, residual materials beneath.

4. BEASLEY CREEK

4.1 INTRODUCTION

The distribution, mineralogy, petrography and geochemistry of lag, soil and selected weathered rocks have been examined in detail to understand the lithologies, their weathering characteristics and geochemistry (Robertson and Gall, 1988; Robertson and Churchward, 1989; Robertson, 1989; 1990). Various lag and soil fractions were compared to assess their value as sample media.

4.2 GEOLOGY

Mineralisation at Beasley Creek is hosted by a black shale, 15-40 m thick, that dips 45° east. It strikes generally north but swings to the west at its southern end and flattens. The black shale is intensely weathered to >230 m and Au is associated with ferruginous (sulphidic) zones within it. The shale is enclosed in a narrow envelope of mafic amphibolite schist, which is less intensely weathered (40 m) where distant from the host rock. The amphibolite is enclosed in komatiites of the Mt Margaret Anticline. Small porphyry, granitoid and meta-dolerite lenses intrude the sequence and are associated with north-west striking faults and shears.

Although no fresh mineralisation has been encountered, it was probably sulphide-rich and had a broad suite of pathfinder elements. The host rock seems analogous to ore-bearing interflow metasediments at Lancefield (Reddell and Schmulian, 1990; Hronsky *et al.*, 1990) which vary from chert to black, graphitic shale, and contain pyrite, pyrrhotite and some arsenopyrite (15% sulphide). Proved and probable reserves of 2.1 Mt at 2 g/t of very clay-rich ore were outlined and mined by WMC from Beasley Creek.

4.3 GEOMORPHOLOGY AND SURFACE GEOLOGY

The landscape around the Beasley Creek Gold Mine leaves a first impression of simplicity but it is actually quite complex (Figure 2). The mine site was on a small rise, 3.5 m above surrounding wash plains that, together, form a low, tabular divide between broad drainage floors to the north (Beasley Creek) and to the south (Skull Creek). The rise was asymmetric, with a very gentle western slope, marked by calcrete and sparse, small, outcrops of saprolite. The crest had sporadic outcrops of ironstone and the steeper eastern slope was protected by lateritic duricrust. The regolith at Beasley Creek had been partly stripped. A lateritic duricrust closely followed the upper surface of the ore-bearing black shale. Almost all this low rise has been removed by mining.

The whole area, including the rise, was mantled by red, friable clay soil and strewn with multi-component lag. The soils on the low-lying wash-plains are deeper (0.3-0.45 m) than on the rise, are relatively acid and were underlain by hardpan; they became alkaline and thin (0.1-0.2 m) on the rise, where they were underlain by saprolite and calcrete. The distribution of a lag with khaki cutans closely follows the hanging wall of the black shale orebody and was related to the lateritic duricrust. A coarse, black, ferruginous lag had a wider distribution, seemed associated with the subcrop of the host black shale and was concentrated within 200 m of its source. Fine-grained, brown, ferruginous lag had a wider distribution and the finest fractions had been partly separated by down slope colluvial sedimentation. Quartz lag was dispersed around small quartz veins, unrelated to mineralisation.

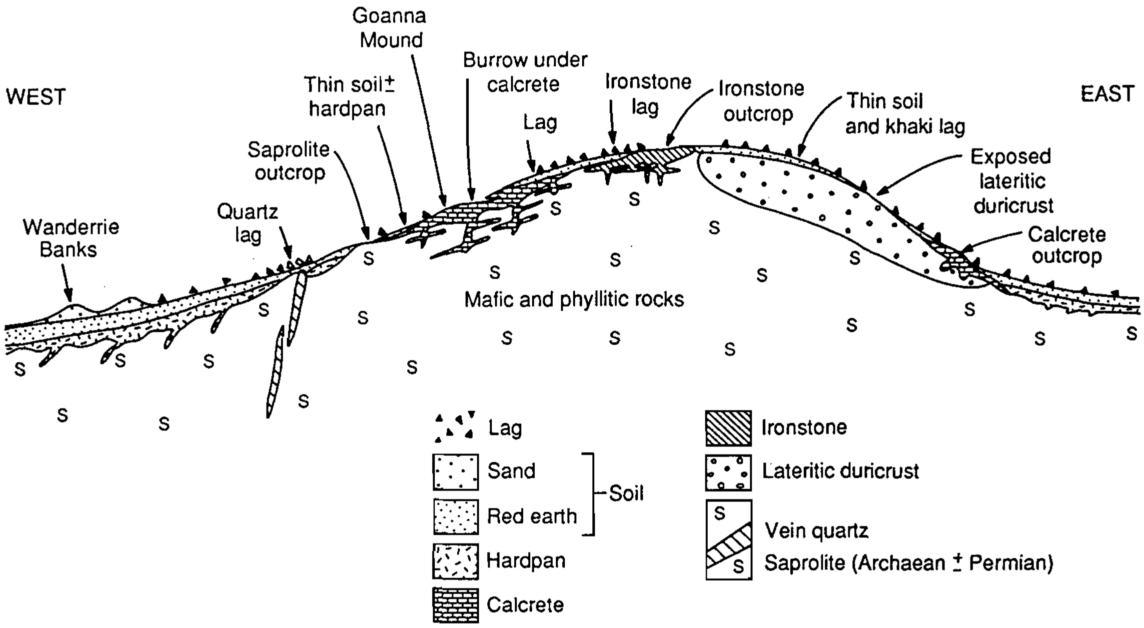

Figure 2: Sketch cross section of the low hill at Beasley Creek showing relationships between major surficial materials (not to scale).

4.4 SUBSURFACE DISPERSION

Locally intense weathering around the mineralisation, to below 230 m, appears to be due to acid conditions generated by the weathering of sulphides in the mineralisation and its sulphidic host rock. Amphibolites 400 m to the west are only weathered to 40 m (Figure 4). The S content of these fresh, mafic wall rocks is relatively low (approximately 0.2%), hence the depth of weathering is less at a distance from the ore.

Apart from Au, the mineralisation is characterised by elevated concentrations of Ag, As, Cd, Cu, Pb, Sb, and Zn (Figure 4). The lateritic duricrust and mottled zone are weakly enriched in Ag, Nb and W but are generally strongly enriched in As, Bi, In, Pb, Sb, W and Sn which enhances the value of these elements as pathfinders. Cobalt, Zn and Cu tend to be depleted near the surface, reducing their effectiveness as pathfinders but they show some enrichment below the mottled zone. Bismuth, Ge and In are at low abundances and have only sporadic anomalies so, despite some surficial enrichment, they are not very effective near the surface. Both Pb and Sb are also at low abundances but they tend to be strongly concentrated a little further below the surface, so their surficial anomalies are not readily interpreted. High concentrations of Al, Fe, Ba, Ce, Cr, Ga, Mn, Ni, Rb, V and Y reflect the composition of the host lithology.

4.5 LAG MINERALOGY AND PETROGRAPHY

The black ferruginous lag consists mainly of goethite and hematite with minor kaolinite, illite, quartz and interstratified clay. Hematite and goethite contents appear to be complementary. The lag contains ferruginous lithorelics with relict and pseudomorphed minerals and fabrics inherited from the underlying primary lithology, the saprolite and the plasmic horizon. Phyllitic host rocks are indicated by relics of slightly K-deficient mica and kaolinite. The mafic and ultramafic rocks are shown by 'fingerprint' fabrics after saprolitic clays. Goethite pseudomorphs kaolinitic accordion structures which, originally, were either saprolitic or plasmic fabrics rather than fabrics of the fresh rock. The Permian glacial sediments are reflected by polymictic breccia fabrics (Figures 3A and B).

The lithorelics are surrounded by several phases of secondary goethite and hematite, which have obliterated much of the original fabric. Hematite appears to be a dehydration product of goethite. Later history is shown by skins and complete nodules of ferruginous clay that have undergone several cycles of solution, clay precipitation and permeation by Fe-bearing solutions. The fine lag contains additional minor components of calcrete, quartz and fragments of a geochemically very important cellular ironstone or gossan.

Fabric information from the coarse lag may be used to determine the underlying lithologies of lag-covered areas, without the need for drilling (Robertson, 1996). Although the fine lag has similar fabrics, it is finer, more fragmentary and more widely dispersed, so that elucidation of the original rock type is more difficult.

4.6 LAG GEOCHEMISTRY

Lag derived from the mineralisation is anomalous in Au, As, Ba, Co, Cu, Fe, Mn, Mo (weak), Pb (possible), Sb, W and Zn. The cellular ironstone appears to be responsible for much of the highly anomalous As, Au, Co, Cu, Mn, Sb, Se and Zn. Gold is the best indicator of mineralisation and shows strong anomalies (1000 ppb over a 10 ppb background) which are 600 - 900 m wide. Other elements show narrower dispersion halos. Superimposed on these broad Au anomalies are narrow, subsidiary peaks (>10,000 ppb Au), specifically in the coarse lag, which accurately locate the ore. The wide Au halo reflects Au distribution in the underlying rocks, prior to mechanical dispersion of the lag at the surface. The Mn and Ba anomalies are thought to be related to the ore host rock rather than to the ore itself.

Both coarse (10-50 mm) and fine (0.2-0.5 mm) lags are effective geochemical media in relict and erosional regimes. Intense Au spikes in the coarse lag locate the mineralisation more precisely than the more dispersed fine lag. The fine lag gave better results for Sb, W and Zn. The non-magnetic component of the fine lag was geochemically superior to the magnetic component as it contains non-magnetic gossanous fragments. As the non-magnetic component makes up about 75% of the total lag, only a slightly improved performance could be gained by analysing it separately.

Fine lag is readily transported by surface water but coarse lag requires either a significant gradient or introduction into a drainage to move any distance. In general, the fine lag shows the greatest dispersion and the coarser fractions show progressively lesser dispersion. Thus, fine lag is better for defining the general area of mineralisation; the coarse lag could be used for follow-up.

The potential of a lag as a geochemical sampling medium depends upon its geomorphic setting and on the underlying geology. Lag from weathered Permian sediments or from a thick blanket of colluvium would be of little use. Lag from underlying duricrust or from the saprolite of partly eroded areas has the best potential. It is therefore necessary to map the geomorphology and underlying geology to subdivide geochemical data prior to sampling and statistical treatment.

4.7 SOIL FRACTIONATION AND MINERALOGY

The soil consists of three contrasting fractions:

(i) A coarse fraction (>710 µm; indistinguishable from the lag) of dense, goethitic granules (some magnetic), slightly less-dense, ferruginous, clay pebbles and granules, a few quartz grains, fragments of calcrete, hardpan and rare cellular gossan. The proportion of gossan fragments is significantly greater close to the mineralisation. The goethitic granules are analogous to the lag and contain mica relics, goethite pseudomorphs after kaolinitic lithorelics and vermicular accordion structures, set in a variety of secondary goethite phases. The clay-rich granules consist largely of hematite- or goethite-stained kaolinite and some include goethite-rich lithorelics.

(ii) An intermediate fraction (75-710 µm), which consists largely of hematite-coated quartz and minor grains of feldspar, is a largely wind-blown diluent and was not studied further.

(iii) The fine fraction (<75 µm) consists of quartz grains and smaller kaolinite and Fe oxide particles, partly locally derived from clay pisoliths and granules and partly wind-blown. This fraction was separated further by clay sedimentation, using pH control, into a relatively quartz-rich (75-4 µm) and the clay- and Fe oxide-rich (<4 µm) fractions. The <4 µm fraction shows maximum abundances in both kaolinite and sericite over the ore, probably related to the phyllitic host rock.

4.8 SOIL GEOCHEMISTRY

The geochemical characteristics of the 710-4000 µm fraction and the fine lag are identical. Gold is distinctively anomalous, giving a very broad peak of >20 ppb but locally reaching 200-300 ppb. The 710-4000 µm fraction is the most effective medium, with the highest values and the greatest anomaly to background contrast. The mineralisation is also depicted by anomalies in As, Cd, Cu, Sb, Se, W and Zn and the host rock by Ba and Mn. A maximum in S over the ore is related to a subcropping gypsiferous horizon which may be landscape related. Although As is concentrated in the 710-4000 µm fraction, the anomaly to background contrast is better in the fine fractions.

A. A ferruginised lithorelic of polymictic fragments set in a ferruginised, arenaceous matrix, derived from Permian glacial sediments at Beasley Creek. Compare Figure 3B. Close-up photograph of polished block of lag from Beasley Creek Au mine in oblique reflected light.

B. A lithorelic of matrix-supported, polymictic sediment, including fragments of sub-angular, bright goethite, a few ferruginised saprolite fragments, after mafic-ultramafic schists, quartz fragments and shadowy lithorelics, all comprising a ferruginised Permian glacial sediment from the Beasley Creek Au Mine. Compare Figure 3A. Specimen 08-120B. Photomicrograph in normally reflected light.

C. Saprolite of Permian conglomerate or till. A wide variety of water-worn greenstone belt and some granitic clasts are loosely-packed in a matrix of similar material. Both clasts and matrix are deeply weathered. Lancefield South Pit.

D. Mottled saprolite in Permian sediments. 'Mega-mottles', developed in Permian sediments, have developed a highly contrasted material. The clastic structure in the mottles is clearly visible and a single bed may be traced between mottles where the clastic structure is less apparent. Lancefield South Pit.

E. Mottled saprolite in Permian sediments. A highly mottled saprolite with pockets of kaolinitic material. Lancefield South Pit.

F. Colluvium. Thin, flat lenses of gravelly sheet flow deposit on saprolite of Permian tillite. There is a thin, cobbley lag at the base of the colluvium and it passes upward into silty-sandy colluvium and soil. Telegraph Pit, south-west access ramp.

G. Permian at Beasley Creek. The western edge of a shallow palaeovalley, filled with mottled clays, exposed in the eastern pit wall at the Beasley Creek Au Mine. At its base is a large quartz boulder. The palaeovalley has been incised in clay-rich saprolites of Archaean mafic and ultramafic rocks which have been fractured and ferruginised.

H. Sand dune. Lightly-consolidated red sands of a sand dune in a road cutting near Windarra showing dune bedding. This is mantled by unconsolidated sand.

