CRCLEME
Cooperative Research Centre for
Landscape Evolution & Mineral Exploration

CSIRO
EXPLORATION
AND MINING

AMIRA
Australian Mineral Industries Research Association Limited ACN 004 448 266

OPEN FILE
REPORT
SERIES

DISPERSION OF GOLD AND ASSOCIATED ELEMENTS IN THE LATERITIC REGOLITH, MYSTERY ZONE, MT PERCY, KALGOORLIE, WESTERN AUSTRALIA

Volume I

C.R.M. Butt

CRC LEME OPEN FILE REPORT 45

October 1998

(CSIRO Division of Exploration Geoscience Report 156R, 1991.
Second impression 1998)

CRC LEME is an unincorporated joint venture between The Australian National University, University of Canberra, Australian Geological Survey Organisation and CSIRO Exploration and Mining, established and supported under the Australian Government's Cooperative Research Centres Program.

CRC

AMIRA
Australian Mineral Industries Research Association Limited ACN 004 448 266

CRCLEME
Cooperative Research Centre for
Landscape Evolution & Mineral Exploration

CSIRO
EXPLORATION
AND MINING

DISPERSION OF GOLD AND ASSOCIATED ELEMENTS IN THE LATERITIC REGOLITH, MYSTERY ZONE, MT PERCY, KALGOORLIE, WESTERN AUSTRALIA

Volume 1

C.R.M. Butt

CRC LEME OPEN FILE REPORT 45

October 1998

(CSIRO Division of Exploration Geoscience Report 156R, 1991.
Second impression 1998)

CRC LEME is an unincorporated joint venture between The Australian National University,
University of Canberra, Australian Geological Survey Organisation and CSIRO Exploration and Mining
Headquarters: CRC LEME c/o CSIRO Exploration and Mining, Private Bag, PO Wembley, Western Australia, 6014

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

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

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

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

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

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

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

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

This report (CRC LEME Open File Report 45) is a Second impression (second printing) of CSIRO, Division of Exploration Geoscience Restricted Report 156R, first issued in 1991, which formed part of the CSIRO/AMIRA Project P241.

Copies of this publication can be obtained from:
The Publication Officer, c/- CRC LEME, CSIRO Exploration and Mining, PMB, Wembley, WA 6014, Australia. Information on other publications in this series may be obtained from the above or from http://leme.anu.edu.au/
Cataloguing-in-Publication:
Butt, C.R.M.
Dispersion of gold and associated elements in the lateritic regolith, Mystery Zone, Mt Percy, Kalgoorlie, Western Australia
ISBN v1: 0 642 28214 5 v2: 0 642 28213 7 set: 0 642 28215 3
1. Regolith 2. Geochemical prospecting 3. Laterite 4. Gold - Western Australia.
I. Title
CRC LEME Open File Report 45.
ISSN 1329-4768

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 over 40 elements, including gold, in the almost complete lateritic regolith present over mineralization at Mt. Percy. 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

TABLE OF CONTENTS

VOLUME I

Page No.

VOLUME II

DISPERSION OF GOLD AND ASSOCIATED ELEMENTS IN THE LATERITIC REGOLITH, MYSTERY ZONE, MT. PERCY, KALGOORLIE, WESTERN AUSTRALIA

C.R.M. BUTT

Division of Exploration Geoscience, CSIRO,
Private Bag, PO, Wembley, Western Australia, 6014

ABSTRACT

The dispersion of gold and over 40 other elements in the lateritic regolith has been studied at the Mt. Percy gold mine, near Kalgoorlie. Primary Au mineralization in the Mystery Zone occurs in fuchsite-carbonate alteration zones at the contact with porphyries intruding the Hannan's Lake serpentinite. The mineralized sequence has been deeply weathered and is concealed beneath an almost complete lateritic regolith over 60 m thick. The regolith consists of saprolite (50 m), which is clay-rich in the top 10 m, plasmic and mottled clays, and surficial horizons of lateritic gravels, lateritic duricrusts and pisolitic soils. The surficial horizons contain pedogenic carbonates. Duplicates of grade-control composite samples from two sections across the Mystery Zone were collected at 1 or 2 m intervals at each 2.5 m level throughout the regolith as mining progressed. Samples of fresh rocks were obtained from diamond drill core. A selection of these samples, including a complete section through the primary mineralization, was analysed to illustrate element distributions in the fresh and weathered rocks. The elements associated with primary Au mineralization appear to be S, Ag, W, As, Sb, Te and, possibly, Ba, K and Pb, but except for Ag and Te, none has a very direct correlation with Au.

