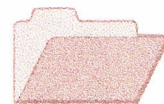# CRCLEME
Cooperative Research Centre for
Landscape Evolution & Mineral Exploration

CSIRO
EXPLORATION
AND MINING

AMIRA
Australian Mineral Industries Research Association Limited   ACN 004 448 266

SELECTIVE AND PARTIAL EXTRACTION ANALYSES OF TRANSPORTED OVERBURDEN FOR EXPLORATION IN THE YILGARN CRATON AND ITS MARGINS

(Volume 1)

D. J. Gray, J. E. Wildman, and G. D. Longman

CRC LEME OPEN FILE REPORT 107

June 2001

(CRC LEME Restricted Report 16R/
CSIRO Division of Exploration and Mining Report 305R, 1996.
2nd Impression 2001.)

SELECTIVE AND PARTIAL EXTRACTION ANALYSES OF TRANSPORTED OVERBURDEN FOR EXPLORATION IN THE YILGARN CRATON AND ITS MARGINS

(Volume 1)

D. J. Gray, J. E. Wildman, and G. D. Longman

CRC LEME OPEN FILE REPORT 107

June 2001

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.

PREFACE

The CRCLEME-AMIRA Project "Exploration in Areas of Transported Overburden, Yilgarn Craton and Environs" (Project 409) has, as its principal objective, development of geochemical methods for mineral exploration in areas with substantial transported overburden, through investigations of the processes of geochemical dispersion from concealed mineralization. The Project has two main themes. One of these, *'Surface and subsurface expression of concealed mineral deposits'* is addressed by this report, which focuses on the use of selective and partial extraction techniques for seven sites in the Yilgarn Craton and adjacent Proterozoic Belts. Over the past few years selective/partial extractions have regained popularity as a technique for the location of buried mineralization. If effective, they would offer an inexpensive and easy method for exploration in areas of transported overburden. Assessment of the utility and range of these methods is considered to be an important component of Project 409.

The investigations carried out as part of this report have been conducted in order to determine: whether soil extraction anomalies exist over buried mineralization; can these anomalies be observed using different techniques; and what is the primary cause of the anomalies ? It is intended that these results would ultimately form part of a database for the areas throughout Australia to determine the utility of such techniques for exploration.

C.R.M. Butt,
Project Leader.
Decmeber, 1996

ABSTRACT

Seven sites from across the Yilgarn Craton and the northern Proterozoic margin were selected to test the utility of partial extractions for exploration for buried mineralization. The techniques used were selective extractions for carbonates, Mn oxides and amorphous Fe, varying HCl treatments, the CSIRO iodide extraction for Au, mobile metal ions (MMI) and Enzyme leach. The selective extractions work consistently and give good correlations with the HCl digests. The MMI method involves two separate extractions: the first, for Cd, Cu, Pb and Zn, gave results that are similar, in terms of comparison between samples at each site, to HCl and selective extractions; whereas the second extraction, for Ag, Au, Co, Ni and Pd, commonly dissolves all of the extractable Au and Ag (commonly 70 - 80% of the total Au, and closely correlated with total, iodide and HCl soluble extractions). Therefore, the MMI extraction does not appear to be giving any additional information for Au or Ag than can not be obtained using standard analyses. The enzyme leach reagent is targeted at an 'amorphous' Mn phase, though the proportion of the Mn dissolved (< 0.5 to 20%) varies dramatically between sites. The enzyme leach method also appears to give unique results, not correlated with other methods, and gives a much larger range of elements than MMI. However, Cs, Fe, Ga, Hf, La, Li, Nb, rare earth elements, Pb, Sc, Sn, Th, Ti and Zr show very close linear correlations, suggesting either a highly specific interaction between these elements and Fe or an analytical interference from Fe.

The extraction results for the soil traverses indicate that soil is a successful exploration medium only where the transported overburden in thin (< 10 m), as at Safari and in restricted areas at Baxter and Fender, and that Au, for a number of methods, is by far the best target element. Use of partial extractions gave a number of strong false positives and/or very poor ability for the extraction methods to shows buried mineralization, except where total extractions would work anyway. Even at those sites where Au successfully delineates mineralization, partial extraction methods for the other elements are unsuccessful.

TABLE OF CONTENTS

1. INTRODUCTION

Selective extraction is a technique whereby particular soil phases are dissolved in a controlled manner, and the resulting solutions analysed for trace elements of interest. These techniques can be used to investigate how trace elements are distributed between the phases. In addition, these extractions have been used in the past for geochemical exploration because it has been perceived that elements associated with mineralization (especially those hosted by sulphides) are more likely to be released during weathering than those in barren rocks (hosted by silicates), more widely dispersed, and more probably held by secondary minerals and hence likely to be preferentially released by extraction solutions. In contrast, many of the new extraction techniques currently been introduced for geochemical exploration are partial rather than selective digests: *i.e.*, they extract part of a phase or phases, rather than a selected mineral. These new methods are being claimed to have a high efficacy in the location of buried or otherwise hidden orebodies, and there has been a high degree of interest in their application. This study has been designed to examine the chemistry of partial and selective extractions and the mineralogical implications more fully.

Various phases that could be of significance in the distribution of trace elements include phyllo-silicates (*e.g.*, kaolinite), Fe oxides[1] (*e.g.*, goethite and hematite), Mn oxides, carbonates or resistate minerals such as chromite, zircon or monazite. In addition to the commercial extractions tested, selective extraction schemes were chosen so as to test easily extractable ions and ions associated with Mn oxides and/or amorphous Fe oxides. These phases are commonly thought to influence the mobilities of a wide range of metals and pathfinder elements and may be important controls for the metals and elements commonly tested in commercial partial leach techniques.

The aims of the project are:

(i) to investigate the potential for selective and partial extractions as an Au exploration method in the Yilgarn Craton and margins;
(ii) to yield data on geochemical dispersion processes;
(iii) to contribute to a database on selective extraction techniques at various sites, and to enhance our understanding of dispersion processes in mineralized zones.

The scope of this study includes the correlation of selective extraction results with the underlying mineralization, effect of Mn oxides and amorphous Fe oxides on extractability of various base metals and investigation of several other partial leach techniques.

2. STUDY SITES - CHARACTERISTICS

2.1 Introduction

Seven different sites have been used for selective/partial extraction investigations (Figure 1). They are grouped by geography as follows:

(i) *Northern* (N Yilgarn and margins) -
　　　Baxter: 90 km N of Meekatharra, in early Proterozoic basin on the northern margins of the Yilgarn Craton, primarily mafic and ultramafic volcanics;
　　　Fender: 28 km WNW of Cue, hosted by a regional volcanic and sedimentary sequence in an attenuated greenstone belt about 830 m wide;

---

[1] In this report Fe oxides and Mn oxides are taken to include all classes of separate phase oxides, oxyhydroxides and hydroxides.

Bronzewing: about 400 km N of Kalgoorlie, within a sequence of mafic volcanics and
    minor sediments, which are intruded by felsic porphyries.
(ii) *Central* (close to and north of the Menzies line) -
    Curara: 70 km SSW of Mt. Magnet, in a tonalitic porphyry stock, bound to the E by
        mafic amphibolite schists;
    Safari: 200 km NNE of Kalgoorlie, in a greenstone assemblage containing a wide variety
        of volcanic and volcaniclastic rocks.
(iii) *Kalgoorlie region* -
    Steinway: a minor palaeochannel system over mafic andesites with trachytes, porphyritic
        tuff and black shales, 15 km W of New Celebration;
    Apollo: reduced palaeochannel system over high-Mg basalts and dolerite, 25 km S of
        Kambalda.
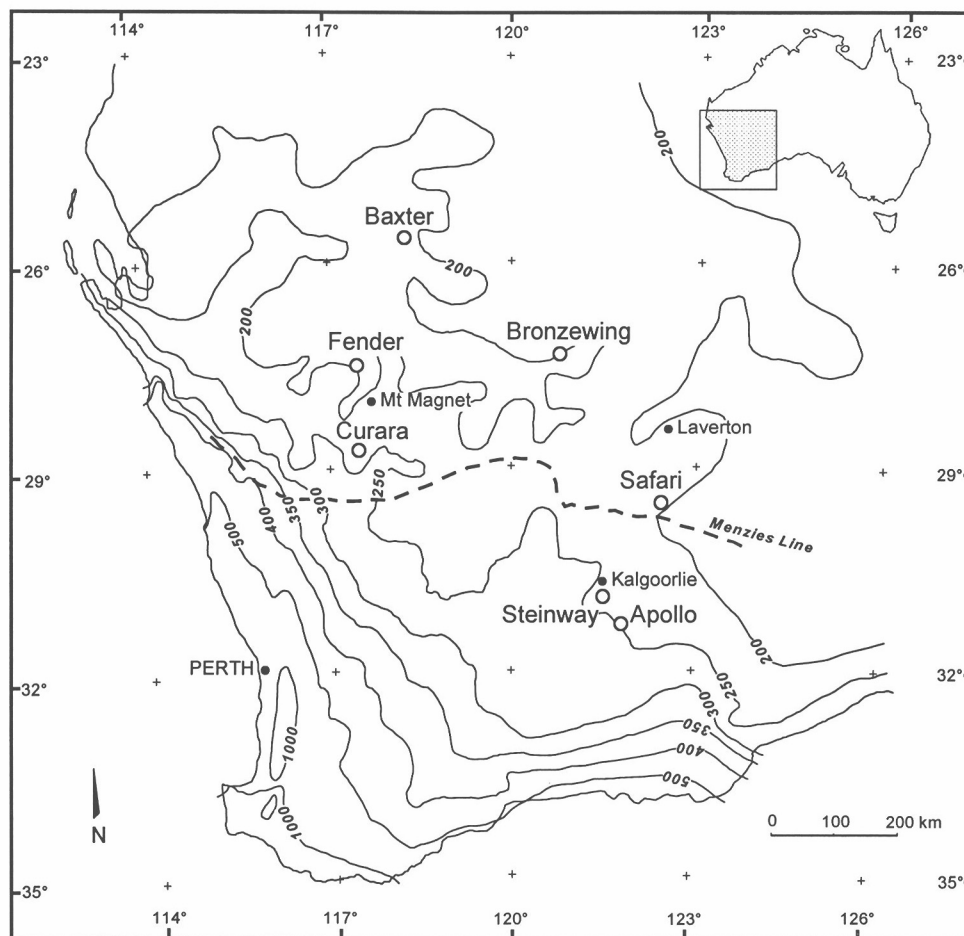
Figure 1: Location map of selective/partial extraction investigation sites.

These sites have all been previously investigated, as part of CSIRO/AMIRA Project 409. The
primary references and abridged site descriptions are given below.

2.2 Harmony deposit, Baxter

Gray (1995), Robertson *et al.* (1996)
The Harmony Deposit is approximately 10km W of Peak Hill and about 90km N of Meekatharra and
is located within a depositional plain bounded to the W by the Robinson Ranges, to the NE by the low

hills of the Horseshoe Range, and to the E and the SE by low hills and rises. The climate is semi-arid, characterized by low irregular rainfall averaging 200mm pa. Vegetation cover is thin, mainly consisting of mulga and other drought resistant shrubs and grasses. The deposit is located on the contact between the folded mafic and ultramafic Narracoota Volcanics and a thick turbidite sequence of fine-grained lithic, feldspathic and mafic wacke of the Ravelstone Formation (Figure 2). Both have been moderately metamorphosed, and are part of the Proterozoic Glengarry Basin.
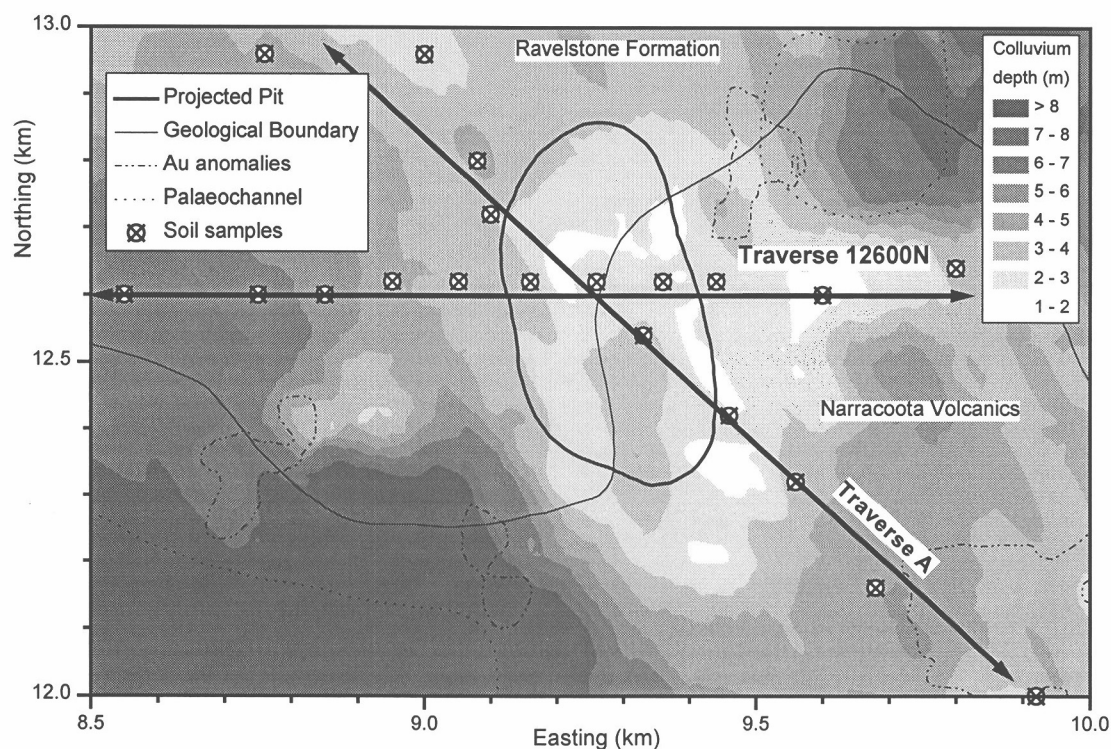
Figure 2: Soil samples from Baxter used for the partial extraction study, with geology, projected pit, other Au anomalies, position of palaeochannels and depth of colluvium shown.

