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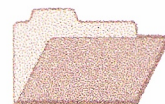
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MULTI-ELEMENT DISPERSION IN THE SAPROLITE AT THE BEASLEY CREEK GOLD MINE - LAVERTON, WESTERN AUSTRALIA

Volume I

I.D.M. Robertson

CRC LEME OPEN FILE REPORT 26

October 1998

(CSIRO Division of Exploration Geoscience Report 152R, 1991.
Second impression 1998)

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

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

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

P241: Gold and associated elements in the regolith - dispersion processes and implications for exploration (1987-1991). Leader: Dr C.R.M. Butt.
The project investigated the distribution of ore and indicator elements in the regolith. It included studies of the mineralogical and geochemical characteristics of weathered ore deposits and wall rocks, and the chemical controls on element dispersion and concentration during regolith evolution. This was to increase the effectiveness of geochemical exploration in weathered terrain through improved understanding of weathering processes. It was supported by 26 companies.

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

P240A: Geochemical exploration in complex lateritic environments of the Yilgarn Craton, Western Australia (1991-1993). Leaders: Drs R.E. Smith and R.R. Anand.
The approach of viewing geochemical dispersion within a well-controlled and well-understood regolith-landform and bedrock framework at detailed and district scales continued. In this extension, focus was particularly on areas of transported cover and on more complex lateritic environments typified by the Kalgoorlie regional study. This was supported by 17 companies.

P241A: Gold and associated elements in the regolith - dispersion processes and implications for exploration. Leader: Dr. C.R.M. Butt.
The significance of gold mobilisation under present-day conditions, particularly the important relationship with pedogenic carbonate, was investigated further. In addition, attention was focussed on the recognition of primary lithologies from their weathered equivalents. This project was supported by 14 companies.

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

FRONTISPIECE

Aerial photograph of the Beasley Creek Gold Mine at an early stage of development. The waste dump (Mc) and the stockpiles (Sp) have been started. Excavation of the northern half of the pit has commenced, revealing the orebody (Ob), the lateritic duricrust (Dr) in the hangingwall and an intervening clay-rich zone (Cly). To the south of the pit, spoil heaps of the assessment drilling are visible, interspersed with patches of calcrete (Cc). Low Wanderrie banks (Wd) may be seen to the north-west of the pit and parts of a weakly incised broad drainage (Id) to the south-east. Scale approximately 1:6800. Kevron Aerial Surveys; 8th February, 1988 (by permission of WMC). Compare with Figures 1B and C.

PREFACE

The CSIRO - AMIRA project "Exploration for Concealed Gold Deposits, Yilgarn Block, Western Australia" has, as its overall aim, the development of improved geological, geochemical and geophysical methods for mineral exploration that will facilitate the location of blind, concealed or deeply weathered gold deposits. This report presents results of research conducted as part of Module 2 of this project (AMIRA Project 241): "Gold and Associated Elements in the Regolith - Dispersion Processes and Implications for Exploration".

The objectives of this Module are, *inter alia*:-

I.   To obtain a better understanding of the nature and genesis of lateritic and supergene gold deposits.

II.   To determine characteristics useful for exploration for supergene and primary Au mineralization.

III.   To increase knowledge of the properties and genesis of the regolith.

IV.   To provide data applicable for exploration for other commodities in and beneath the regolith.

The study reported herein addresses each of these objectives by examining the vertical and lateral distribution of 36 elements, including gold, in the partly truncated regolith present over mineralization at the Beasley Creek Gold Mine. It should be read in conjunction with Report 26R, which covers the surface geology and geomorphology of this deposit, and it is supplementary to Report MG67R which covers the geochemistry, mineralogy and petrography of materials collected from diamond drillhole BCD1. This report may be used to assist in the interpretation of the geochemistry of the lag (Report 27R) and the soil (Report 105R).

Open-cut mining during the past decade has provided the opportunity to study complete lateritic regoliths in a detail not previously possible. This investigation is one of a number of such studies being carried out at sites in a range of different geomorphological and geological settings in the Yilgarn Block.

C.R.M. Butt
Project Leader, P241

April, 1991

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1.0 ABSTRACT

A fence of 11 inclined percussion drill holes, which crossed from the hangingwall to the footwall of the Beasley Creek Orebody, was selected for study of geochemical dispersion in the near surface materials and in the deep saprolite. Of these, four drillholes intersected the ore, its immediate foot- and hangingwall rocks and overlying calcretes, another four intersected amphibolitic saprolites and clay-rich materials proximal to the ore (40-160 m distant) and a further three cut amphibolites and amphibolitic saprolites distal to the ore (250-400 m distant). Samples were selected from these to maximise geochemical detail near the surface and to give adequate information to bedrock or to the limit of the drilling (60-100 m). They were analysed for eight major and 28 trace elements.

The zone around the orebody has been intensely weathered to below the depth of current diamond drilling (230 m) but amphibolites 400 m to the west are only weathered to a depth of 40 m. This locally intense weathering appears to be due to acid conditions generated by the weathering of sulphides in the orebody and its sulphidic host rock. The surficial materials immediately to the east of the ore host unit (to a distance of at least 75 m) contain calcrete and some gypcrete.

Some Rb- and muscovite-rich rocks in the footwall, enriched in Au, As, Cd, Cu and Pb and sporadically enriched in Ag, Bi, Mo, Sb, Sn and W, form an ill-defined zone about 100 m wide, 150 m to the west of the orebody, at a depth of 20-50 m. This zone, which straddles the saprolite-saprock boundary, appears to be a partly-weathered phyllic alteration halo which apparently has not been fully investigated by drilling.

Apart from Au, the orebody is characterised by elevated concentrations of Ag, As, Cd, Cu, Pb, Sb, W and Zn. 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.

2.0 INTRODUCTION

A substantial study of the Beasley Creek Gold Deposit, owned by Western Mining Corporation Ltd., is being carried out within the CSIRO/AMIRA Yilgarn Gold Research Programme. This deposit lies about 12 km west north-west of Laverton at 122° 18'E, 28° 34'S. Here, Archaean rocks appear to be exposed through a small window in the surrounding Permian glacial sediments. The Archaean and Permian rocks have all been deeply weathered. Only the saprolite of the Archaean rocks outcrops in a few places.

Proved and probable ore reserves of 2.1 million tonnes at 2 g/t have been outlined by Western Mining Corp. Ltd. The CSIRO research programme commenced prior to mining, which began at the end of 1987 and had ceased at the time of writing this report.

2.1   CSIRO Work Program

Research being carried out by CSIRO at Beasley Creek comprises studies of the surface geology and geomorphology, the geochemistry of surface materials and the geochemistry of, and dispersions in, the saprolite. Reports have already been issued discussing the geology, geochemistry and mineralogy of the ore zone and footwall rocks (Robertson and Gall, 1988), the pre-mining geomorphology and surface geology (Robertson and Churchward, 1989), the geochemistry, petrography and mineralogy of the ferruginous lag (Robertson, 1989) and the mineralogy and geochemistry of the soils (Robertson, 1990). This report covers the geochemistry of the saprolite.

In November 1987, when the mine was at an advanced assessment stage and mining was imminent, the occurrence of surface materials (soil, lag, vein quartz fragments, calcrete, ironstone and saprolite) were mapped and samples of both surface lag and soil were collected along two lines, 38820N and 38940N. Percussion drilling along line 38820N was later sampled to determine dispersion of key elements in the deep saprolite.

3.0 GEOLOGY AND GEOMORPHOLOGY

3.1   Geology

The solid geology, as determined by WMC from percussion drilling, is illustrated in Figure 1A. The orebody lies in a black shale zone, some 15-40 m thick, which dips at 45° to the east. The shale strikes generally north but swings to the west at its southern end and flattens. This black shale unit is intensely weathered to considerable depth (>200 m) and gold is associated with ferruginous zones within it. The black shale is enclosed in a narrow, north-striking mafic amphibolite schist, which is less intensely weathered, particularly where distant from the black shale. The amphibolite schist is, in turn, enclosed in komatiitic lithologies 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.

3.2   Geomorphology and Physiography

The geomorphology and surface geology were described by Robertson and Churchward (1989). The Beasley Creek Mine site is on a low rise (Figure 1B), flanked by wash plains, consisting of low, broad rises or Wanderrie banks (see Frontispiece), and intervening flat ground. This tract of Wanderrie country forms a low, tabular divide above broad drainage floors, in which the channels of ephemeral streams are incised.

Figure 1A.
Solid Geology of the
Beasley Creek Gold Mine

Permian glacials

Granitoids and porphyries

Dolerite

Talc-carbonate ± chlorite schists

Ore-bearing black shale unit

Basalts

— — Shears and faults

— · — Permian unconformity

After WMC plan BCG/50/1

33600mE   33800mE   34000mE   34200mE

39200mN

39000mN

38800mN

38600mN

38400mN

N

0   100   200m

1:5000

Gravel pit

3
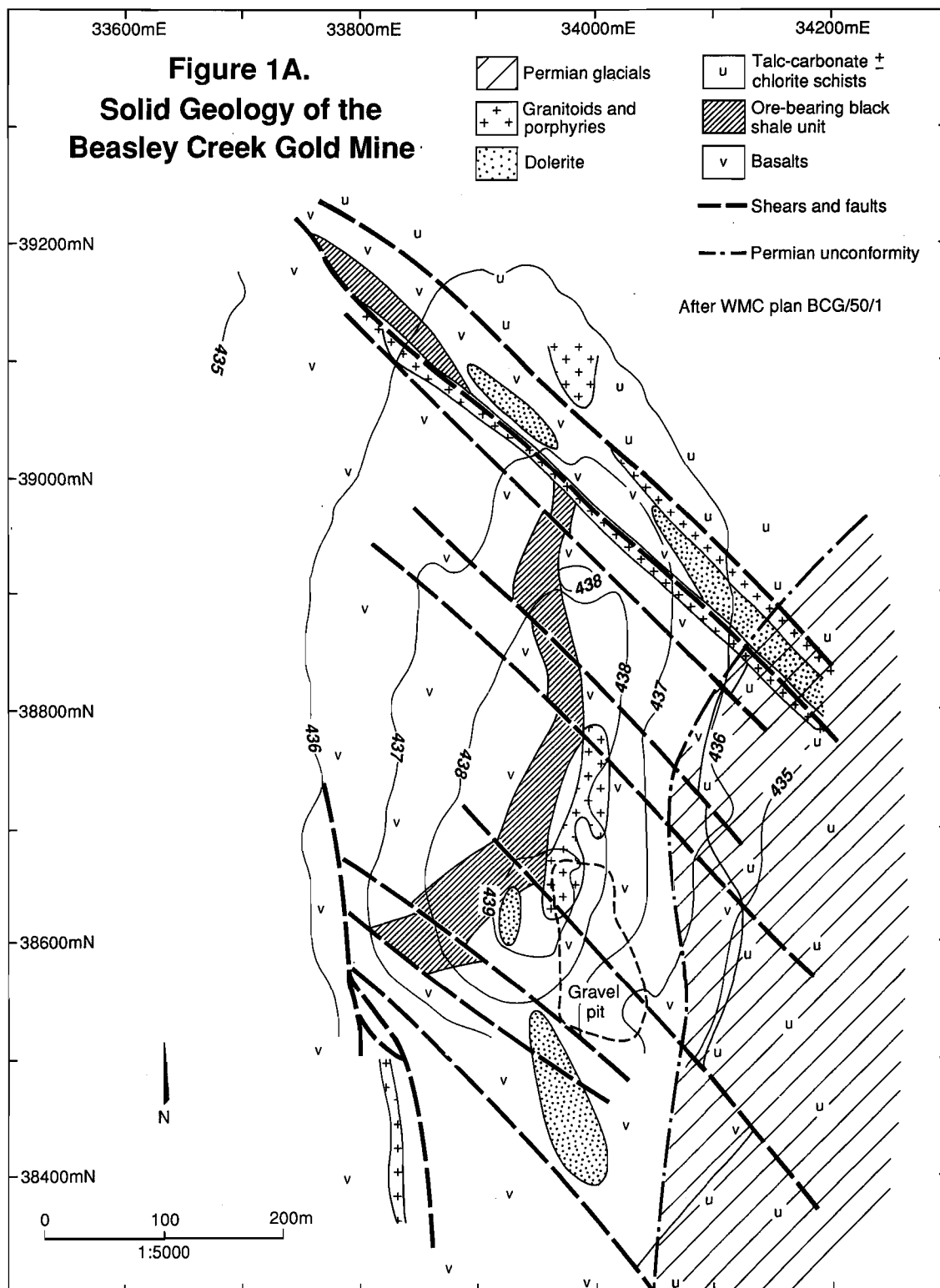
Figure 1B.
Location of sampled drillholes
at the Beasley Creek Gold Mine
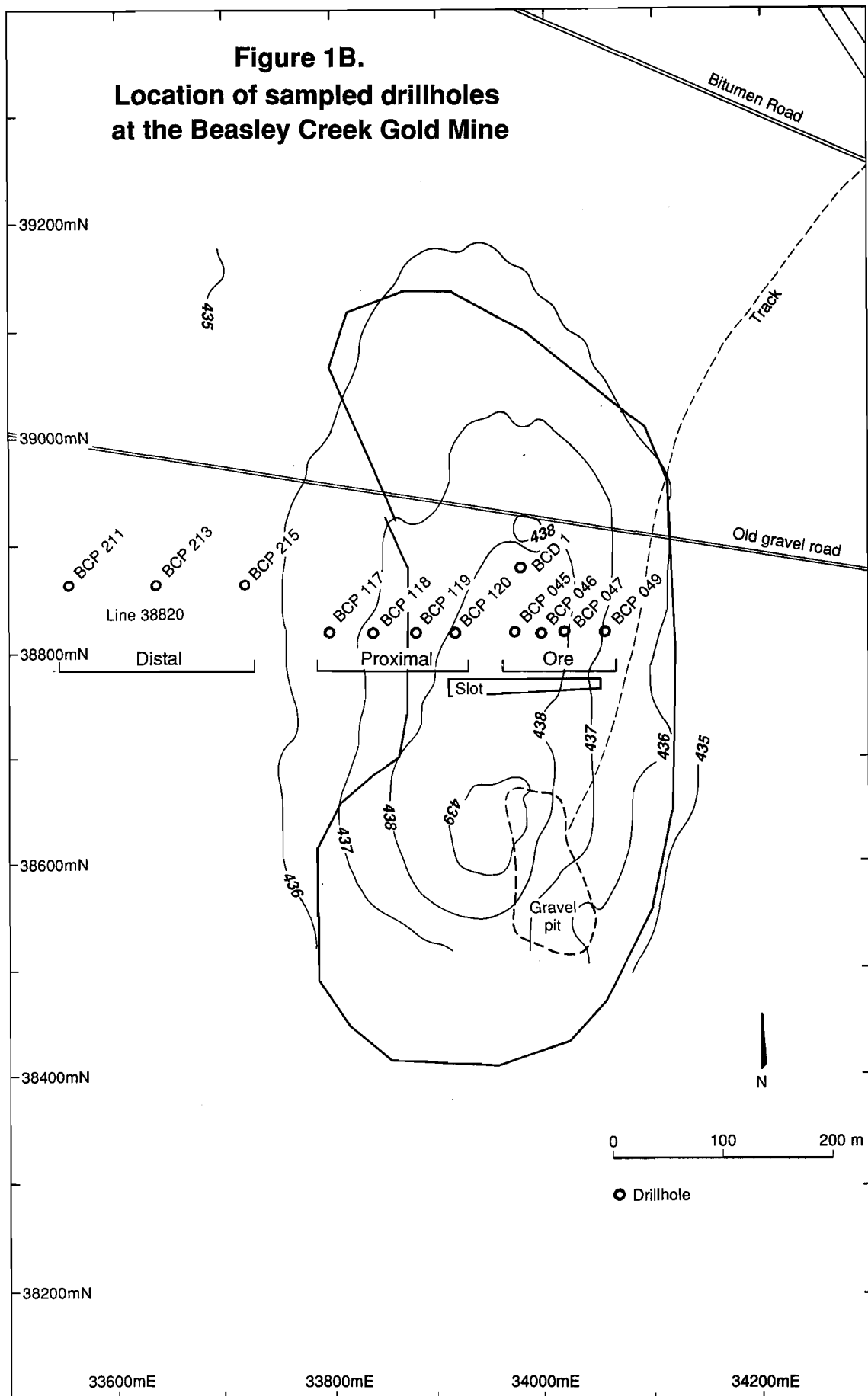
Figure 1C.
Distribution of calcrete outcrop and calcrete exposed by goanna mounds over the Beasley Creek Gold Mine