The Au distribution in the regolith is typical for the region, with minor enrichment and wide lateral dispersion in surficial gravels and duricrust (particularly associated with the presence of pedogenic carbonates), leaching and depletion in the underlying clay-rich horizons and some secondary concentration and minor dispersion in the saprolite. Primary and saprolitic Au mineralization is indicated by a broad superjacent Au anomaly (100->1000 ppb) in the soils and lateritic horizons, and by high concentrations of W (5->40 ppm), Sb (7->16 ppm) and As (10-200 ppm). High K contents, corresponding to resistant muscovite, give surface expression to the alteration zone. Although Au contents are <100 ppb in the underlying clay-rich horizons, Sb, W and, to a lesser extent, As remain anomalous; similarly, Ba and K contents remain high, indicating the porphyries and alteration zones respectively.

The porphyries and ultramafic rocks can be discriminated geochemically throughout much of the regolith by relative abundances and ratios of Ti, Zr, Ba and K. However, the lateritic horizons, particularly the duricrusts overlying the talc chlorite rocks of the Hannan's Lake serpentinite, have abnormal geochemical signatures. These duricrusts have low Cr contents (<1000 ppm), because primary Cr is present in weatherable chlorite rather than resistant chromite, but are enriched in "immobile" elements derived from the porphyries. The distribution patterns of the elements are discussed in terms of landform evolution and their significance to exploration.

1.0 INTRODUCTION

The Mystery Zone of the Mt. Percy Mine was selected for a substantial study within the CSIRO/AMIRA Research Project because it offered the opportunity to investigate geochemical dispersion from gold mineralization at a site with a mostly complete lateritic regolith. It was also expected to exemplify many of the characteristics of dispersion in similar sites in the Kalgoorlie area. This is one of a number of broadly similar studies being undertaken in the Yilgarn Block, both as part of this Project (e.g., Beasley Creek, Callion, Panglo) and by Lawrance (in preparation) at Hannan South and Mt. Pleasant. Together, these represent dispersion from several styles of mineralization, in geomorphological environments ranging from complete to fully stripped lateritic regoliths, including sites now high in the landscape and others close to and beneath playas.

2.0 GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

Mt. Percy is about 2 km NE of the centre of Kalgoorlie. It lies at the northern end of the Kalgoorlie-Kambalda greenstone sequence, about 8 km N. of the Golden Mile and 1.5 km N. of Mt. Charlotte (Figure 1). At Mt. Percy, the Hannan's Lake Serpentinite, Devon Consols Basalt, Kapai Slate and Williamstown Dolerite here form part of the hinge zone and steeply east-dipping limb of the Kalgoorlie Anticline (Travis et al., 1971). The sequence is cross-cut by a series of north-trending, west-dipping dextral faults, including the Maritana, Reward, Charlotte and Mystery Faults. The Golden Mile Dolerite and the Black Flag Beds are west of the Mystery Zone, separated from the other units by the Golden Mile fault. In contrast to the Golden Mile and Mt. Charlotte, therefore, where primary Au mineralization occurs mainly in the Golden Mile Dolerite, mineralization at Mt. Percy is lower in the sequence, being located in the Hannan's Lake Serpentinite in the Mystery Zone and the Devon Consols Basalt in the Union Club and Sir John Zones (Sauter et al., 1988). In the Mystery Zone, the chlorite talc carbonate rocks of the Hannan's Lake Serpentinite are intruded by porphyries, with strong fuchsite-carbonate alteration occurring at their contacts (Figure 2). Primary gold mineralization is largely confined to a series of irregular, mostly steeply-dipping lenses within the porphyries and adjacent alteration zones.