The deposit has a reserve of 2.148Mt @ 3.6g/t Au. Primary stratabound gold mineralization is associated with quartz veining, and is hosted within a mafic sequence at the top of the Narracoota Volcanics. The deposit is low in sulphides, with pyrite >> pyrrhotite. Mineralization also occurs as a near-surface, relatively flat-lying supergene deposit, occurring mainly within the volcanic saprolite, lateritic residuum and extending into the base of the overlying colluvium. The depth of oxidation is variable but averages about 80 m, with the water-table at 30 m.

The transported overburden in the vicinity of the Harmony Deposit is a variably thick, red-brown, colluvial-alluvial blanket (Figure 2). The cover is thickest over the palaeochannels (7-12 m) and the upper part is hardpanized. The colluvium on the palaeohigh (0.5-3.0 m) lies directly over a basement of ferruginous saprolite, saprolite and saprock. Ferruginous duricrust is developed on the flanks of the palaeohigh and is complete with lateritic nodules and pisoliths. The colluvium over the palaeochannels is underlain by various mottled clay sediments, which may by subdivided into an upper unit of dark puggy clays, and a lower unit of pallid clays with silica. Beneath the palaeochannel sediments, thick mottled zones and clay-rich saprolites have developed. Most soils tested are dominated by the > 2000 μm fraction (removed before partial extractions; Section 3.1), with the < 75 μm fraction also very important. This fine fraction showed weak Au, W, Ta anomalies over Harmony, though only where the colluvium is particularly thin (0.5 - 1.0 m).

3

The groundwaters at the Harmony deposit are neutral (pH 6-8) and have very low salinity (mean 0.04% TDS), and as such they are distinct from the saline acid groundwaters of the southern Yilgarn. They have a similar Eh range to neutral groundwaters of the central Yilgarn. The low salinity at Harmony means that the dominant mechanism for mobilization of Au in the southern Yilgarn, namely through the formation of halide complexes, is not expected to be significant. Other important mechanisms for Au mobilization (*i.e.*, formation of complexes with organic ligands or thiosulphate) are also unimportant because of the low organic matter content of the groundwater and the negligible degree of present day sulphide oxidation.

Soil samples for the partial extraction tests were taken from two traverses (Figure 2), at 12600N and Traverse A, running from the NW to the SE of the study area. Both intersect mineralized area near the middle of the traverse, though the colluvium thickness varies from 1 to 8 m, being greatest in the western part of line 12600N.

2.3 Fender

Butt (1996)
Fender is approximately 2 km south of Big Bell, about 28 km WNW of Cue. It is hosted by a volcanic and sedimentary sequence in a steeply-dipping, strongly attenuated and overturned greenstone belt about 830 m wide. It is confined by granitic rocks to both east and west. The regional metamorphic grade is low to middle greenschist. Exploitable mineralization (Figure 3), estimated at 248000t @ 2.4g/t Au, appears to be confined to the weathered zone, as a small 'laterite' resource, in the southern part of the deposit, and weathered primary mineralization in saprock and saprolite (Figure 4). Primary mineralization is hosted by quartz-muscovite-potassium feldspar schists. In addition to Au, the primary mineralization is enriched in Ag, As, Sb, W, Mo, Tl, Zn and, surprisingly, Hg, a similar suite to that present at Big Bell.
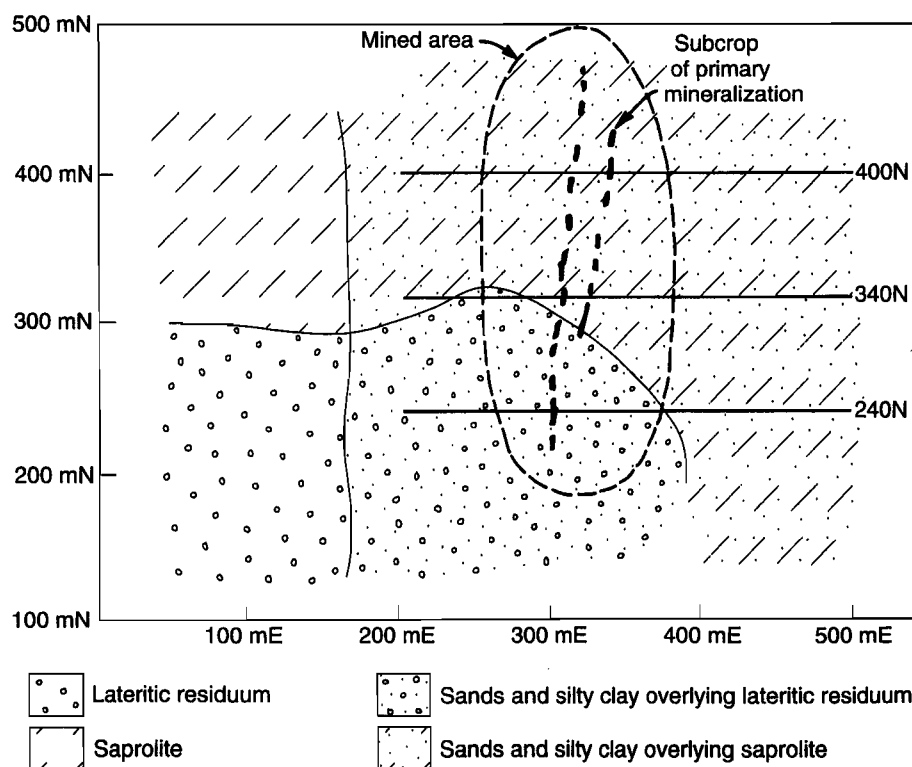
Figure 3: Mined area and traverse locations, Fender.

4

Depth (m) — Fender 400N
200 mE 300 mE 400 mE 500 mE

Depth (m) — Fender 340N
200 mE 300 mE 400 mE 500 mE

Depth (m) — Fender 240N
200 mE 300 mE 400 mE 500 mE

Hardpan   Pisoliths and nodules   Nodular ferruginous clay   Unconformity

Sand   Silty clay   Saprolite   • Samples
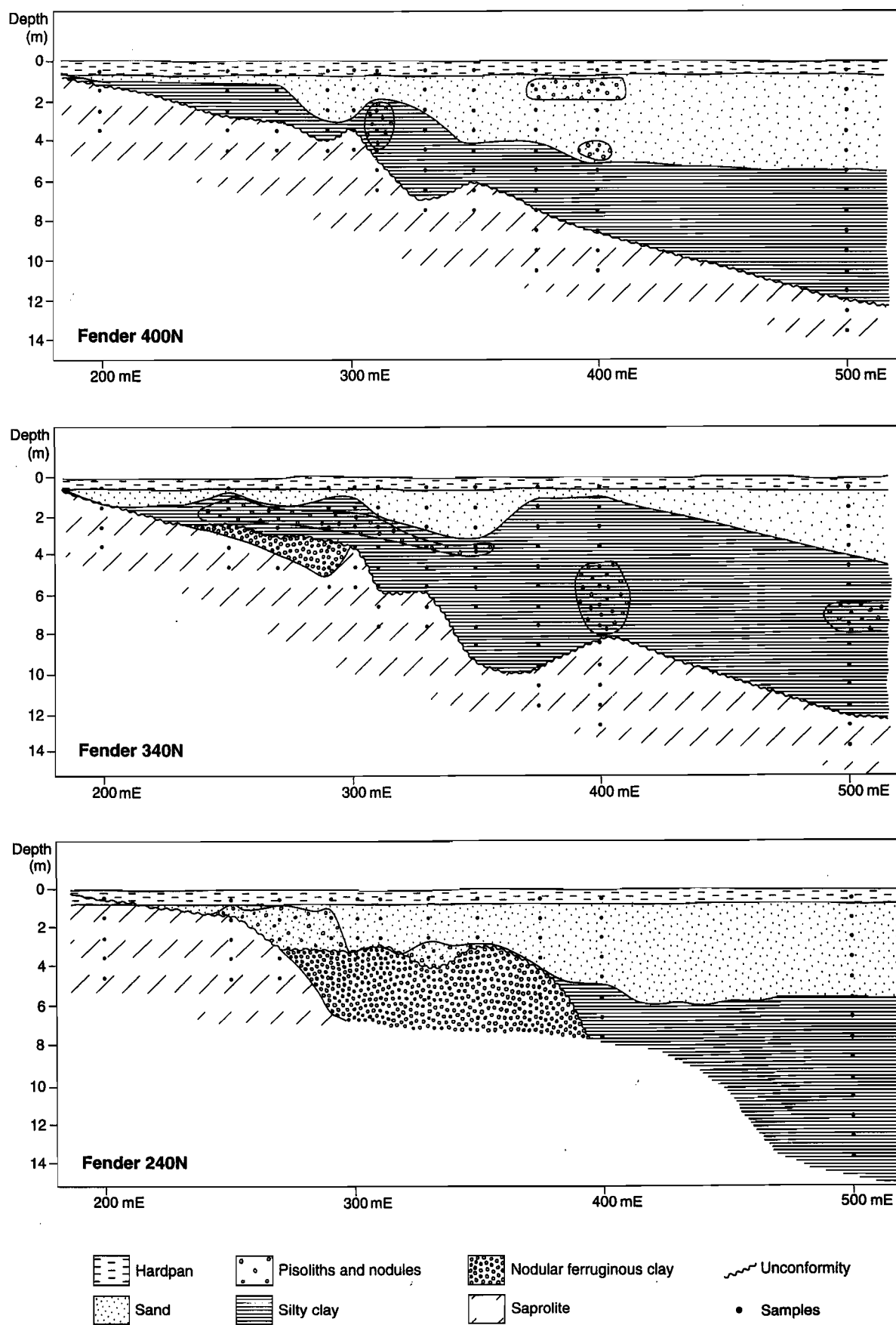
Figure 4: Regolith sections, Fender. Samples from the top metre were used for the extraction tests.

The ferruginous nodular clays and ferruginous saprolite host the laterite resource in the south of the deposit, and are enriched in Au, As, Sb and, in part, W. Arsenic (100->300 ppm) and Sb (30->130 ppm) give the most widespread anomaly, which extends to the surface 200 m west of the deposit. Gold enrichment (100->6000 ppb) is also quite extensive, but has no surface exposure, whereas W (10-16 ppm) is confined to the centre of the ferruginous nodular clays, possibly indicating the position of the primary source.

Rocks in the vicinity of the deposit are weathered to 40-60 m. Nodular lateritic residuum, continuous with the buried nodular ferruginous clay, and saprolite both outcrop about 200 m to the west (Figure 4). The site is on the margin of a colluvial-alluvial plain which slopes gently to the north and east. The deposit itself is entirely overlain by a thin cover of transported overburden, although residual regolith is exposed within 200 m west of the mineralized unit. The sediments are 3 to 8 m thick over the deposit, thickening to over 13 m, 200 m to the east, with 1-5 m of fine- to coarse-grained sandy clay, sand and gravel, overlying 1-8 m of silty clays. Both the sands and, particularly, the silty clays contain detrital lateritic gravels. The sands are weakly cemented in the top metre to form hardpan and some deeper sediments are mottled; there is no pedogenic carbonate. The sediments contain feldspar and are probably derived from the granites to the west.

Soil and hardpan over Fender are developed in the top metre of the sandy sediments (Figure 4). Over the laterite resource, these sands are less than 3 m thick and the overlying soil/hardpan is weakly anomalous in Au (10-27 ppb compared to <5 ppb background). The As, Sb and W contents of the soils are at background abundances over mineralization, but As and Sb contents increase to the west, reflecting the contribution of shallowly buried and outcropping lateritic residuum to the soil. To the north, where the sands and silty clays overlie saprolite, Au, As, Sb and W are at background abundances although, again, As and Sb contents increase to the west.

The medium-coarse sand is slightly enriched in Au (20-80 ppb), where it directly overlies lateritic residuum and there is a greater concentration of Fe-rich nodules and clay. Elsewhere, Au abundances are less than 5 ppb. Arsenic, Sb and W contents are at background in this unit.

The silty clays directly overlie saprolite, but appear to be absent where the lateritic residuum is preserved. Gold abundances are generally <5 ppb. However, there are some spot concentrations (80-245 ppb) immediately above subcropping mineralization, and an associated weak enrichment (5 - 16 ppb) extending 50 m downslope. In comparison, the silty clays E of the deposit are significantly anomalous (60 ppb Au) for over 100 m east of the subcropping lateritic residuum, probably representing mechanical dispersion of this Au-rich unit.

Arsenic (40-120 ppm), Sb (12-50 ppm) and, in the north, W (5-17 ppm) are enriched in the clays and yield an anomaly extending at least 200 m downslope to the east. For As, like Au, the enrichment is strongest in the more ferruginous silty clays, closest to the lateritic residuum; in comparison, the W content is below detection here, and increases to the north. Essentially all of the As and Sb in the silty clays unit is hosted by mechanically transported ferruginous nodules (80->100 ppm Sb, 300-450 ppm As). Neither Au nor W are concentrated in the nodules.

The vegetation around Fender consists of scattered shrublands dominated by *Acacia* and *Eremophila* spp, with ephemeral grasses and herbs. The region is characterized by a warm semi-arid climate, with hot summers and mild to cool winters. The mean annual rainfall at Cue is 224 mm, with a weakly bimodal distribution (January-February and May-June).

Samples of the top 1 m from all three traverses (240N, 340N and 400N) were used for the partial extraction tests. The holes were specially drilled to avoid cross-over contamination.

2.4 Bronzewing

Varga *et al.* (1996)

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. The deposit is situated on an alluvial plain adjacent to the Bates Creek drainage and slopes very gently NE in a broad undulating terrain of low relief. The few hills are secondarily silicified or relatively fresh Archaean greenstone sequences. Locally, greater relief is provided by breakaways.

The climate is semi-arid, with hot summers and mild winters. The mean annual rainfall of 205 mm falls mainly in the summer months during erratic local thunderstorms. The area is subject to both drought and short-term floods. Vegetation corresponds to the four principal physiographic units in the area. The sandplains are characterized by a sparse to moderate cover of *Triodia* and *Eucalyptus* spp. Halophytes such as saltbush grow on the salt lake margins. Areas of rock outcrop are dominated by *Casuarina* and kurrajong. The broad plains of transported overburden are dominated by *Acacia* spp. and a range of small shrubs, with eucalypts and sandalwood in the creeks.