Calcrete

Photo-mappable calcrete outcrop and goanna mounds

c   Small outcrops

39200mN

39000mN

38800mN

38600mN

38400mN

435.00

438.00

437.00

436.00

435.00

436.00

437.00

438.00

439.00

Gravel pit

N

0   100   200m

1:5000

33600mE   33800mE   34000mE   34200mE
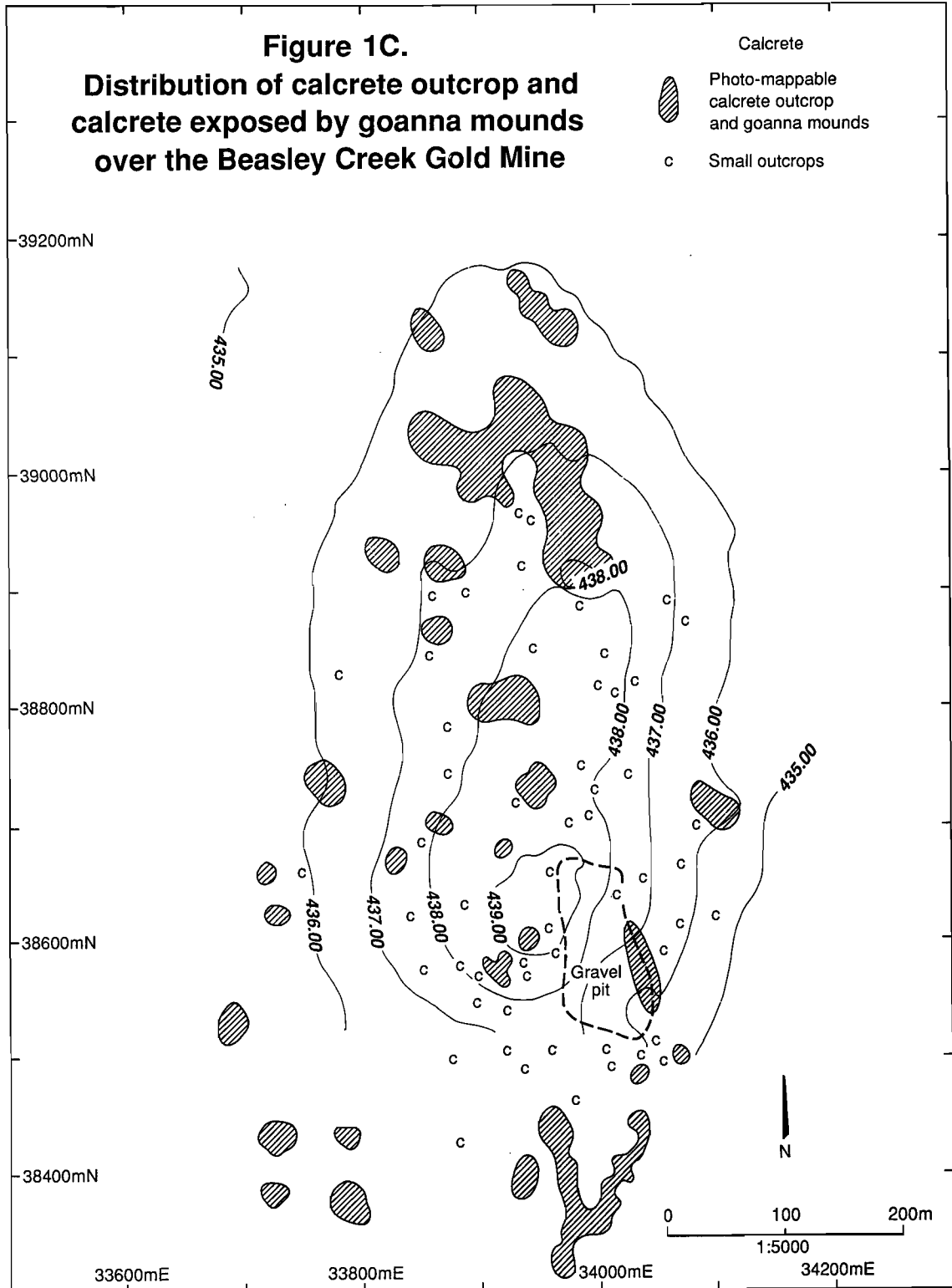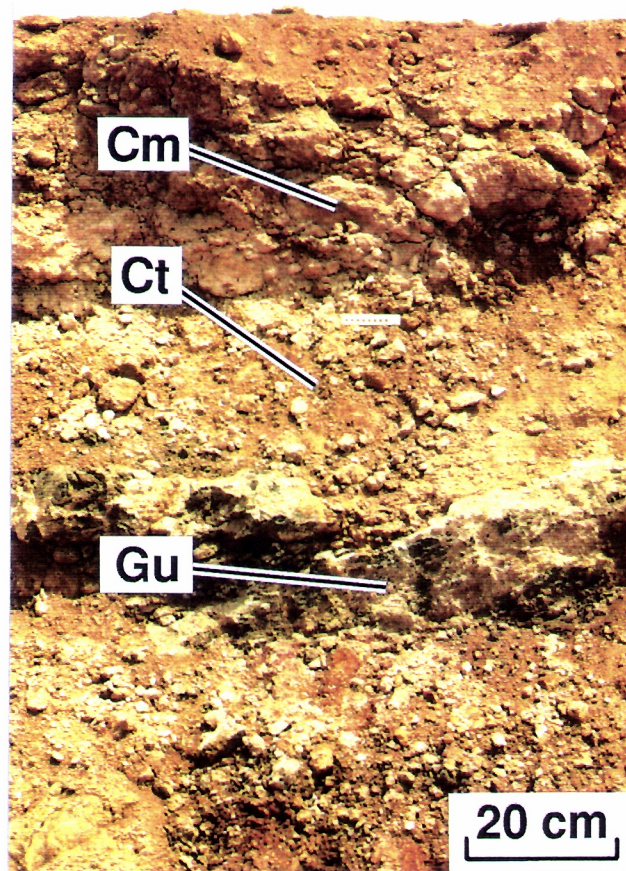
FIGURE 2

A. Zone of massive calcrete (Cm), underlain by earthy calcrete (Ct) which caps saprolite brecciated with gypsum veins (Gu) in the immediate footwall of the orebody. Location: Slot trench (see Figure 1B), co-ordinates 38760 mN 33963 mE.
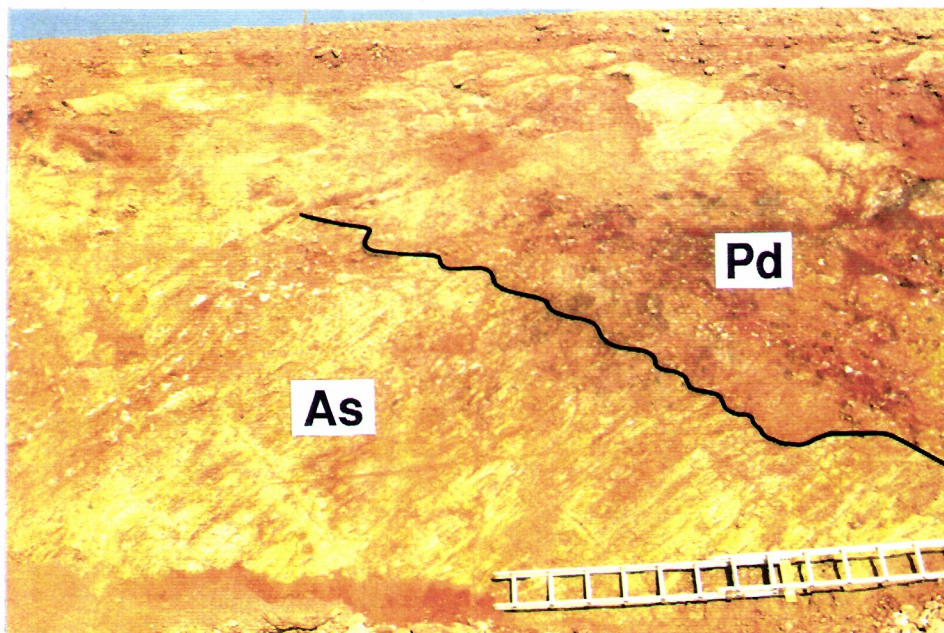
B. Part of the west face of the pit showing cleaved amphibolitic saprolite (As) in contact with a pedolithic clay zone (Pd), in which the saprolitic fabric has been lost. Note the lack of lateritic duricrust at this point, indicating a partly stripped profile.

The regolith at Beasley Creek has been partly stripped. This is indicated by the absence of a lateritic duricrust over all but the eastern flank of the rise. The western edge of the ferruginous lateritic duricrust closely follows the upper surface of the ore-bearing black shale unit (see Frontispiece) and it seems likely that iron in this shale unit, probably present originally in sulphides, was the source of iron for the lateritic duricrust. Sporadic outcrops of ironstone overlie both the ore-bearing black shale and the meta-dolerites. Calcretes occur near the top of the rise (Figure 1C). The saprolites of Permian sediments overlap mafic and ultramafic Archaean saprolites in the eastern margin of the pit (Figure 1 A).

All the Archaean and Permian rocks at the Beasley Creek mine site are deeply weathered to saprolite and some to lateritic duricrust. The low rise, near the crest of which the phyllitic ore host rock subcrops, is almost completely mantled by colluvial soil. This soil is thin near the top of the rise (100 mm) and thickens slightly (300-500 mm) on the flanks of the rise and on the wash plains to the east and west. The base of the soil is generally marked by a substrate of red-brown hardpan and/or saprolite, in places permeated by calcrete, or by massive calcrete. Drilling by WMC indicates that, to the west of the rise, the soils of the Wanderrie country appear to be underlain by a thin veneer (1-3 m) of hardpan, logged by WMC as Lateritic Iron Zone. Exposure on the west side of the pit shows that saprolite and related materials reach the surface (Figure 2B) or are concealed beneath a very thin veneer of hardpan (<0.5 m) with sporadic development of calcrete and gypcrete (Figures 1C and 2A).

A detailed contour map (0.25 m contour interval) (Robertson and Churchward, 1989) shows that the rise at Beasley Creek is asymmetrical, with its steeper slope to the east. This steeper slope is preserved by an underlay of hard lateritic duricrust and appears to be maintained by more active erosion at the foot of the rise, due to runoff from the gently undulating terrain to the east. The crest of the rise is partly protected by lateritic duricrust, calcrete and surficial ironstone. The phyllitic unit, which contains the orebody, follows the crest of the rise.

4.0 STUDY METHODS

By the time the samples had been obtained, mining had started, so the logging by WMC was used. The WMC logging units have been translated into the regolith terminology used in this project as shown in Table 1. Most units translate directly, though there is some confusion with the Lateritic Iron Zone which may refer either to the thick lateritic duricrust, generally to the east of the orebody, or to the thin layer (<3.0 m) of hardpan and hardpanised saprolite, generally to the west of the orebody. There is no distinction made by WMC between fresh rock and saprock.

TABLE 1

WMC DRILL LOGGING UNITS AND CSIRO REGOLITH TERMINOLOGY

WMC Code	WMC Logging Unit	CSIRO Terminology
Scl	Calcrete	Calcrete
Liz	Lateritic Iron Zone	Lateritic Duricrust or Hardpan
Lmz	Lateritic Mottle Zone	Mottled Zone
Lcz	Lateritic Clay Zone	Plasmic or Clay Zone
Lsz	Lateritic Saprolite Zone	Saprolite

4.1   Drillhole Sampling

Samples were obtained from a fence of drill intersections mostly along line 38820N (Figure 1B). This corresponds to the southern line which has been intensively studied with lag and soil sampling (Robertson, 1989; 1990). Of these 11 percussion drillholes, four intersected the ore host unit, four lay in the footwall, proximal to the ore (25-175 m distant), and three lay in the footwall, distal to the ore (225-450 m distant). These last three, part of a pattern testing the sterility of the ground planned for the waste dump, were drilled on section 38860N (i.e. 40 m north of 38820N) and have been used here as a background suite. All these drillholes were inclined at 60° from the horizontal on 270° azimuth (Appendix 5) and all reached 60 m down hole depth, except for BCP 47 (80 m) and BCP 49 (100 m). No samples were available from any of the hangingwall drilling.

Although a suite of subsamples were specially collected for this study during the drilling of percussion drillholes BCP 211, 213 and 215, most of the samples were obtained from splits of the assay rejects of the assessment drilling. A few samples were only obtainable as pulps. All these samples, apart from those specially collected, had been given some prior treatment by WMC. This involved oven drying, followed by jaw crushing in Mn steel and hammer milling in Cr steel. Milling equipment was cleaned out with fresh, mafic, road base-gravel. Mild steel splitters were used in the field.

The following sample selection procedure was used :-

i)   Close to the surface, in the calcrete, lateritic duricrust and the top of the mottled zone, where the geochemical variance was expected to be high, single samples of each of the WMC 1.0 m down hole samples were selected.

ii)   Near the base of the mottled zone, in the clay-rich saprolite and in the weathered ore, pairs of samples were selected and combined in equal parts prior to pulverisation.

iii)   In the saprolite, at a still greater depth, combined sample pairs were alternated with 1.0 m intervals which were not sampled.

iv)   In the deeper parts of the saprolite and in relatively fresh rock, groups of three neighbouring samples were selected and combined in equal proportions and these were interspersed with variable distances (2-3 m) which were not sampled.