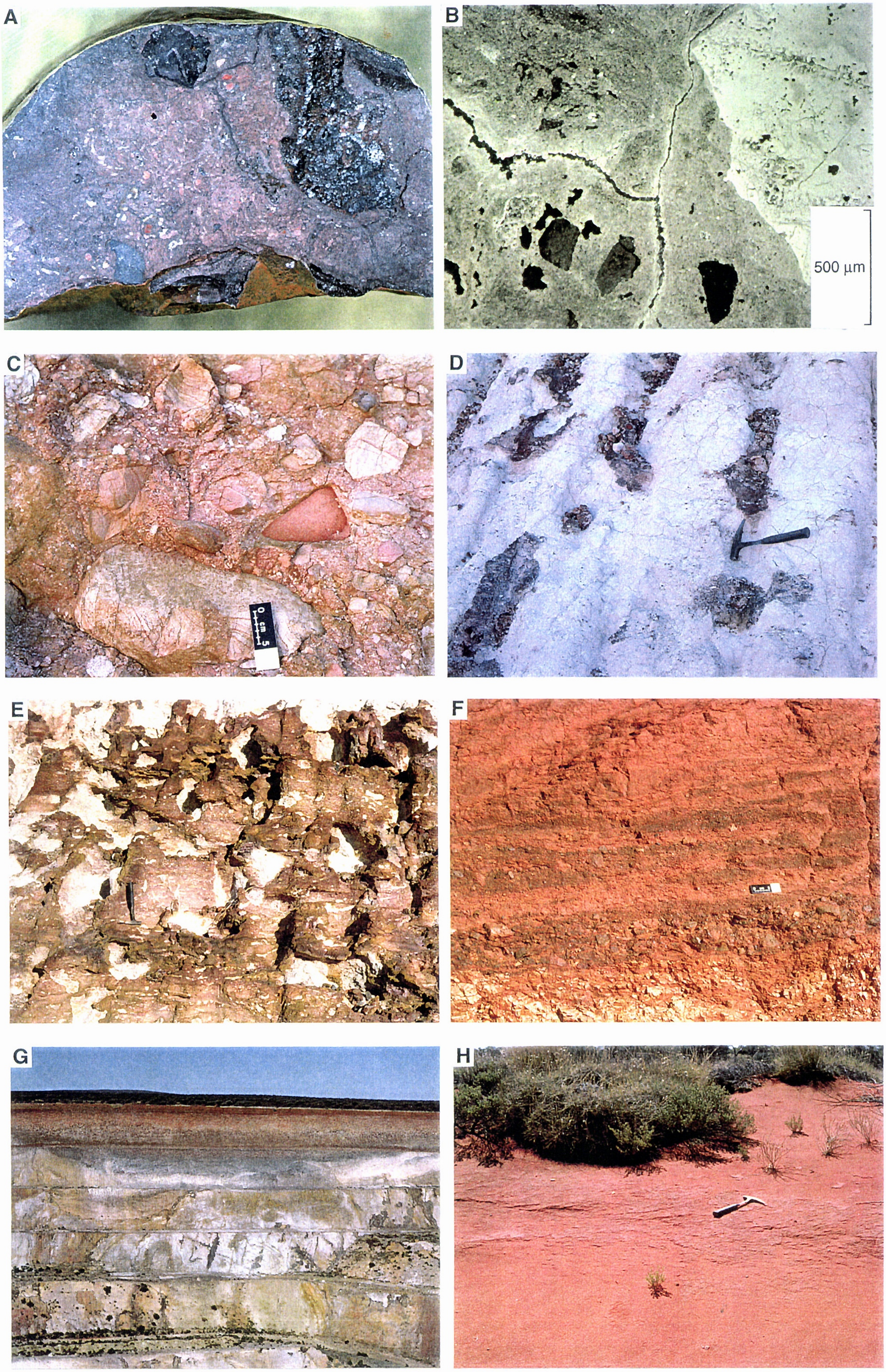

Figure 3: Transported overburden Laverton area

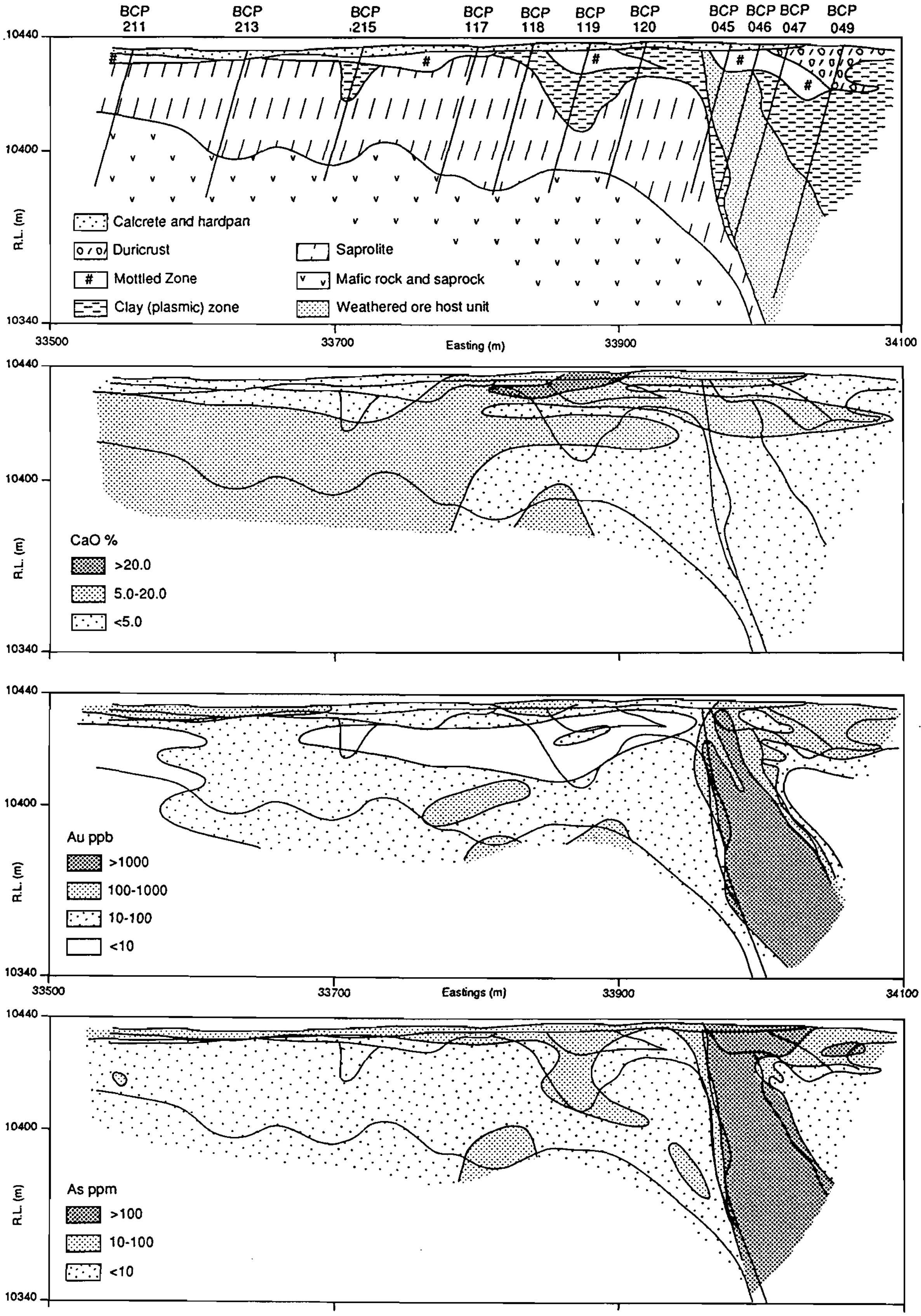

Figure 4: Geological and geochemical cross sections through the Beasley Creek Au deposit.

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6. ACKNOWLEDGMENTS

E.H. Nickel assisted with XRD interpretation and H. Linderfelt provided technical assistance. XRD analysis was by M.K.W. Hart and sections were prepared by R.J. Bilz. A.D. Vartesi completed the artwork and G. Ashton formatted the document. G. Taylor of Metex assisted in the field and M. Killick provided sedimentological input. All this is acknowledged with appreciation.

STOPS

Stop 1: Lancefield South pit - access ramp

Here a thick, deeply weathered Permian fluvial sequence is exposed abutting and unconformably overlying Archaean ultramafic rocks. The steep, possibly, in places, overhanging wall of the channel is apparent. The base of the Permian consists of a matrix-supported, coarse, bouldery conglomerate, consisting of a variety of rounded and angular metavolcanic and granitic boulders and some BIF, set in a gritty matrix of similar material, interbedded with gritty cross-laminated sandstones (Figure 3C). Some beds show evidence of stream action and, possibly, some bioturbation.

Higher in the profile, the saprolite (after Permian rocks) is mottled, accentuating the gritty, polymictic fabric (Figures 3D and E). Between the mottles the saprolite retains the gritty structure but this is less obvious.

Stop 2: Telegraph pit - south-west access ramp.

The lensoid form of gravelly layers within the colluvium-alluvium are well-exposed in the top metre. It has a cobbly lag at its base and some gritty lag higher up (Figure 3F). The lags suggest a fluvial channel deposit. Mineralogically, the colluvium-alluvium consists of quartz, hematite, goethite and kaolinite. This overlies a yellow, mottled saprolite of matrix-supported Permian conglomerate. Mottling and pedogenesis has largely obscured the nature of the weathered Permian in its upper parts but, further down the access ramp, it consists of a conglomerate of polymictic, rounded cobbles and boulders of metavolcanic rocks, granites and gneiss set in a gritty matrix of similar composition (now kaolinite, quartz, hematite and minor muscovite). Further down still, steep-dipping structures of saprolite, developed on pillowed Archaean komatiites, occur below a very sharp unconformity.

The south face of the main part of the Telegraph Pit shows a sequence of weathered, easterly inclined, tholeiitic basalts, argillaceous metasediments, differentiated metatholeiites and dolerites, magnesian tholeiites, a chert and pillowed komatiites. Some magnificent pillow structures occur in the saprolites of tholeiitic basalts in the southeast corner of the pit.

Stop 3: Beasley Creek Pit

Varicoloured saprolites with ferruginised fractures are exposed in the eastern pit wall. Eroded into this is a shallow, dish-shaped Permian channel, filled with clays and other weathered sediments (Figure 3G). Unfortunately it is no-longer accessible, due to pit wall instability. A large quartz boulder is visible at its base and weathering of its upper part has produced a pattern of 'megamottles'.

Stop 4: Sand dune

Plains of aeolian sands are extensive in the Laverton area (Gower, 1976) and commonly overlie granitic rocks, but there may be some encroachment over greenstones. The road to Windarra cuts through an orange-brown sand dune. The dunes on-lap mafic hornfels and amphibolite saprock of the greenstone belt to the north-east. Vestiges of dune bedding can be seen in section (Figure 3H). The consolidated sands are mantled by loose sand and spinifex.

The dune sands consist largely of hematite-stained quartz, with a few hematite granules and minor feldspar (perthitic microcline), chert and epidote. The larger quartz grains are slightly rounded and frosted; small grains are angular and clear. The hematite grains are highly polished and nodular but a few pseudomorph magnetite (octahedra and cubes). There are a few, small, rounded pellets of ferruginised clay and a trace of fresh, angular actinolite fragments. All the grains are very lightly cemented by minor kaolinite; this cement readily breaks down on moistening.

There is a very close similarity between these sands and the intermediate soil size fractions encountered at Beasley Creek. This intermediate fraction was not analysed because it was considered to be wind-blown (Robertson, 1990).

BRONZEWING GOLD DEPOSIT

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CRC Landscape Evolution and Mineral Exploration, c/-CSIRO Exploration and Mining

1. INTRODUCTION

The Bronzewing Au deposit is located in the Yandal Greenstone Belt, about 400 km north of Kalgoorlie at approximately 120°59.5′E 27°23.1′N (Figure 1). The deposit was discovered in 1992 using buried lateritic residuum and saprolite geochemistry. Since then, intensive RAB, RC and diamond drilling have outlined zones of mineralisation that have been developed to become the Discovery, Central and Laterite pits. The schematic geology of the tenement area is shown in Figure 1.

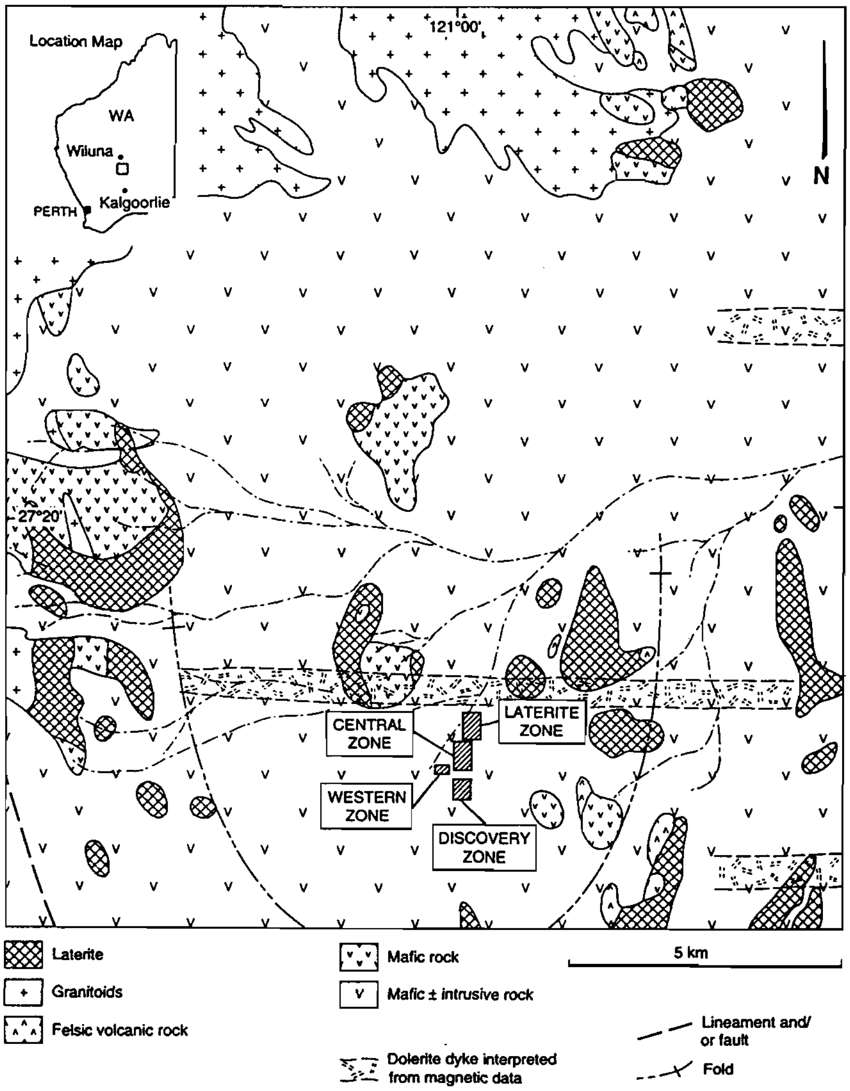


Figure 1: Schematic map showing interpreted regional geology in the vicinity of the Bronzewing deposit (after Great Central Mines N.L. 1993).

Total indicated and inferred resources at Bronzewing, as at June 1995, were reported as 19.8 Mt at 4.7 g/t yielding 3 million ounces using uncut grades, or 3.6 g/t yielding 2.3 million ounces using cut grades. Mineralisation occurs within a sequence of mafic volcanics and minor sediments that strike NW and dip to the SW. The sequence is intruded by porphyries which reflect a N-striking structural control. Gold mineralisation is associated with a dense stockwork of quartz veining, alteration of the host basalts, dolerites and felsic porphyries, and is accompanied by pyrite, pyrrhotite and minor chalcopyrite and scheelite. Gold is often visible in the core. The predominant foliation of the host rocks is N-S and primary mineralisation generally follows this structural orientation.

Prior to excavation, the mineralisation was totally obscured by deep transported overburden and leached residual clays derived from intense weathering of the bedrock, to depths of approximately 90 m; fresh rock is encountered below 80 - 120 m.

2. GEOMORPHOLOGY AND REGOLITH

2.1 REGIONAL SETTING

The Bronzewing district is a broadly undulating terrain characterised by the low relief typical of the Yilgarn Craton. The few hills that exist comprise secondarily silicified or relatively unweathered Archaean greenstone sequences. Locally, greater relief variation, such as at breakaway scarps, is the result of differential stripping of a deeply weathered regolith. Below the breakaways, the gentle, often imperceptible, slopes of the main trunk valleys are produced by active but intermittent drainage and by localised deposition of sediments.

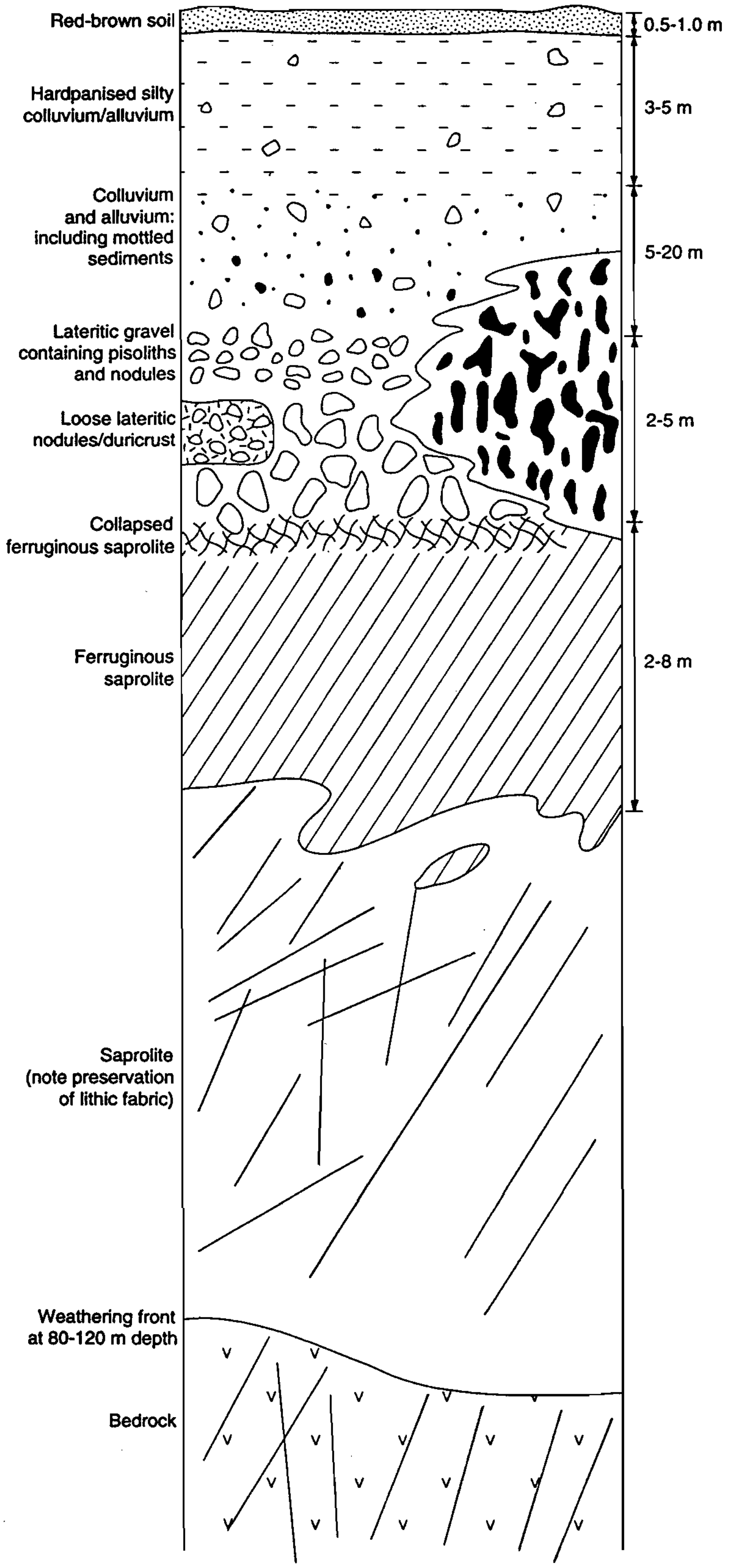
The Bronzewing site at about 500 m asl is situated on an alluvial mulga flat adjacent to the Bates Creek drainage and slopes very gently W-SW. Transported overburden (alluvium and colluvium) is up to 30 m thick in the vicinity of the deposit, and contains components derived from the partial or complete stripping of upslope lateritic regoliths. Hardpanisation is extensive and, in places, the overburden has been mottled during post-depositional weathering. Both complete and truncated lateritic profiles are common beneath the sediments.