Gold mineralization occurs within a sequence of mafic volcanics (basalts, dolerites) and minor sediments, which are intruded by felsic porphyries. The mineralization is associated with a dense stockwork of quartz veining and alteration of the host sequence, and is accompanied by pyrite, pyrrhotite and minor chalcopyrite and scheelite. The predominant foliation of the host rocks is N-S and primary mineralization generally follows this structural orientation.

The use of lateritic residuum and ferruginous saprolite sampling methods was an important factor in drawing initial attention to the area, eventually leading to the discovery of the Bronzewing Au deposit in 1992 by the Creasy-Great Central Mines N.L. Joint venture. Drilling for buried geochemical halos in laterite included initial intersections of 4.65 g/t Au. Pre-mining reserves at Bronzewing were calculated to be 9.137Mt @ 4.6 g/t cut or 9.137Mt @ 5.7 g/t uncut. Four mineralized zones have been found - the Western, Central, Laterite, and Discovery, of which the later three are now pits. The buried lateritic residuum contains Au to ore grade, which sometimes extends into the colluvium.

The transported overburden consists of colluvium and alluvium and covers much of the weathered Archaean sequence (Figure 5). The thickness of the transported overburden reflects the palaeotopography. There are three principal units:
1.   Red-brown sandy, silty, clay soils, 1 m thick, developed on the colluvium and alluvium.
2.   Alluvial channel deposits, colluvial talus and sheetwash. The unit fines towards the top and can be subdivided into an upper silty and a lower gravelly component. Hardpanization is generally restricted to the upper silty component.
3.   Fine silty lacustrine clays that appear to occupy a palaeochannel and have been subjected to intense post-depositional mottling.

Where fully preserved, the residual profile beneath the transported overburden has a 2-5 m thick lateritic horizon consisting of ferruginous gravels, mainly pisoliths and lithic nodules, set in a silty clay matrix. The nodules were formed by the fragmentation and collapse of the underlying ferruginous saprolite. The ferruginous saprolite, a few metres thick, grades downwards into saprolite. Fresh rock is encountered at 80 to 120 m depth.

Bulk soils were collected from 30-50 cm depth. The < 250 µm fraction consists mainly of aeolian silt-sized quartz, kaolinite and hematite. The hematite is present as fine sand to clay-sized particles, as fine coatings on quartz grains and, presumably, within the clay matrix. No significant concentrations of Au or pathfinder elements are present in the soil; the Au content rarely exceeds the detection limit of 5 ppb.
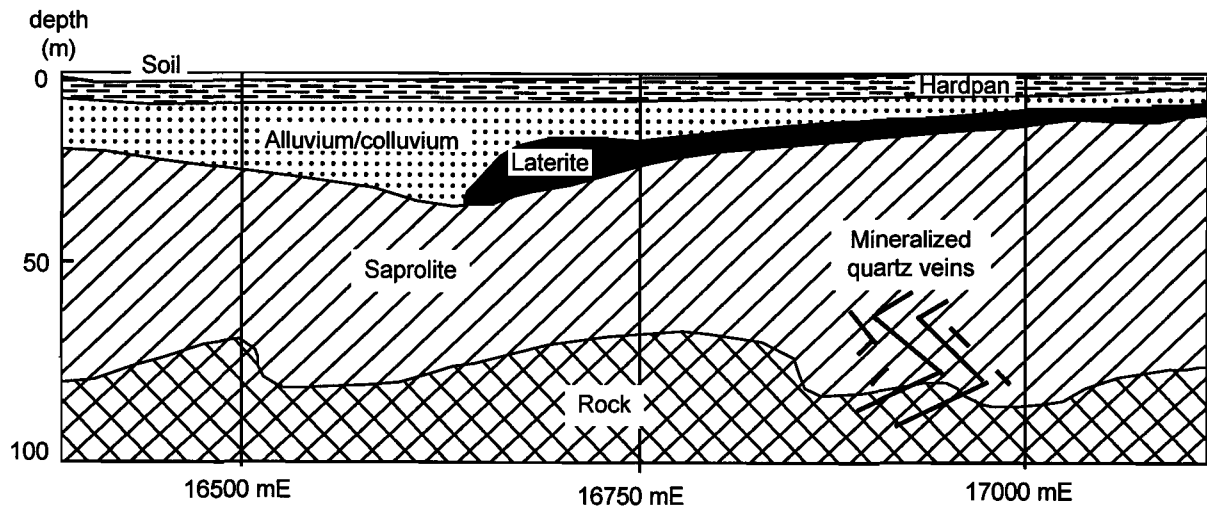
7

Figure 5: Regolith cross-section for Bronzewing traverse 9800N.

Size fractionation of the colluvium that occurs within 1 m of the residuum/colluvium interface, indicates that Au is concentrated in the > 2 mm fraction, and is depleted in the < 75 μm fraction, relative to the bulk sample. It can be inferred that the enrichment in the coarse fraction represents clastic dispersion of lateritic detritus. The palaeosurface represented by the unconformity has sufficient slope for the colluvium to have been derived from mineralized lateritic residuum upslope, thus accounting for the Au enrichment in the coarse fraction. There is no evidence to show that hydromorphic dispersion is currently accumulating Au, and the present fresh groundwaters are unlikely to be able to dissolve or disperse Au.

2.5 Curara Well

Gray (1996)
The Curara Well Au prospect is located some 420 km NNE of Perth and 70 km SSW of Mt Magnet. It is situated within the Wydgee Fold Belt immediately south of the Mount Magnet Greenstone Belt. Outcrop is extremely poor (< 1%). Exploration to date has identified a possible 100,000 oz laterite resource overlying mineralized bedrock. The prospect is located over a tonalitic porphyry stock that is bounded on its eastern side by a package of mafic amphibole schists. Detailed aeromagnetics have shown that the porphyry stock is cut by a number of NW-NNW trending fault splays off a regional shear that occurs to the east of the prospect. The laterite mineralization straddles one splay in particular, and the greatest tenor of mineralization is developed where a wedge of porphyry has been faulted off the main stock by this splay. The present day drainage system over the mineralized zone also follows this fault splay. Bedrock mineralization is present within both the porphyry fault wedge and the hanging wall mafic schists immediately to the east. The Au mineralization shows some association with thin (< 1 cm) quartz-actinolite veins. The overall percentage of sulphide (pyrite±pyrrhotite and trace chalcopyrite) associated with the mineralization is low (< 3%).

The majority of the prospect is covered by 0-10 m of alluvium and hardpanized colluvium, and 30 - 60 m of partially preserved lateritic regolith, with a deeper palaeochannel to the east (Figure 6). The buried residual profile is generally stripped back to lower laterite, nodular mottled zone or upper saprolite. The laterite mineralization is approximately 2.5 km S-N and 0.5 km W-E, and is dominantly hosted by the nodular mottled zone, with deeper supergene Au enrichment. The laterite outcrops in the south west corner of the anomaly, but over much of the deposit the laterite is covered by up to 10 m of sediments. Laterite Au enrichment defines the primary mineralization well.
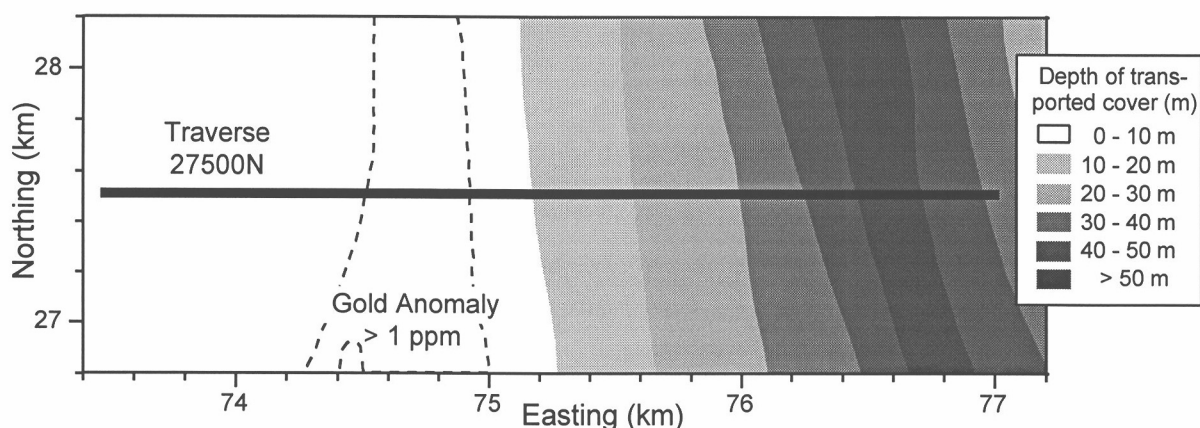
Figure 6: Soil traverse, position of the laterite Au anomaly and depth of transported overburden at Curara (using data provided by CRA Exploration Ltd.).

The area has a semi-arid climate, with an average annual rainfall of approximately 230 mm. Rainfall variability is high and results mostly from frontal systems from the west and south-west in winter and from patchy, convectional storms and cyclone-related rain-bearing depressions in summer. Summers generally are dry and hot to very hot; winters are cool to mild, with a few frosts. The vegetation is dominated by mulga and turpentine and by various types of poverty bush (*Eremophila* spp).

The soils were collected by spade, after scraping away the top 1 to 2 cm, including litter and humus, to approximately 20 cm depth. Three traverses were used for a previous study (Gray, 1996), of which one, at 27500N (Figure 6), was used in this investigation.

2.6 Safari prospect, Mt Celia

Bristow *et al.* (1996)
The Safari Prospect is located 200 km NNE of Kalgoorlie and 9 km NE of the margin of Lake Raeside and is situated on a broad, sandy, colluvial valley which slopes gently SW. The vegetation is medium to dense woodland of *Acacia* and *Eucalyptus* spp. The climate is semi-arid, and the mean annual rainfall of 200-250 mm falls variably throughout the year, resulting from frontal systems in winter, or convectional storms and cyclone-related depressions in summer.

The Safari Prospect lies within the southern extension of the Laverton Tectonic Zone. The bedrock geology consists of a greenstone assemblage comprised of a wide variety of volcanic and volcaniclastic rocks. These rocks are heterogeneously deformed and generally strike NNW and have nearly vertical to WSW dipping tectonic foliation, and sub-horizontal to down-dip mineral lineation. Porphyritic syenite, coarse granodiorite and ademellite intrude the greenstone sequence, which has been metamorphosed to amphibolite facies beside the larger plutons. Elsewhere, the regional metamorphism is lower greenschist facies.

Drilling to date indicates a resource of 1.08Mt @ 3.3g/t Au. The mineralization is hosted by andesite to dacite metavolcanic rocks, now largely represented by quartz-chlorite-sericite ± carbonate schists that are bound to the west and east by serpentinized komatiite and talcose schists. Gold is primarily associated with quartz veins within an anastomosing shear. High concentrations of Au (maximum 31 ppm) are usually accompanied by enrichments of Pb (maximum 1100 ppm), although, in general, correlation with grade is not particularly good. Not specifically related to Au grade are general enrichments of As (maximum 1000 ppm), S (maximum 1.1 %) and W (maximum 79 ppm); enrichment of Zn (maximum 1300 ppm) in one of the intersections suggests that there may have been more than one mineralizing event.

Most of the residual regolith consists of saprolite with a variable clay content, although in isolated areas in the north of the prospect, there are deep profiles with highly ferruginous upper horizons. Incipient mottling is present throughout the saprolite and the upper few metres are commonly indurated by silica and/or carbonate. Fresh rock is generally encountered 10 - 20 m below the unconformity. Anomalous Au occurs in the saprolite just below the unconformity (Figure 7), especially where it directly overlies primary mineralization (eg. 1200 ppb in a quartz vein from the top 2 m of the saprolite). The mean Au contents of the top 1 m give a very strong anomaly peaking over mineralization (1000 ppb), with a reasonably elevated and noisy background (10 - 50 ppb).
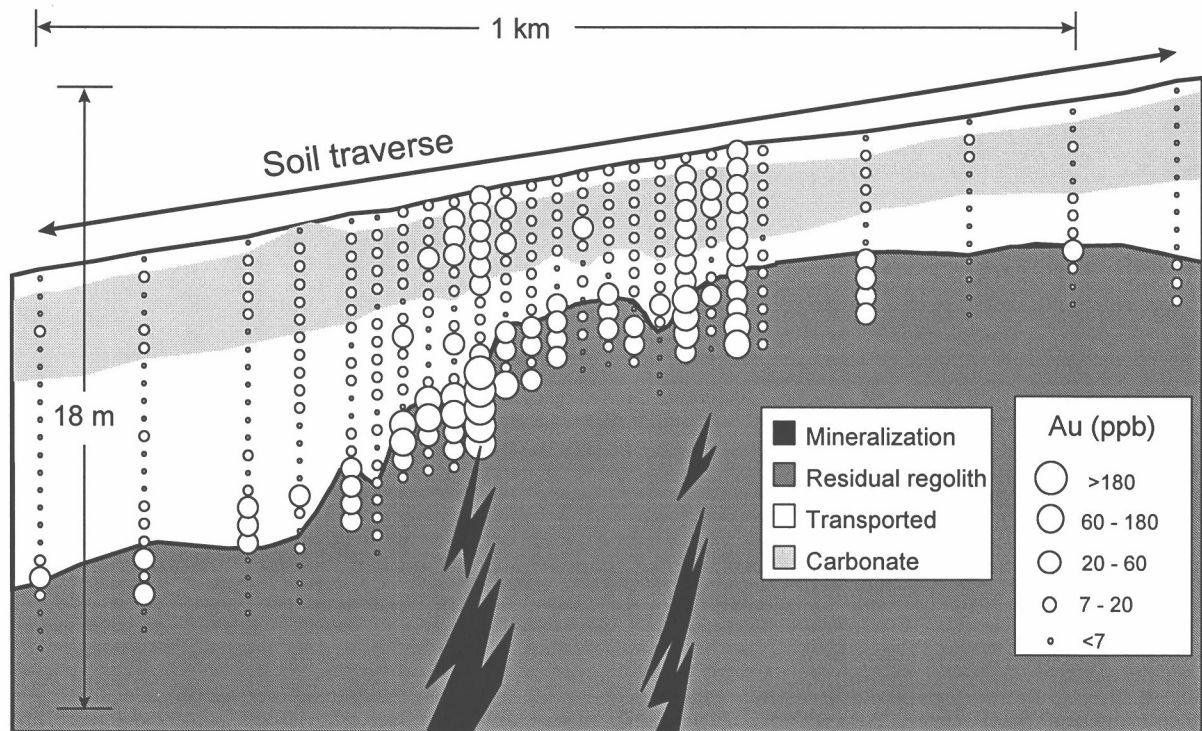

Figure 7: Soil traverse, regolith and mineralization at Safari, traverse 6732300N.