The geological drill sections were used in planning the sampling so as to avoid sampling across contacts. This sampling pattern is reflected in the Field Numbers in Appendix 1. The integer part of the Field Number is the WMC Sample Number. The fractional part (.0, .2 or .3) indicates whether that particular sample only was collected (.0), a pair of samples, that one and the next below (.2), or that sample and its two neighbours were collected (.3). The middle of each sample or sample combination is recorded as the down-hole depth. These, the collar co-ordinates and the drillhole inclination and azimuth were used to calculate the co-ordinates of each sample centre.

4.2   Sample Preparation and Sources of Contamination

Each sample was split on a PVC riffle splitter. Where necessary (Section 4.1) samples were combined in the appropriate proportions by weight to about 100 g. The sample was then pulped to a nominal <75 μm in a case hardened steel mill (Robertson and Crabb, 1988), using a double sand clean and alcohol wipe of the mill components between samples.

There are several possible sources of contamination:-

i)   A small amount of down-hole salting is inherent in percussion drilling and this possibility should be considered in interpreting the data.

ii)   Chips shed by the WC drill bits could be included in the sample but, should this occur, the extent of W and Co contamination would be expected to be obvious as 'spikey' data. This would be expected to be significant if the ground was hard and quartz-rich, which generally was not the case.

iii)   Small amounts of Cr and Ni contamination would be expected from the WMC hammer mill and jaw crusher but experience has shown that, where the degree of comminution is slight, so too is the contamination. The most significant contamination from this source would be expected from the mafic 'road base' material used in cleaning the WMC milling equipment.

iii)   The CSIRO case-hardened ring mill, which was used for the comminution of these samples (except for the pulps collected direct from WMC), has well-established maximum contaminations of Mn (45 ppm), Cu (6 ppm), Cr (5 ppm), Mo (2 ppm) and Nb (2 ppm), measured with a quartz charge. Actual contamination from soft, saprolitic material would probably be <10-20% of this. Appendix 1 shows that any Mn, Cr or Cu mill contamination would be completely camouflaged by the natural abundances of these elements. All other contaminating elements would be well below the detection limits for the analytical methods used.

4.3   Geochemical Analysis

This study necessitated the analysis of 254 samples (including 26 standards for analytical control) for 36 elements, some elements being analysed in duplicate by different methods. Detection limits and methods used for the analysis of each trace element are given in Table 1. Neutron activation analysis was by Becquerel Laboratories on 30 g aliquots. Most of the other minor and trace elements were determined on glued pressed discs, using a Philips PW1220C XRF at Floreat Park, by the methods of Norrish and Chappell (1977) and Hart (1989). Iron was determined on pressed powder samples, for matrix correction, and these results are included. Sodium data were also gathered from pressed powder samples. Some difficulties have been experienced with this method due to the concentration of soluble salts at the surface of the glued disc by capillary action during oven drying of the disc. Major elements and some minor elements were also determined at Floreat Park by ICP analysis on a Hilger E-1000, after Li-metaborate fusion. Their precision is not as good as may be expected from fused disc XRF analysis but it is generally acceptable.

Five characteristically low-abundance elements, Ag, Cd, In, Sn and Bi, were determined by ICP/MS at Analabs, Perth. A total of 200 mg of each sample was dissolved in hot HCl. HF and $HClO_4$ were added and the whole evaporated to dryness. The sample was taken up in concentrated HCl and made up to 20 ml. An aliquot of 1 ml of this stock solution was diluted with a further 9 ml of 10% HCl before presentation to the ICP/MS. Below 7.5 ppm in solution, Ag remains soluble.

The geochemical data, comprising 8 major and 28 trace elements, are tabulated in Appendix 1, displayed graphically in Appendices 2 and 5, and are shown as frequency distribution plots in Appendix 3. Except for data from the ICP/MS, all data below the detection limits have been reported without censorship, to aid future mathematical treatment. It must be emphasised that values in this range are of suspect precision, are estimates and should be interpreted with caution. Reference should be made to Table 2 for the detection limits. A geochemical data disc is supplied as Appendix 7.

TABLE 2

TRACE ELEMENT
DETECTION LIMITS AND METHODS

Element	Det.Limit (ppm)	Method
Ag	0.1	ICP/MS
As	2	INAA
Au	0.005	INAA
Ba	15, 100	XRF, ICP
Bi	0.1	ICP/MS
Cd	0.1	ICP/MS
Ce	2,10	INAA, XRF
Co	1	INAA
Cr	5,100	INAA, ICP
Cu	5, 100	XRF, ICP
Ga	5	XRF
Ge	3	XRF
In	0.05	ICP/MS
La	0.5	INAA
Mn	20, 100	XRF, ICP
Mo	5	INAA
Nb	5	XRF
Ni	10, 50	XRF, ICP
Pb	5	XRF
Rb	5	XRF
S	50	XRF
Sb	0.5	INAA
Sn	0.5	ICP/MS
Sr	3	XRF
V	10, 100	XRF, ICP
W	2	INAA
Y	3	XRF
Zn	5	XRF
Zr	4, 100	XRF, ICP

INAA - Instrumental Neutron Activation Analysis - Becquerel Laboratories
XRF - X-ray Fluorescence Analysis - CSIRO, Floreat Park
ICP - Inductively Coupled Plasma Spectrometry - CSIRO, Floreat Park
ICP/MS - Inductively Coupled Plasma Mass Spectrometry - Analabs, Perth

4.4   Sequencing and Standards

The samples were analysed in random order and in-house weathered rock standards (STD 3 ,10 and 11) were introduced into the analytical batches at a ratio of 1:10, to monitor both accuracy and precision. The performance of the analytical method in relation to these standards, together with their mean values and the currently accepted values (November, 1990) for these standards are reported in Appendix 1. The results are generally satisfactory in terms of both accuracy and precision.

5.0   GEOCHEMISTRY

The geochemical data are tabulated in Appendix 1 and have been plotted for each drill intersection, together with the regolith units, in Appendix 2 (where the most detail is available and to which continual reference will be necessary in this section). These drill intersections have been grouped into distal, proximal and ore localities and discussion of the results is initially centred on this grouping. Trends in the complete geochemical section are later discussed and illustrated with summary plots both in the text and Appendix 5.

5.1   Frequency Distributions

Frequency distributions of the entire data set are shown in Appendix 3. Although a few elements approximate a normal distribution (Si, Al, and Ti), most show a positively skew distribution. Many are bi- or poly-modal (Fe, Ca, Na, S, Ag, Cd, Cr, Ga, In, Mn, Pb, Rb, Sr, V and Zn) and this is probably due to the presence of differing rock types, regolith units and mineralisation.

5.2   Major Element Distributions

The distributions of the major elements, essentially Si, Al and Fe $\pm$ Ca and S are shown as ternary plots (Figure 3) and illustrate the weathering process. The relatively fresh rocks (amphibolite and dolerite) form a coherent group on the Si-Al-Fe plot (Figure 3A) together with the saprolites formed from them. However, the clay or plasmic zone, in which pedogenic processes have been active, shows the expected decrease in Si, a corresponding increase in Al and some scatter towards the Fe apex due to ferruginisation. A ternary plot of the surficial materials (Figure 3B) emphasises the Fe-rich nature of the lateritic duricrust and the Si-rich nature of the hardpan. The mottled zone samples show a broad spread between the two, apparently forming a ferruginous extension of the field of the clay or plasmic zone (compare with Figure 3A). The lateritic duricrust samples are significantly more Al-rich than the corresponding ferruginous mottled zone samples. The calcretes have variable Si and Fe contents, due to the inclusion of lateritic nodules, silicates and quartz.

The mottled zone samples show a variable Ca content (Figure 3C), largely due to calcrete partings, veins and pendants and concentrations of carbonates at depth, though a few also show a high S content due to veining with gypsum. The calcretes show a similar variability in Ca but only the very Ca-rich calcretes and mottled zone samples contain appreciable S. This is more clearly illustrated by a plot of Ca against S (Figure 3D). Here the gypsum-rich parts of the mottled zone show a distinct, though interrupted trend through the origin but the trend of the gypsum-rich calcretes intercepts the Ca axis at about 10% CaO. This suggests that significant gypsum veining only occurs in strongly developed calcretes, though the number of samples is small.

Where expressed on the Si-Ca-S diagram (Figure 3C) the hardpan contains virtually no Ca or S and forms a distinct group at the Si apex. Hardpan formation may post-date the deposition of both carbonate and sulphate and so the hardpan forms a distinct group.

Figure 3

A — Ternary diagram SiO_2 / Al_2O_3 / Fe_2O_3
  - ▲ Clay Zone
  - × Dolerite
  - □ Saprolite
  - • Amphibolite

B — Ternary diagram SiO_2 / Al_2O_3 / Fe_2O_3
  - ◇ Calcrete
  - ○ Mottled Zone
  - ■ Duricrust
  - • Hardpan

C — Ternary diagram SiO_2 / CaO / S
  - + Calcrete
  - ○ Mottled Zone
  - □ Hardpan

D — Scatter plot S vs CaO
  - • Mottled Zone
  - ▲ Calcrete
  - Mottled Zone trend
  - Calcrete trend

E — Ternary diagram SiO_2 / Al_2O_3 / Fe_2O_3
 - + Ore Zone

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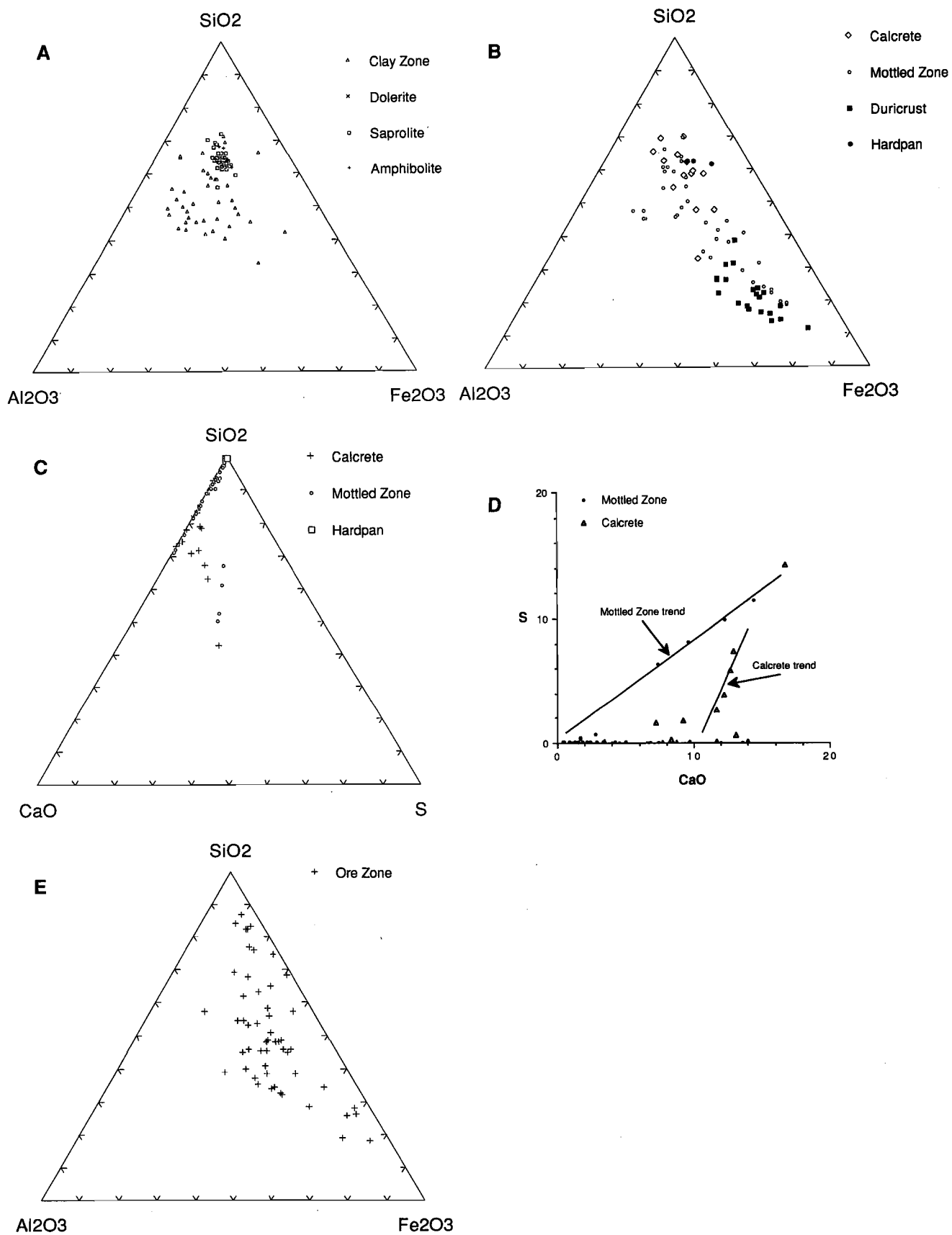
TABLE 3
COMPARISON OF GEOMETRIC MEANS FOR REGOLITH UNITS