A general stratigraphic column for the regolith in the vicinity of the Bronzewing deposit is provided in Figure 2, and Figures 3 and 4 are provided as guides to identification of units in the field. In this case, logging of cuttings from RAB and RC drilling was sufficient to gain an understanding of the local stratigraphy (Varga, 1994; Crawford, 1994), which has been confirmed by the exposures visible in the pit walls.

2.2 TRANSPORTED OVERBURDEN

Deposition of colluvium and alluvium on slopes and in valleys and basins has covered much of the weathered Archaean bedrock. In the Discovery Zone, a 20 to 30 m thick mantle of sediments directly overlies saprolite. The sedimentary cover is 15 to 20 m thick in the SW of the Central Zone and thins toward the NE to less than 5 m in the Laterite Zone. The sediments have been derived from the NE as alluvium, and from the subdued breakaway to the east as colluvial talus shed during sheetwash erosional events. The thickness of transported overburden, shown in Figure 5, represents the palaeotopography. The basin to the SW of the deposit area was the site of clay and silt deposition over the present Discovery orebody. A general 3D regolith-landform model for the Bronzewing district is given in Figure 6.

Central Zone Bronzewing



Unconsolidated red-brown sandy clay.

Hardpanised silty colluvial and alluvial gravels - Characterised by coarse subhorizontal laminations of opaline silica or hyalite cement. Hardpanisation decreases with depth.

Gravelly colluvium and alluvium - The coarse fraction consists of polymict clasts, including vein quartz, fine ferruginous nodules, and lithic fragments of distal provenance, and locally transported ferruginous, lateritic nodules and pisoliths. The western wall of the Central Pit exposes a section through mottled sediments. The mottled cover here directly overlies saprolite. The interface between cover and saprolite represents the predepositional landsurface.

Lateritic horizon - When fully preserved, the top metre or so of this horizon is composed of 0.5 to 2 cm diameter lateritic nodules and pisoliths loosely set within a matrix of red-brown silty clay. Toward the base of the ferruginous horizon larger nodules up to 4 or 5 cm diameter are also set within an unconsolidated silty matrix. Pods of highly indurated lateritic duricrust are present in some exposures about the Central Pit. Duricrust is far more common, however, in the Laterite Pit to the north.

Ferruginous saprolite - The ferruginous saprolite is stained a yellowish brown to purple colour by the concentration of Fe oxides in the uppermost few metres of the saprolite directly underlying the lateritic horizon. This unit consists of a puggy clay matrix containing 1 to 5 cm purple-brown to black incipient ferruginous nodules. These nodules or ferruginous segregations are subspherical to tabular in shape and commonly preserve primary fabrics.
The ferruginous saprolite has been subjected to solution weathering processes whereby much of the clay matrix has been removed. This has led to collapse, resulting in a relatively nodule-rich (matrix-poor) unit. With further ferruginisation, this material is thought to give rise to the lateritic nodules which lie above. Fragmentation of the nodules as the uppermost portion of the profile continues to collapse gives rise to the smaller nodules and pisoliths in the lateritic gravel.

Saprolite - Note presence of structural features and the structurally controlled collapse features at the base of the ferruginous saprolite/lateritic horizons. Solution processes concentrated along structural partings have removed clays from the uppermost saprolite creating voids and subsequent slumping of overlying materials.

Fresh bedrock is encountered at 80 to 120 m below the surface.

Figure 2: Stratigraphic column

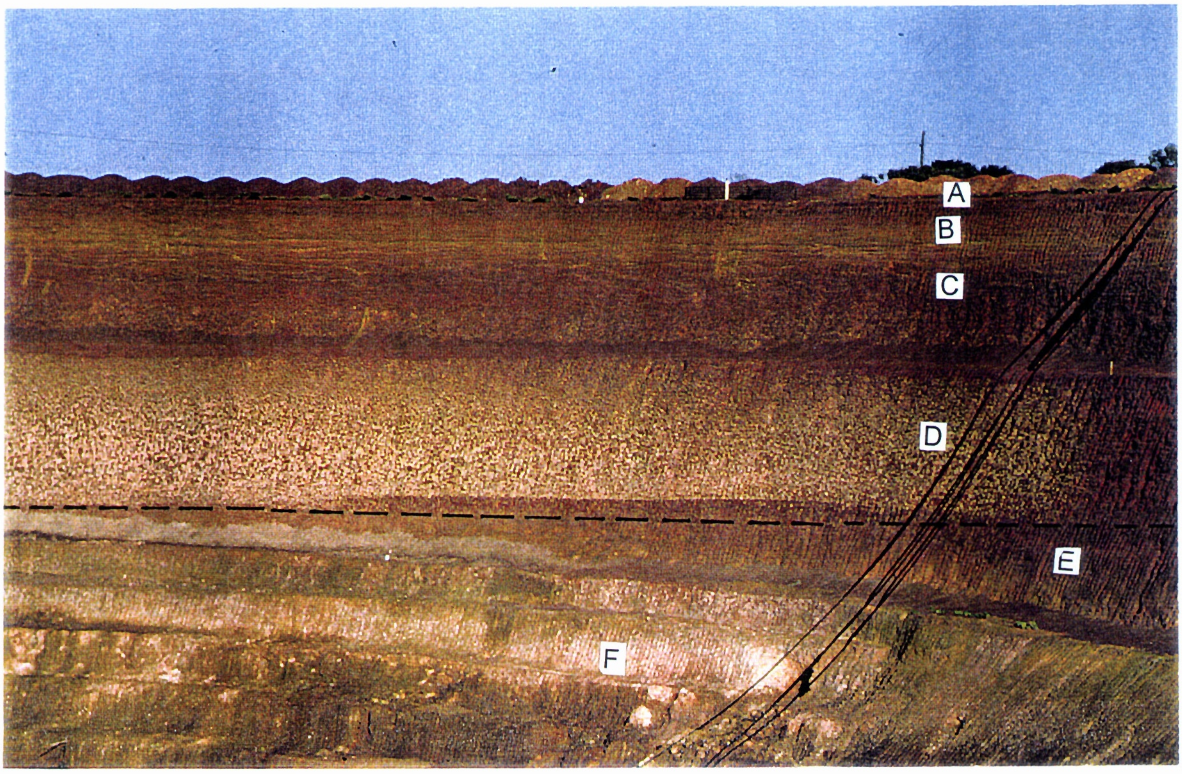
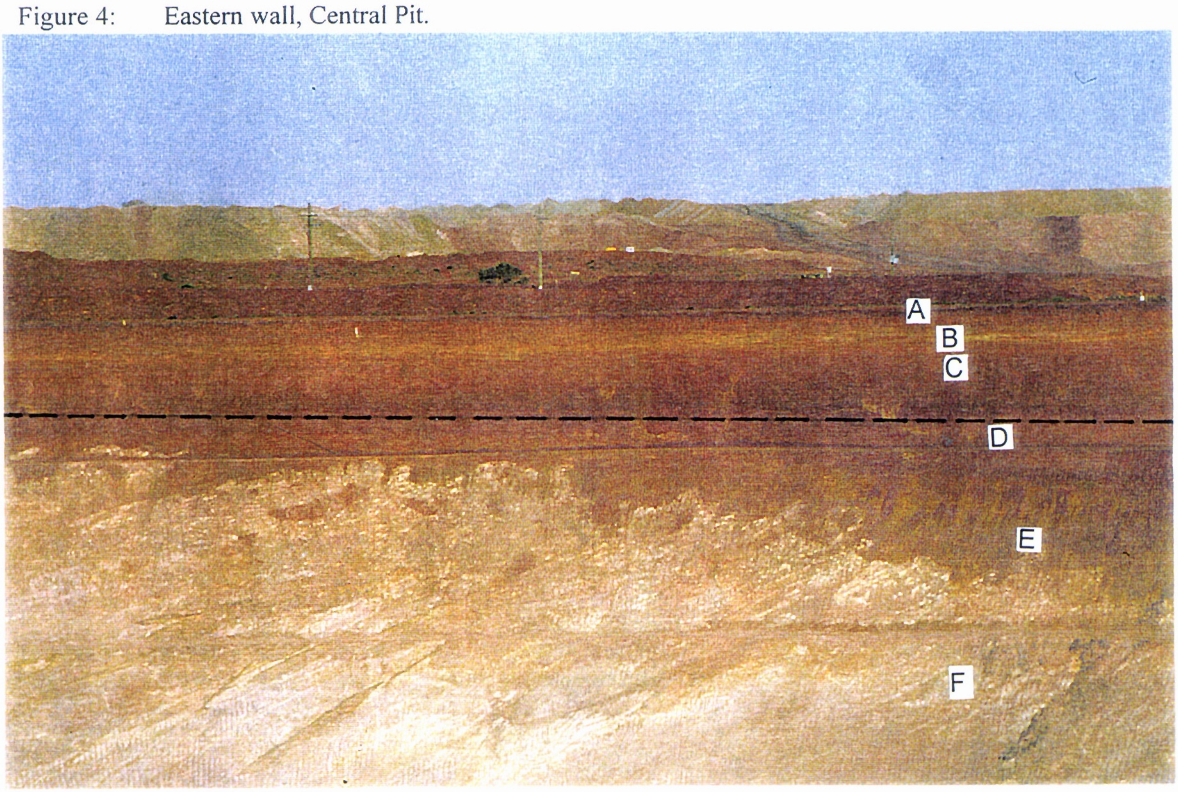


Figure 3: Western wall, Central Pit.

Dashed line = base of transported overburden

A. Red-brown soil to approximately 1 m depth.
B. Hardpanised silty colluvium and alluvium cemented by yellow laminae of hyalite.
C. Gravelly colluvium/alluvium containing transported ferruginous clasts which are usually no coarser than 0.5 cm in diameter and largely devoid of cutans. The red-brown colouration is due to the hematite-rich nature of the silty clay matrix.
D. Western wall: Mottles developed in silty sediments overlying saprolite.
Eastern wall: Nodular and pisolitic lateritic residuum. Nodules are pisoliths have yellow-brown to red cutans and are set in a goethite-rich clay matrix.
E. Ferruginous saprolite.
F. Saprolite.

Figure 4: Eastern wall, Central Pit.



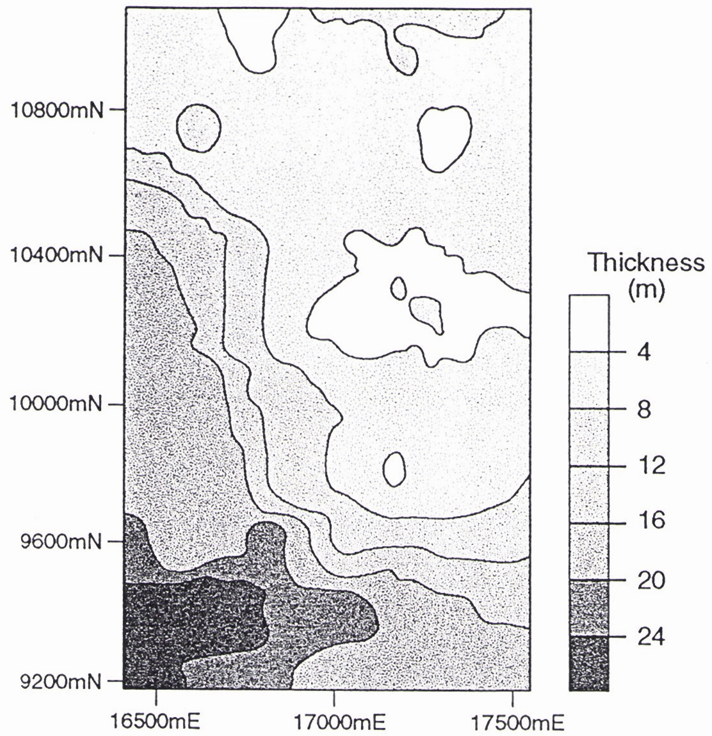


Figure 5: Thickness of transported overburden, indicating palaeotopography.

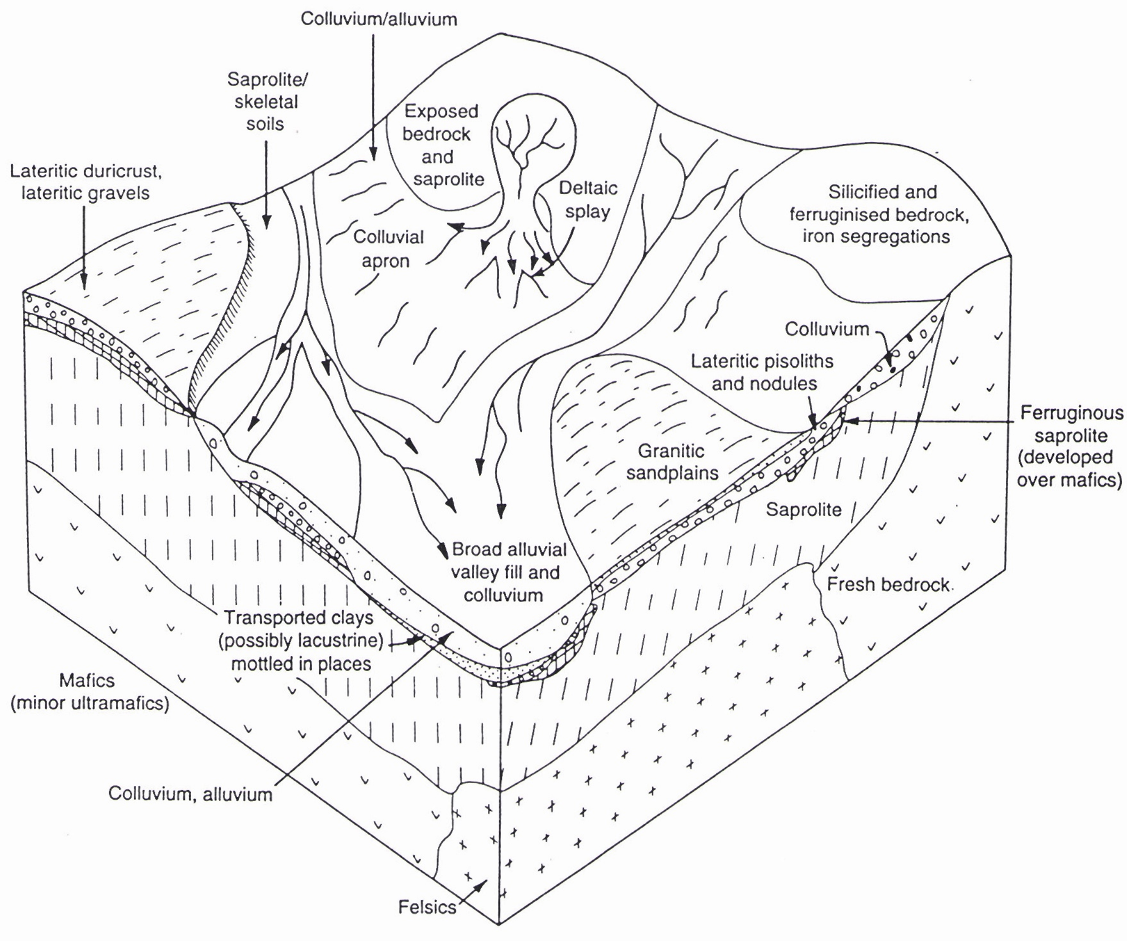


Figure 6: Generalised regolith-landform model for the Bronzewing district.

There are three principal sedimentary units:

1. Red-brown sand-silt-clay soils. These are developed in colluvium and alluvium and overlie the extensive hardpanised colluvium and alluvium.

2. Colluvium and alluvium. These sediments consist of alluvial channel deposits, colluvial talus and detritus shed from upslope during occasional flooding and sheetwash events. In general, the colluvial and alluvial deposits fine toward the top so that this unit may be subdivided into an upper, silty component, and a lower gravelly component, which often comprises the lower few metres of the cover. Hardpanisation is largely restricted to the upper silty component.