The study area is completely blanketed by transported overburden except in the small area coinciding with the palaeohigh, where almost fresh Archaean bedrock outcrops. There is a uniform distribution of sheetwash and aeolian sand up to 1 m thick at the surface. The composition of the sediments is variable, and the thickness, including the sheetwash, is generally 5-10 m, reaching 20 m in the northern palaeovalley. The sediments below the sheetwash are a polymictic assemblage containing 2 - 10% coarse material, commonly towards the base, in a matrix of sand, silt and, in places, clay. The coarse fraction comprises angular, weakly weathered rock fragments near to the mineralization and indeed over most of the area, except in the northern palaeovalley where there is a mixture of ferruginous pisoliths, nodules and lithorelics. In places, drilling has intersected narrow lenses of coarse alluvial sand and gravel.

Post-depositional modification of the sediments is widespread; most significant is the widespread calcification from about 0.5 to 5.0 m below the surface. Beneath the zone of intense calcification, the sediments are commonly moderately to strongly indurated by silica and Fe oxides. Anomalous Au (22 - 60 ppb) is also present in the carbonate horizon, with enrichment strongest from approximately 0.5 - 2.5 m depth directly over mineralization. Concentrations of Au (>7 ppb) above background occur in the calcareous horizon for over 800 m across strike of the mineralization. Even in the top

half metre, an anomaly with excellent contrast peaks directly over the primary mineralization, with concentrations exceeding 5 ppb for over 600 m across strike. Despite having higher absolute Au contents, preferentially sampled highly calcareous fragments do not increase anomaly contrast and the Au/Ca ratio in these is consistently lower than a bulk sample from the same interval.

Gold solubility in the saprolite varies from less than 10% in the mineralization, to over 80% further away. This implies secondary lateral dispersion in the saprolite, probably prior to sedimentation. Later, the Au has been mobilized upwards into the overburden, where it has associated with carbonate. Gold solubility is uniformly high (over 70% iodide soluble) throughout this calcareous horizon.

The soil traverse used for the partial extraction study is shown in Figure 7.

2.7 Steinway

Lintern and Gray (1995a)
The Steinway prospect is located about 27 km SSW of Kalgoorlie at approximately 121º29'E 30º58'S. It is located adjacent to the regional contact between mafic-ultramafic rocks of the Saddle Hills Greenstone Belt, and the overlying intermediate to felsic volcanics and sedimentary rocks of the Black Flag Group. Mineralization at Steinway is twofold; *primary* mineralization is associated with quartz stockwork veining within mafic andesites/amphibolites, and *supergene* mineralization is located below a palaeochannel.

Climate is semi-arid with an unreliable mean annual rainfall of 280 mm. Vegetation consists of open woodland of *Eucalyptus* spp. and a sparse understorey that includes *Maireana* (bluebush). Steinway is located on a flat depositional plain, with higher areas rarely rising 5 m above it. Approximately 1 km to the S, an erosional area composed of mafic saprolite hosts the nearby Penfold Au mine and, 400 m to the SE, another palaeochannel hosts the Greenback Au deposit. Present day ephemeral channels cross the depositional plain, generally flowing N to White Lake, a playa about 10 km distant. The ephemeral channels separate the Steinway and Penfold soil anomalies.

Fresh rock is encountered at about 50 m depth, and the residual regolith profile at Steinway consists of saprolite, becoming more clay-rich towards the top (Figure 8). It is about 20 m thick and is overlain by four sedimentary units. These consist of a basal sand and silty clay unit, between 25 and 30 m depth, overlain by massive clays between 5-25 m depth that contain zones of Fe-rich material such as mottles. A non-calcareous clay containing large amounts of ferruginous granules occurs between 2 and 5 m depth, and the uppermost unit consists of calcareous, clay-rich red soil with abundant ferruginous granules.

Gold and Ca are probably associated in the upper horizons. Iron concentrations gradually increase with depth and, in the lower profile (below 0.5 m), Au may be associated with Fe. In the most mineralized soil profile analysed, Au concentrations average 200 ppb in the top metre, with higher concentrations in the second metre. Sequential extraction (water, iodide, cyanide) of Steinway soils, indicates that while total Au increases with depth, the proportion of water soluble Au in the profile is greatest (20% of total) in the topsoil, and decreases with depth, appearing to be strongly related to organic C content. The mean proportion of iodide soluble Au is approximately 80% of total Au.

The Au anomaly in 0 - 1 m composite samples from Steinway reaches 150 ppb against a background of less than 20 ppb. The anomaly is over 150 m wide in an E-W direction and stretches over 1 km to the NW, following the direction of the palaeochannel, and appears spatially correlated to underlying mineralization (Figure 8). However, the presence of detrital broken pisoliths, lithic nodules and other transported fragments, and the random concentration of Au in these granules all suggest that the

apparent association is coincidental. There are also high concentrations of Fe coincident and adjacent to the Au soil anomaly, and Cr, As, Sc and Sb appear to be associated with Fe. The REE, Zn, Co, and possibly Ni, tend to be associated with Mn.
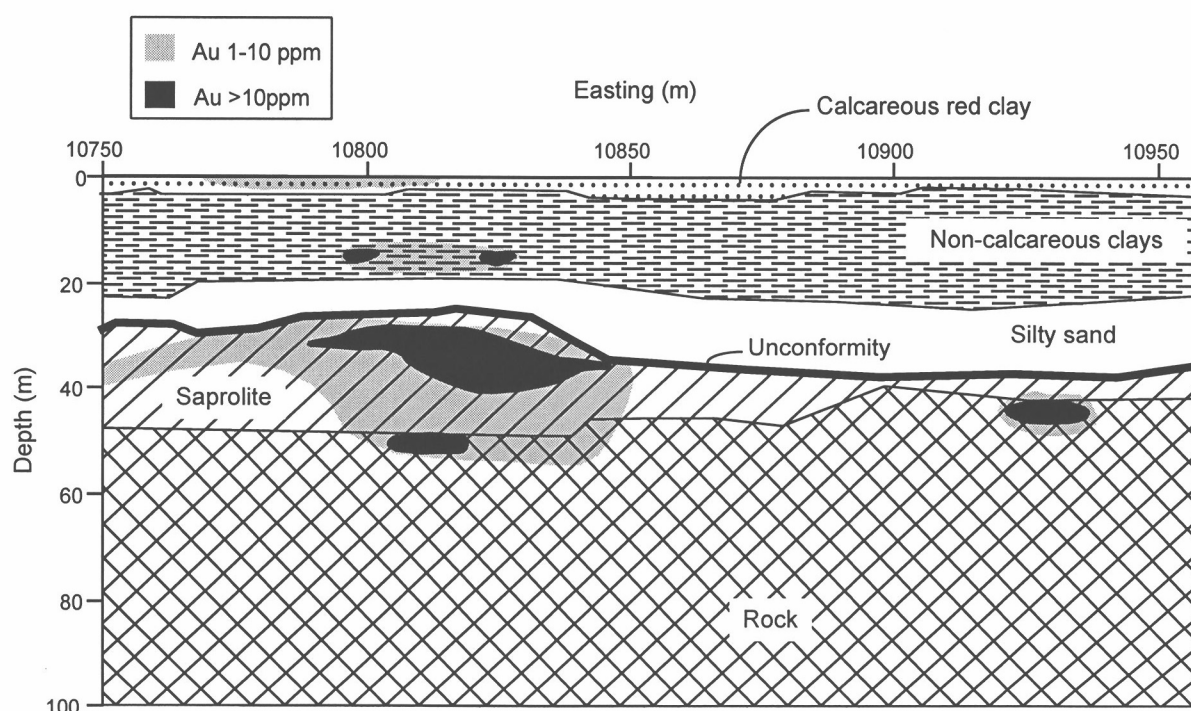

Figure 8: Soil traverse location, regolith and mineralization at Steinway line 4250N.

Analysis of *Eucalyptus* (leaves, bark, twig and mull) and *Maireana* do not indicate the presence of mineralization. Gold concentrations in both *Eucalyptus* and *Maireana* over the mineralization are similar to background. The *Eucalyptus* mull has a maximum concentration of 4.4 ppb over mineralization compared to a maximum background of 4.1 ppb, and the *Maireana* has a maximum concentration of 1.7 ppb over mineralization, compared to a maximum background concentration of 1.8 ppb Au.

Groundwaters at Steinway vary from moderately acidic (pH 5.8) to highly acidic (pH 3.4) and are saline. Halides (chloride and/or iodide) are important mechanisms for Au dissolution in such groundwaters. The groundwaters are also enriched in Al, Si, Mn, Fe, Co, Ni, Cu, Zn, Yb, Pb and REE, with the most acid groundwaters also enriched in U. These enrichments commonly occur where acid groundwaters contact mafic rocks. Iodine also has high concentrations in Steinway groundwaters, as observed in other mineralized sites in the Yilgarn. Anionic chalcophile elements, As, Mo, W, Sb and Tl are at low concentrations.

2.8 Apollo

Lintern and Gray (1995b), Lintern (1996)
Apollo is approximately 25 km SE of Kambalda, and 2 km E of Lake Lefroy, located in the western limb of the St Ives Antiform. The local bedrock consists of the Paringa Basalt, the Black Flag Group and the Condenser Dolerite, all of which strike NE, dip 70 - 80° SW and are metamorphosed to low grade. Mineralization is encountered at about 15 m depth and dips to 760 m or more to the W. It is confined to bedrock and saprolite, and is associated with albite alteration products within two NNE-trending mylonitic shear zones.

There is a palaeochannel 250 m to the S, where it cuts approximately E-W across the nearby Argo deposit. The U-shaped palaeochannel has a maximum depth of 60 m and average width of 400 m, and has been incised into the residual profile. The residual regolith profile consists of variably coloured, dark, clay-rich saprolite (Figure 9). The saprolite is generally between 20 - 30 m thick, though it is thinner beneath the palaeochannel. Gold contents of deeper saprolite exceed 500 ppb close to mineralization. The saprolite is covered by a unit of hard red and grey clays, with variable ferruginous mottling. This unit contains zones of indurated ferruginous and siliceous material, forming pans of variable thickness, generally between 2 and 7 m depth. It is covered by a calcareous clay-rich red soil, up to 2.0 m deep, that has a dark manganiferous horizon at 1.5 m depth. The soil is characterized by locally abundant calcrete nodules, 1-2 cm in diameter. Carbonates also coat the clays and lithorelics in the soil, and forms cutans on the nodules. A sandy aeolian topsoil, about 0.2 m thick, but is up to 2 m thick in places, covers the calcareous soil
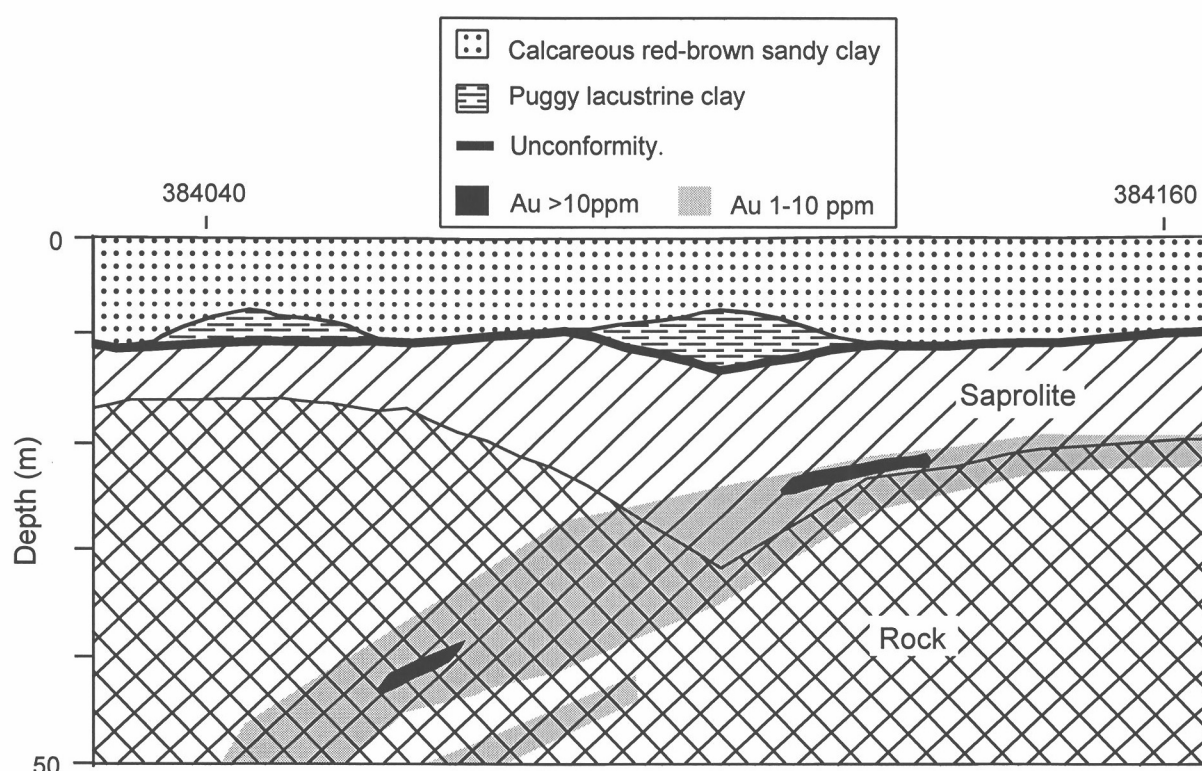
Figure 9: Soil traverse location, regolith and mineralization at Apollo line 526080N.