Regolith Unit Facies	ORE	AMPHIBOLITE		SAPROLITE		CLAY ZONE		MOTTLED ZONE			DURICRUST	CALCRETE		HARDPAN
	Ore %	Distal %	Proximal %	Distal %	Proximal %	Proximal %	Ore %	Distal %	Proximal %	Ore %	Ore %	Proximal %	Ore %	Distal %
SiO2	38.1	50.18	48.41	51.73	44.42	40.09	38.38	57.16	34.31	27.5	16.48	38.77	32.88	56.04
Al2O3	9.4	13.9	13.56	13.97	12.69	13.33	21.62	13.85	12.2	15.47	15.09	10.68	13.16	11.85
Fe2O3	25.07	14.73	12.69	13.41	12.12	10.07	15.78	12.55	17.88	25.77	44.86	10.49	19.49	21.59
MgO	0.45	6.47	5.01	4.69	4	1.86	0.45	1.42	1.3	1.55	0.3	2.07	0.95	0.31
CaO	0.53	9.45	5.12	7.55	4.16	7.79	0.58	2.01	6.14	3.07	1.35	11.22	8.65	0.23
Na2O	0.1	2.69	0.81	0.89	0.14	0.12	0.08	0.06	0.13	0.29	0.046	0.39	0.31	0.17
TiO2	0.73	0.98	0.95	0.91	0.99	1.02	1.12	0.64	1.07	0.81	1.32	0.88	0.776	0.68
S	0.006	0.125	0.004	0.02	0.005	0.108	0.004	0.017	0.171	0.068	0.053	0.47	0.951	0.028
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Ag	0.69	0.14	0.35	0.13	0.27	0.21	0.62	0.15	0.21	0.47	0.68	0.154	0.55	0.6
As	126	1	2	3	4	7	19	9	5.74	84	36	12	45	25
Au	1.557	0.008	0.066	0.014	0.023	0.01	0.028	0.103	0.006	0.087	0.093	0.039	0.329	0.048
Ba	459	162	240	95	198	125	93	320	122	199	94	297	326	564
Bi	0.20	0.10	0.12	0.08	0.08	0.13	0.13	0.24	0.12	0.23	0.4	0.21	0.44	0.62
Cd	0.61	0.13	0.28	0.07	0.27	0.26	0.21	0.05	0.11	0.11	0.22	0.13	0.1	0.05
Ce	37	5	10	7	10	6	13	19	5	6	4	7	9	48
Co	94	57	53	56	52	26	29	14	29	15	24	13	10	18
Cr	133	101	70	72	51	51	174	227	77	208	534	106	207	540
Cu	244	125	180	154	173	157	154	68	186	183	101	121	129	68
Ga	10	15	15	16	15	16	22	19	16	15	29	15	16	21
Ge	1	1	1	1	1	1	1	1	1	2	2	1	1	1
In	0.12	0.10	0.10	0.1	0.11	0.11	0.12	0.08	0.14	0.16	0.2	0.13	0.14	0.17
La	23	3	4	5	5	3	6	15	3	3	4	5	6	31
Mn	11578	1671	1872	1744	1447	414	807	381	631	1018	1062	323	722	812
Mo	5	4.4	4.5	4.3	4.1	4.2	3.9	3.4	5.8	3.9	5.1	4.2	3.5	4.2
Nb	2	1	3	2	3	3	3	5	2	2	4	3	3	5
Ni	100	79	62	69	64	48	75	73	67	41	69	42	33	59
Pb	14	1	2	10	2	7	6	26	11	11	18	8	13	24
Rb	24	19	36	10	32	11	11	31	15	19	3	19	19	36
Sb	0.84	0.21	0.21	0.23	0.2	0.25	0.52	0.54	0.25	1.39	0.79	0.24	0.87	1.45
Sn	0.49	0.54	0.38	0.51	0.35	0.55	0.4	1.06	0.82	0.65	0.9	0.96	1.16	1.92
Sr	69	116	127	134	130	119	30	95	105	75	29	262	122	43
V	423	310	303	307	326	395	362	226	575	440	934	412	378	433
W	5.5	3.1	2.8	4.1	2.7	2.9	3.5	1.9	6.6	3.6	4.4	2	3.3	2.5
Y	31	20	16	22	20	12	9	14	8.3	6	5	5	5	22
Zn	123	112	105	111	99	74	65	63	109	81	67	67	48	52
Zr	47	55	63	67	65	69	84	102	63	57	98	86	95	157

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TABLE 4
DISTAL GEOCHEMICAL DATA
GEOMETRIC MEANS AND RANGES

	Amphibolite n=6			Saprolite n=10			Mottled Zone n=2			Hardpan n=3		
	G.Mean %	Min %	Max %	G.Mean %	Min %	Max %	G.Mean %	Min %	Max %	G.Mean %	Min %	Max %
SiO2	50.18	49.34	51.52	51.73	46.86	57.71	57.16	56.57	57.76	56.04	54.78	56.72
Al2O3	13.9	13.36	14.54	13.97	13	14.58	13.85	10.95	17.51	11.85	9.34	13.86
Fe2O3	14.73	13.87	17.16	13.41	8.58	15.58	12.55	11.72	13.44	21.59	18.87	25.73
MgO	6.47	5.65	7.19	4.69	1.99	6.78	1.42	1.01	2	0.31	0.18	0.48
CaO	9.45	8.67	10.33	7.55	3.02	10.9	2.01	1.01	3.98	0.23	0.18	0.33
Na2O	2.69	2.19	3.41	0.89	0.05	3.5	0.06	0.01	0.33	0.17	0.14	0.21
TiO2	0.98	0.86	1.12	0.91	0.72	1.06	0.64	0.62	0.65	0.68	0.64	0.73
S	0.125	0.034	0.371	0.02	0	0.062	0.017	0.017	0.018	0.028	0.024	0.037

	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Ag	0.14	0.05	0.66	0.13	0.05	0.97	0.15	0.05	0.43	0.6	0.48	0.76
As	1	1	1	3	1	10	9	7	11	25	20	28
Au	0.008	0.005	0.02	0.014	0.005	0.088	0.103	0.077	0.137	0.048	0.015	0.226
Ba	162	128	273	95	37	425	320	198	512	564	429	860
Bi	0.10	0.05	0.18	0.08	0.05	0.28	0.24	0.17	0.34	0.62	0.48	0.79
Cd	0.13	0.10	0.17	0.07	0.05	0.33	0.05	0.05	0.05	0.05	0.05	0.05
Ce	5	4	7	7	3	27	19	7	49	48	21	101
Co	57	51	63	56	47	65	14	11	18	18	17	19
Cr	101	66	218	72	39	197	227	195	265	540	396	729
Cu	125	85	157	154	96	232	68	67	69	68	66	70
Ga	15	14	17	16	14	20	19	15	24	21	16	25
Ge	1	0	2	1	0	2	1	0	1	1	0	1
In	0.10	0.09	0.12	0.1	0.03	0.13	0.08	0.07	0.1	0.17	0.15	0.18
La	3	3	4	5	3	21	15	6	39	31	17	42
Mn	1671	1425	1841	1744	1105	3857	381	247	587	812	417	1478
Mo	4.4	4.2	4.5	4.3	3.9	4.5	3.4	3.3	3.5	4.2	4	4.4
Nb	1	0	3	2	0	4	5	4	7	5	4	7
Ni	79	58	129	69	56	127	73	71	76	59	51	67
Pb	1	0	4	10	0	55	26	12	58	24	20	32
Rb	19	10	38	10	3	54	31	22	44	36	26	43
Sb	0.21	0.19	0.26	0.23	0.19	0.37	0.54	0.44	0.67	1.45	1.08	2.11
Sn	0.54	0.25	1.11	0.51	0.25	1.2	1.06	0.55	2.03	1.92	1.42	2.45
Sr	116	106	155	134	85	184	95	78	116	43	30	57
V	310	275	350	307	234	348	226	220	233	433	343	535
W	3.1	2.9	3.3	4.1	2.6	44.6	1.9	1.8	2.1	2.5	2.1	2.7
Y	20	19	24	22	16	32	14	7	27	22	13	30
Zn	112	102	143	111	84	168	63	49	80	52	50	54
Zr	55	46	63	67	49	118	102	76	136	157	144	176

TABLE 5
PROXIMAL GEOCHEMICAL DATA
GEOMETRIC MEANS AND RANGES

	Amphibolite n=7			Saprolite n=26			Clay Zone n=14			Mottled Zone n=9			Calcrete n=8		
	G.Mean %	Min %	Max %	G.Mean %	Min %	Max %	G.Mean %	Min %	Max %	G.Mean %	Min %	Max %	G.Mean %	Min %	Max %
SiO2	48.41	43	56.68	44.42	30.42	56.72	40.09	31.68	51.38	34.31	26.55	43.53	38.77	34.41	42.53
Al2O3	13.56	11.74	14.69	12.69	7.45	19.98	13.33	7.7	20.83	12.2	8.92	16.51	10.68	7.55	12.49
Fe2O3	12.69	11.44	14.73	12.12	8.01	17.16	10.07	4.43	17.59	17.88	10.29	36.31	10.49	6	17.44
MgO	5.01	3.89	5.95	4	1.16	9.82	1.86	0.64	4.83	1.3	0.76	2.74	2.07	1.14	3.83
CaO	5.12	2.97	8.46	4.16	0.71	21.97	7.79	2.28	21.1	6.14	0.89	14.41	11.22	7.7	13.99
Na2O	0.81	0.04	4.58	0.14	0	3.3	0.12	0	15.15	0.13	0	0.73	0.39	0.03	3.85
TiO2	0.95	0.76	1.22	0.99	0.55	1.35	1.02	0.51	1.83	1.07	0.83	1.45	0.88	0.51	1.12
S	0.004	0	0.03	0.005	0	0.065	0.108	0	5.288	0.171	0.01	11.439	0.47	0.027	7.33

	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Ag	0.35	0.21	0.56	0.27	0.05	0.83	0.21	0.05	0.57	0.21	0.05	0.77	0.154	0.05	0.3
As	2	1	10	4	1	50	7	2	31	5.74	2	30	12	7	20
Au	0.066	0.013	0.356	0.023	0.005	0.257	0.01	0.004	0.102	0.006	0.004	0.014	0.039	0.017	0.129
Ba	240	74	932	198	20	593	125	35	738	122	38	743	297	175	407
Bi	0.12	0.05	0.25	0.08	0.05	0.5	0.13	0.05	0.23	0.12	0.05	0.23	0.21	0.05	0.44
Cd	0.28	0.05	0.61	0.27	0.05	0.78	0.26	0.05	0.55	0.11	0.05	0.4	0.13	0.05	0.29
Ce	10	8	13	10	1	26	6	2	17	5	1	73	7	4	17
Co	53	46	67	52	16	199	26	5	113	29	7	378	13	8	48
Cr	70	38	170	51	21	146	51	24	184	77	50	138	106	62	205
Cu	180	135	226	173	92	275	157	72	269	186	114	326	121	67	161
Ga	15	14	18	15	9	23	16	9	24	16	12	20	15	11	18
Ge	1	0	2	1	0	3	1	0	2	1	0	2	1	0	3
In	0.10	0.1	0.2	0.11	0.03	0.23	0.11	0.03	0.23	0.14	0.08	0.2	0.13	0.08	0.18
La	4	3	6	5	1	21	3	1	19	3	1	34	5	2	11
Mn	1872	1439	2438	1447	316	3051	414	120	4183	631	201	7868	323	176	491
Mo	4.5	3.9	5	4.1	3	5.3	4.2	3.2	5.4	5.8	4.7	11.4	4.2	3	5.6
Nb	3	1	5	3	0	6	3	0	6	2	0	5	3	2	7
Ni	62	53	87	64	44	112	48	11	146	67	26	186	42	20	78
Pb	2	0	3	2	0	6	7	1	80	11	1	169	8	3	26
Rb	36	15	100	32	3	113	11	3	26	15	5	43	19	11	66
Sb	0.21	0.16	0.35	0.2	0.13	1.68	0.25	0.13	2.73	0.25	0.15	0.77	0.24	0.14	0.57
Sn	0.38	0.25	0.71	0.35	0.25	1.25	0.55	0.25	2.14	0.82	0.25	1.46	0.96	0.25	1.9
Sr	127	90	169	130	48	334	119	49	292	105	38	242	262	169	506
V	303	188	400	326	136	548	395	147	781	575	345	1167	412	197	561
W	2.8	2.2	3.8	2.7	1.4	8	2.9	1.2	7	6.6	2.2	31.7	2	1.3	2.6
Y	16	10	20	20	3	95	12	2	123	8.3	2	230	5	3	10
Zn	105	84	148	99	38	150	74	42	198	109	74	167	67	45	110
Zr	63	49	78	65	36	97	69	44	112	63	45	76	86	69	126

TABLE 6
ORE ZONE GEOCHEMICAL DATA
GEOMETRIC MEANS AND RANGES

	Ore n=54			Clay Zone n=31			Mottled Zone n=25			Duricrust n=22			Calcrete n=6		
	G.Mean %	Min %	Max %	G.Mean %	Min %	Max %	G.Mean %	Min %	Max %	G.Mean %	Min %	Max %	G.Mean %	Min %	Max %
SiO2	38.1	14.33	83.1	38.38	23.37	61.13	27.5	15.4	46.39	16.48	9.5	33.5	32.88	23.11	44.3
Al2O3	9.4	1.22	25.78	21.62	6.95	30.89	15.47	9.09	29.5	15.09	8.49	21.35	13.16	7.93	20.2
Fe2O3	25.07	8.72	59.76	15.78	7.29	37.17	25.77	11.58	55.9	44.86	28.45	63.05	19.49	16.87	27.88
MgO	0.45	0.11	4.74	0.45	0.05	4.62	1.55	0.41	6.2	0.3	0.1	2.63	0.95	0.33	1.63
CaO	0.53	0.06	14.2	0.58	0.07	12.76	3.07	0.41	12.31	1.35	0.23	13.84	8.65	3.41	16.75
Na2O	0.1	0	0.21	0.08	0.04	0.15	0.29	0.11	2.12	0.046	0.005	0.31	0.31	0.12	0.57
TiO2	0.73	0.08	2.06	1.12	0.24	2.3	0.81	0.41	1.33	1.32	0.61	2.23	0.776	0.36	1.16
S	0.006	0	0.033	0.004	0	0.982	0.068	0.004	9.955	0.053	0.008	1.971	0.951	0.037	14.234
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Ag	0.69	0.13	2.18	0.62	0.16	1.48	0.47	0.2	1.27	0.68	0.05	1.65	0.55	0.4	0.78
As	126	16	1270	19	3	245	84	6	1759	36	6	99	45	23	143
Au	1.557	0.16	46.072	0.028	0.004	0.833	0.087	0.012	7.834	0.093	0.011	1.038	0.329	0.043	1.599
Ba	459	47	2356	93	25	523	199	23	1807	94	12	1440	326	244	856
Bi	0.20	0.05	1.94	0.13	0.05	0.39	0.23	0.05	3.86	0.4	0.05	0.82	0.44	0.17	0.23
Cd	0.61	0.05	2.09	0.21	0.05	0.71	0.11	0.05	1.49	0.22	0.05	0.47	0.1	0.05	0.4
Ce	37	3	239	13	1	132	6	1	236	4	1	25	9	6	15
Co	94	3	795	29	4	163	15	5	877	24	8	84	10	5	17
Cr	133	38	319	174	34	503	208	47	865	534	322	1391	207	157	291
Cu	244	85	932	154	17	571	183	55	561	101	45	220	129	88	232
Ga	10	0	30	22	5	40	15	4	38	29	3	54	16	7	31
Ge	1	1	8	1	1	3	2	1	5	2	1	8	1	1	2
In	0.12	0.03	0.62	0.12	0.03	0.32	0.16	0.03	0.76	0.2	0.07	0.35	0.14	0.03	0.38
La	23	6	74	6	0	50	3	1	23	4	1	32	6	4	9
Mn	11578	205	91981	807	88	16541	1018	280	88438	1062	116	9010	722	298	2223
Mo	5	2.6	16.9	3.9	2.5	6	3.9	2.6	5.8	5.1	3.4	6.4	3.5	3.2	5
Nb	2	1	10	3	1	21	2	1	8	4	1	11	3	3	4
Ni	100	25	356	75	27	198	41	8	139	69	27	581	33	22	46
Pb	14	1	122	6	1	79	11	1	95	18	1	132	13	5	25
Rb	24	4	77	11	2	37	19	5	137	3	1	19	19	8	27
Sb	0.84	0.16	9.12	0.52	0.15	4.55	1.39	0.22	11.82	0.79	0.18	1.56	0.87	0.25	3.08
Sn	0.49	0.25	3.56	0.4	0.25	2.9	0.65	0.25	7.88	0.9	0.25	2.22	1.16	0.53	3.91
Sr	69	12	305	30	9	223	75	26	219	29	10	65	122	43	273
V	423	67	1688	362	93	708	440	227	1163	934	216	2083	378	255	676
W	5.5	1.5	24.4	3.5	1.5	10.4	3.6	1.3	12.5	4.4	1.8	11.1	3.3	1.6	4.4
Y	31	5	112	9	0	64	6	1	48	5	1	25	5	1	8
Zn	123	8	411	65	13	286	81	30	333	67	27	462	48	25	115
Zr	47	5	134	84	41	399	57	20	139	98	25	183	95	77	123

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5.3 Distal or Background Geochemistry

In order to distinguish the geochemical signal of mineralisation in a variably weathered sequence of rocks, geochemical background needs to be established for each rock type. The effects of weathering on this geochemical background also have to be understood. Finding suitable subsurface material, which is representative of the rocks but sufficiently distant from ore, is limited by the extent of drilling in the region.