3. Clays. Fine silty clays, are exposed in the western wall of the Central Pit (Figure 3), occupying the lower 5 to 20 m of the cover. These silty clays appear to occupy a palaeochannel and have been subjected to intense post-depositional mottling.

2.3 RESIDUAL PROFILE

The top of the residual profile is composed of a layer of lateritic gravels, mainly lateritic nodules and some pisoliths set in a silty clay matrix, some 2 to 5 m thick (Figure 2). The lateritic gravels are underlain by a zone of ferruginous saprolite that grades downward into saprolite. The nodules are formed by the fragmentation of ferruginous saprolite. The ferruginous saprolite is a yellowish-brown, hematite-goethite-kaolinite-rich, indurated mass produced by the infusion of Fe oxides into clay-rich saprolite. Slightly higher in the profile, the clay matrix has been dissolved, leading to the numerous irregular voids. These voids weaken the whole saprolite structure, eventually leading to collapse. The fragments then become further broken down into nodules, prior to the later development of a yellow-brown cutan formed by the hydration of hematite to goethite.

3. GEOCHEMICAL DISPERSION IN THE REGOLITH

3.1 SAMPLE MEDIA

Soil <250 µm fraction
Bulk soils were collected from 30 to 50 cm depth using a hand auger. The sieved fine fraction consists mainly of aeolian silt-sized quartz grains, kaolinite and hematite. The hematite is present as fine ferruginous sand- to clay-sized particles, and as fine coatings on quartz grains and, presumably, within the clay matrix. Any hydromorphic dispersion of Au into soil would be expected to be relatively concentrated in the fine hematitic clays and silt, including fine ferruginous granules, due to their greater surface area.

Mottles developed in overburden
The most hematite-rich mottle fragments were extracted for analysis. The selected mottle fragments consist of hematite, quartz and kaolinite, with minor amounts of goethite.

Lateritic residuum
Nodules and pisoliths (0.3-1 cm diameter) selected for analysis typically have a red-brown earthy to black metallic hematite-rich core, encased by a 0.1-1 mm thick yellow-brown goethite-rich cutan. Many of the cutans had been slightly worn, suggesting local transport. Such materials were considered relict if close to their probable source, or if they were in stratigraphic continuity with clearly *in situ* lateritic residuum. Hematite, goethite, and kaolinite were identified as the dominant minerals, with minor maghemite, gibbsite and anatase, and a trace of quartz.

Ferruginous saprolite
Smooth 0.5-3 cm equidimensional to tabular hematite-rich fragments, with a black metallic to purple-brown earthy lustre, were selected for analysis. Hematite and goethite are the dominant minerals, with minor kaolinite, anatase, quartz, and a trace of mica in some samples. Primary fabrics are commonly well preserved by pseudomorphic replacement by Fe oxides (mainly hematite).

The mean elemental abundances and standard deviations for each of the four sample media are given in Table 1.

Table 1: Summarised geochemical results.

	Fe_2O_3 %	Ag	As	Au ppb	Bi	Cr	Cu	Mo	Ni	Sb	V	W
Soil fine fraction (n = 64)	7.2 (3.1)	0.59 (0.1)	5.8 (1.3)	1.9 (1.1)	0.38 (0.09)	167 (69)	13 (13)	1.28 (0.17)	31.6 (6.5)	0.44 (0.07)	133 (87)	0.7 (0.2)
Mottles in cover (n=12)	34.4 (12.4)	0.46 (0.14)	20.2 (15.4)	2.7 (2.5)	0.25 (0.11)	617 (288)	67 (18)	1.97 (0.73)	77.1 (21.1)	0.9 (0.51)	911 (257)	2.2 (4.4)
Lateritic residuum (n=76)	48.5 (9.9)	1.01 (0.51)	25.9 (11.7)	558.3 (1477)	0.61 (0.87)	1476 (1364)	97 (96)	2.25 (0.84)	76.2 (45.7)	1.19 (0.42)	1402 (544)	6 (9.7)
Ferruginous saprolite (n=8)	56.4 (11.1)	0.41 (0.19)	17.1 (6.2)	16.4 (21.7)	0.26 (0.24)	840 (395)	252 (260)	1.99 (1.08)	59 (16.1)	0.91 (0.34)	1213 (359)	2.1 (2.7)

all values in ppm unless otherwise marked.

Key to table. Mean 558.3; Standard deviation (1477)

3.2 GEOCHEMICAL RESPONSE IN TRANSPORTED OVERBURDEN

No Au or pathfinder element response was gained from the <250 µm fraction of the soil (Table 1, Figure 7) or the mottled clay fragments. The maximum Au contents of these sample media barely exceeded the detection limit of 5 ppb.

No additional information was gained by partial extraction analysis carried out on the soil <250 µm fraction. Two sequential extraction methods were used, (1 M acetate buffer at pH 5, followed by 0.25 M hydroxylamine hydrochloride), to extract Mn oxides and amorphous Fe oxides.

Extensive Au anomalies occur in the colluvium overlying lateritic residuum in the Central Pit area. Similar anomalies in colluvium have been noted at Mt Gibson (S, C, N and Midway pits), Lawlers (North and Turret pits) and at Mt McClure (Calista Deposit) (Anand *et al,* 1989, Anand *et al,* 1993). The processes involved in their development are discussed in section 3.4.

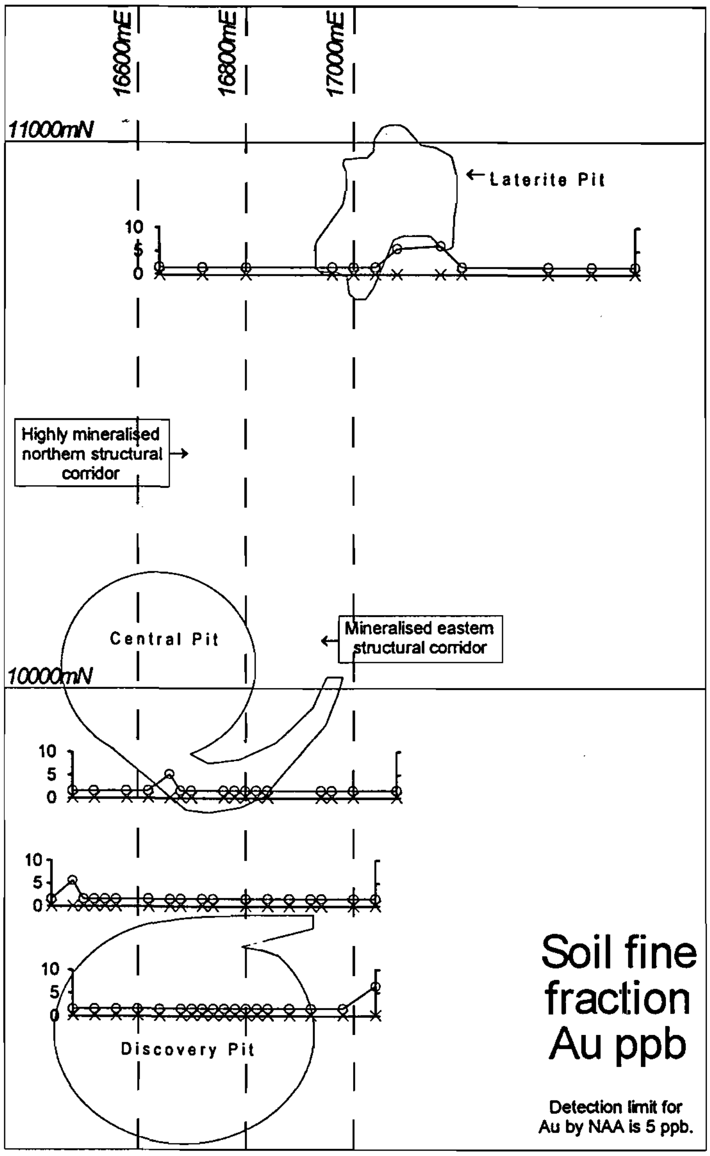


Figure 7: Soil <250 µm fraction: Au distribution.

3.3 GEOCHEMICAL RESPONSE IN THE LATERITIC GRAVELS AND DURICRUST

Lateritic gravels and duricrust in the Laterite and southern Central Zones contain significant Au signatures (Figure 8) over the primary mineralisation. The most notable zone of Au enrichment in the regolith at Bronzewing was within the variably indurated lateritic duricrust of the Laterite Zone with concentrations up to 9060 ppb (Figure 8). The underlying bedrock is mineralised, although subeconomic. Euhedral secondary Au crystals, to approximately 5 µm diameter, were observed in the lateritic nodules and pisoliths, precipitated within cracks and voids. In contrast, the Discovery Zone has less consistent Au anomalies than those further north (Figure 8).

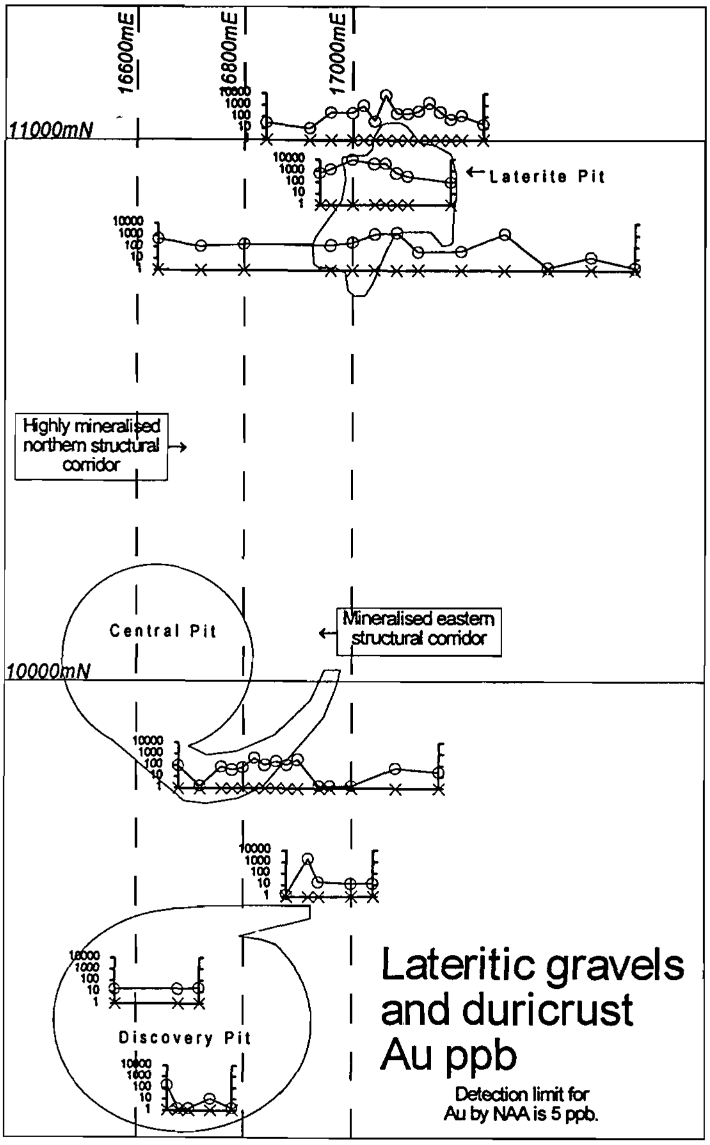


Figure 8: Lateritic gravels and duricrust: Au distribution.

In the Laterite Zone, elements associated with Au mineralisation in the lateritic gravels and duricrust are Ag, Ga, Ba, Ce, W, Mo, As, Sb and Cu. Further south, in the Central and Discovery Zones, Cu and W are enriched within lateritic gravels, duricrust and ferruginous saprolite close to primary mineralisation. Stacked profile plots of Cu, W and Ag in lateritic gravels and duricrust are shown in Figures 9 to 11.

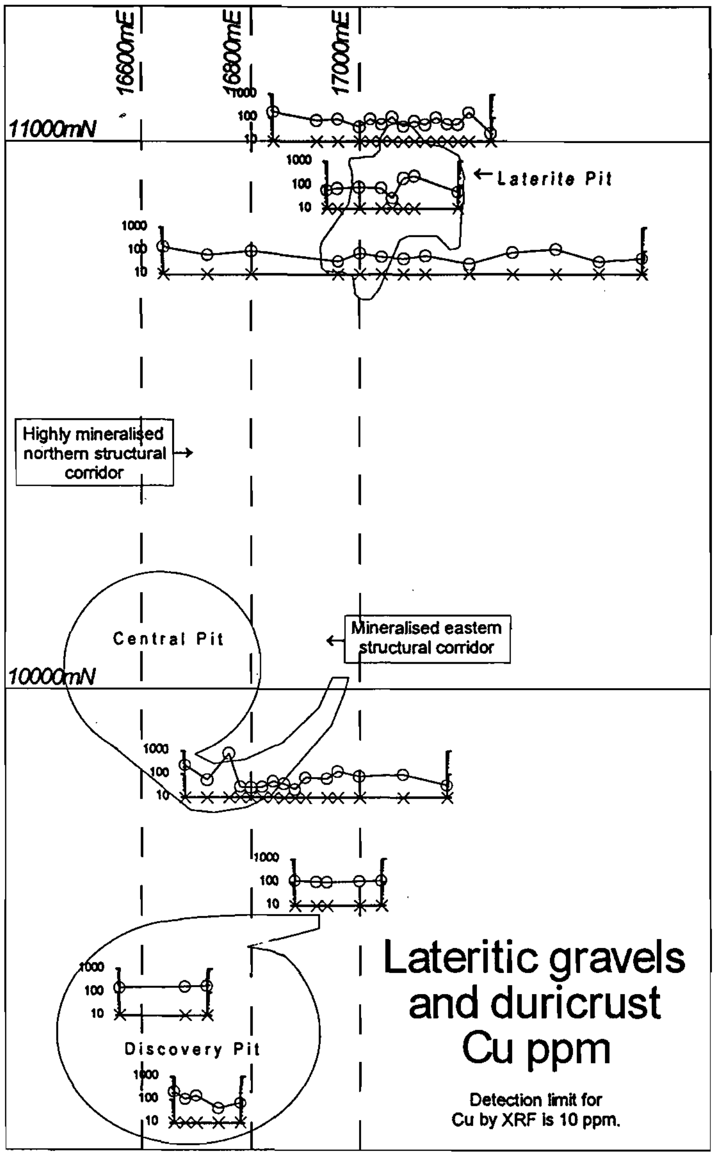


Figure 9: Lateritic gravels and duricrust: Cu distribution.

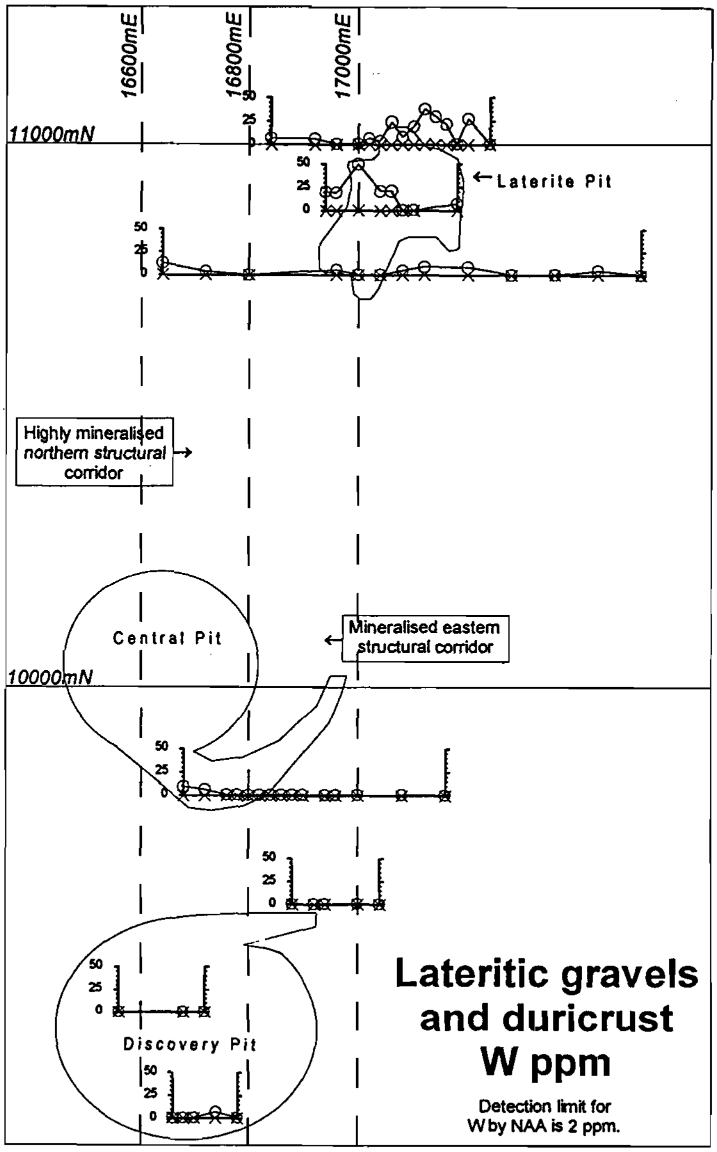


Figure 10: Lateritic gravels and duricrust: W distribution.