The climate is semi-arid with an unreliable average annual rainfall of 280 mm. Vegetation is sparse and composed of open woodland of *Eucalyptus* spp., the occasional *Casuarina* (she-oak), and small shrubs including *Eremophila* (poverty bush) and *Maireana* (bluebush). The landscape is typical of the floodplains bordering the salt lake regimes of the region. A broad colluvial plain with occasional clay pans drains the study area to the SW towards Lake Lefroy, where dunes cover large areas.

Ferruginous materials, including sediments and lithorelics, taken from the transported overburden, have Au concentrations close to, or below, the detection limit of 5 ppb. However, Au concentrations are slightly higher (7 and 10 ppb) in the south, where depth to mineralization is less. Gold concentrations are not related to Fe content, which varies from 18 to 31%. The highest concentrations of Au appear in the calcareous horizon. Extractions using water, iodide and cyanide, conducted as part of the site study, did not directly assist in the location of buried mineralization at Apollo.

Compared with other sites, Apollo has the most water and iodide-soluble Au. This suggests that the Au is in a potentially more mobile form than that of other sites. Arsenic is not significantly associated with mineralization, and As concentrations are generally low. In contrast, Zn concentrations are strikingly elevated in soils over mineralization (maximum 540 ppm).

Groundwaters in this area are acid and highly saline; salinity and pH both increase with depth (about 5-8% TDS, pH 3.5-4.0 for shallow samples, and 19-26% TDS, pH 4.5-5.5 for deep samples). Major element abundances suggest the waters have been evaporated within a salt lake environment. Dissolved trace element compositions are very similar to Steinway (Section 2.7). The only element enrichments that appear associated with mineralization are Mo, which has relatively high concentration for an acid groundwater, and Co, Ni and Au. Halides (chloride and/or iodide), are expected to be an important mechanism for the dissolution of Au in such groundwaters.

A cross-section of the regolith for the traverse used for the partial extraction tests is shown in Figure 9.

3. METHODS

3.1 Sample collection and preparation

Samples from each site were taken on traverses across buried Au mineralization (Section 2). Samples from Safari, Apollo and Curara were collected into calico bags and air dried then stored in plastic, whereas samples from Fender, Bronzewing, Baxter and Steinway were collected into plastic bags and air dried (Table 1). Samples were sieved to < 2 mm, and then riffle split into four aliquots for analysis by MMI, enzyme leach, HCl extraction and sequential partial extraction.

Table 1: Summarized sample treatments

Site	Sample	Treatment	Storage
Baxter	5 - 20 cm (spade)	plastic bag air dry	sealed plastic bags
Fender	0 - 1 m (drilled)	plastic bag air dry	sealed plastic bags
Bronzewing	30 - 50 cm (spade)	plastic bag air dry	sealed plastic bags
Curara	2 - 20 cm (spade)	calico bag air dry	sealed plastic jars
Safari	2 - 50 cm (drilled)	calico bag air dry	sealed plastic bags
Steinway	0 -1 m (power auger)	plastic bag air dry	sealed plastic bags
Apollo	0 -1 m (drilled)	calico bag air dry	sealed plastic bags

3.2 Sequential selective extractions

The three methods detailed below are observed to be commonly highly selective for particular mineral phases in soils (Chao, 1984). Five grams of sample were weighed into a centrifuge tube and then sequentially extracted by the methods described below:

3.2.1 pH 5 acetate (carbonates and surface adsorbed metals).
The 5.00 g of sample was shaken with 95 mL 1 mole/litre ($\underline{M}$) ammonium acetate at pH 5 for 6 hours. The mixture was then centrifuged (4000 rpm, 15 minutes) and the supernatant decanted. The extraction was repeated. The solid was then mixed with 10 mL 0.1 $\underline{M}$ ammonium chloride and centrifuged. The three aliquots were combined for analysis by ICPMS for Ag, As, Au, Be, Ba, Bi, Ca, Cd, Ce, Co, Cr, Cu, Fe, Hg, Li, Mn, Mo, Ni, Pb, Pt, Sb, Se, Sn, Te, Th, Tl, U, W, Zn and Zr.

3.2.2 0.1M hydroxylamine (Mn oxides).

The residual solid from the extraction was then mixed with 90.0 mL 0.1 $\underline{M}$ hydroxylamine hydrochloride in 0.01 $\underline{M}$ HNO_3 for at least 30 minutes. The mixture was centrifuged and the supernatant decanted and analysed by ICPMS for the same suite of elements as the pH 5 extraction (Section 3.2.1).

3.2.3 0.25M hydroxylamine (amorphous Fe oxides).

The residual solid from the extraction was then mixed with 90.0 mL 0.25 $\underline{M}$ hydroxylamine hydrochloride in 0.25 $\underline{M}$ HCl at 50°C for at least 30 minutes. The mixture was centrifuged and the supernatant decanted and analysed by ICPMS for the same suite of elements as the pH 5 extraction (Section 3.2.1).

3.3 HCl extractions

HCl extractions were performed by Ultra Trace Pty Ltd using their commercially available procedures. Four grams of sample was digested in 8 mL 4 $\underline{M}$ hydrochloric acid (HCl) at 15°C for 4 hours for analysis by ICPMS the same suite of elements as the pH 5 extraction (Section 3.2.1), less Cr. There was also a separate extraction using concentrated (10 $\underline{M}$) HCl. In addition, extra extractions were performed with an added oxidizing agent, giving an "enhanced" Au digest.

3.4 Mobile metal ion analysis

The MMI (Mobile Metal Ions; ® Wamtech Pty Ltd.) process uses two leachant solutions to dissolve target metals. The technique involves acid solution analysis by ICPMS for Cd, Cu, Pb, Zn and alkaline solution analysis by ICPMS for Ag, Au, Co, Ni, Pd. The extractions and analyses were performed by Analabs Pty Ltd, using approximately 100 g for each of the two extractions.

3.5 Enzyme leach analysis

Enzyme leach (EL) is an selective leaching procedure utilizing a reaction between glucose oxidase and dextrose to produce low concentrations of hydrogen peroxide to partially leach amorphous MnO_2 (Clark, 1993), prior to analysis by ICPMS for Ag, As, Au, Ba, Bi, Br, Cd, Ce, Cl, Co, Cs, Cu, Dy, Er, Eu, Ga, Gd, Ge, Hf, Hg, Ho, I, In, Ir, La, Li, Mn, Mo, Nb, Nd, Ni, Os, Pb, Pd, Pr, Pt, Rb, Re, Ru, Sb, Sc, Sm, Sn, Sr, Ta, Tb, Te, Th, Ti, Tl, Tm, U, W, Y, Yb, Zn and Zr.

4. RESULTS

4.1 Introduction

The data derived from this investigation are voluminous and only selected results have been plotted and discussed in the report. The results are presented in the appendices, as follows:

Appendix 1:   Full data set (also included in the enclosed computer disk);
Appendix 2:   Graphical summary of comparative extraction results for each element;
Appendix 3:   Plots of 4 $\underline{M}$ HCl vs. selective extraction results;
Appendix 4:   Plots of MMI vs. 4 $\underline{M}$ HCl extraction results;
Appendix 5:   Plots of MMI vs. enzyme leach extraction results;
Appendix 6:   Selected Enzyme leach plots;
Appendix 7:   Traverse data for Baxter;
Appendix 8:   Traverse data for Fender;   Northern
Appendix 9:   Traverse data for Bronzewing;

The methods are compared in Section 4.2; particular elements are discussed in Section 4.3; results for the sites are discussed in general in Section 4.4. The authors are aware that this involves a certain degree of duplication, but this is considered necessary for all aspects of this research to be adequately and coherently assessed.

4.2 Comparisons between methods

4.2.1 Sequential selective extractions

The selective extractions are, as the name implies, designed to specifically extract certain minerals or phases, and results indicate this has occurred. The pH 5 reagent successfully extracts ALL of the Ca from the carbonate-rich Kalgoorlie sites (i.e., Steinway and Apollo) and the low carbonate Safari[2] and Curara sites. In contrast, in the Northern sites, where some to all of the Ca is as non-carbonate minerals, the Ca tends NOT to be dissolved with pH 5 acetate. Other elements partially (bracketed) or mostly to wholly extracted by this reagent are As (Kalgoorlie sites) Ba, (Be), Cd (Kalgoorlie), (REE), (Cr), (Cu) (Kalgoorlie), (Li) (Kalgoorlie), (Mn), (Ni) (Apollo), (Pb), Th, U and Zn (Apollo). For a number of these elements, particularly As, REE, Th, U, only a small proportion were extractable by any reagent, so this comment is for the extractable component only. Total Cd and Cr were not determined, so it may be that these elements behave in a similar manner.

It should not be assumed that all these cases indicate that the elements occur within carbonates, especially those such as REE, Th and U which are extracted by pH 5 acetate even in the Northern sites. These elements may (partially) occur as soluble secondary minerals, that dissolve in an acid acetate solution, which strongly complexes most high charge (3+ or greater) ions. More Ba was dissolved by pH 5 acetate than by the HCl extraction, possibly due to barite being soluble in acetate (due to complexing of Ba), but not in acid.

The second extraction, namely 0.1 $\underline{M}$ hydroxylamine, is designed to dissolve separate phase Mn oxides. Although most of the total extractable Mn is dissolved with this reagent, considerable amounts of Mn are dissolved by the prior pH 5 acetate reagent, possibly representing more soluble Mn, either within carbonates, separate-phase $MnCO_3$, or particularly soluble Mn oxides. This is particularly marked at Apollo, for which pH 5 acetate-soluble Mn is commonly up to half of the extractable Mn. Other elements partially (bracketed) or mostly to wholly extracted by the 0.1 $\underline{M}$ hydroxylamine reagent are (Au) (Steinway), (Ba), Co, (Ni), (Pb) (Bronzewing and Baxter) and (Tl) (Bronzewing). The low number of elements substantially dissolved by this reagent is surprising, given the accepted capacity of separate phase Mn oxides to be major sinks for metals. The extractable Mn broadly correlates with total extractable Fe (Figure 10), even though these two elements are dissolved by different reagents, indicating an indirect secondary cause for these two phases, such as presence of a drainage channel, or particular biological effects. Thus, at specific sites (e.g., Curara; Section 4.4.4), a number of extractable metals correlate with total and extractable Mn, even though most of these elements are only dissolved by 0.25 $\underline{M}$ hydroxylamine and are thus hosted by amorphous Fe oxides.

---

[2] Note that although Safari soils contain low carbonate, significant carbonate occurs at > 0.5 m depth
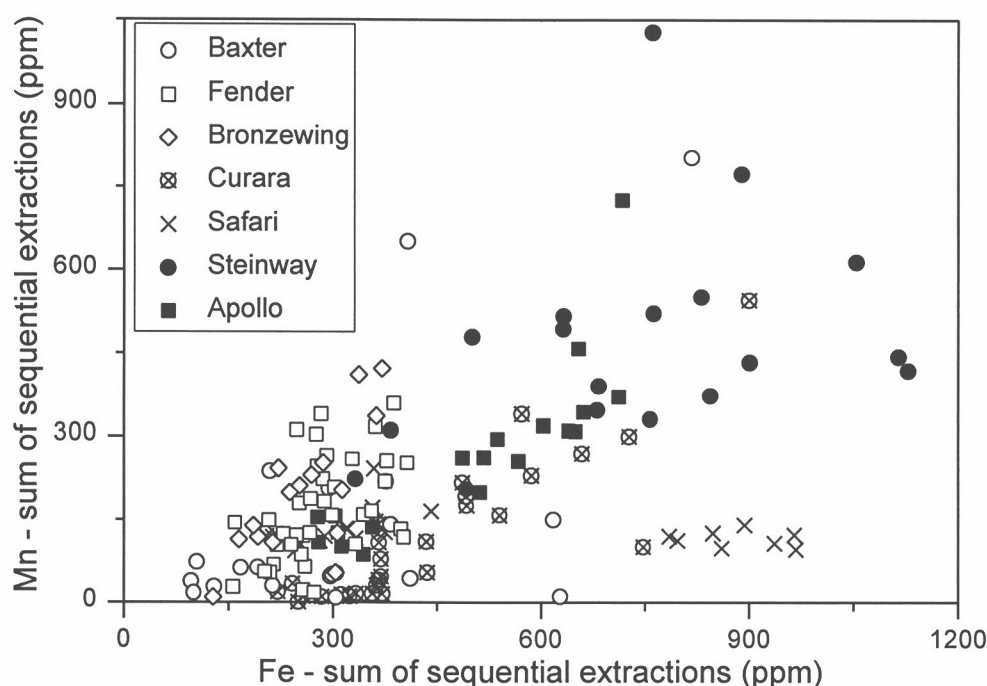
Figure 10: Correlation between Mn and Fe extracted by the three sequential extractions.

Most of the Fe dissolved by the three extractants is done so by the 0.25 $\underline{M}$ hydroxylamine reagent (85 - 99%). This reagent is designed to dissolve 'amorphous' Fe oxides. Though this is not a clearly defined phase, the good agreement between the sum of the selective extractions and 4 $\underline{M}$ HCl (Appendix 3; Section 4.2.2), despite only a very minor proportion of the total Fe being dissolved, suggest that the extraction is dissolving specific Fe-rich components, be they separate phase minerals or disordered surfaces. Other elements partially (bracketed) or mostly to wholly extracted by 0.25 $\underline{M}$ hydroxylamine are Ag, (Ba), Be, (Cd), (Co), Cr (Safari and Kalgoorlie), Cu, Li (Kalgoorlie), (Mn), Ni, Pb, REE, (U) and (Zn).

4.2.2 HCl extractions

The acid extractions involve two separate (not sequential) reagents. The first, 4 $\underline{M}$ HCl, dissolves similar concentrations to that of the combined sequential results for all elements for which there are adequate data, namely Ca (except for Ca > 7.5%, for which the acid extraction does not dissolve all of the carbonate), Fe, Mn, Ba, Be, Cd, Ce, Co, Cu, Li, Ni, Th (not for Northern sites), U and Zn (Appendix 3). For Fender and, to a lesser extent, Safari, combined sequential extractions were higher for Co, Ce and, particularly, Ba than for 4 $\underline{M}$ HCl. This may represent lithological effects, due to the presence of sandy granite-derived material at surface at these sites. For other elements, the higher detection limits from the solution matrix, plus the cumulative errors, means that the results for the combined sequential analyses are not sufficiently precise for comparison.