Drillholes BCP 211, 213 and 215 form part of a drill pattern designed to test the sterility of the region under the site of the (then proposed) waste dump. Although they provide the best material approximating local geochemical background in the near surface materials (lateritic duricrust and mottled zone), in the saprolite and in the underlying 'fresh' amphibolite, this region is still quite close to the ore and lies within a broad Au dispersion halo (Robertson, 1989; 1990).

Geometric means and ranges of element abundances are given for the 'fresh' amphibolite, the saprolite, the mottled zone and the lateritic duricrust in Table 4. The data are summarised as scatter plots in Appendix 6 and Table 3. From these it is clear that, on passing upward from 'fresh' amphibolite, through saprolite to mottled zone and lateritic duricrust, there are marked decreases in the abundances of Mg, Ca, Na, S, Mn and Sr, less marked decreases in Ti, Cd, Co, Cu, Ge, Ni and Zn, marked increases in Fe, As, Au, Ba, Bi, Ce, Cr, La, Sb, Sn and Zr, with less marked increases in Si, Ga, Nb, Pb and V. These general geochemical changes need to be related in detail to the interfaces between the major regolith units.

Rock-saprock-saprolite Interfaces
The base of the saprolite is comparatively shallow in the distal drilling, generally 40 m (but as shallow as 25 m in BCP 211). This boundary, recorded by WMC's drill logs as the base of oxidation, seems to approximate the saprolite-saprock interface (as defined by Butt and Zeegers, in press). About 5-10 m below this junction, the content of S increases sharply (0.05 to 0.35%), implying the appearance of fresh sulphides (Appendix 2). The change from saprock to saprolite is geochemically gradational.

Saprolite-mottled zone-hardpan Interfaces
There are particularly sharp increases in the abundances of some chalcophile elements (Ag, As, Au, Ba, Bi, Pb and Sb), in the supposedly residual elements (Cr, Nb, Sn, V and Zr), in Fe, in the rare earth elements (Ce and La but not Y), Ga and In in the top 10 m of the regolith, associated with the interfaces between saprolite and mottled zone and between mottled zone and hardpan. There are also similarly sharp decreases in the abundance of the alkalis and alkaline earth elements (Ca, Mg, Sr and Na) and in Cu, Zn, Al, Co, Ni, Mn and Ti. Scatter plots of element pairs for the background data set (not shown) emphasise the As-, Fe-, Ce-, Cr-, Ga-, La- and Sb-rich and Mg-, Ca-, Co-, Cu- and Mn-poor nature of these more deeply weathered materials.

5.4 Proximal Geochemistry

A group of four drillholes, BCP 117-120, lie in the footwall, close to the ore host unit, but do not intersect it. These have been used to test for geochemical dispersions proximal to the orebody (25-175 m distant). The geometric means and ranges of the data are given in Table 5 and may be compared with the distal and ore zone data in Tables 3, 4 and 6.

At depth, these drillholes intersected a similar, weathered mafic stratigraphy to the distal drillholes, so the geochemistry would be expected to be similar, but for the proximity of the orebody and a marginally higher position in the topography (2 m). However, near the surface, there is a calcareous and gypsiferous component (absent in the distal location) in the upper regolith which underlies the very thin hardpan.

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Lower down there is a clay zone overlying the saprolite in the two drill intersections closest to the orebody, forming part of its footwall.

The geometric means of elemental abundances, obtained from the proximal drill intersections, may be compared with those of the distal drilling (Table 3). Scatter in this data is illustrated in Appendix 6. Some significant differences were found. In passing from the distal to the proximal locations, the relatively fresh amphibolite (saprock) shows a decrease in Ca (slightly increased weathering) but increases in the abundance of Ba and Cd (proximity to the ore). Similarly the saprolite shows significant increases in Au, Ba and Cd. The mottled zone shows decreases in Si and Au contents and increases in the abundances of Fe, Mn and W (proximity to the ore) and in Ca and S (calcrete and gypcrete component). The clay zone has a very similar major element composition to that of the saprolite but it is poorer in Mg and Na and slightly richer in Ti.

As in the distal drill intersections, the interface between saprock and fresh rock is indicated by a marked increase in the S content (below 55 m in BCP 117, the most westerly drill intersection). This increase in S is not apparent in any of the drill intersections to the east, where the S abundances in the saprolite and 'fresh' amphibolite are strongly depleted. This implies that the saprock-fresh rock boundary lies below the limit of the drilling here and therefore weathering penetrates much deeper near the orebody.

In contrast to the S depletion at depth, the drill intersections nearest the ore show a massive increase in the S content very close to the surface. Here there is a very sharp peak between 2 and 7 m depth with S abundances at between 1.6-11.4 % (corresponding to between 8.6-61.0% gypsum). This zone is particularly S rich and wide in the two drill intersections closest to the ore. The high S zone at the surface corresponds with a gypsum/carbonate breccia which was exposed in the west end of the slot trench 50 m to the south (Figure 1B). Here, a thin hardpan and massive calcrete overlie an earthy calcrete which, in turn, overlies a breccia of highly ferruginised saprolite fragments, veined and cemented by gypsum (Figure 2A). Major gypsum, with quartz, dolomite and kaolinite were confirmed by XRD in the S-rich samples. Sulphur is strongly correlated with Pb and Sn, moderately correlated with Mo and Na and weakly correlated with Sr and Zr (Appendix 4).

The top part of the profile has an enrichment in both Ca and Sr, reflecting calcrete ($\pm$ gypcrete) in the top 5 m in all drill intersections apart from BCP 117. Silver abundances are higher in all the proximal drilling (approximately 0.35 ppm) than the distal background of 0.14 ppm. Arsenic shows anomalies (25-50 ppm in a background of 3 ppm) at variable depths between 10 and 50 m in the three eastern proximal drill intersections. Gold is anomalous (100-350 ppb in a background of 12 ppb) at between 30 and 55 m depth and the greatest Au anomaly is closest to the ore. Barium has a generally high abundance (350 ppm in a background of 130 ppm) throughout most of these proximal drill intersections.

Although Zn is only weakly anomalous in BCP 119, Cd is anomalous (0.5 ppm in a background of 0.1 ppm) between 10 and 60 m depth. BCP 117 and 118 show weak W anomalies (7 ppm in a background of 2 ppm) at depth (45 m) but the W anomalies in BCP 119 and 120, closer to the ore, are shallow (10 m) but stronger (25 ppm in a background of 3 ppm). Rubidium is also anomalous (90 ppm in a background of 20 ppm) between 35 and 55 m. There are also weak and sporadic peaks in Bi, Ce, Co, Ge, La, Sb, V and Y.

In summary, there is a zone of rather inconsistent anomalies in a number of trace elements (Ag, As, Bi, Cd, Cu, Mo, Pb, Sb, Sn, V and W) scattered through the footwall saprock and saprolite at a depth of 30-50 m within 200 m of the ore. This will be discussed further in Section 5.6.

5.5   Ore Host Unit and Wallrock Geochemistry

A group of four drillholes, BCP 45-47 and 49, intersect the ore host unit and parts of the footwall and hangingwall rocks. These have been used to define the geochemistry of the weathered host rock and elements associated with the mineralisation. The geometric means of elemental abundances, obtained from the ore drill intersections, may be compared with those of the other drilling (Table 3). The ranges of this data are given in Table 6 and the scatter is illustrated in Appendix 6.

On passing from the proximal location to the ore zone, the clay zone shows decreases in Ca and Na coupled with increases in Al and Fe (due to intense weathering) and increases in the abundances of the pathfinder elements Ag, As, Au and Sb. The mottled zone shows a similar decrease in Ca and increases in the concentrations of Fe, Ag, As, Au, Bi and Sb. With decreases in abundances of Mg and Sr, the calcrete shows increases in Fe and S as well as in the pathfinder elements As, Au, Bi and Sb.

Major Elements (Al, Ca, Fe, Mg, Na, Si)
Silicon is abundant near both the foot and hangingwall of the ore host unit. As would be expected, *Fe* is concentrated in the ore host unit as well as in the overlying lateritic duricrust and mottled zone, in places reaching 60% Fe_2O_3 in a background of 10%. The Si-Al-Fe relationships (Figure 3E) shows that the ore host rocks do not show a tight grouping like the amphibolitic saprolites, are less *Al*-rich than the clay zone rocks and show a broad spread between Si and Fe. The base of the drill intersection is all highly depleted in *Ca*, indicating the extreme depth reached by weathering around the orebody. Calcium is enriched near the top of all the drill intersections. This is evident both at the surface, where it has been logged as calcrete and gypcrete, and at a depth of 20 m (also a carbonate accumulation) within both the ore and its overlying clay zone. Similar *Sr* backgrounds (100-200 ppm) are encountered in the ore host unit as in the distal and proximal drill intersections except that there is a significant Sr enrichment (200-300 ppm) in the orebody below 40 m in BCP 47 and there is sporadic Sr enrichment associated with the calcrete near the surface (0-5 m). There is little *Mg* in the calcrete at the surface but it is abundant at 10-20 m. There seems to be a tendency for *Na* to concentrate in the top 2-8 m (presumably as halite) in BCP 45-47. Although some errors in the Na data (due to efflorescence during disc making; Section 4.3) may be expected, the Na concentration near the surface appears to be real, though the single point spike in BCP 45 may not be.

Lithology-Associated Trace Elements (Ba, Ce, Cr, La, Mn, Nb, Ni, Rb, Ti, V, Y, Zr)
Barium anomalies (1500 ppm) are an important indicator of the ore host unit in the ferruginous surficial materials (Robertson, 1989; 1990) and similar high Ba concentrations (1500-2300 ppm) are encountered in all ore intersections except the deepest. There is also evidence for Ba concentration near the surface in calcrete, lateritic duricrust and the mottled zone. A *Mn* anomaly is associated with the ore host rock and, in places, this reaches 100 000 ppm (10%) in a background of 1000 ppm. There is also a tendency for Mn to be concentrated in the lateritic duricrust and calcrete in the hangingwall where abundances of 1000-10 000 ppm are common. In contrast, Mn tends to be depleted near the surface in the proximal and distal areas.

The ore host unit has increased *rare earth element (Ce and La)* abundances compared to its wall rocks but these elements are strongly depleted in the surficial environment both over the ore and in the proximal area. In contrast, they are enriched near the surface in the distal part of the section. The three most proximal drill intersections and those through the ore show a marked deviation from the relatively constant Y background of 20-40 ppm. Close to ore, *Y* is strongly depleted in the most intensely weathered zone (0-20 m) but is enriched deeper in the profile (40-60 m; 50-100 ppm) regardless of the rock type.

The *residual elements,* Ti and Zr are well correlated in the ore zone rocks but this correlation decreases significantly in the surficial materials (Appendix 4). The *Ti* content of the mottled zone and lateritic

duricrust (0.6% TiO$_2$) tends to be slightly lesser than that of the saprolite (1.0% TiO$_2$), though some proximal drill intersections (BCP 118, 119, 120) show increases of Ti in the clay zone (1.0-1.7% TiO$_2$). Near the ore, however, the mottled zone and lateritic duricrust have higher Ti contents (1.2-2.2%). As in the distal and proximal profiles, the profiles through the orebody show an increase in the Zr content in the top 5-10 m, related particularly to development of the lateritic duricrust and to a lesser extent to the mottled zone. The mafic saprolite and the orebody are indistinguishable on Zr content alone. It seems that Zr is the least mobile of these elements and is the only one that remains residual in the mottled zone and lateritic duricrust. The *Cr* abundances are generally low (200 ppm), though there is a sharp maximum in Cr abundance (800-1400 ppm) at the base of the lateritic duricrust in BCP 47 and BCP 49. The majority of the *Nb* data lie at or below the 5 ppm Nb detection limit but there appears to be a tendency for Nb to be weakly enriched (6-10 ppm) where the lateritic duricrust is well developed.

The ore host rock is a black shale, rich in *micas* (Robertson and Gall, 1988; Robertson, 1989). Although the orebody is marked by abundant *Rb*, due to remnant muscovite, the clay-rich zone and the saprolites in places also have similar abundances of Rb. The highest Rb abundances (>100 ppm) occur in the mottled zone of BCP 46. There is a concentration in the abundance of *V* (1000-1500 ppm) in the footwall and hangingwall of the orebody (BCP 46) and V is more strongly concentrated (1500-2000 ppm) in the lateritic duricrust of BCP 47 and 48. Vanadium abundances in the weathered ore are 500-800 ppm.

Although Ni has a small variance (40-180 ppm) in the distal and proximal areas, its variance is greater (40-600 ppm) near the ore. A similar increase in variance was observed in the soil geochemistry for Co, Ni and V over the rise at Beasley Creek, with less variance on the flat ground to the east and west (Robertson, 1990). There is a sharp Ni maximum at the base of the lateritic duricrust in BCP 49 and a similar feature near the footwall of the ore in BCP 46. The ore host tends to be more Ni-rich than the surrounding saprolite and clay zones (see also Robertson and Gall, 1988). High concentrations of Co, Mn, Ba, Ce, La and, weakly, Y are typical of the ore host unit.