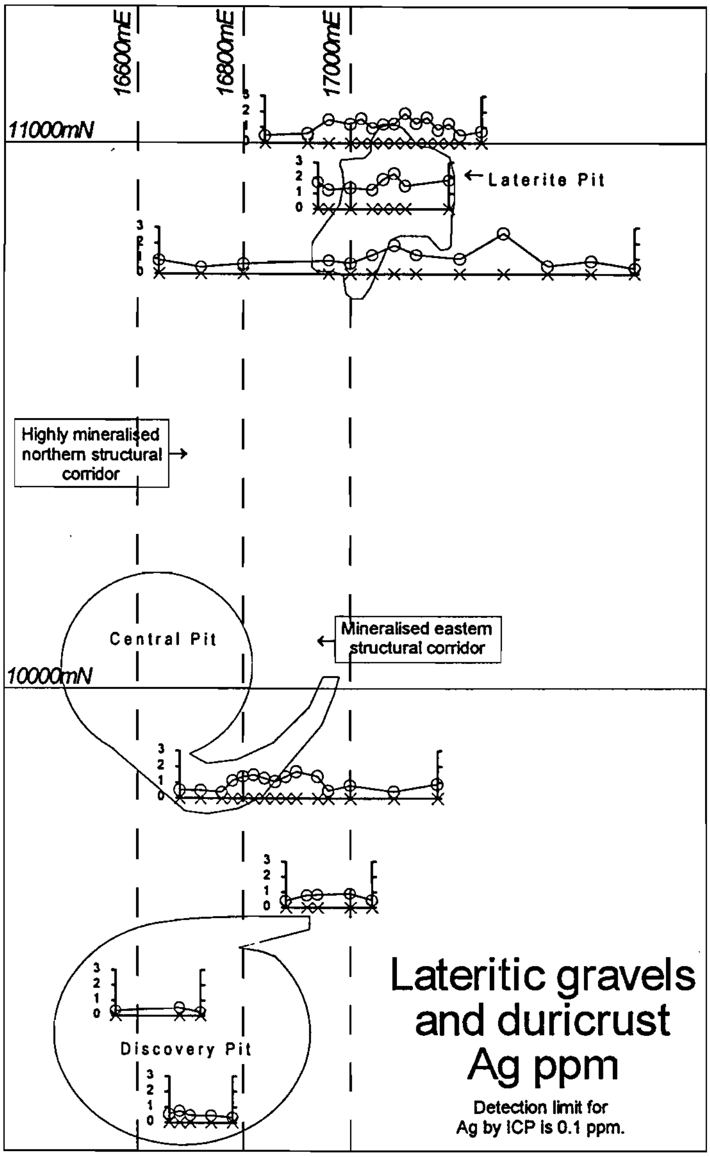


Figure 11: Lateritic gravels and duricrust: Ag distribution.

3.4 DISPERSION INTO COLLUVIUM

The buried lateritic residuum contains Au to ore grade which, in places, extends into the colluvium. This relationship was examined in the Central Pit where essentially residual materials were overlain by 15 m of colluvium in a mineralised environment. In the north wall, the colluvium consists of hematitic clays and ferruginous nodules and pisoliths of probable local origin. The Fe gravels in the colluvium are generally fine-grained (<0.5 cm), with worn, or no cutans. The underlying lateritic gravels consist mainly of nodules and pisoliths larger than 0.5 cm, with goethitic cutans, in a goethite-clay matrix.

In order to distinguish between mechanical and hydromorphic dispersion processes across the contact, the samples were separated into different size fractions. This is based on the assumption that hydromorphic dispersion will precipitate Au on the more chemically active surfaces of finely divided Fe oxides and clays, in contrast to mechanical dispersion of Au in nodules and fragments of ferruginous saprolite. Concentration of the Au in the fine fractions would suggest hydromorphic processes are predominant and concentration in the coarse fraction would suggest mechanical dispersion.

Eighteen samples were collected from the pit wall above and below the interface (Figure 12). The samples were each separated into six size fractions and the largest (>2 mm) and smallest (<75 µm) analysed by XRF and INAA, together with a bulk sample.

The Au analyses for bulk, fine and coarse samples are shown in Figure 13. In most samples the Au is concentrated in the >2 mm fraction and depleted in the <75 µm fraction relative to the bulk sample. The only reversal of this trend is at two metres above the interface in profile one, where the fines contained over 4 ppm Au. No reason could be found for this variation.

There is no evidence to show that hydromorphic dispersion is leading to an accumulation of Au in the fine fraction. Mechanical dispersion is strongly suggested by the concentration of Au in the coarse fraction above the unconformity. The palaeosurface represented by the unconformity has a 6% slope and there are sufficient mineralised lateritic nodules upslope to source the Au in the colluvium. Another factor in Au dispersion at Bronzewing is that complexation and dispersion of Au by chloride in the oxidised environment cannot occur because the groundwater is fresh. Chemical dispersion above the water-table would therefore be dependent on organic complexes and, below the water table, on sulphur complexes derived from the two percent sulphur in the ore.

4. ACKNOWLEDGMENTS

Assistance from Great Central Mines was provided by Jim Wright, Ian Herbison, Gus Bravo, Ian Blucher, Mo Munshi, Jim Cooper, Kevin Alexander and Murray Surtees. Support was given to the two honours projects carried out by Steven Varga and Roger Crawford by the Centre for Ore Deposits and Exploration Studies at the University of Tasmania Geology Department. Polished sections were prepared by John Crabb and Ray Bilz. Geochemical and mineralogical analyses were by Mike Hart (XRF and XRD) at CSIRO, Analabs (ICPMS) in Perth and Becquerel Laboratories (INAA) at Lucas Heights. Drafting and artwork was prepared by Angelo Vartesi and the document was formatted by Gill Ashton. General assistance was also provided by Cajetan Phang. Charles Butt provided critical review of the manuscript. All this assistance is acknowledged with thanks.

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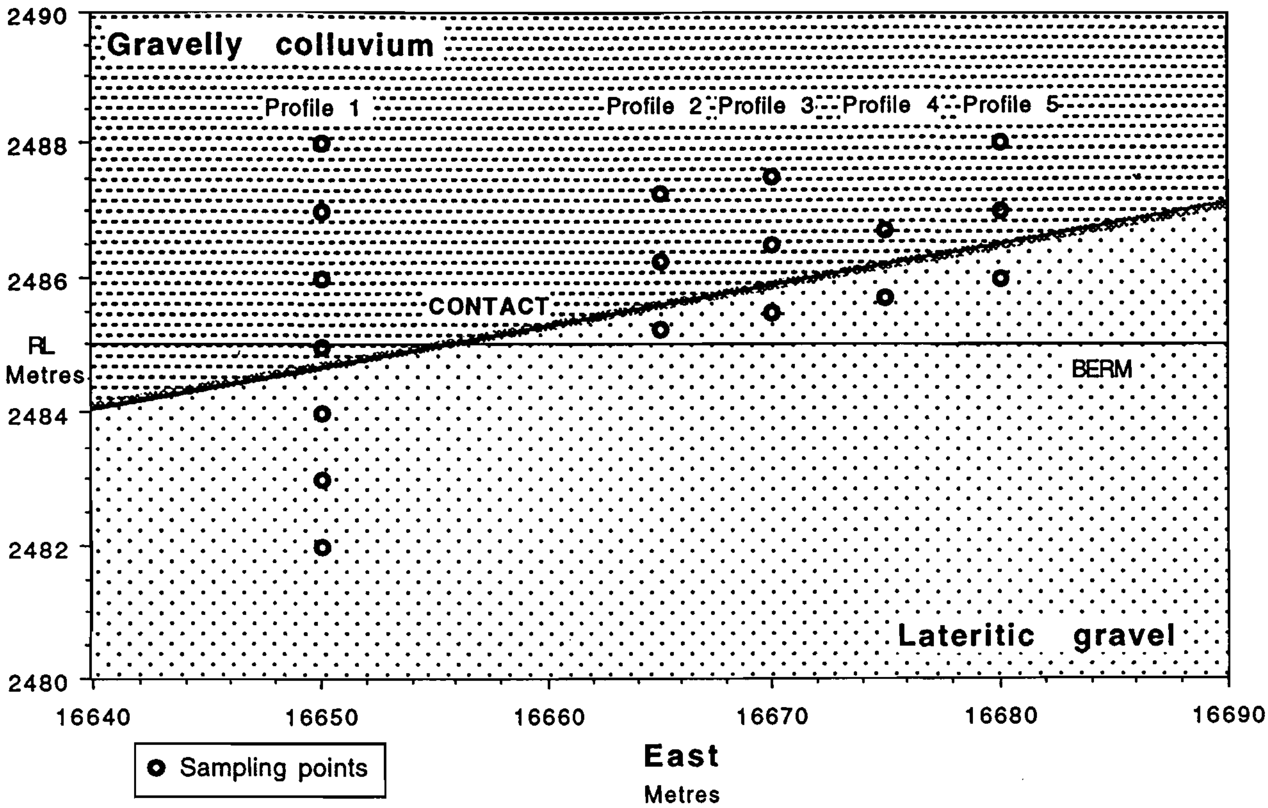

Figures 12: North wall of Central Pit: geochemical dispersion sample points.

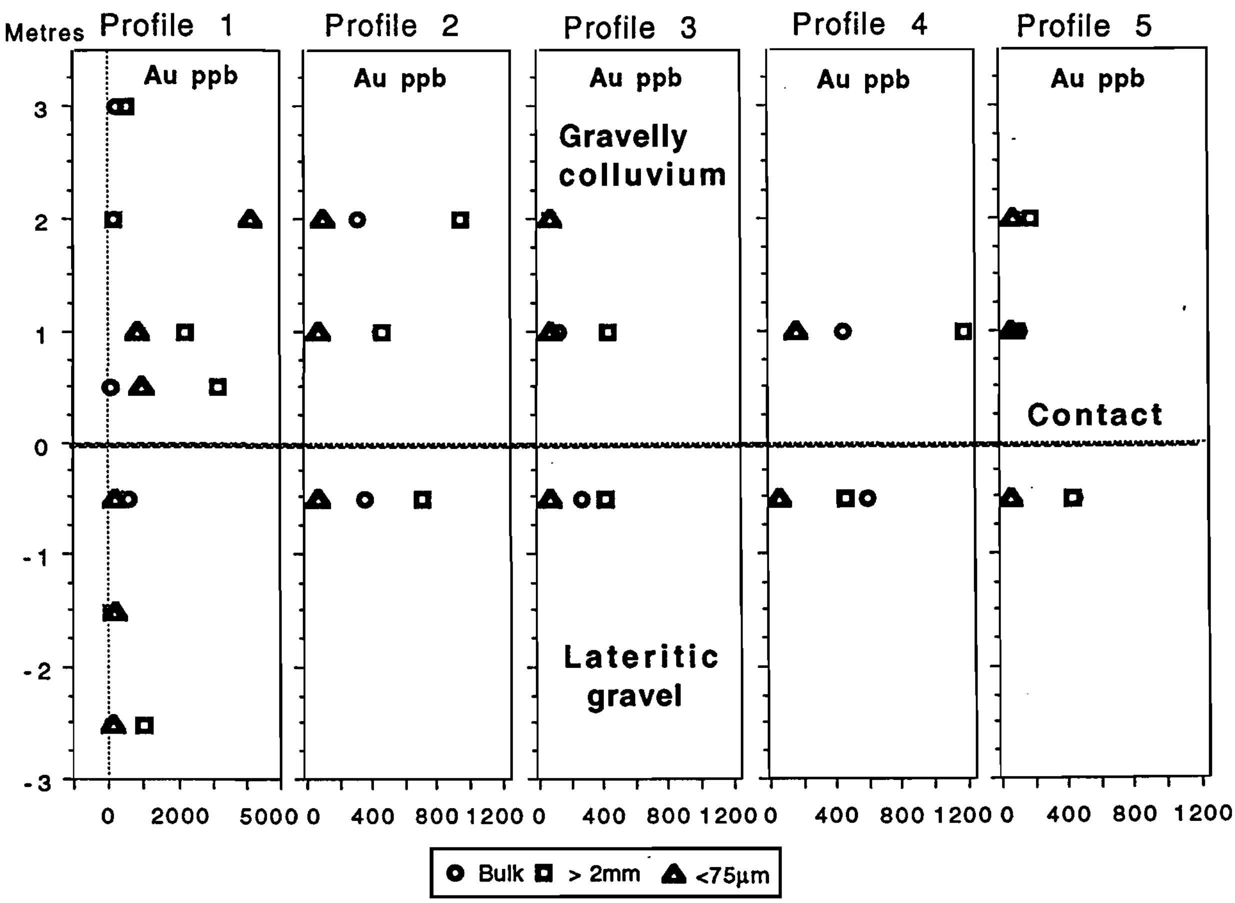

Figure 13: North wall of Central Pit: Au concentration.

LAWLERS DISTRICT

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1. INTRODUCTION

The Lawlers district, an area of some 500 km^2, contains truncated laterite profiles on uplands and lateritic residuum buried under thick transported sequences, marked by extensive plains. The sparse vegetation permits interpretation of processes of regolith and landscape evolution not visible in thickly vegetated, high rainfall regions. The Lawlers district is an example of some important exploration problems in the north Yilgarn Craton (Anand *et al.*, 1991a).

Geochemex Australia commenced a regolith geochemical exploration programme over the Lawlers district for Forsayth N.L. in 1987. An early phase of that work was a district-scale surface and near-surface laterite sampling programme.

The CSIRO research at Lawlers, which commenced in November 1988, provided an understanding of the regolith and became an integral part of the exploration. It included regolith mapping, regolith stratigraphy, characterization of regolith units, regolith evolution and mechanisms of geochemical dispersion in type areas as a basis for the development of regolith-landform and geochemical dispersion models.

A satisfying result of the collaboration at Lawlers was the discovery of the Turrett and Waroonga Au deposits as a direct result of the experimental exploration programme. Both were discovered by drilling and recognizing buried geochemical haloes in laterite. The halo of the Waroonga deposit was beneath 7 m of hardpanized transported sediments. Open pit mining commenced at these deposits in the latter half of 1990 and has provided exposure of both the cover sequences and the buried laterite profiles. This account is derived largely from Anand *et al.*(1991a) and Smith *et al.* (1992).

Plutonic Operations Limited manages operation at McCaffery, North, Turrett, Waroonga and Genesis open cut gold mines.

2. REGIONAL AND LOCAL GEOLOGY

The Lawlers district lies within the Agnew supracrustal belt of the Archaean Yilgarn Craton. The Lawlers greenstone sequence is up to 3 km thick and consists of interlayered high-Mg basalt, ultramafic rocks, gabbro and differentiated gabbro-pyroxenite-peridotite sills, thin, fine-grained sedimentary and silicic, volcanogenic layers (Platt *et al.*, 1978). Some ultramafic units show spinifex textures. The gabbroic sills are up to 300 m thick; they are concordant to the stratigraphy and are laterally very extensive. Volcanic and sedimentary units are interlayered with sills throughout the sequence which is also intruded by tonalite. The most prominent structural feature in the area, a major north plunging upright fold, the Lawlers Anticline.

The Lawlers greenstone sequence is overlain on the west side of the Lawlers Anticline by the Scotty Creek sedimentary sequence. This is about 1500 m thick and consists of a basal conglomerate derived from mafic and ultramafic units within the Lawlers greenstone sequence (Platt *et al.*, 1978).

Gold deposits in the Lawlers district fall into the three broad categories. These are: disseminated Au within alteration haloes ± quartz vein systems in shear zones (*e.g.* Great Eastern, McCaffery, Weight Hill, North Pit and Turrett); altered and sulphidic shoots with little or no quartz in major shear zones (*e.g.* Emu, Redeemer); and quartz stockworks and ladder veins in metasediments (*e.g.* Genesis).