The good agreement between the combined sequential and the 4 $\underline{M}$ HCl extractions for most elements is consistent with the extraction model illustrated in Figure 11. In addition to the minor exceptions described above, there was also poor agreement for Fe, particularly for dominantly granite-derived soils at Safari, for which the sequentially extracted Fe is 4 - 5 times greater than 4 $\underline{M}$ HCl soluble Fe, again suggesting lithological effects. In Figure 11, this variation in Fe is represented by the double-headed arrow for 4 $\underline{M}$ HCl, indicating that this reagent in some cases does not dissolve all of the amorphous Fe (defined as all 0.25 $\underline{M}$ hydroxylamine-soluble Fe) whereas, in other samples, it dissolves some of the crystalline Fe. The good agreement between methods for a number of elements associated with amorphous Fe (e.g., Cu and Ni) indicates that these elements are primarily associated with the most soluble, amorphous, Fe oxides, rather than with less-soluble Fe oxides.
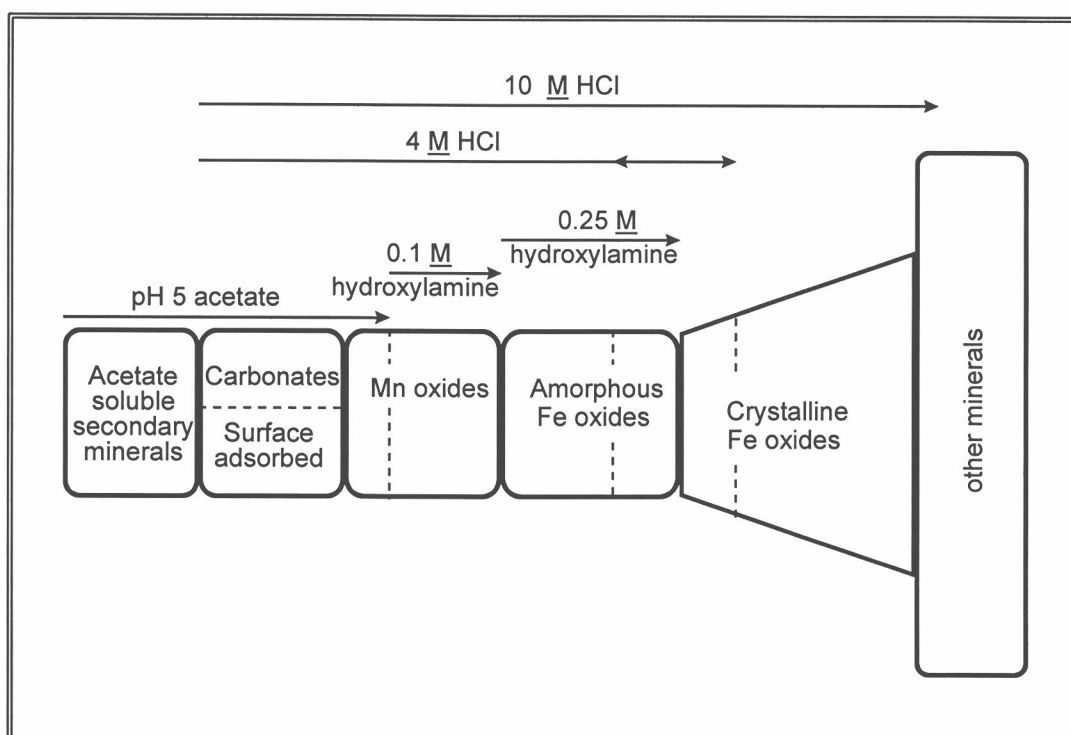
Figure 11: Diagrammatic representation of the phases dissolved by selective and acid extractions.

The 10 $\underline{M}$ HCl reagent dissolves 10 - 50 times more Fe than 4 $\underline{M}$ HCl. Although a significant proportion, this is still well less than half of the total Fe (commonly dominantly present as separate phases Fe oxides), with the exception of Safari, where most of the Fe is dissolved by this reagent. Other elements for which moderately (bracketed) or significantly more was extracted by 10 $\underline{M}$ HCl than for 4 $\underline{M}$ HCl are (Ag) (Fender and Apollo), As, (Ba) (Baxter and Bronzewing), (Ca) (Safari), (Cd), (Co) (Fender only), (Cu) (Northern and Central), Hf (though still only 0.1% of total Hf), Mn (Northern), Mo, Nb, (Ni) (Central and Northern), Pb, (REE), Sb, Se (Baxter, Fender, Bronzewing and Safari), Sn, Th, Tl, (U) (Northern and Central), W and Zn (all except Apollo).

Most of the elements partially extracted by 10 $\underline{M}$ HCl appear, on the basis of proportional extractability, to be associated with crystalline Fe oxides. For elements for which totals are available (As, Ca, Ce, Co, Cu, Fe, Hf, Mn, Ni, Pb, Sb, Th, U, W and Zn), most are either fully extracted with the less extreme reagents or proportionally with Fe in 10 $\underline{M}$ HCl. Exceptions are Hf (highly insoluble), As (Bronzewing and Safari), Co (particularly Baxter, and to a lesser extent Bronzewing, Curara and Safari), Ni (Baxter and Curara), Sb (Safari), Th (Baxter, Bronzewing, Curara and Safari), W (Baxter) and Zn (Baxter, Bronzewing, Fender and Curara). That is, Sb (for example) appears to dissolve proportionally with Fe at all sites except Safari, where a significant proportion is in the resistate phase(s).

4.2.3 Mobile metal ions
The MMI analysis is, in fact, two separate techniques. The first, an acid extraction for Cd, Cu, Pb, Zn, give results that are similar, in terms of comparison between samples at each site, to HCl and selective extraction (Appendix 4). Note that the carbonate-rich Kalgoorlie sites give much lower MMI responses, relative to the HCl solubility; this may be related to the ability of the carbonate to quickly neutralize the acid MMI reagent and therefore keep the metal solubility low.

The second method is an alkaline extraction for Ag, Au, Co, Ni and Pd. This method appears to be optimized for Au and gives very similar extractable Au contents to the CSIRO iodide method (Gray and Lintern, 1993) and the enhanced HCl digests (Figures A4.2 and A4.3). In soils containing significant carbonate (Safari, Steinway and Apollo) 70 - 80% of the total Au is dissolved (Figure 12), whereas in the northern sites the extractable Au proportion is significantly lower, probably because of occlusion of Au. The MMI extraction is also very effective at dissolving Ag (Figure A4.1), as expected for a method optimized for Au. Therefore, the MMI extraction does not appear to be giving any additional information for Au or Ag than can not be obtained using total or standard (*e.g.*, BLEG or *aqua regia*) analyses. Probably as a consequence of this MMI method being done under alkaline conditions, the Co (though not the Ni; Section 4.3.7) data (Figures A4.6 and A4.8) are unlike those observed for other techniques. Also note that MMI gives much greater (generally by at least 5 times; Appendix 5) extraction than enzyme leach for all elements except Co and Ni.
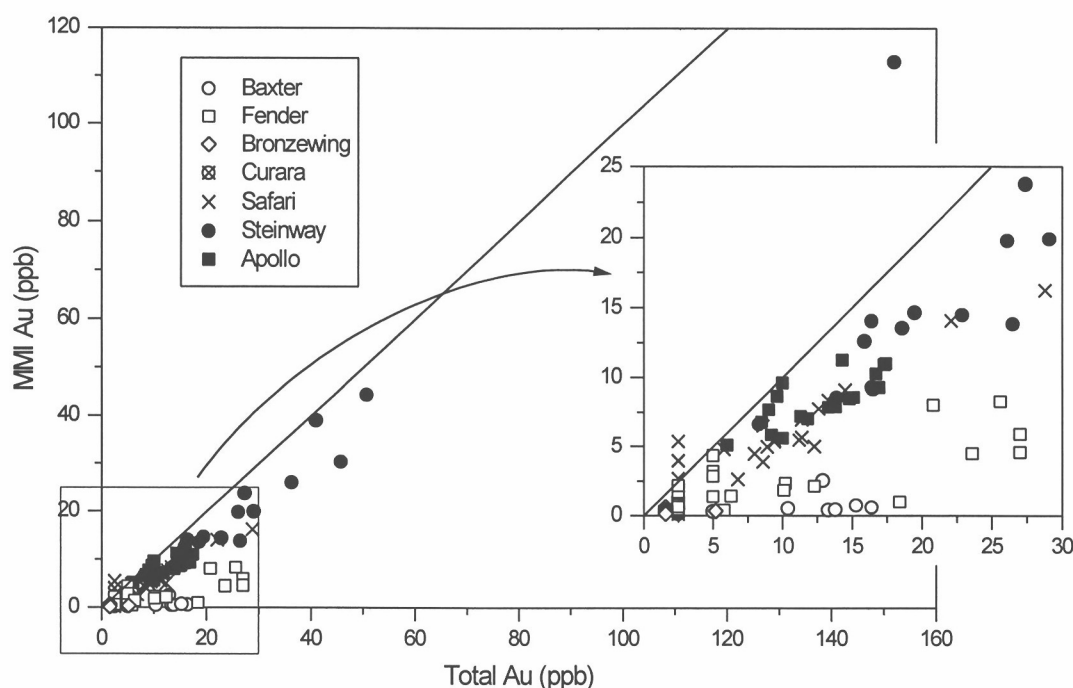

Figure 12: MMI Au vs. CN-extractable Au for all sites

4.2.4 Enzyme leach

The enzyme leach reagent is targeted at an 'amorphous' Mn phase, although the proportion of enzyme leach to total extractable Mn varies dramatically between sites (Figure 13) from about 20% at Bronzewing to < 0.5% at Steinway. Other elements did not show any clear correlation with Mn, except for enzyme leach Co, which correlates with enzyme leach Mn (Figure A6.2). The enzyme leach method also appears to give unique results, not correlated with other methods, and gives a much larger range of elements than MMI. Interestingly a number of enzyme leach elements, namely Cs, Fe, Ga, Hf, La, Nb, all REE with significant concentrations, Pb, Sc, Sn, Th, Ti and Zr, show very close linear correlations with each other (Appendix 6). Most, but not all, of these elements tend to be high-charge, with only low concentrations (except for Fe extracted by this method). These surprising close correlations suggest either a highly specific interaction between these elements and Fe within those soil phase(s) dissolved by enzyme leach or an analytical interference from Fe. This effect should be understood before these elements are routinely used.
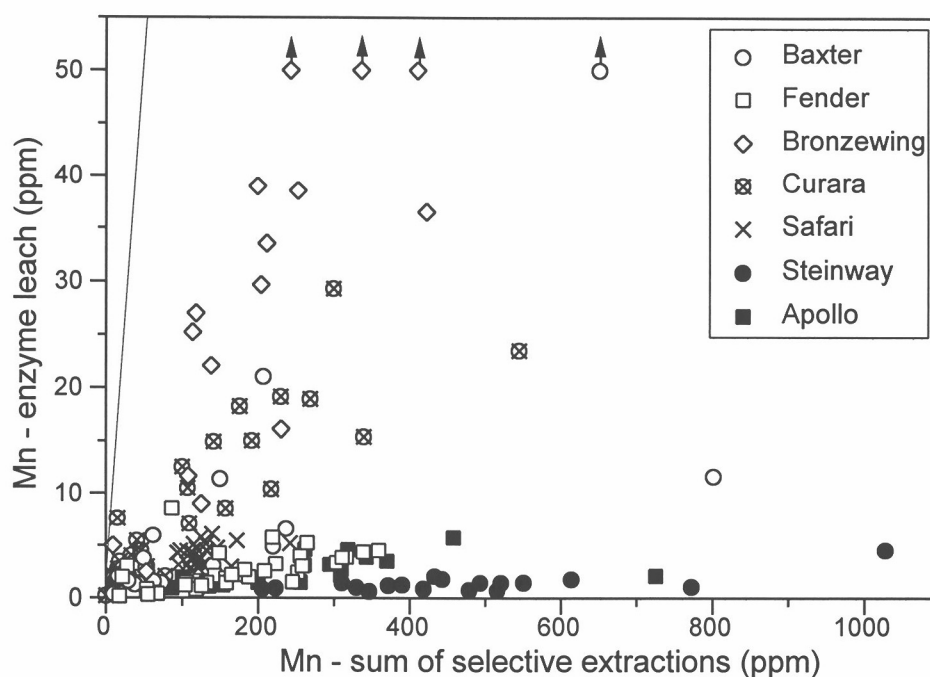
Figure 13: Enzyme leach vs. selective extractions for Mn.

4.3 Specific elements

4.3.1 Calcium

Calcium is successfully extracted with pH 5 acetate, indicating the effectiveness of this reagent to dissolve carbonates. At Fender, the small amount of undissolved Ca may be present in feldspars. The Kalgoorlie sites, Steinway and Apollo, contain high Ca (> 3%), Safari and Fender > 0.1% Ca and the other northern sites contain virtually no Ca.

4.3.2 Iron

Iron oxides can be a significant scavenger of a number of metals and anions (e.g., As and Sb), with more amorphous forms, such as ferrihydrite ($Fe_2O_3.nH_2O$) being particularly active. With the exception of 10 $\underline{M}$ HCl, the reagents dissolved very minor proportions of the total Fe (Figure A2.11), consistent with Fe being dominantly present as crystalline Fe oxides, such as goethite and hematite. Of the sequential extractants, only 0.25 M hydroxylamine dissolved significant Fe (approximately 0.05%), probably representing amorphous Fe oxides. Very similar amounts were dissolved by 4 $\underline{M}$ HCl, suggesting that this reagent is dissolving a similar component of the soil as the sum of the sequential extractions (Section 4.2.2). The pH 5 acetate and enzyme leach reagents dissolved similar concentrations of Fe, though the patterns were different. The enzyme leach results were highly site-specific, with a variation of up to 30 x between sites (Figure A2.11).