Pathfinder Elements (Ag, As, Au, Bi, Cd, Cu, Co, Ge, In, Mo, Pb, Sb, Sn, W, Zn)
In many instances, pathfinder elements show significant enrichments near the surface. Compared to the distal (0.14 ppm) and proximal drill intersections, the *Ag* background[1] is elevated to 0.5-1.0 ppm in the ore zone and shows a substantial, though sporadic, enrichment to 1.0-1.5 ppm in the lateritic duricrust of the hangingwall. This tends to support the validity of the ICP/MS-determined soil Ag abundances reported by Robertson (1990). The association of *As* with the ore is very clear, particularly in the deepest intersection in BCP 49, where it reaches a maximum of over 1200 ppm. Although the As abundances seem to decrease in the shallower intersections, there is marked enrichment in As at about 5 m depth in the mottled zone, beneath the calcrete. Where this zone and the orebody intersect, as in BCP 45, there is a single point As maximum of 1800 ppm. The *Au* abundance in the orebody exceeds 1 ppm and in places 10 ppm. The lateritic duricrust is locally enriched to 0.15-1.0 ppm Au, compared to a background of 0.010 ppm in the clay zone overlying the ore.

Drillholes BCP 47 and BCP 49 show little *Pb* in the orebody (5-50 ppm), only BCP 46 shows elevated Pb abundances (50-120 ppm) in the footwall and hangingwall of the ore. All of the drill intersections show a Pb enrichment, some with sharp maxima (130 ppm) close to the surface (0-5 m; BCP 49) and similar phenomena were observed for BCP 118 and 119. This surficial Pb enrichment may account for the sporadic high Pb concentrations encountered in the coarse lag (Robertson, 1989) which were previously suspected of being due to contamination by lead shot (Robertson, 1990). *Tungsten* is concentrated (18-22

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1   Background Ag abundances in fresh mafic rocks have been reported in the range of 0.05-0.19 ppm (Vincent, 1978). The Ag abundances in the weathered rocks at Beasley Creek would be influenced both by the natural (lithological) abundance plus any additional Ag added by primary and/or secondary mineralising processes.

ppm) near the footwall (BCP 45-46) and hangingwall (BCP 47-48). Elsewhere background abundances (3 ppm) are common, though there is some W concentration in the lateritic duricrust (5-12 ppm).

Where the ore zone, with high relative abundances of some elements, intersects the enriched surface zone, the anomalies in these elements are reinforced. *Antimony* shows enrichment to x2 of background in the lateritic duricrust and mottled zone of BCP 47 and 49. Generally background abundances (0.5 ppm) occur in the hangingwall clay zones, in the footwall clay zones and saprolites. Rather sporadic anomalies (3-10 ppm) occur close to both the hangingwall and footwall of the orebody. BCP 46 shows a marked Sb enrichment (13 ppm) in the duricrust and in the adjacent orebody hangingwall where the two enriched zones co-incide. Surficial Sn enrichments (reaching 1.5-2.0 ppm) are apparent in BCP 119, 120, 47 and 49 and they are similar to surficial *Sn* enrichment (x2.0-5.0) above background (0.5-1.0 ppm) in the lateritic duricrust and mottled zone of the distal drilling. There is also an enrichment in the hangingwall of the orebody (3-4 ppm). Where the orebody hangingwall coincides with the mottled zone and lateritic duricrust (BCP 46) the Sn content is enriched to 8 ppm.

Some chalcophile elements are significantly depleted near the surface. The *Zn* abundance decreases sharply from 100 to about 50 ppm in the top two or three metres. The Zn content of the orebody is 200-300 ppm and is further concentrated to 300-500 ppm at a depth of 12 m at the base of the mottled zone and in the lateritic duricrust. There is a very distinct *Cd* anomaly of 1.5-2.0 ppm over a background of 0.1 ppm in all ore intersections, though the deepest intersection is the weakest (1.0 ppm). Although there does not appear to be any tendency for Cd to concentrate in the Fe-rich surficial materials, a distinctive Cd anomaly (0.6 in a background of 0.1 ppm) is present in the ferruginous coarse soil fraction (Robertson, 1990). There are sporadic *Cu* anomalies (800-1400 ppm) within the orebody but, near the surface, Cu tends to be depleted (100 ppm). Despite this, the ferruginous fraction of the soil has a quite distinct Cu anomaly of 150-180 ppm in a background of 100 ppm. There is also a *Co* anomaly associated with the ore host unit which reaches 300-900 ppm but Co is strongly depleted near the surface, which is reflected by the lack of Co response in the soil and lag.

The maximum *Mo* content of the orebody is 16 ppm and there is no tendency for Mo to be concentrated near the surface, hence the rather ambiguous Mo results in the lag and soils. Although the *In* abundance in the ore zone appears to be about twice that shown by the distal drill intersections, there are isolated maxima of 0.3-0.6 ppm associated with the ore. Indium shows a slight tendency to concentrate in the lateritic duricrust and mottled zone but not in the surface calcrete. There is little concentration of *Bi* in the ore, though there is a small peak of 2 ppm in a background of 0.2-0.5 ppm in the hangingwall of the ore host unit. Bismuth shows a slight tendency to concentrate in the lateritic duricrust and mottled zone (1 ppm) and it is very strongly enriched (4 ppm) in the mottled zone of BCP 46. The majority of the *Ge* data lie at or below the detection limit and the data represent analytical noise.

5.6   The Complete Geochemical Section

Parts of this geochemical section have so far been considered separately (distal, proximal and ore) so as to compare and contrast their geochemistry. Appendix 5 shows them combined with a x2 scale expansion applied to the vertical axis. Anomaly maps such as these make use of cut points which inevitably introduce some user bias. In contrast, the individual down-hole plots of Appendix 2 are without bias.

Lithology Associated Elements (Al, Ca, Ce, Cr, Fe, Ga, La, Mg, Na, Ni, Rb, S, Si, Ti, Y, Zr)
High concentrations of Al and Ga would be expected to distinguish the phyllitic host unit from the enclosing weathered mafic rocks. This is not the case. Robertson and Gall found a close correlation between Al and Ga in DDH BCD1. This correlation is confirmed (Appendix 4) but the host rock has a very slightly greater Ga/Al ratio than its enclosing rocks, though the two populations overlap (Figures 4A

TABLE 7
MINERALOGY AND GEOCHEMISTRY
OF CALCIUM-RICH NEAR-SURFACE SAMPLES

Sample	BCP	Depth	Qtz	Kao	Cc	Dol	Gyp	Hm+Gt	Mic	SiO2	Al2O3	Fe2O3	MgO	CaO	S	Rb
08-617	49	12.5	13	31	120	0	0	40	0	14.74	12.31	41.46	0.46	9.54	0.026	3
08-621	49	16.5	15	36	133	43	0	40	0	15.58	13.74	28.45	2.63	13.84	0.023	5
08-656	46	1.5	72	16	60	0	65	34	13	23.11	7.69	17.59	0.96	16.75	14.234	25
08-665	46	10.5	65	102	46	45	0	27	16	34.1	20.31	19.59	2.51	6.68	0.021	16
08-671	46	19	100	15	127	18	0	16	33	36.13	13.01	17.16	1.8	14.2	0.026	51

and 5A). In contrast, the duricrust is strongly enriched in Ga relative to Al. This Ga enrichment in the duricrust is probably due to the affinity of Ga for Fe^{3+} minerals (Burton and Culkin, 1978).

Although high Fe concentrations characterise parts of the ore zone, they also characterise the duricrust, mottled zone and hardpan. Iron has been dispersed laterally for at least 100 m in the top 20 m of the profile. There is a slight tendency for Si to be concentrated along the footwall and hangingwall of the host unit, probably reflecting quartz veining and faulting. However, although some high Au concentrations are associated with quartz veining, much of the Au-rich saprolite is Si poor and there is a poor Au-Si correlation (Appendix 4). There is no significant silicification near or at the surface, apart from that in hardpan.

Weathering of the mafic rocks leads to a progressive decrease in Mg in relation to Ca. The amphibolites and the saprolites that formed from them have similar and relatively high Mg/Ca ratios. The clay zone and mottled zone together have lesser Mg/Ca ratios and the duricrust has a Mg/Ca ratio which is lower still (Figures 4B and 5B).

Calcretes occur both at the surface, where they are 3-4 m thick and extend for over 120 m from the ore subcrop, and also occur at depths of 8-25 m where they permeate weathered host unit, clay zone rocks and the base of the duricrust. The mineralogy of these deep-seated calcretes was briefly investigated (Table 7) by X-ray diffractometry. Most contain both calcite and dolomite but one contains calcite only. A similar carbonated horizon, lying within a mottled zone below a lateritic surface, has been noted by Butt (1979) at Killara, near Meekatharra. The calcrete occurrences are shown by the distribution of Ca and particularly well by the Ca/Mg ratio (Figure 5C). Strontium is correlated more closely with Ca than with Mg (Appendix 4).

The Ti/Zr ratio, used by Hallberg (1984) to distinguish the major igneous rock types, shows the mafic nature of the amphibolites and the saprolites formed from them (Ti/Zr >60; Figures 4C and 5D). Two saprolitic samples lie above this limiting ratio and it is possible that some of these are saprolites of locally rare felsic rocks. There is a little more scatter in the Ti/Zr ratio if the clay zone samples are included and a further five samples have ratios of <60. If the mottled zone and duricrust are included (Figure 4D), most are mafic but a further 12 samples have a Ti/Zr ratio of <60. Thus the Ti/Zr ratio becomes progressively less reliable as a rock-type discriminator in the more intensely weathered near-surface materials. This implies that either Zr is being added or, more probably, that Ti is being removed by intense weathering in the mottled zone and duricrust.

The host unit is characterised by much higher concentrations of the rare earth elements (Ce>20; La>10; Y>50 ppm) than the surrounding mafic rocks. Yttrium is strongly correlated with Ce and La but the Ce-La correlation is weak in the host unit (Appendix 4). There is a concentration of rare earth elements in the clay zone of the proximal part of the section at a depth of 10-30 m. The surficial materials (duricrust and particularly hardpan) show concentrations of Ce and La but not of Y. Barium is concentrated in the host unit (>1000 ppm) and shows a weak, diffuse dispersion (>200 ppm for up to 200 m) into the footwall; it is also concentrated in the duricrust, calcretes and hardpans at the top of the profile.

Nickel is concentrated in the host unit (>200 ppm), within the mottled zone and the base of the duricrust but is depleted near the surface. Chromium, however, is strongly concentrated at the surface (duricrust and hardpan) in relation to both the host unit and its enclosing rocks.

The host unit is particularly poor in Na (<0.2% Na_2O) but, in the other rocks, the Na distribution reflects the intensity of weathering and alkali leaching. Fresh amphibolites and their saprolites are comparatively Na rich (2-5% Na_2O) but the mottled zone and clay zone are very Na poor (0.1% Na_2O) and the duricrust particularly so (0.05% Na_2O). Some calcrete samples are enriched in Na (3% Na_2O), presumably due to

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Figure 4

Figure 5

Figure 5 (cont.)

D

Easting (m)

Ti/Zr

● 12-60 ● 60-100 · 100-1000

E

Easting (m)

CHI x 0.001

· -1 ● 1-2 ● 2-5 ● 5-10

BCP211 BCP213 BCP215 BCP117 BCP118 BCP119 BCP120 BCP045 BCP046 BCP047 BCP049

Easting (m)