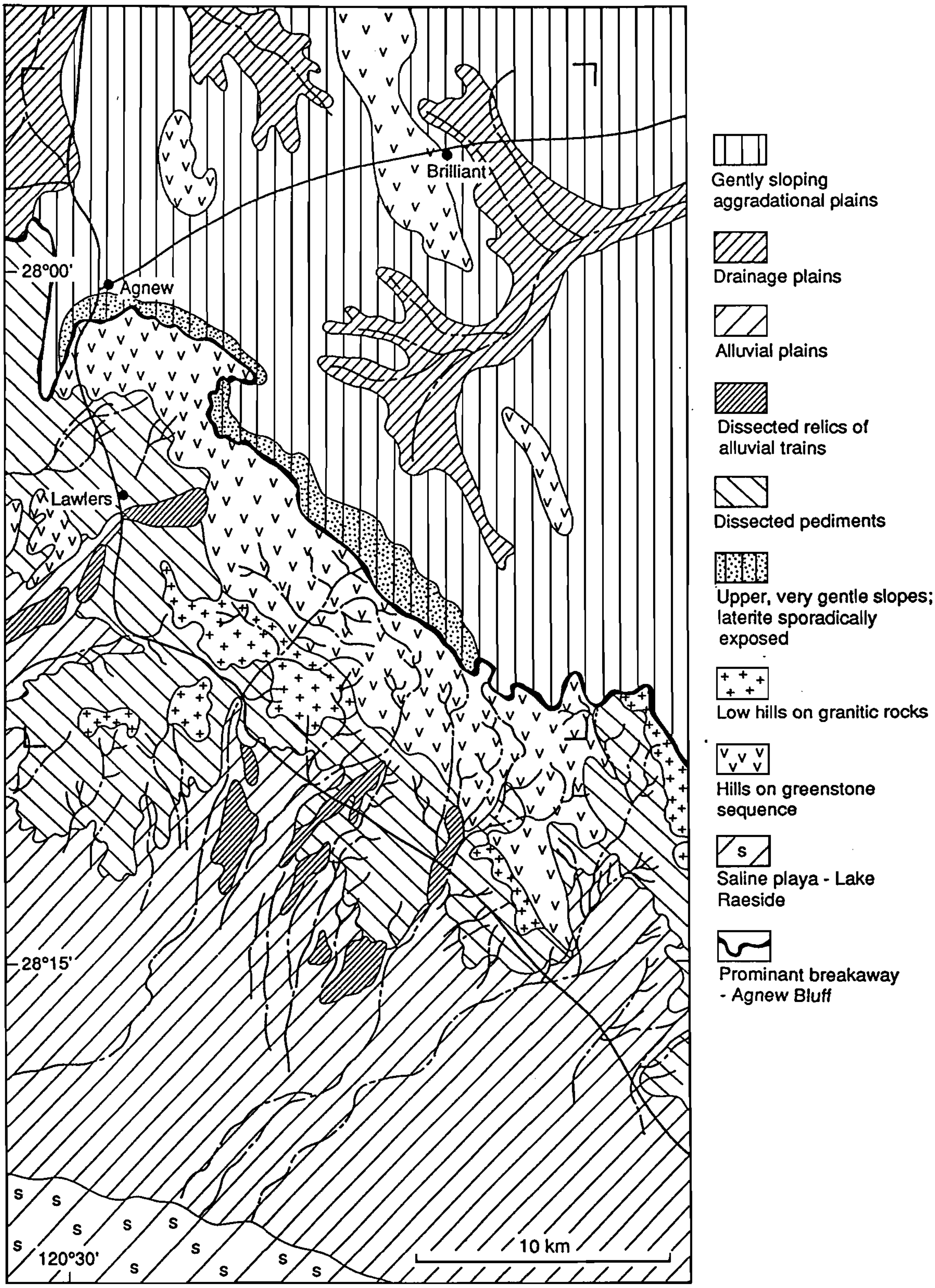


Figure 1 Generalized geomorphology of the Lawlers region. (From Anand *et al.*, 1991.)

Gold from any of the primary categories has been redistributed and concentrated by weathering into the saprolite and in the overlying lateritic residuum. This secondary Au mineralization forms a new category. It is important as it forms low to medium tonnages of low-grade Au resources that are easily mined and processed, (*e.g.* the laterite ore at North Pit, Turrett and Waroonga).

3. GEOMORPHOLOGY AND DRAINAGE

The Lawlers district is situated on the Great Plateau of Western Australia (Jutson, 1950). It is a broadly-undulating terrain with scattered belts of hills providing some local relief. More detailed relief variation, such as at breakaway scarps, is the result of differential stripping of an extensive deeply-weathered mantle and by localized deposition of detritus resulting from this process.

This district straddles a divide between the Lake Raeside drainage to the south and that of Lake Miranda and Lake Darlot to the north. For much of its length, the northwest oriented divide comprises the crests of prominent breakaways, the Agnew Bluff (Figure 1). Extensive erosional tracts extending south from these breakaways are first dominated by hill belts. These hill belts give way, southwards, to gently-sloping pediments, thinly mantled by debris from the immediate hinterland.

By way of contrast, north of the divide the topography is dominated by long, very gentle, smooth slopes. Many of these have their origin on the broadly-convex laterite-mantled crests, immediately above the Agnew breakaway and gradually merge down to broad alluvial floors of tributary valleys, and thence to the main drainage sumps of Lake Darlot and Lake Miranda. Alluvial floors, often associated with a complex of minor meandering channels, are little incised below the main alluvial plain and the drainage often terminates on sandplain tracts over granitic rocks.

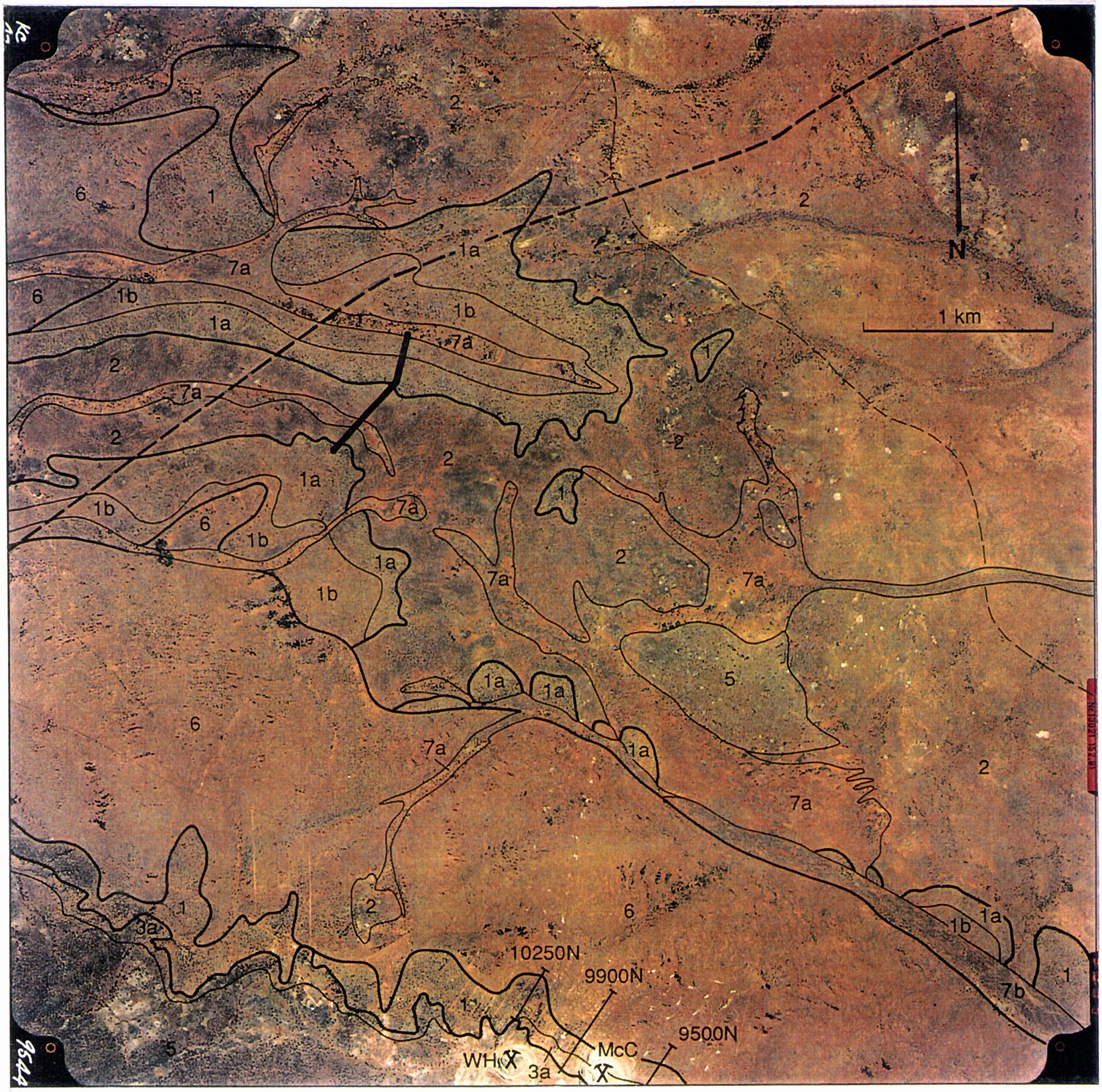
4. REGOLITH

4.1 THE SURFACE DISTRIBUTION OF REGOLITH UNITS

Figure 2 shows the distribution of regolith-landform units for the Agnew-McCaffery area. *Relict regimes,* characterized by widespread preservation of lateritic residuum, constitute about 15% of the surface landscape. Unit 1 in the relict regime is mantled by Fe-rich black pisolitic-nodular lateritic duricrust, yellowish brown duricrust and lateritic nodules and pisoliths. This unit generally merges downslope into colluvium, Unit 6. *Erosional regimes* comprise terrain within which ferruginous saprolite, mottled zone, saprolite, or fresh bedrock are either exposed, or are concealed beneath soils or patchy locally derived sediments. Units in the erosional regimes are dominated by largely residual soils on bedrock and saprolite, lag derived from bodies of iron segregations, ferruginous saprolite, saprolite and vein quartz. *Depositional regimes* include colluvial and alluvial outwash plains (Units 6 and 7). These form widespread regolith-landform units that account for about 40% of the mapped area. The origin of the sediments may range from local to distal and the thickness of which can reach tens of metres. These depositional units commonly conceal extensive areas of complete or nearly complete lateritic weathering profiles.

4.2 REGOLITH STRATIGRAPHY AND MINERALOGY

Although regolith mapping indicated a general relationship between the surface regolith types and landforms, drill spoil and open pits examined during this phase, showed changes in the regolith which were not evident on the surface. A more complete picture of the regolith, including stratigraphic relationships are needed to formulate a rational sampling strategy for mineral exploration in this type of weathered terrain. Detailed observations were made at a number of type locations including McCaffery, North, Turrett, Meatoa, Waroonga and Genesis gold deposits.



EROSIONAL REGIMES

2 Soil, lag, on saprolite

3a Mottled zone saprolite

5 Subcrop of bedrock

RELICT REGIMES

1 Lateritic residuum

1a duricrust

1b gravel

Gradational subdivision within Unit 2

DEPOSITIONAL REGIMES

7 Alluvium

7a in minor tributaries

7b in major tributaries

6 Colluvium as sheet wash

Traverse

Regolith cross sections from Anand et al (1989)

McCaffery and Weight Hill mine pits

Agnew-Leinster road

Figure 2 Map showing the surface distribution of regolith units and vegetation for the Agnew-McCaffery area as an overlay to the colour air photograph (Photo 4/9544, 6.12.1988). Bedrock lithologies are mafic and ultramafic. (Modified after Anand *et al.*, 1991a.)
Airphotograph taken by Kevron Aerial Surveys, published with permission of Homestake Gold of Australia Limited

McCaffery-North-Turrett Deposits

The McCaffery-North-Turrett pits are located on the backslopes of the breakaway. Colluvial outwash plains, sloping at approximately 1°, extend eastwards from a breakaway scarp, towards a southeast-draining braided fluvial system. Here, bedrocks are generally weathered to 30-80 m depth. In the *McCaffery-North Pit* area, an extensive, but somewhat discontinuous, horizon of essentially-residual laterite is unconformably overlain by a varying thickness of colluvium, which itself has components derived by partial or complete stripping of lateritic residuum and ferruginous saprolite (see Figure 7).

Transported overburden

The plains in the North Pit area, as elsewhere in the Lawlers tenements, have a loose surface veneer of mixed lithic and lateritic debris that overlies a layer (up to 4 m in thickness, but typically 0.5-2 m) of unconsolidated, coarse, polymictic gravels. It is crudely bedded and shows some imbrication of the larger flattened clasts. These gravels fine downwards into thick deposits of loams, sandy loams and puggy grey-white and white clays interstratified with more gravel-rich intervals that may include transported lateritic nodules and pisoliths. Drilling has established that the total colluvial sequence exceeds 10 m in thickness and may reach about 40 m (see Figure 7). In places, the transported overburden is lateritized, showing development of mottles and nodules.

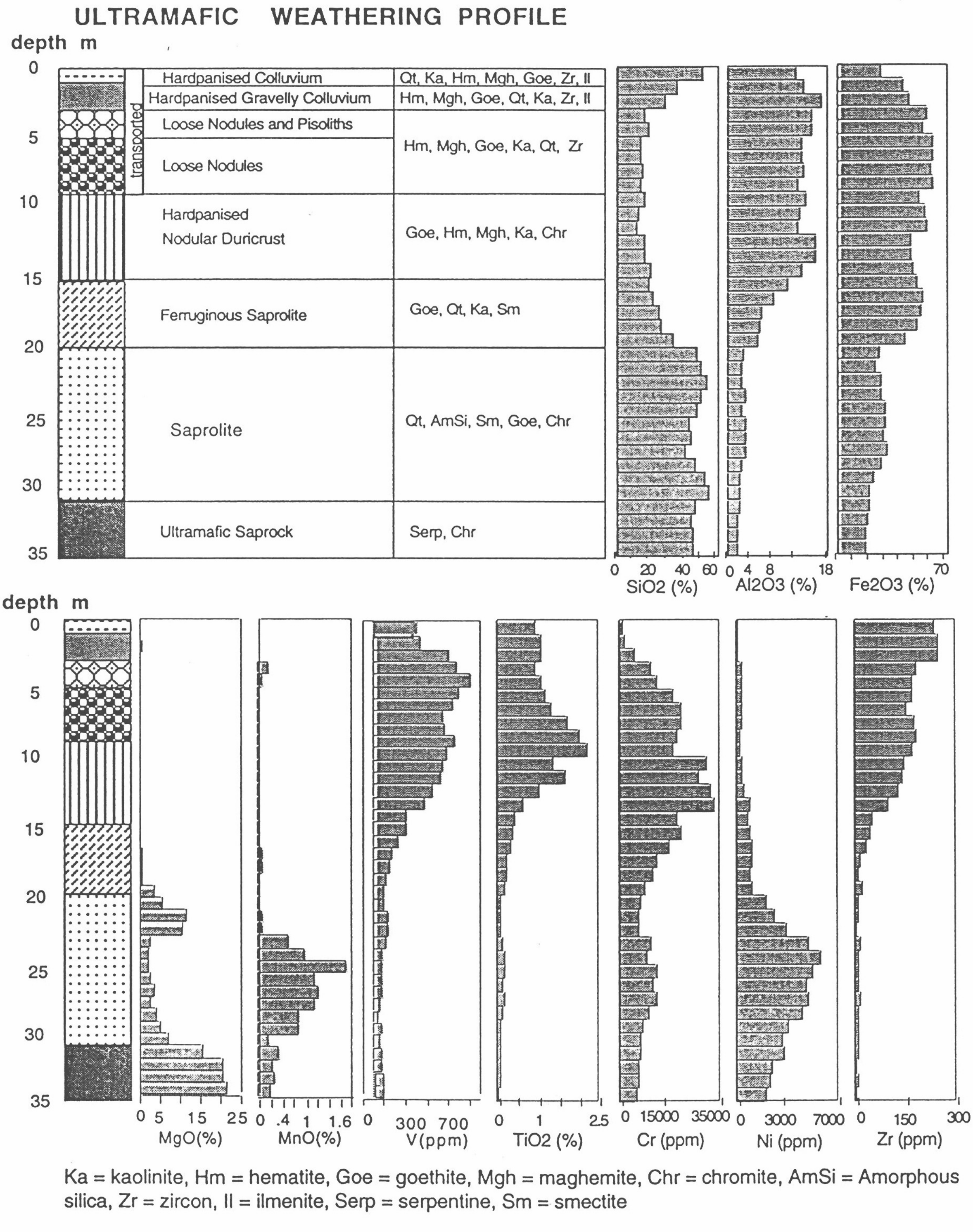
Within the colluvium, there is a type of lateritic gravel that differs from the other gravels in colour, presence or absence of cutans and/or lithorelics, and mineralogy. Variations in concentions of Fe_2O_3, Al_2O_3 and SiO_2 in the colluvium are due mainly to differences in the abundance of Fe oxides (hematite, goethite, maghemite), quartz and kaolinite (Figure 3). Smectite, ilmenite, rutile and zircon also occur in colluvial units. Differences in the nature and abundance of secondary minerals in colluvium simply reflects the diverse provenance of these materials.

Authigenic *hardpanization* affects much of the colluvial profile and reaches a maximum development in the near-surface, more coarsely-clastic gravels. Near surface, hardpan exhibits a sub-horizontal lamination or inter-clastic "pseudo-foliation" or parting and the colour is brownish changing to a characteristic brick-red with depth. The hardpan matrix is characteristically porous. Deposits of glassy, botryoidal opal (hyalite) and films of black Mn oxide are present in pores and fractures in the upper half of the hardpanized profile. In detail, hardpanization is not stratigraphically controlled, but transgresses lithologic contacts and locally extends down through colluvium into the underlying residual loose nodular laterite.