4.3.3 Manganese

Most extractable Mn is dissolved using 0.1 M hydroxylamine: indicating Mn oxide phases. Plotting extractable vs. total Mn (Figure 14) indicates an approximately linear relationship at each individual site, with a residual of unextractable Mn, that varies from approximately 100 ppm at Apollo to 500 ppm at Baxter. Enzyme leach dissolves between 0.5 to 14% of extractable Mn, depending on the site (Figure A2.13).
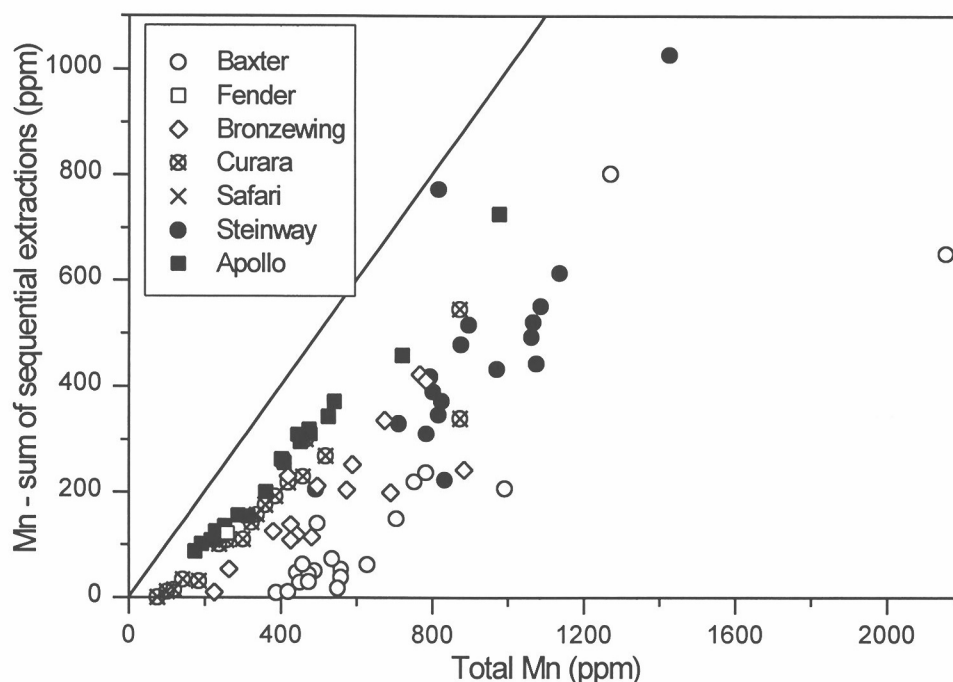
Figure 14: Sequentially extracted Mn vs. total Mn for all sites

4.3.4 Cobalt

Results for Co closely match Mn, consistent with the close association between these elements in secondary minerals. Enzyme leach and alkaline MMI reagent results are not related to each other nor to any of the other extractions (Figure A5.4). The enzyme leach:MMI ratio varies from 0.14 (Steinway) to 3 (Bronzewing).

4.3.5 Copper

The extractable Cu appears to occur mostly with amorphous Fe, with significant proportions also dissolved by pH 5 acetate (Figure A2.10). The acid MMI reagent dissolves between 1 and 17% of the extractable Cu (Figure A4.7), which is significantly more than enzyme leach (Figure A5.5).

4.3.6 Zinc

At all sites except Apollo, only small proportions of the total Zn are soluble (Figure A2.20). The greatest proportion dissolved in the selective extractions is by 0.25 M hydroxylamine (amorphous Fe oxides), with significant proportions dissolved by pH5 acetate (carbonates and/or surface adsorbed). The acid MMI reagent dissolves 0.03% of the extractable Zn at Steinway and 3 - 25% at the other sites (Figures A4.10 and A4.11), which is significantly more than enzyme leach (Figures A5.9).

The data for Apollo are significantly different. There is up to 550 ppm total Zn in the soil (Figure 16), virtually all of which is extractable with pH 5 acetate, suggesting the presence of secondary Zn carbonates or oxides. The acid MMI reagent dissolves 7.5% of the extractable Zn, which is proportionally similar to the other sites (except for Steinway).

4.3.7 Nickel

Extractable Ni is greatest for the Kalgoorlie sites (Figure A2.14). Most extractable Ni is in the amorphous Fe oxides (0.25 $\underline{M}$ hydroxylamine). There is a good correlation between alkaline MMI and 4 $\underline{M}$ HCl extractions (Figure A4.8).

4.3.8 Gold

The selective extractants are poor at dissolving Au, as are normal acids. The addition of an oxidizing agent to the HCl reagents (Section 3.3) significantly increases Au dissolution. This enhanced acid reagent, the alkaline MMI reagent, and the CSIRO iodide reagent all dissolve significant proportions of Au (averaging 70 - 80% of total Au at Safari, Steinway and Apollo; Figure 12). The Northern sites have lower proportions of acid-, MMI- and iodide-soluble Au, most probably because of occlusion of the Au. The proportion extracted by enzyme leach is approximately 10% of the total Au.

4.3.9 Silver

For the selective extractions, Ag is soluble principally in the 0.25 M hydroxylamine reagent, implying that it is hosted by amorphous Fe oxides (Figure A2.1). Virtually all of this extractable Ag is also dissolved by MMI, with enzyme leach concentrations much lower.

4.3.10 Rare earth elements

A minor proportion of the REE are dissolved by the selective extractants (Figure A2.8), dominantly by 0.25 M hydroxylamine, implying that they are hosted by amorphous Fe oxides, with a good correlation between selective and acid extractions (Figure A3.4). Enzyme leach dissolves < 0.5% of extractable REE.

4.4 Comparison of sites

4.4.1 Baxter (Appendix 7)

Two traverses were used at this site (Figure 2). With the exception of Au (Figures A7.3 and A7.4), no elements appear to give useful exploration data. As described in Section 2.2, the Harmony deposit has 0.5 - 3 m colluvium over mineralized ferruginous saprolite, and there has been sufficient mechanical or biological mixing to bring some Au to the surface. There are up to 15 ppb Au in soils over mineralization, and HCl digests and MMI both give useful results. However, these reagents dissolve most of the accessible Au, and it is expected that either *aqua regia* or CN digests, including BLEG, would give equivalent results.

There is a higher concentration of Mn oxides (500 ppm compared with < 100 ppm background) in the eastern part of both traverses, although the multi-element response differs dramatically for these two Mn-rich samples, as summarized below:

12600N Mn anomaly: Ag (Figure A7.1) - HCl, EL, MMI (selective extractions below detection);
Cd (Figure A7.7) - HCl, possibly EL, MMI (selective extractions below detection);
Ce (Figure A7.9) - 0.1 M hydroxylamine and 0.25 M hydroxylamine ;
Co (Figure A7.11) - all methods except MMI (pH 5 acetate below detection);
Cu (Figure A7.13) - HCl, 0.1 M hydroxylamine and 0.25 M hydroxylamine;
Fe (Figure A7.15) - 0.1 M hydroxylamine and MMI;
Mn (Figure A7.17) - all methods;
Ni (Figure A7.19) - 4 M HCl, possibly 0.1 M hydroxylamine and EL;
Zn (Figure A7.25) - all methods.

Traverse A Mn anomaly: Ce (Figure A7.10) - HCl and selective extractions (most dissolved by pH 5 acetate);
Cu (Figure A7.14) - MMI only;
Mn (Figure A7.18) - 10 M HCl, 0.1 M hydroxylamine and 0.25 M hydroxylamine.

Interestingly, the enzyme leach shows a Mn response for the eastern-most 12600N sample, but not the east of Traverse A. The reason for the differences between the two samples is not known, but the critical observation is that they appear to represent FALSE positive anomalies: *i.e.*, there is a positive soil response that appears to be unrelated to any mineralization.

Enzyme leach I (not shown) and Cu (Figure A7.13) appear to correlate with mineralization on Traverse 12600N. However, on Traverse A, enzyme leach Cu has a maximum 200 m W of the position of buried mineralization (Figure A7.14) and I shows no systematic variation across the traverse. The MMI Ni appears to correlate with mineralization on one traverse. The poor repeatability, and the stronger false positives (see above), would suggest these correlations are accidental.

4.4.2 Fender (Appendix 8)
This site has 2 - 8 m sand and silty clay over mineralization (which is in saprolite or lateritic residuum). Primary mineralization contains Au, Ag, As, Sb, Cu, W and Mo. Three traverses were used, one of which was Au-poor at depth. The total and extractable (not enzyme) Au in the soils peak over mineralization on line 240N, which (as at Baxter) is probably due to the thin cover. No other elements (total or extractable) are correlated with mineralization. Concentrations are comparable for all 3 traverses, despite the major variation in the magnitude of mineralization at depth for the three traverses. This poor success includes extractions possibly successful at other sites (*e.g.*, enzyme leach Cu and I, MMI Ni).

The clearest soil anomaly is for the eastern-most sample of line 340N (*i.e.*, the Au-poor traverse), which shows high concentrations of Ag (up to 480 ppb, HCl, 0.25 $\underline{M}$ hydroxylamine, enzyme leach and MMI), Cd (up to 180 ppb, all methods), Cu (up to 12 ppm, all methods), Pb (up to 45 ppm, all methods), Zn (up to 7 ppm, all methods) and, to a lesser extent W (up to 5 ppm, all methods). For this sample the element concentration ratios for MMI vs. 10 $\underline{M}$ HCl (the most extreme extractant used) were: Ag (38%), Cd (42%), Cu (16%), Pb (5%) and Zn (55%). Thus, the MMI reagent is dissolving a highly significant proportion of the base metal. This sample appears to be a false anomaly.

4.4.3 Bronzewing (Appendix 9)
Mineralization at Bronzewing is covered by 5 - 25 m of colluvium and alluvium derived from non-local sources. Despite Au concentrations up to 1.9 ppm at 10 m depth, there is no significant anomaly at surface. It is expected that any dispersion into the colluvium has been physical. The present fresh/neutral groundwaters are not able to dissolve Au, hence active chemical dispersion is improbable. Enzyme leach Co and Mn, are higher than elsewhere, and Co is correlated with Mn for most of the extraction methods. At this site, there is an active major drainage that is not coincident with the mineralization (compare with Curara; Section 4.4.4), and the geochemical signal is stronger in the channel than over mineralization (*i.e.*, a false positive), possibly related to Mn in the hardpan precipitated by ephemeral drainage in the channel. Enzyme leach Cu correlates (weakly) with mineralization.

4.4.4 Curara (Appendix 10)
At Curara an active drainage system overlies the buried mineralization. Soils in the drainage have high concentrations of separate phase Mn oxides (up to 500 ppm Mn;) and amorphous Fe (up to 600 ppm Fe). All methods, including total analysis, give anomalous response directly overlying mineralization. No method showed particular superiority in terms of signal to noise, though the worst methods in this respect were pH 5 acetate (high detection limits), totals and 10 M HCl (high backgrounds). Other elements that are greatest over mineralization are As (EL), Au (HCl), Ba (HCl, 0.1 $\underline{M}$ and 0.25 $\underline{M}$ hydroxylamine, EL), Be (pH 5 acetate, 0.1 $\underline{M}$ and 0.25 $\underline{M}$ hydroxylamine, EL), Cd (HCl, MMI), Ce (0.1 $\underline{M}$ and 0.25 $\underline{M}$ hydroxylamine, EL), Co (all except MMI), Cs (EL), Cu (all), Ga

(EL), Hg (HCl), Mo (HCl), Nb (EL), Ni (all but poor), Pb (all except pH 5 acetate), Pd (MMI), Pt (HCl), REE (Total, EL), Sb (total), Sn (HCl), Te (HCl), Th (total, EL), Tl (HCl), U (all except EL), W (HCl), Zn (total, HCl, 0.25 M hydroxylamine, MMI), Zr (EL).
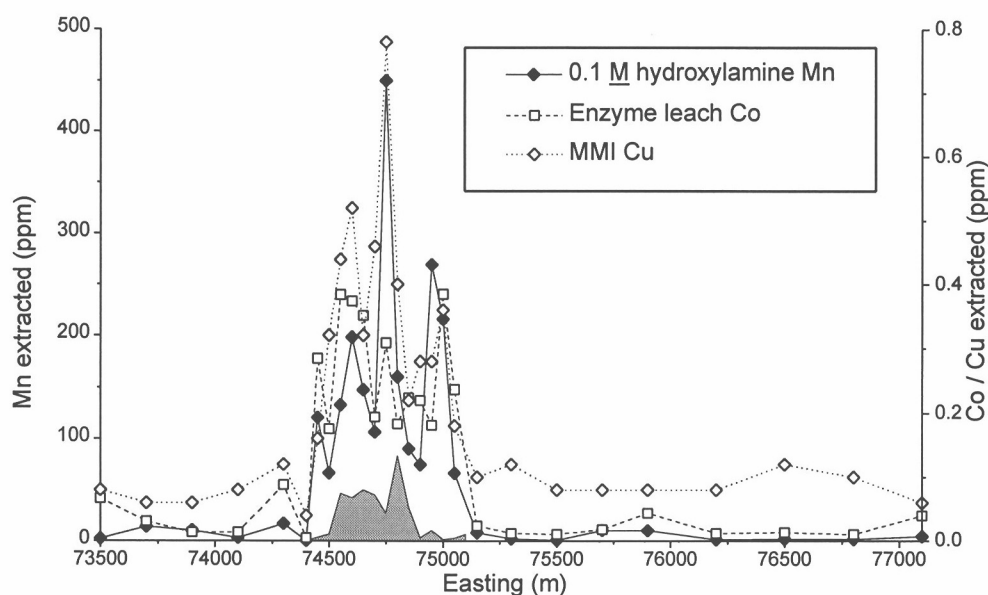

Figure 15: Selected extraction results across the Curara traverse
(Shaded area represents Au in buried laterite).

It is postulated that accumulation of amorphous Fe oxides and Mn oxides is the main control over metal solubilities, and the good correlation of element concentration with buried mineralization is coincidental. This is discussed in further detail in Gray (1996). These results can be compared with those for Baxter (Section 4.4.1) and Bronzewing (Section 4.4.3), for which the Mn drainage anomaly is not over mineralization.

4.4.5 Safari (Appendix 11)
The Safari traverse has 4 - 6 m sandy calcareous cover over Au-rich saprolite. Total and extractable Au in the soils (by most methods) peak over mineralization (Figure A11.2), probably as a function of the thin cover. Tungsten (4 M HCl and enzyme leach) also appeared correlated with mineralization, though not as closely as Au. No other elements correlate with the position of mineralization. Distribution of Ce, Co, Cu, Ni, Pb and Zn appear to be weakly correlated with that of extractable Mn or Fe, for some extractions.