Calcrete and hardpan

Duricrust

Mottled zone

Clay (plasmic) zone

Saprolite

Mafic rock and saprock

Weathered ore host unit

0   100 m

Scale 1:30000
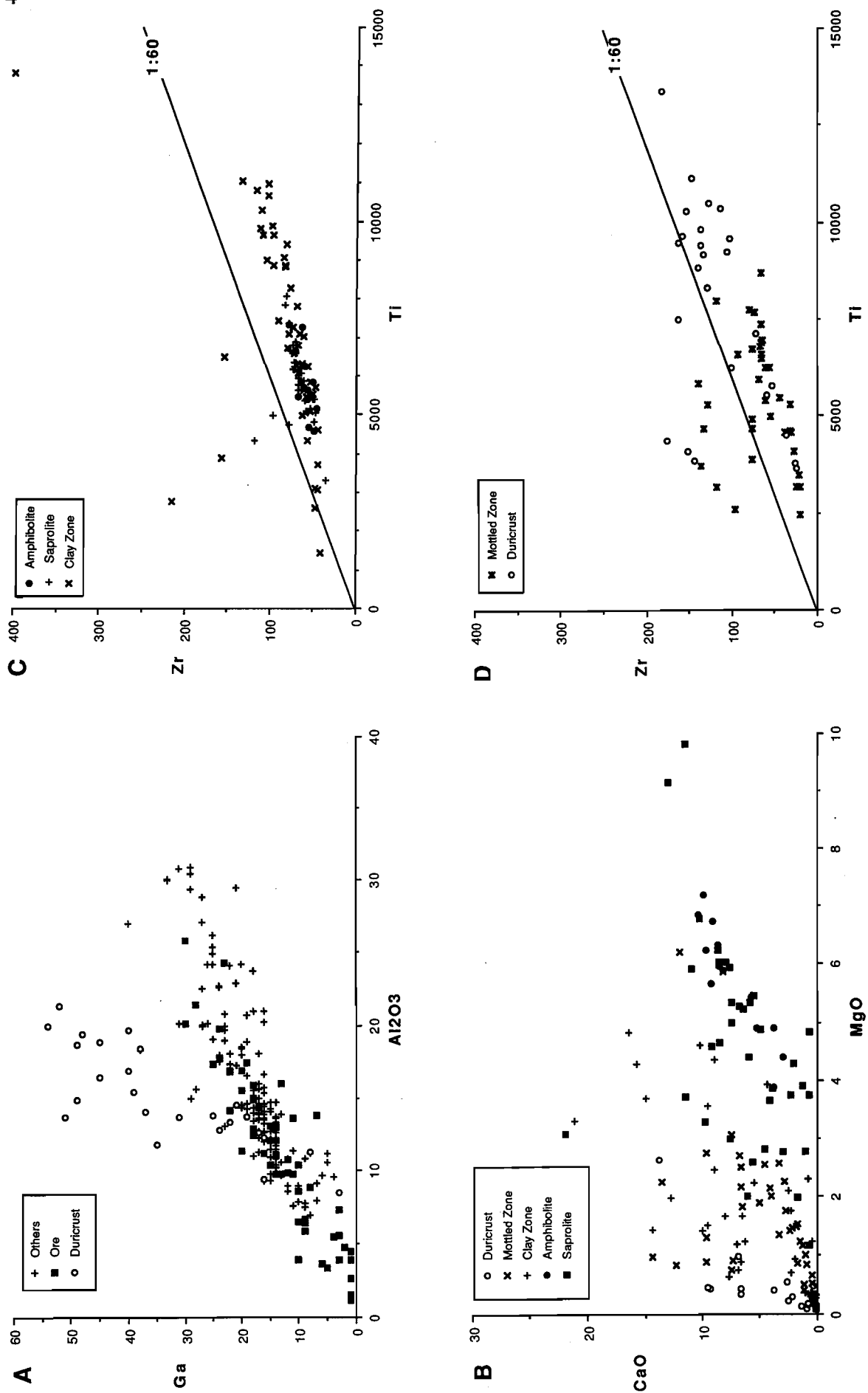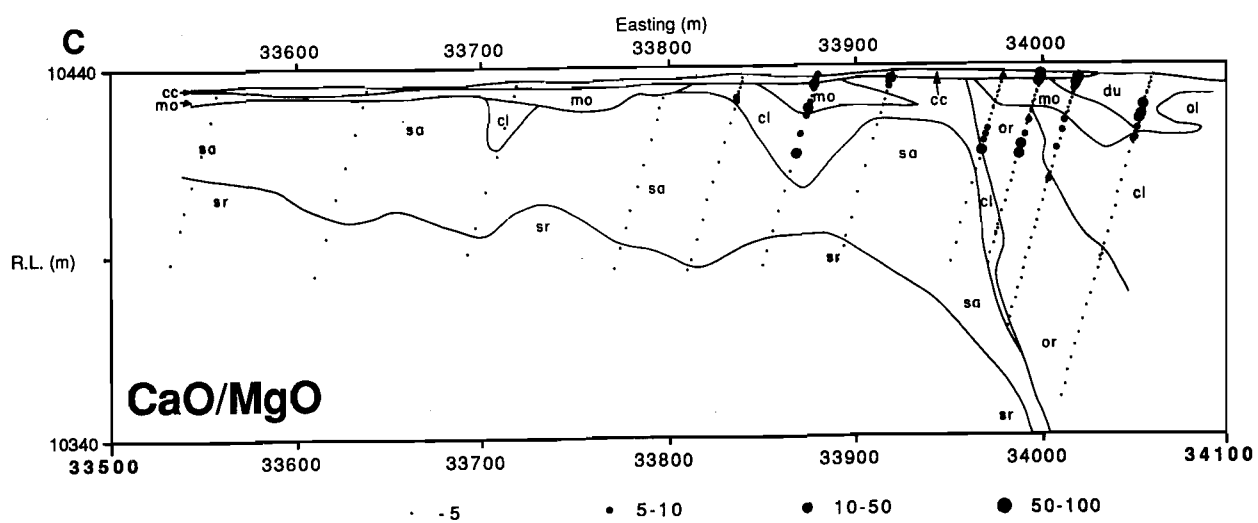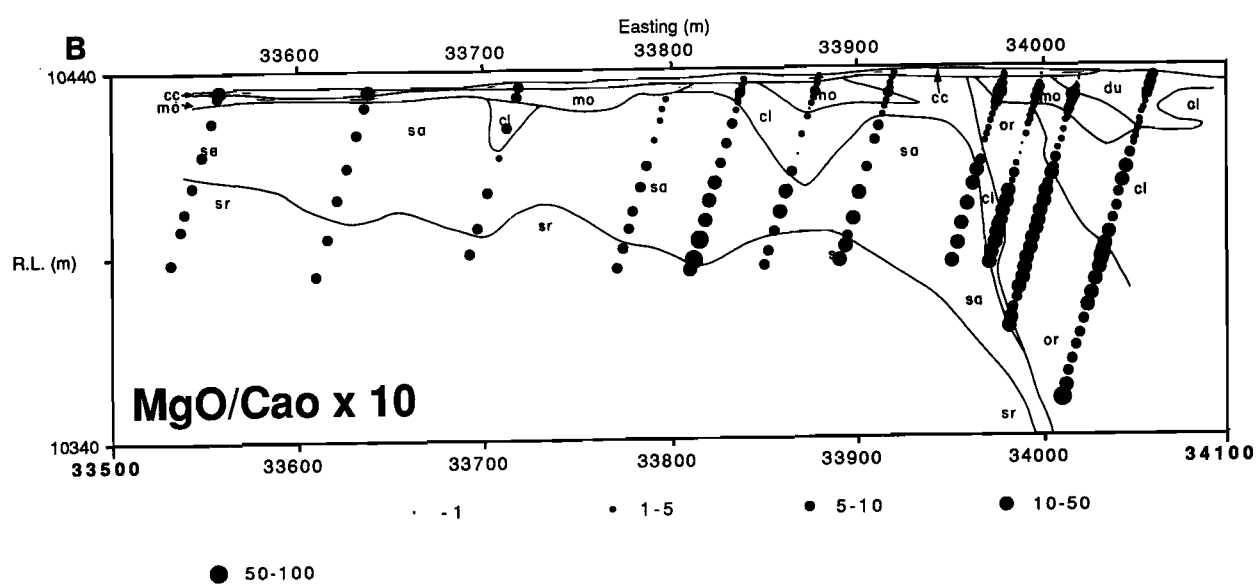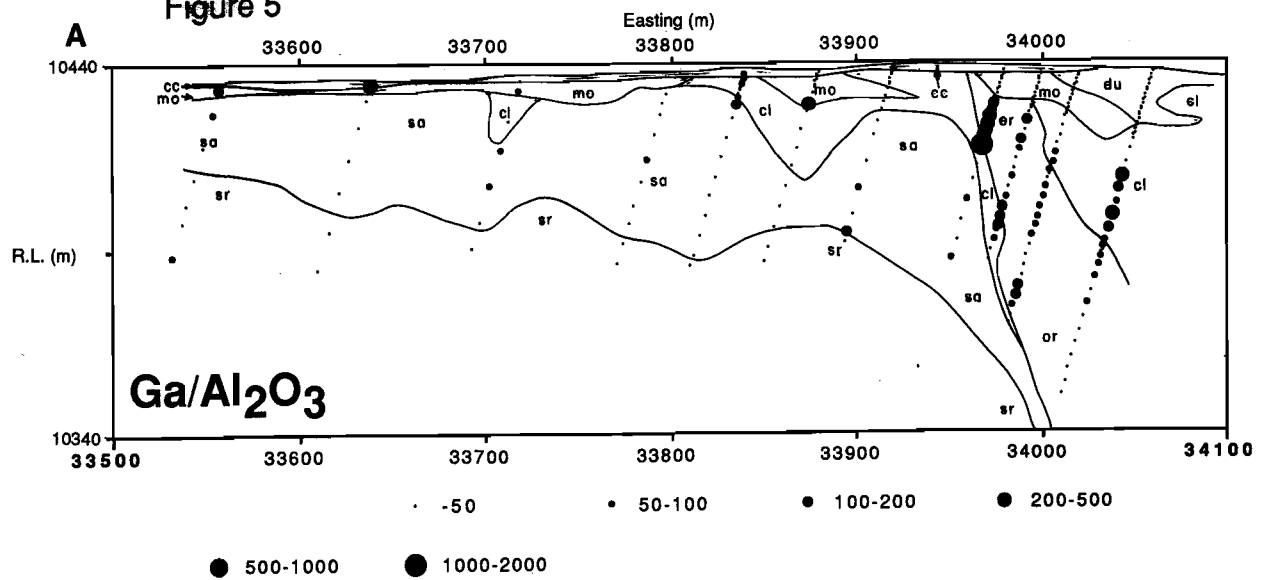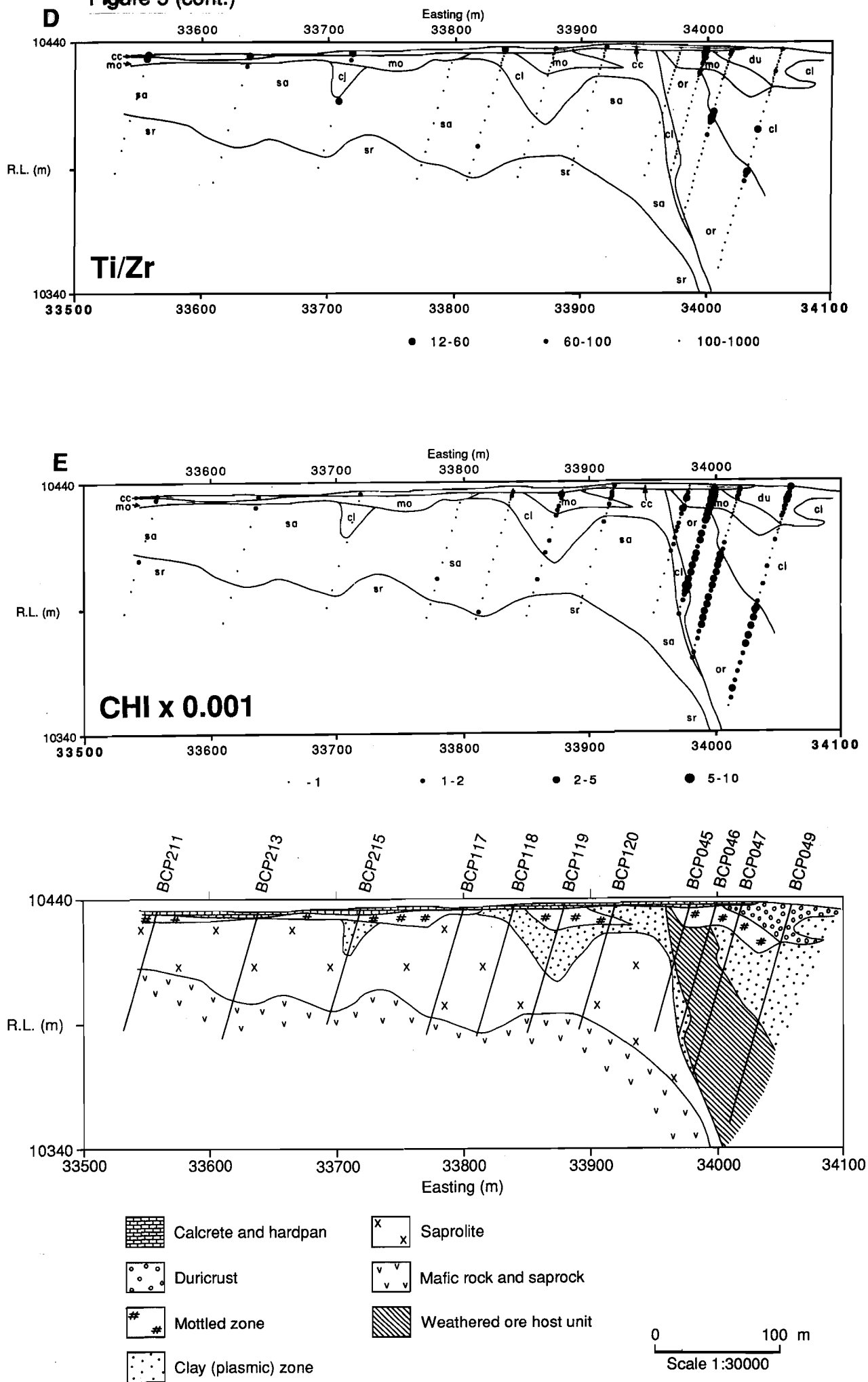
precipitation of halite. Muscovite mica is the least easily weathered alkali-bearing mineral and some has been found near and at the surface, encased in ferruginous materials (Robertson and Gall, 1988; Robertson, 1989; 1990).

In no rock type is there a clear relationship between Rb and depth. Rubidium seems to be concentrated towards the hangingwall of the host unit and shows a strong correlation with Al, Ga and Ti in this rock (Appendix 4). The first two correlations suggest it is present in micas which have been variably weathered. This is also indicated by X-ray diffractometry (Table 7) where near-surface materials from BCP 46, which intersects the hangingwall of the host unit, contain detectable quantities of micas and 16-51 ppm Rb but similar samples from BCP 49, which intersects duricrust and mafic clay zone rocks, contain no detectable mica and only 3-5 ppm Rb. Most of the Rb is leached from the mafic rocks at the base of the saprolite in the distal part of the section but, in the proximal part, Rb is locally concentrated in the mottled zone and deep in the saprolite. In BCP 119, the Rb-poor saprolites (<10 ppm Rb) contain no detectable mica, whereas all the Rb-rich saprolites (>50 ppm Rb) are mica rich and their (semiquantitative) abundance of mica correlates closely with Rb. This appears to indicate a weathered phyllic alteration zone which is discussed further below.

The distribution of S outlines a well-developed capping of gypsum which extends some 150 m to the west of the ore subcrop. High concentrations of S (>1%) are largely restricted to calcretes, with a few in the mottled and clay zones and some in duricrust. In the zone permeated with carbonates, S is correlated with Ca and Sr and weakly with Na (Appendix 4).

Ore-related Elements (Ag, As, Au, Bi, Cd, Cu, In, Mo, Pb, Sb, Sn, V, W and Zn)
The host unit and the overlying duricrust and mottled zone are enriched in Ag, As, Bi, Cd, In, Mo, Pb, Sb, Sn, V, W and Zn. Of these Cd, Sn, V, W and Zn tend towards the footwall of the host unit; Ag and In tend towards the hangingwall; As, Pb and Sb are more evenly distributed. Cobalt and Cu are concentrated towards the hangingwall of the ore but are not concentrated to any significant extent in the duricrust. The Cd anomaly is more distinct than the Zn anomaly, though it is less abundant by more than two orders of magnitude.

Gold is enriched in the proximal part of the section at a depth of 30-50 m to concentrations of 100 ppb Au relative to a background of 10 ppb. Several other elements (Ag, As, Bi, Cd, Cu, Mo, Pb, Sb, Sn, V and W) also show sporadic concentrations in the same part of the section; the anomalies are rarely co-incident but occupy a general area about 140 m wide that straddles the saprock-saprolite boundary. The Au-enriched rocks consist of quartz, weathered amphiboles and feldspars with some mica, smectite and minor kaolinite. A significant mica content is reflected by enrichment of Rb. The Au- and Rb-poor rocks above are more intensely weathered and consist largely of kaolinite, calcite, goethite and ubiquitous quartz, with no detectable mica. Micas are generally resistant minerals that do not weather readily, so it is suspected that the upward decrease in the mica content is probably not linked to weathering. The lower, mica-rich horizon may represent a partly-weathered phyllic alteration or primary mineralogical halo. It is also possible that some of the deeper concentrations of carbonates could be related to such a halo. Sericitic and carbonate wall-rock alterations are described by Hronsky *et al* (1990) from the Lancefield Mine. Unfortunately neither the percussion drilling nor the diamond drilling avaiable to the author had penetrated sufficiently to investigate adequately the possibility of mineralisation in the footwall rocks of the Beasley Creek orebody.

Gold characterises the host unit and is also strongly anomalous in the lateritic surface materials proximal to and over the orebody. Gold shows a very poor correlation with all other elements, the best being Cd (r=0.25). Although the pathfinder elements are generally anomalous in the host unit, they are generally concentrated in different parts of the host unit and so their concentrations do not accurately portray its

limits. Spurious concentrations of individual pathfinder elements, not reinforced by other pathfinders, occur elsewhere in the regolith and constitute geochemical noise.