Residual profile

The top of the residual laterite profile is composed of a layer of lateritic residuum averaging some 3 to 8 m in thickness (Figure 3 and Figure 4). It consists of layer of loose pisoliths and nodules than may be underlain by a layer of nodular duricrust. The lateritic duricrust, in turn, is underlain by a zone of ferruginous saprolite characterized by bodies of iron segregations (Figure 4). Ferruginous saprolite forms a continuous horizon, several metres thick, through much of the Lawlers district, particularly over mafic and ultramafic lithologies. Ferruginous saprolite grades downwards into saprolite, which extends to vertical depths of 20 to 70 m.

Serpentinized ultramafics have three chemical components, MgO, SiO_2, Fe_2O_3; the Al content is very low (2%) (Figure 3). The restricted mineralogical and chemical composition results in a very distinctive regolith, characterized by intense silicification and ferrugnization of the saprolite. The ultimate effect of weathering is the complete loss of Mg and the partial retention of Si and Fe. However, there has been some lateral addition of Al.



Ka = kaolinite, Hm = hematite, Goe = goethite, Mgh = maghemite, Chr = chromite, AmSi = Amorphous silica, Zr = zircon, Il = ilmenite, Serp = serpentine, Sm = smectite

Figure 3 Mineralogy and geochemistry of weathering profile developed over ultramafics, Lawlers.

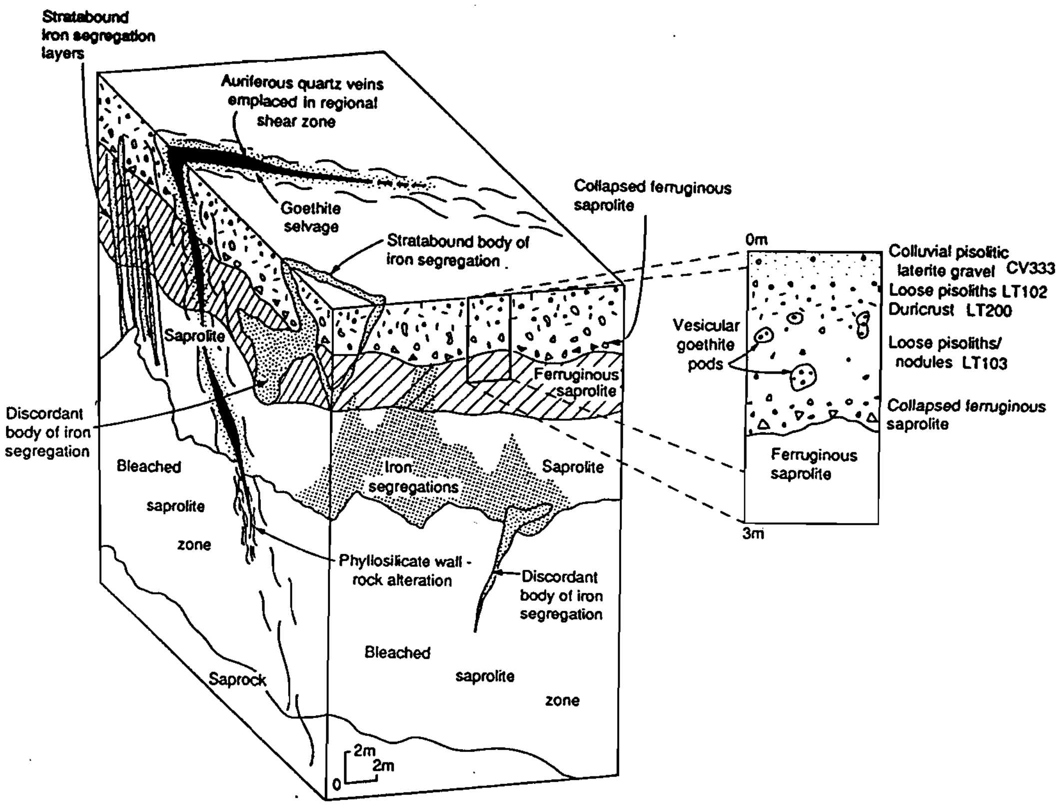


Figure 4 Detailed block diagram showing field relationships for several categories of lateritic materials and iron segregations. (From Anand *et al.*, 1989b.).

The mineralogy and geochemistry of the lateritic profile reflect the composition of underlying bedrocks (Figure 3). Iron oxides (hematite, goethite, maghemite) and kaolinite constitute the two mineral phases, both can represent 70-90% of total. However, in lateritic duricrust developed over ultramafics, kaolinite is generally much less abundant compared to duricrust developed over mafic rocks. Gibbsite occurs in residual duricrust but not in the transported lateritic nodules and pisoliths. These differences in mineralogy may be, in part, explained by the absence of cutans in transported nodules; cutans are generally rich in goethite and gibbsite. Residual resistant minerals such as chromite and rutile are also present.

Goethite, smectite, kaolinite and quartz are present in ferruginous saprolite. Smectite is more abundant on ultramafic rocks than on mafic rocks. Saprolite is composed of moderately well crystalline kaolinite and di-octahedral smectite with various amounts of goethite, amorphous silica and quartz.

In general terms, stratigraphic sequences observed in eastern and western walls of *Turrett Pit* are similar to those of North Pit. However, the colluvium is shallow and reaches a maximum thickness of only 6 m and bodies of *iron segregations* are relatively more abundant. In the western wall of Turrett Pit, gravelly colluvium (3 m) overlies the 6-7 m thick pisolitic lateritic residuum. At depth, lateritic residuum merges into yellowish-brown collapsed ferruginous saprolite.

Waroonga-Genesis Deposits

The deposits are located within the Scotty Creek Sequence of metasedimentary rocks and thus contrast with the dominantly mafic/ultramafic settings of the McCaffery, North Pit, Turrett and Meatoa areas. The Scotty Creek metasediments consist mainly of a series of very fine grained, psammitic units within which a 15 m thick coarser unit occurs, which hosts the orebody. Weathering is most advanced in the vicinity of the orebody, although its resistant nature results in persistence, unaltered, through the saprock. Immediately adjacent to the orebody, the southern wall comprises fresh bedrock (7 m), saprock (17 m), saprolite (16 m), mottled zone (6 m) and transported overburden (6 m). The weak development of lateritic residuum and the lack of iron segregations may be related to the Fe-poor bedrock. In contrast, lateritic residuum over mafic and ultramafic rocks at North Pit and Turrett Pit is relatively much thicker and ferruginous.

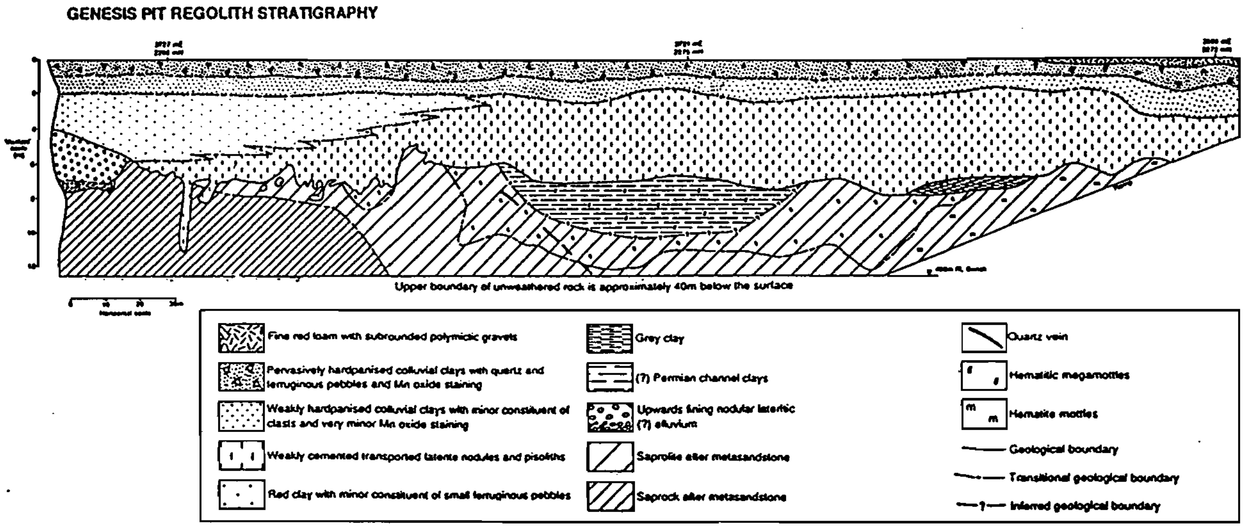


Figure 5 Regolith stratigraphy of the south and west walls of the Genesis Pit. (From Ward, 1993.)

In the Genesis Pit, the Archaean bedrock has been incised by Permian glaciofluvial channels. The saprolite and part of the mottled zone are developed in Archaean rocks but the upper mottled zone and lateritic horizon are developed in Permian clays (Figure 5). These, in turn, are overlain unconformably by various colluvial/alluvial horizons, including upper layers of lateritic gravel and silt, silicified to hardpan. A thin palaeosol occurs between mottled Permian clays and the colluvium/alluvium.

5. REGOLITH-LANDFORM MODEL

The generalized regolith-landform model summarizing the regolith-stratigraphy for three dominant regimes is shown in Figure 6. The development of the regolith of the Lawlers district can be related to processes of deep lateritic weathering, subsequent erosion, deposition and modification through leaching and cementation. The dominant features are a residual lateritic weathering profile that undulates over the landscape, erosion partly dismantling the lateritic residuum and ferruginous saprolite, cutting into the saprolite, and the resulting debris being deposited as colluvium and alluvium in areas of low relief. From this study, it is now well established that the buried residual laterite profiles are widespread beneath the sediments. Their distribution is, however, erratic and difficult to predict because of the partial stripping of the old surface.

The general distribution of lag gravels can be understood in terms of regolith-landform relationships. In the erosional regimes, coarse black lags of iron segregations, or lags of fragments of ferruginous saprolite (where stripping is less extensive), appear to be largely the result of present-day *in situ* weathering. Similarly, lateritic lag comprising nodules and pisoliths is the *in situ* product of present-day weathering of lateritic duricrust. The lag may have been concentrated at the surface by a variety of processes including deflation, sheetwash and bioturbation (Mabbutt, 1980; Carver *et al.*, 1987). These *in situ* lags have been further subjected to physical and chemical weathering and dispersion processes. Lateral dispersion of these lags by the action of water has resulted in a layer of fine lag comprising a variety of clasts on the colluvial outwash plains.

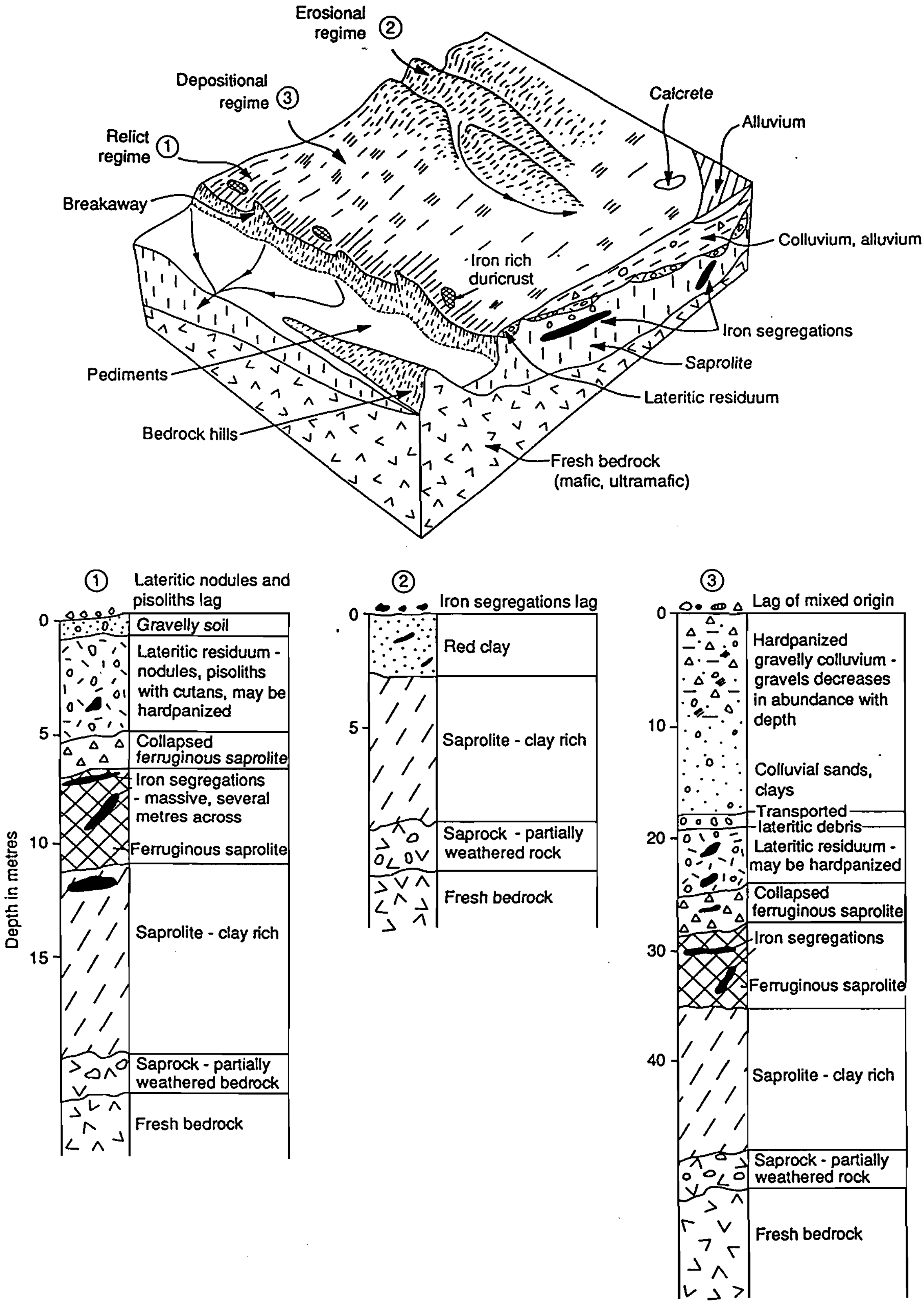


Figure 6 Regolith-landform model for the Lawlers district. Columns show units of the regolith stratigraphy in the regimes. (From Anand *et al.*, 1991a.)

6. GEOCHEMICAL DISPERSION - NORTH AND TURRETT DEPOSITS

North Deposit

The discovery of the North and Turrett Pits within Lawlers district demonstrate the effectiveness of drilling for buried geochemical haloes in laterite and ferruginous saprolite. The deposits form the high-grade part of a chalcophile multi-element (Au, As, Cu, W, Sb and Bi) geochemical anomaly. (Figure 7 and Figure 8.)

Prior to mining at North Pit, lateritic and saprolitic Au resources lay beneath 10 to 20 m of hardpanized colluvium. The bedrock mineralization continues to the south within the McCaffery Pit. Gold from this source has been redistributed and concentrated by weathering into the saprolite and overlying lateritic residuum.

Samples of specific units within vertical profiles were taken from drill spoil. Residual lateritic pisoliths/nodules of lateritic residuum typically have 1-2 mm thick yellowish-brown/greenish cutans around black/red nuclei. Pisoliths are round to sub-round and are 5-20 mm in diameter. The presence of cutans may be used to recognize nodules derived from the breakdown of lateritic residuum. Fragments of ferruginous saprolite differ from lateritic residuum in having a yellow-brown colour, irregular shape and are non-magnetic with incipient nodular structure. The gravel fraction from colluvium displays features that are indicative of an inherited, transported origin. Iron segregations can be recognized by their irregular, black, non-magnetic and pitted surfaces.

Unconsolidated colluvium: The inhomogeneity of the colluvium, with varying amounts of gravel, sand and clay, imparts a wide variation in major element composition. Manganese abundance is greatest in the upper part of the colluvium, reaching several thousand ppm within 10-40 cm of the surface, a function of pedogenic processes. This enrichment is visible in exposures as coatings of black Mn oxides on pebbles within the near-surface zone.

Detailed sampling showed high relative abundances of Fe, Mn, Cr, V and Ni in loose, near-surface colluvial gravels due to a higher content of lateritic debris and fragments of iron segregations in the upper part of the profile. Gold, Ag, Pb and Sb are also moderately abundant in the near-surface colluvium.

Hardpanized colluvium: Most chalcophile elements have similar abundances to those in the unconsolidated colluvium, but As (to 640 ppm) and Au (to 140 ppb) are significantly higher. Detailed profiles show a strong correlation between the content of Si, Mg, Ca, Na and K and the development of hardpan. The same detail shows a trend of increasing As downward in the colluvium, the highest As abundances being below the hardpan zone.