4.4.6 Steinway (Appendix 12)
Mineralization at Steinway is overlain by 5 m of leached saprolite and 25 m of palaeochannel sediments. Despite this, total Au peaks at 155 ppb over mineralization at 10880 mE on the traverse, and other extraction methods confirm this result (Figure A12.2). However, this sample with the highest Au content at Steinway (and, indeed, for all the sites in this study) differs from other samples (for which MMI, iodide and the enhanced HCl reagents extracted similar proportions of the Au) in having relative solubility differences in the order MMI > Iodide > Conc. HCl (enhanced) > 4 M HCl (enhanced) (see Figures A4.2 - A4.4). Thus, for example, the 4 M HCl (enhanced) reagent dissolved only 11% of the total Au in the soil sample at 10880 mE, but $73\pm18\%$ of the total Au for other samples in the traverse. This indicates that Au in this sample is less soluble, and therefore suggests that it to be primary and physically transported. Total and extractable Ag also show a well defined peak over mineralization, though at 10800 mE, 80 m to the W of the main Au peak. Total and HCl extractable (but not enzyme leach) W also overlie mineralization. Other elements that appear to

correlate with the position of buried mineralization are Co (selective extractions only) and Zn (HCl and selective extractions). In contrast, Ni and Pb correlate with the Mn high 200 m E of the position of buried mineralization and do not appear to define mineralization. Cobalt and, possibly, Cd appear to have two peaks: one above mineralization and the other associated with the Mn high.

Several aspects of the Steinway soil anomaly, namely:

   (i) the very high Au concentration;
   (ii) the poor solubility of the high Au sample
   (iii) the single point Ag anomaly, shifted 80 m west of the Au anomaly;
   (iv) a W (which is generally highly insoluble) anomaly, most using total concentrations;

suggests that the signal is probably due to physical transport, possibly from outcropping mineralization approximately 1 km south of Steinway (Lintern and Gray, 1995a).

4.4.7 Apollo (Appendix 13)
This site has 5 - 10 m transported cover over 10 - 30 m variably leached saprolite and saprock. Gold concentrations show no correlation with buried mineralization. In contrast, there is a major Zn anomaly (550 ppm; Figure 16 and A13.13) directly overlying mineralization. This Zn is quantitatively extracted by HCl or selective extractants (85% by pH 5 acetate), suggesting an association with carbonates. Both enzyme leach and MMI gave good Zn responses, as did the other methods. Thus, this is not a subtle (gas-transported ?) anomaly only observed by the subtle partial extractions, but a zone with a major enrichment of Zn.

A second anomaly was observed for the western-most soil sample (383900 mE) was anomalous in Ag (450 ppb), Cd (170 ppb), Cu (15 ppm), pH 5 acetate Fe (27 ppm) and 4 $\underline{M}$ HCl W (26 ppb). The Ag was dissolved by 0.25 $\underline{M}$ hydroxylamine, suggesting incorporation in amorphous Fe oxides, whereas the Cd and Cu are pH 5 acetate soluble. It is possible that this anomaly could increase to the west of the traverse. Thus soils at this site showed two separate anomalies, each with distinct multi-element signatures, in which the anomalous elements were highly extractable, even by the weak reagents. Further work would probably define the source(s) of these anomalies, but they could be explained by elemental dispersion from weathering sulphides N of the traverse, precipitating in the soils either as separate phase carbonates, or within the pervasive soil calcite.

Cerium, Co, Cu (aside from the 383900 mE sample), Ni and Pb have distributions and solubilities indicating association with Mn oxides and/or amorphous Fe, which have greatest concentrations to the E of the traverse. Thus, this site shows a number of soil anomalies that appear unrelated to buried mineralization.
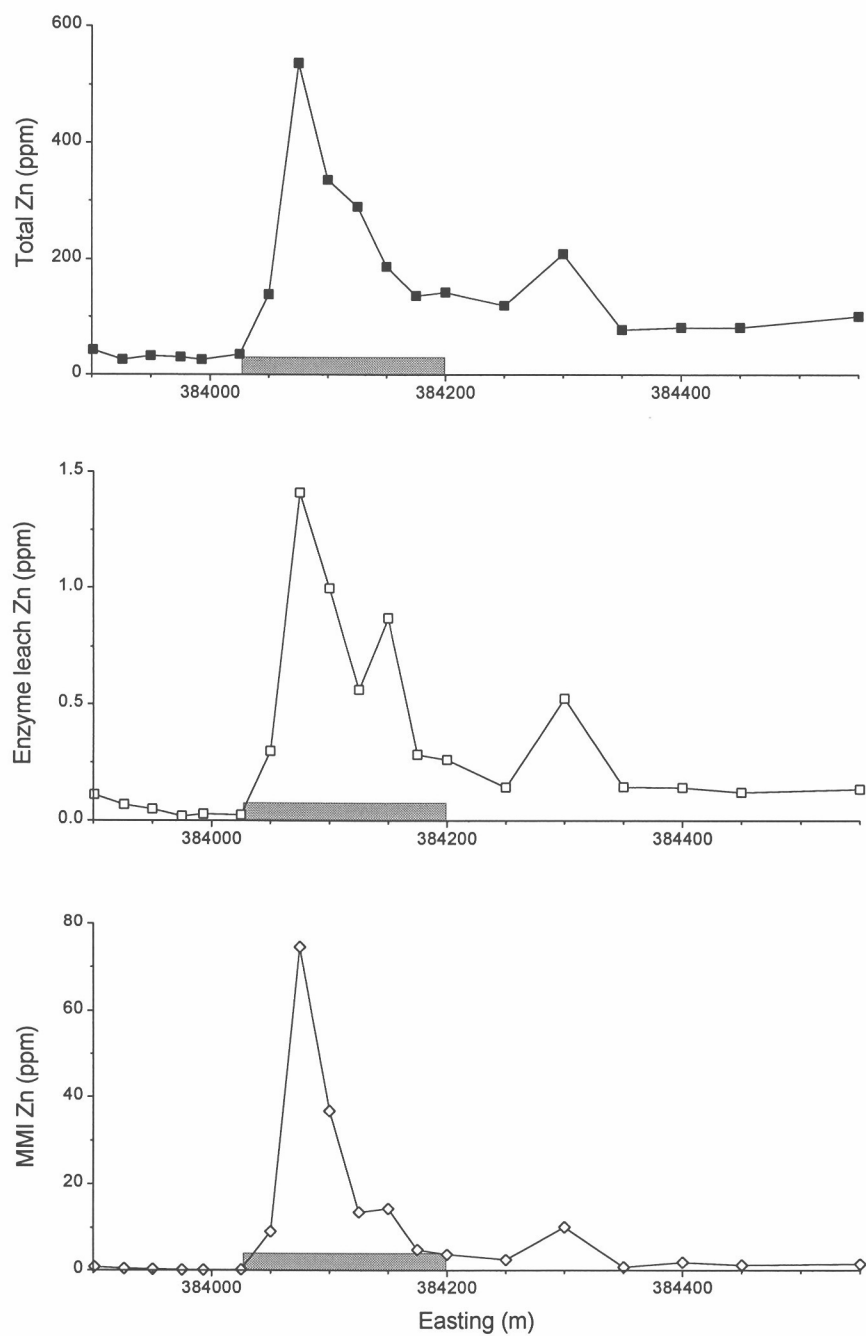
Figure 16: Total, enzyme leach and MMI Zn from Apollo traverse.
(Shaded area represents Au mineralization in Archaean)

5. DISCUSSION AND CONCLUSIONS

The results discussed here are highly site-specific. This may be due to effects of the soil matrix, such as the presence or absence of carbonates, Mn oxides and/or less crystalline Fe oxides. There may also be a significant effect from landscape position, and presence of drainage channels. The groundwater conditions vary considerably from fresh and neutral to the N, to highly saline and acid in the Kalgoorlie area, which has major consequences for the transport of a number of elements (see Hydrogeochemistry section). Another factor that can vary significantly in arid environments is the amount of organic material, which will be affected by the ephemeral nature and/or scattered distribution of the vegetation. The depth of transported cover appears to be significant. With the exception of Steinway, for which the anomaly appears to be due to physical transport from up-gradient (Section 4.4.6), sites with greater than 10 m transported material do not appear to show any anomaly at surface.

The selective and HCl extractions gave results that were sensible and comparable: in particular, the 4 $\underline{M}$ HCl digests gave results that commonly agreed well with the sum of the selective extractions, with the minor discrepancies appearing to be related to granitic material in the soils. The selective extractions gave much information about the location and/or chemical characteristics of many of the major and trace elements, which appeared to be strongly controlled by surface factors and lithological source, with little effect from buried mineralization

The partial extraction methods have particular characteristics that are important for interpretation. The MMI analysis is two separate techniques. The first, an acid extraction for Cd, Cu, Pb, Zn, give results that are similar, in terms of comparison between samples, to HCl and the selective extraction reagents. However, the absence of Fe and Mn data for this extraction, makes inference on the effects of surface conditions very difficult. As these are the primary metal scavengers, inclusion of analyses for these elements is judged to be an important addition for this method. The second MMI method is an alkaline extraction for Ag, Au, Co, Ni and Pd, which appears to be optimized for Au and Ag. In soils containing significant carbonate, 70 - 80% of the total Au is dissolved, whereas the proportion of Au extracted is significantly lower in the northern sites. These results closely match the CSIRO iodide method and the enhanced HCl digests. These extractants do not appear to be giving any additional exploration information for Au or Ag than cannot be obtained using standard analyses. In comparison, probably because the extraction is alkaline, Co data are unlike those observed for other techniques. In only one case (MMI Ni for one of two traverses at Baxter) do MMI results show any correlation (albeit weak) with buried mineralization, that could not be observed using other methods.

The enzyme leach method also appears to give unique results, not correlated with other methods, although the strong correlation between Fe and Cs, Ga, Hf, La, Nb, Pb, REE, Sc, Sn, Th, Ti and Zr is a significant issue for interpretation. With a few minor exceptions (I and Cu for one of two traverses at Baxter, and a weak Cu correlation at Bronzewing), enzyme leach does not appear to give useful correlations with buried mineralization.

Use of partial extractions, as summarized here, showed either strong false positives (or in the case of Curara, possibly a 'false positive' coincidentally over mineralization), or very poor ability for the extraction methods to shows buried mineralization, except where totals would work anyway. At several sites (*e.g.*, Baxter, Fender and Safari), Au (using a number of methods) successfully delineates mineralization, but partial extraction methods for the other elements are unsuccessful. It is concluded that, at the sites investigated, partial extractions only successfully locate buried mineralization where this can be done using conventional methods. Although partial extractions may still have value in giving better signal-to-noise ratios, or making subtle anomalies more obvious, they do not appear to offer any advantages for Au exploration in areas of transported overburden in the Yilgarn.

REFERENCES

Bristow, A.P.J., Lintern, M.J. and Butt, C.R.M., 1996. Geochemical and spatial characteristics of regolith around the Safari Prospect, Western Australia. (CSIRO/AMIRA P409: Weathering Processes Group). CSIRO Division of Exploration and Mining Restricted Report 281R.

Butt, C.R.M., 1996. Geochemical dispersion in transported and residual regolith, Fender Gold deposit, Cue, Western Australia. (CSIRO/AMIRA P409: Weathering Processes Group). CSIRO Division of Exploration and Mining Restricted Report 313R.

Chao, T.T., 1984. Use of partial extraction techniques in geochemical exploration. J. Geochem. Explor., 20: 101-135.

Clarke, J.R., 1993. Enzyme-induced leaching of B-horizon soils for mineral exploration in areas of glacial overburden. Trans. Instn. Min. Metall. (Sect. B: Appl. Earth sci.), 102:, Jan-Apr 1993

Gray, D.J., 1995. Hydrogeochemical Dispersion of Gold and other Elements at Baxter, Western Australia. (CSIRO/AMIRA P409: Weathering Processes Group). CSIRO Division of Exploration and Mining Restricted Report 26R. 85 pp.

Gray, D.J., 1996. Selective extraction techniques for the recognition of buried mineralization, Curara Well, Western Australia. (CSIRO/AMIRA P409: Weathering Processes Group). CSIRO Division of Exploration and Mining Restricted Report 210R. 72 pp.

Gray, D.J. and Lintern, M.J., 1993. Further aspects of the chemistry of gold in some Western Australian soils. (CSIRO/AMIRA P241: Weathering Processes). CSIRO Division of Exploration Geoscience Restricted Report 391R. 50pp.

Lintern, M.J., 1996. Geochemical studies of the soil and vegetation at the Apollo Au deposit, Kambalda, Western Australia. (CSIRO/AMIRA P409: Weathering Processes Group). CSIRO Division of Exploration and Mining Restricted Report No. 274R.

Lintern, M.J., and Gray, D.J., 1995a. Progress Statement for the Kalgoorlie Study Area - Steinway Prospect, Western Australia. (CSIRO/AMIRA P409: Weathering Processes Group). CSIRO Division of Exploration and Mining Restricted Report No. 95R. 121 pp.

Lintern, M.J., and Gray, D.J., 1995b. Progress Statement for the Kalgoorlie Study Area - Argo Deposit, Western Australia. (CSIRO/AMIRA P409: Weathering Processes Group). CSIRO Division of Exploration and Mining Restricted Report No. 96R. 153 pp.

Robertson, I.D.M., Phang, C. and Munday, T.J., 1996. The regolith geology and geochemistry of the area around the Harmony Gold Deposit, (Baxter Mining Centre), Peak Hill, Western Australia. (CSIRO/AMIRA P409: Weathering Processes Group). CSIRO Division of Exploration and Mining Restricted Report 194R / CRC LEME Restricted Report 5R. 130 pp.

Varga, Z.S., Anand, R.R. and Wildman, J.E., 1996. Regolith landscape characteristics, evolution and geochemical dispersion about the Bronzewing Gold deposit, Western Australia. (CSIRO/AMIRA P409: Weathering Processes Group). CSIRO Division of Exploration and Mining Restricted Report. (In prep.).