An empirically-based, additive function, similar to that of Smith (1979) and Smith and Perdrix (1983), was used to smooth the pathfinder data. A CHI function of 500.Cd + Cu + 10.Pb + As + 300.Bi + 200.Sb + 200.Sn + 30.W + 300.Ag was devised so as to give each element approximately equal weight. Gold was deliberately excluded. This smoothed the data, removed most of the geochemical noise and outlined the host unit and the overlying anomalous laterite (Figure 5E). This technique seems robust; minor variations (up to half an order of magnitude) in the constants would probably make little difference to the result.

6.0 CONCLUSIONS

6.1 Weathering Depth and Sulphur Content

At the time of completion of the field investigations, the only diamond drill intersections of the orebody and host rock at Beasley Creek were intensely weathered, despite drilling below 230 m. Drilling from the hangingwall intersected, in sequence, weathered and then fresh hangingwall rocks, the weathered ore host unit, within a wide, weathered envelope and, finally, fresh footwall rocks. There is, therefore, little but supposition on which to base an understanding of the nature of the fresh mineralisation and its accompanying pathfinder element suite.

It is supposed, from the extent of localised ferruginisation in at least two main zones within the ore host rock, that significant amounts of sulphides accompanied the Au mineralisation. Apart from providing a source of iron for this ore-associated ferruginisation and the lateritic duricrust, weathering of these sulphides appears to have provided acid solutions which locally promoted the destruction of silicates surrounding the orebody, leading to extremely deep weathering. The most important weathering reactions, such as the weathering of feldspar, chlorite, muscovite and talc to kaolinite and the dissolution of tremolite are all promoted by acid conditions (see Robertson *et al.*, 1990). Such reactions would be expected to have occurred where the mafic amphibolite wall rocks and the micaceous, carbonaceous shale host unit have been converted to their corresponding kaolinitic saprolites. The S content of the fresh, mafic wall rocks is relatively low (approximately 0.2%), hence the depth of weathering is less at a distance from the ore. It is probable that the sulphur content of the orebody was one or even two orders of magnitude greater than the enclosing mafic rocks. The ore host unit at Beasley Creek seems analogous to the W10 and M1 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 (a total of 15% sulphide).

6.2 The Surficial Sulphur Anomaly

The role played by S, which appears to be strongly anomalous as gypsum in the near-surface environment, is still somewhat enigmatic. The S may have been derived locally from the oxidation of ore-associated sulphides (in which case its presence has considerable implications for exploration) or from syn-sedimentary sulphides of the ore host rock or it may be aeolian, as a product of deflation of a playa or an aerosol from the ocean. Whatever its origin, continued solution and reconcentration by evaporation means that S may have been mobile in this semi-arid landscape for a very long time. Obvious gypsum occurs in the top of the profile only close to the orebody (or ore host rock) and is responsible for the strong S anomaly reported by Robertson (1990) from all soil fractions. It is possible that a study of the isotopic composition of the S may indicate the origin.

Figure 6
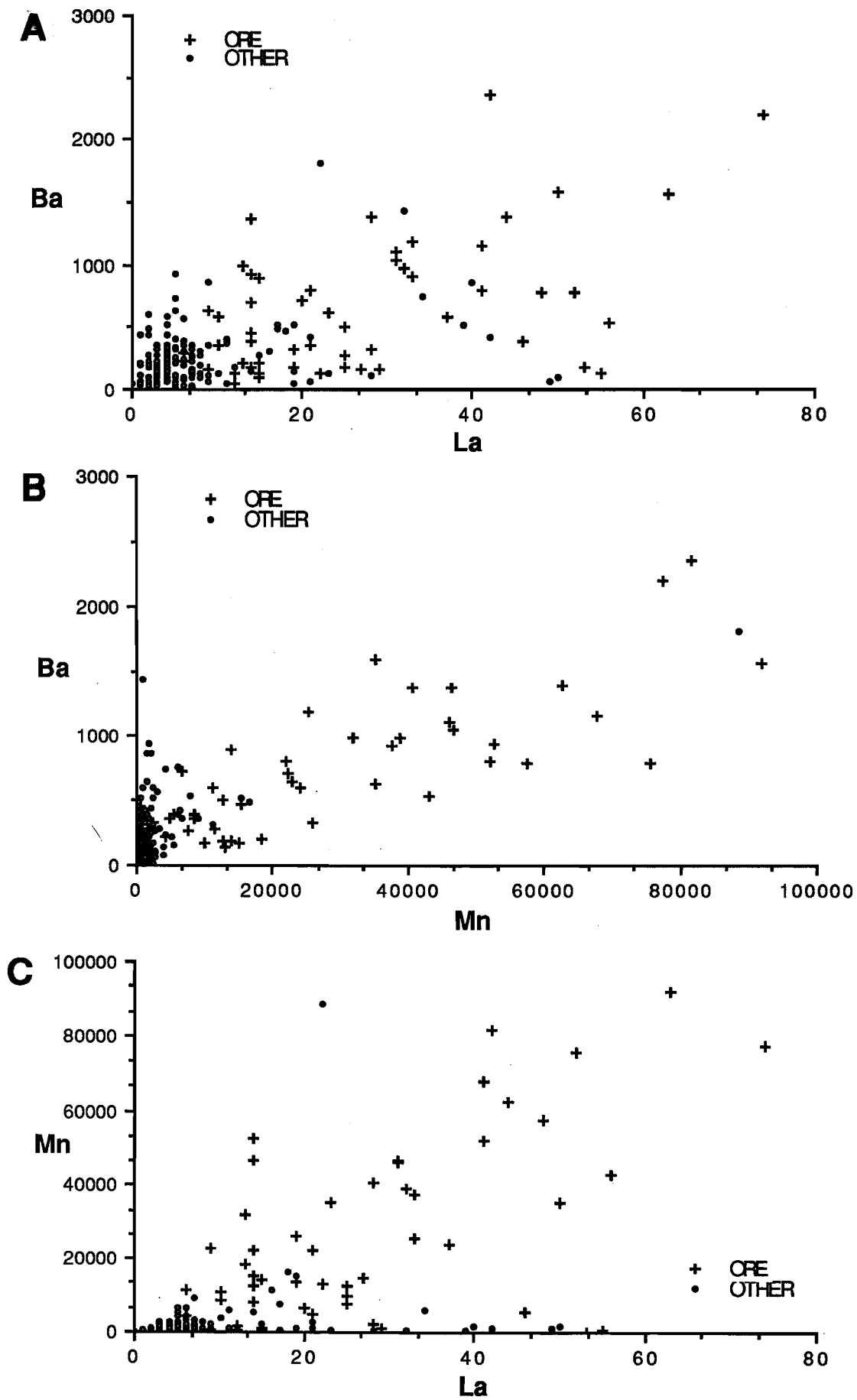
6.3   Major Elements

In terms of their Si-Al-Fe relationships, the fresh rocks and their saprolites form a coherent group. The clay zone rocks show an expected but variable decrease in Si, a generally corresponding increase in Al and very variable Fe contents. On the ternary diagram the mottled zone occupies a field overlapping with the clay zone but extending even further towards the Fe apex. These two materials appear to be related. Although highly ferruginous, the lateritic duricrust is comparatively richer in Al than the mottled zone. The hardpan is rich in Si and poor in S and Ca.

6.4   Pathfinder Elements

Apart from Au, the orebody is depicted by concentrations of Ag, As, Bi, Cd, Cu, In, Pb, Sb, W and Zn. Many of these elements show at least some weak enrichment (Ag, Nb and W) but generally strong enrichment (As, Bi, In, Pb, Sb and Sn) in the lateritic duricrust and in the mottled zone. Both Zn and Cu tend to be depleted near the surface but show some enrichment below the mottled zone.

If this suite of pathfinder elements is compared with the pathfinder elements which have been shown to depict the orebody in the ferruginous lag and in the soil (Robertson 1989; 1990) there is a large degree of commonality. The proven pathfinders, As, Au, Cd, Cu, W and Zn, are useful indicators of mineralisation throughout the profile and in the surficial materials. Although Bi, Ge and In are potential pathfinders deeper in the profile, their low abundances and the sporadic nature of their anomalies makes them ineffective in the surficial materials. Both Pb and Sb are also at low abundances but they tend to be strongly concentrated just below the surface. The anomaly that reaches the surface is not readily interpretable.

The significance of the Sn anomaly in the ore zone is difficult to determine. It could be associated with sulphides (reported from Teutonic Bore as cassiterite by Nickel, 1984), no primary mineralisation is available at Beasley Creek. It could also be associated with hydrothermally generated micas and sphene (Hamaguchi and Kuroda, 1978). Tin shows essentially chalcophile correlations with Bi, In, Cu and Sb, so the former is more probable.

6.5   Host Rock-Associated Elements

The ore host rock is essentially a partly carbonaceous, manganiferous and ferruginous phyllite with characteristic abundances of Al, Fe, Ba, Ce, Cr, Ga, La, Mn, Ni, Rb, V and Y. Mica is shown by high Ba, Rb and V; both mica and clay are reflected by the Al and Ga contents. High concentrations of Mn and Ba have also been noted from the saprolite of the ore host unit, from the ferruginous lag and from the soils overlying the orebody (Robertson and Gall, 1988; Robertson 1989; 1990). Preliminary multivariate analysis confirmed that the elements which most effectively define the ore host unit are increased concentrations in Mn, Ba, the rare earth elements (La, Ce and possibly Y) and Co (Figures 6A-C).

6.6   Proximal Dispersion

The proximal drilling shows a concentration of Ca and Sr associated with calcretes, related to the position in the landscape and not to the orebody. This is eclipsed by a massive, near-surface concentration of S, as gypsum, which becomes particularly strong and thick close to the orebody.

A zone enriched in Au, with approximately coincident enrichments in As, Cd, Cu, Pb, sporadic enrichments in Ag, Bi, Mo, Sb, Sn and W is characterised by elevated abundances of mica and associated Rb. It is about 100 m wide and is centred 150 m to the west of the orebody at a depth of 30-50m. It is suspected that this represents a partly-weathered primary phyllic alteration halo. Such a halo may also

explain the broad Au distribution in the lags and soils, the distribution of Ba and rare-earth elements in the deep saprolite proximal to the host unit and the occurrence of the wide gypsum cap and may be worthy of further investigation.

6.7 Surficial Enrichments and Depletions

Some pathfinder elements show slight to considerable enrichments in the surficial materials. Gold, Ag, As, Pb, Sb, W and Sn are enriched in the mottled zone and particularly in the lateritic duricrust. Where ore-related anomalies in these elements intersect these regolith units, the anomalies are greatly reinforced, enhancing their values as pathfinders. Other elements are depleted in the near-surface environment, namely Co, Cu and Zn, so reducing their effectiveness.

7.0 ACKNOWLEDGEMENTS

8.0 REFERENCES

Burton, J.D. and Culkin, F., 1978. Gallium. in K.H. Wedepohl (ed). Handbook of Geochemistry. Springer-Verlag. New York.

Butt, C.R.M. 1979. Geochemistry of a pseudo-gossan developed on a black shale-dolerite contact, Killara, Western Australia. Journal of Geochemical Exploration, 11. 131-156.

Butt, C.R.M. and Zeegers, H. (in press) Profile terminology and glossary of terms. in C.R.M. Butt and H. Zeegers (eds). Handbook of exploration geochemistry No 4. Regolith exploration geochemistry in tropical and sub-tropical terrains. Appendix 3.

Hallberg, J.A., 1984. A geochemical aid to igneous rock type identification in deeply weathered terrain. Journal of Geochemical Exploration. 20. 1-8.

Hamaguchi, H., and Kuroda, R. 1978. Tin. in K.H. Wedepohl (ed). Handbook of Geochemistry. Springer-Verlag. New York.

Hart, M.K.W. 1989. Analysis for total iron, chromium, vanadium and titanium in varying matrix geological samples by XRF, using pressed powder samples. Standards in X-ray analysis. Australian X-ray Analytical Association (WA Branch) Fifth State Conference. 117-129.

Hronsky, J.M.A., Perriam, R.P.A. and Schmulian, M.L. 1990. Lancefield gold deposit, Laverton. In Geology of the Mineral Deposits of Australia and Papua New Guinea (Ed. F.E. Hughes). Australasian Institute of Mining and Metallurgy: Melbourne. pp 511-517.

Nickel, E.H. 1984. The mineralogy and geochemistry of the weathering profile of the Teutonic Bore Cu-Pb-Zn-Ag sulphide deposit. Journal of Geochemical Exploration, 22. 239-264.

Norrish, K. and Chappell, B.W. 1977. X-ray fluorescence spectrometry. in J. Zussman (ed). Physical methods in determinative mineralogy. Academic Press, London. 201-272.

Reddell, C.T and Schmulian, M.L. 1990. Windarra nickel deposits, Laverton. In Geology of the Mineral Deposits of Australia and Papua New Guinea (Ed. F.E. Hughes). Australasian Institute of Mining and Metallurgy: Melbourne. pp 561-566.

Robertson, I.D.M. 1989. Geochemistry, petrography and mineralogy of ferruginous lag overlying the Beasley Creek Gold Mine - Laverton, WA. CSIRO Division of Exploration Geoscience, Restricted Report 27R, 180 pp.

Robertson, I.D.M. 1990. Mineralogy and geochemistry of soils overlying the Beasley Creek Gold Mine - Laverton, WA. CSIRO Division of Exploration Geoscience, Restricted Report 105R, 160 pp.

Robertson, I.D.M., Chaffee, M. A. and Taylor, G.F. 1990. The petrography, mineralogy and geochemistry of a felsic, mafic, ultramafic and metasedimentary weathered profile at Rand Pit, Reedy Mine - Cue, WA. CSIRO Division of Exploration Geoscience, Restricted Report 105R, 206 pp.

Robertson, I.D.M. and Churchward, H.M. 1989. The pre-mining geomorphology and surface geology of the Beasley Creek Gold Mine, Laverton, WA.

Robertson, I.D.M. and Crabb, J. 1988. A case-hardened carbon steel swingmill. CSIRO Division of Exploration Geoscience Technical Files. 6 pp.

Robertson, I.D.M. and Gall, S.F. 1988. A mineralogical, geochemical and petrographic study of rocks of drillhole BCD1 from the Beasley Creek Gold Mine - Laverton, WA. CSIRO Division of Exploration Geoscience, Restricted Report MG 67R, 44 pp.

Smith, R.E. 1979. Exploration geochemical methods for the Bangemall Basin, Western Australia. In: J.E. Glover, D.I. Groves and R.E. Smith (Editors), Pathfinder and Multi-element Geochemistry in Mineral Exploration. Univ. W.A.., Geol. Dept. Extension Serv., Publ., 4. 83-98.

Smith, R.E., and Perdrix, J.L. 1983. Pisolitic laterite geochemistry in the golden grove massive sulphide district, Western Australia. Journal of Geochemical Exploration, 18. 131-164.

Vincent, E.A. 1978. Silver. in K.H. Wedepohl (ed). Handbook of Geochemistry. Springer-Verlag. New York.