Loose nodules and pisoliths: Loose nodules and pisoliths are enriched in SiO_2 and Al_2O_3 and depleted in Fe_2O_3 relative to the underlying duricrust. Copper, Pb and Bi are enriched in loose nodules near the base of residual laterite, below the nodular duricrust in this area. Arsenic, Ag and Au give a stratigraphically-confined response associated with the laterite horizon, generally with a very sharp reduction in the underlying saprolite and overlying colluvium.

Nodular duricrust: Analyses of duricrust indicate that highly-anomalous Au (to 18 ppm), Ag (to 0.8 ppm), As (to 1680 ppm) are associated with residual duricrust. There are significant geochemical differences between the residual loose, nodular unit and the duricrust in the North Pit area.

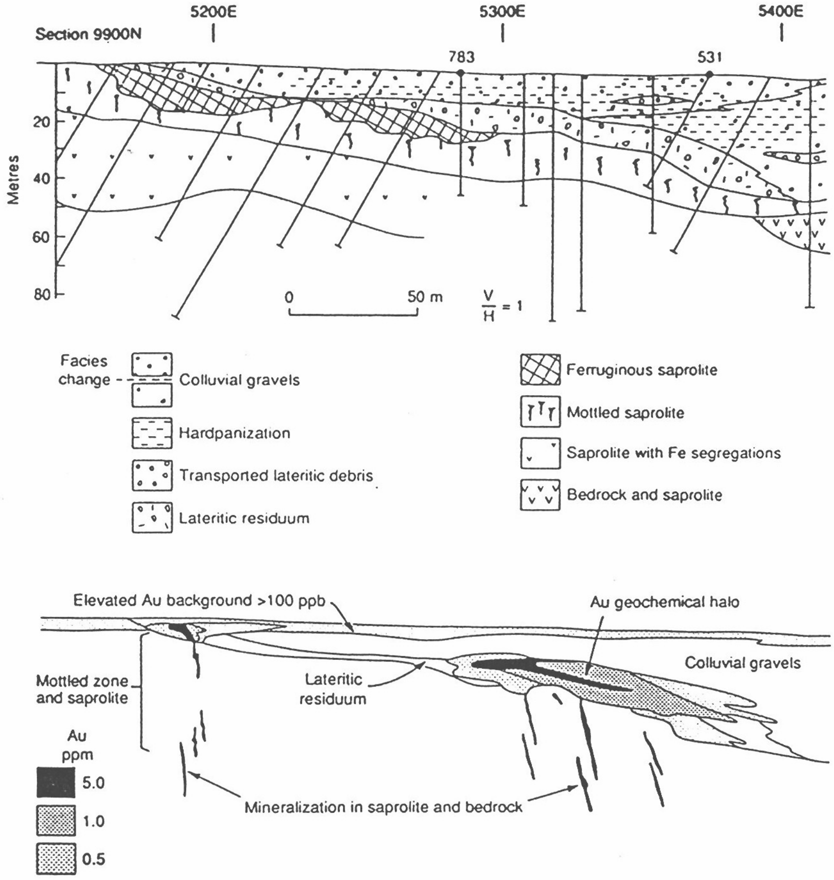


Figure 7 Diagrammatic cross-section along line 9900N in the North Pit area showing regolith stratigraphy and dispersion of Au in lateritic residuum. (From Smith *et al*., 1992.)

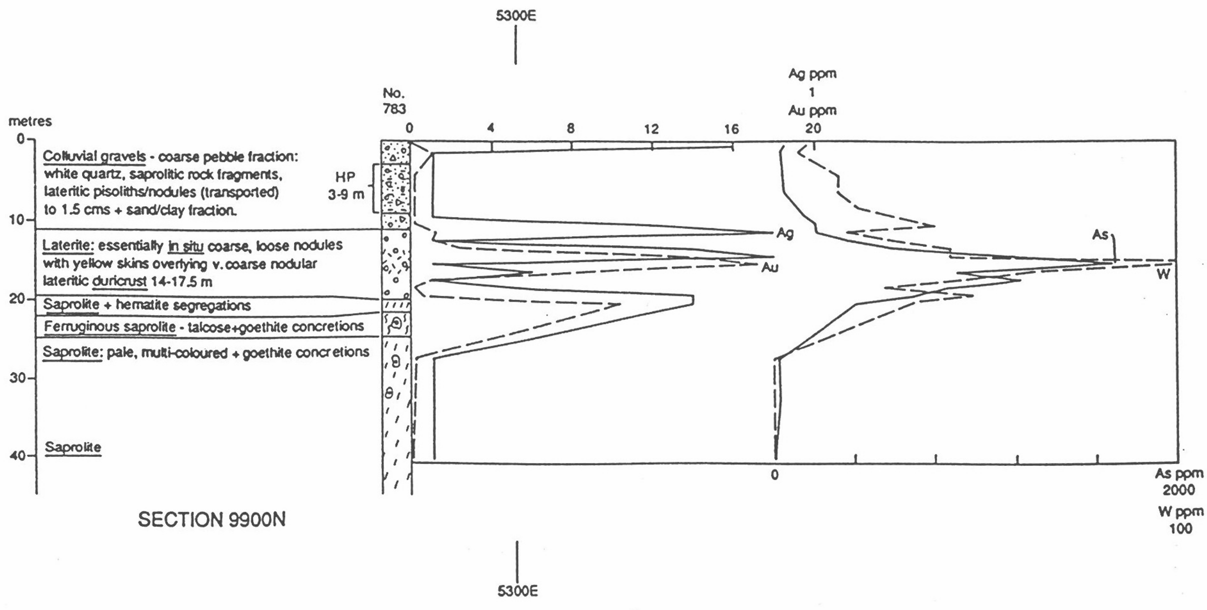


Figure 8 Vertical profile of regolith stratigraphy and geochemistry of regolith units intersected by drill hole 783. (From Smith *et al*., 1992).

Gold in lateritic nodules from the North Pit occurs as fine particles (<15μm) in cracks, and as relatively large, dendritic grains (to 70μm), attached to the surface of goethite. Both types are almost free from Ag and are probably secondary.

Ferruginous saprolite: Many of the ore-related elements (Cu, As, W, Ag) in ferruginous saprolite exhibit similar or higher abundance to those in the overlying nodular duricrust and in the layer of loose pisoliths. However, Au contents are relatively low.

Saprolite: Major-element compositions of the saprolite can be expected to vary greatly according to parent lithology, the extent of development of a mottled zone and the presence or absence of iron segregations. This is reflected in the large range of abundances of SiO_2, Al_2O_3, TiO_2, CaO, MgO, Na_2O and K_2O. The high levels of Mn, Ni, Co, Cu and Zn probably reflect significant amounts of iron segregations in the saprolite.

Iron segregations : Iron segregations occur as pods, slabs or lenses within the upper part of saprolite or ferruginous saprolite, and form a dominant coarse, black lag on erosional surfaces on partly-truncated profiles. This is a common feature in the Lawlers district and, indeed, in other areas in the Leonora-Wiluna region. Iron segregations differ from lateritic residuum by having abundant goethite and less hematite and kaolinite. Maghemite is typically absent in iron segregations. Lateritic residuum can be distinguished from ferruginous saprolite by having abundant hematite and less kaolinite. Colluvium differs from other groups in having abundant quartz, kaolinite and some heavy minerals.

Samples of iron segregations collected from surface over an area of 1.5 km by 0.5 km, and from pit walls, illustrate the multi-element characteristics of McCaffery-North Pit Au deposits, including dispersion during lateritic weathering of the hosting mafic and ultramafic lithologies. The mineralization is depicted by a multi-element anomaly in Au, As (Figure 9), Cu, Zn, W, Mn and, to some extent, in Bi, Ag and Sb. The ore-related elements in iron segregations, with the exception of Mn and Zn, are similar in abundances to those in the lateritic nodules and pisoliths. Gold has however, a relatively low abundance. Gold gives a consistent anomaly 200-300 m wide over a a strike length in excess of 700 m. The Au background is 3-5 ppb, with a threshold of 10 to 20 ppb.

Arsenic, Zn, Cu and Mn show more consistent and widespread distribution than those of W, Bi and Sb. The As, Zn and Cu patterns are strong and extensive, some 300 m wide and more than 1 km long. However, caution is needed because Mn and Zn are highly mobile during weathering and can be easily adsorbed by goethite, which is the dominant mineral. The W and Bi patterns lack the continuity of Cu, Zn and As. Localized patterns of W and Bi reach 1100 and 250 ppm respectively. High values of Au (62 ppm) coincide with the high Bi (250 ppm) and are related to mineralized veins. The Sb anomaly is weak.

Turrett Pit

The Turrett Pit, 2 km N of the McCaffery-North Pit area, is located in broad depositional regime. At Turrett, colluvium is shallow and reaches a maximum thickness of 5 m. Gravelly colluvium overlies a 3 to 5 m thick residual laterite (Figure 10). A continuous zone of yellow to red-brown ferruginous saprolite, underlies the residual laterite. Development of lateritic nodules and pisoliths in residual laterite is associated with fragmentation of ferruginous saprolite.

Colluvium: Colluvium has anomalously high concentrations of Au (maximum 72 ppb), As (to 190 ppm) and Sb (to 17 ppm) (Figure 10).

Lateritic residuum: Gold is distinctively anomalous, reaching 9 ppm. Apart from Au, the ore body is also depicted by strong As, Cu, Sb, Bi and W anomalies.

Ferruginous saprolite: The ferruginous saprolite and loose nodules are dominated by goethite and kaolinite; they contain high concentrations of Cr, Ni and Co, suggesting an ultramafic origin. Gold is highly anomalous (to 5.5 ppm). Arsenic (to 2200 ppm), Cu (to 80 ppm) and Bi (to 145 ppm) give a stronger expression of mineralization in ferruginous saprolite than in the overlying laterite. Tungsten is relatively low in abundance in ferruginous saprolite. Antimony (to 30 ppm) in ferruginous saprolite is similar in abundance to that in lateritic residuum.

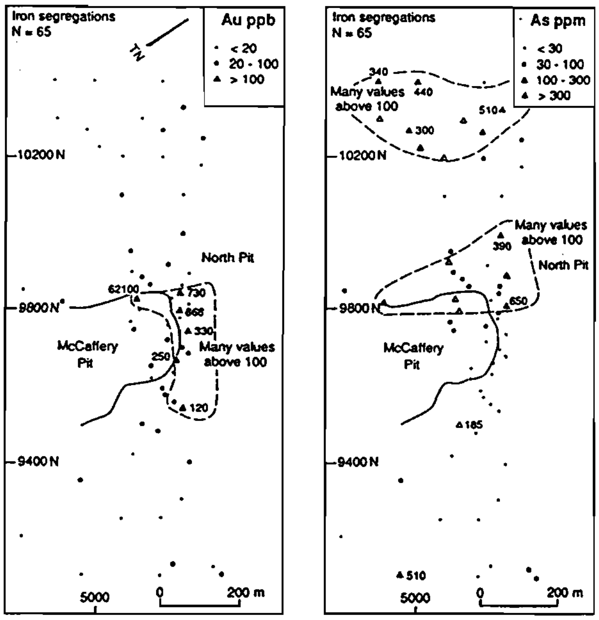


Figure 9 Maps of the distribution of Au and Ag in iron segregations, McCaffery-North Pit areas. (From Smith *et al.*, 1992).

7. CONCLUSIONS AND IMPLICATIONS FOR EXPLORATION

Extensive areas of complete laterite profiles occur buried beneath widespread alluvial and colluvial plains. This in marked contrast with the restricted area of lateritic residuum exposed at surface, the latter being about 15% of the total area. Exploration beneath the plains at Lawlers carried out by Forsayth and Geochemex, with research support by CSIRO, has clearly demonstrated the effectiveness of drilling for buried geochemical haloes in laterite and ferruginous saprolite. This requires accurate, sub-surface sampling of the lateritic materials and knowledge of the regolith stratigraphy. In drilling to sample buried laterite, it is important to recognize and distinguish between the transported lateritic debris and residual laterite.

Broad Au anomalies and anomalous concentrations of other ore-associated elements such as As, Cu, Bi, Sb and W are effective indications of primary and supergene Au mineralization in the lateritic residuum and ferruginous saprolite at North and Turrett Pits. Compared with lateritic residuum, the ferruginous saprolite is less weathered and is closer in geochemical characteristics to the mineralization.

The iron segregations, and the lag derived therefrom, are appropriate sampling media in partly truncated areas of the Lawlers district, in lieu of lateritic residuum and ferruginous saprolite. Elevated levels of Au, As, Cu and, to some extent Bi and Sb, anomalous geochemical associations in the iron segregations. The colluvium and hardpanized colluvium are also anomalous in Au while As and Sb have only moderate abundances in the near-surface colluvium.

Enrichment in Au and ore-related elements occur in the hardpanized colluvium. Similar results were also obtained in the Mt. Gibson and Mt. McClure areas. The occurrence of Au and ore-related elements in the transported overburden has considerable exploration significance.

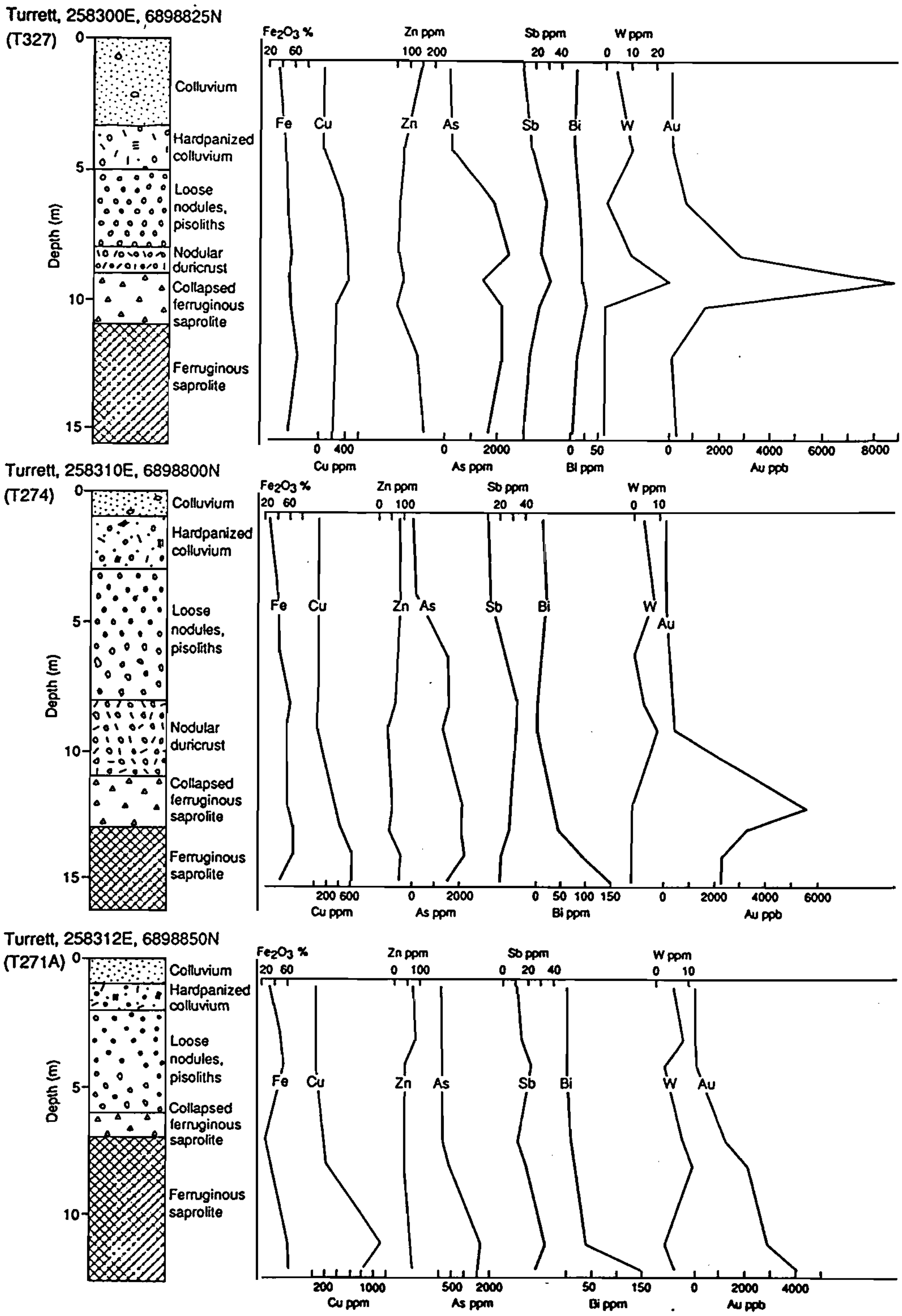


Figure 10 Vertical profiles showing the regolith stratigraphy and geochemistry of the regolityh units intersected in the drill holes T327, T274 and T271A, Turrett Pit area. (From Smith *et al.*, 1992).

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