Mt. Percy is situated in a relatively high part of the landscape, in a region that has a total relief of only a few tens of metres. The elevation is probably due to the armouring effect of the lateritic duricrust (*cuirasse*), here developed most strongly over the Hannan's Lake Serpentinite. As a consequence, an almost complete lateritic regolith, 50-70 m thick, is present over most of the area. The duricrust is developed most strongly over the talc chlorite carbonate rocks and the Golden Mile Dolerite, and these form the highest points at the south end of the Mystery Pit and Mt. Percy, upon which the Mt. Percy water-tank is situated. The regolith is the host to secondary gold mineralization within both the lateritic duricrust and the saprolite.

Mining at Mt. Percy originally took place in the period 1893-1910, extracting about 70,000 tonnes of primary and secondary ore from underground workings (Sauter et al., 1988). Most of the surface was dry-blown. Recent exploration commenced in 1977 by Occidental Minerals and was continued by Windsor Resources. Open cut mining at the Union Club - Sir John pit commenced in 1985. Mining of the southern end of the Mystery Zone commenced in 1987 and sampling for this study was undertaken from that time.

3.0 SAMPLING AND ANALYSIS

3.1 Sampling

The objective of the sampling programme was to obtain a suite of samples in order to illustrate the vertical and lateral distribution of a range of elements in the regolith developed over gold mineralization and its wallrocks. Two sections across the mineralized zone, 15850N and 15900N (Figure 2), have been studied, selected on the basis of features evident from exploration percussion and diamond drilling. Four sampling procedures were used.

1. Channel rip samples. Samples for mine grade-control were taken by ripping shallow trenches across strike by bulldozer and hand-collecting and compositing the spoil over 1 m horizontal intervals. Duplicates of the grade-control samples were used for the study. The samples were collected from the original ground surface and thereafter at 2.5 m intervals, as mining progressed. From RL 392.5, composite samples were collected every second horizontal metre. Between RL 390.0 and 365.0 inclusive, sampling was on traverse lines 5 m to the north, i.e., 15855 N and 15905 N; this was necessary because of a change in the procedure used for grade-control sampling on the original lines.

2. Rock drill samples. From RL 360 to the base of the pit at RL 345, the hardness of the weathered and fresh rock necessitated a change to drill-and-blast mining. Grade-control samples were obtained from the drill spoil and duplicates were collected for this study. The holes were drilled at one or two metre intervals across strike, at an angle of 60°, for a vertical depth of 5 m. An upper and lower sample were collected from each hole, each representing a composite sample of a 2.5 m vertical interval.

3. Percussion and diamond drill samples. A diamond drill hole, KND 181, was drilled at an angle of 51° to pass vertically below Section 15850N. The hole was precollared by percussion drilling to 90 m down-hole and diamond-drilled to 181.4 m. Samples of the percussion precollar from within the pit area (1 m composites) and sections of approximately 1 m of quarter core were collected for the study. Representative 1 m intervals of core were selected from the unmineralized wallrocks, but close to and through the mineralization, the samples were of a continuous section. Each core sample included heterogeneities due to veining, but was otherwise lithologically homogenous. On Section 15900N, diamond drill hole KND 22 passes beneath the pit area; a small number of representative 1 m samples of quarter core were collected.

4. Special samples. A few additional lump samples were collected at the surface and close to the base of the pit.

A total of approximately 1940 samples were collected, of which about 550 have been selected for analysis. The locations of these samples are shown on the geology and regolith sections (Figures 3, 4, 8 and 9) and on the element distribution sections (Appendices I and II).

In addition to these samples, about 100 percussion and diamond drill samples were collected approximately 1 km north of the Mystery Pit, in order to examine the characteristics of "background" rocks along strike from the mineralization. These will be the subject of a later report.

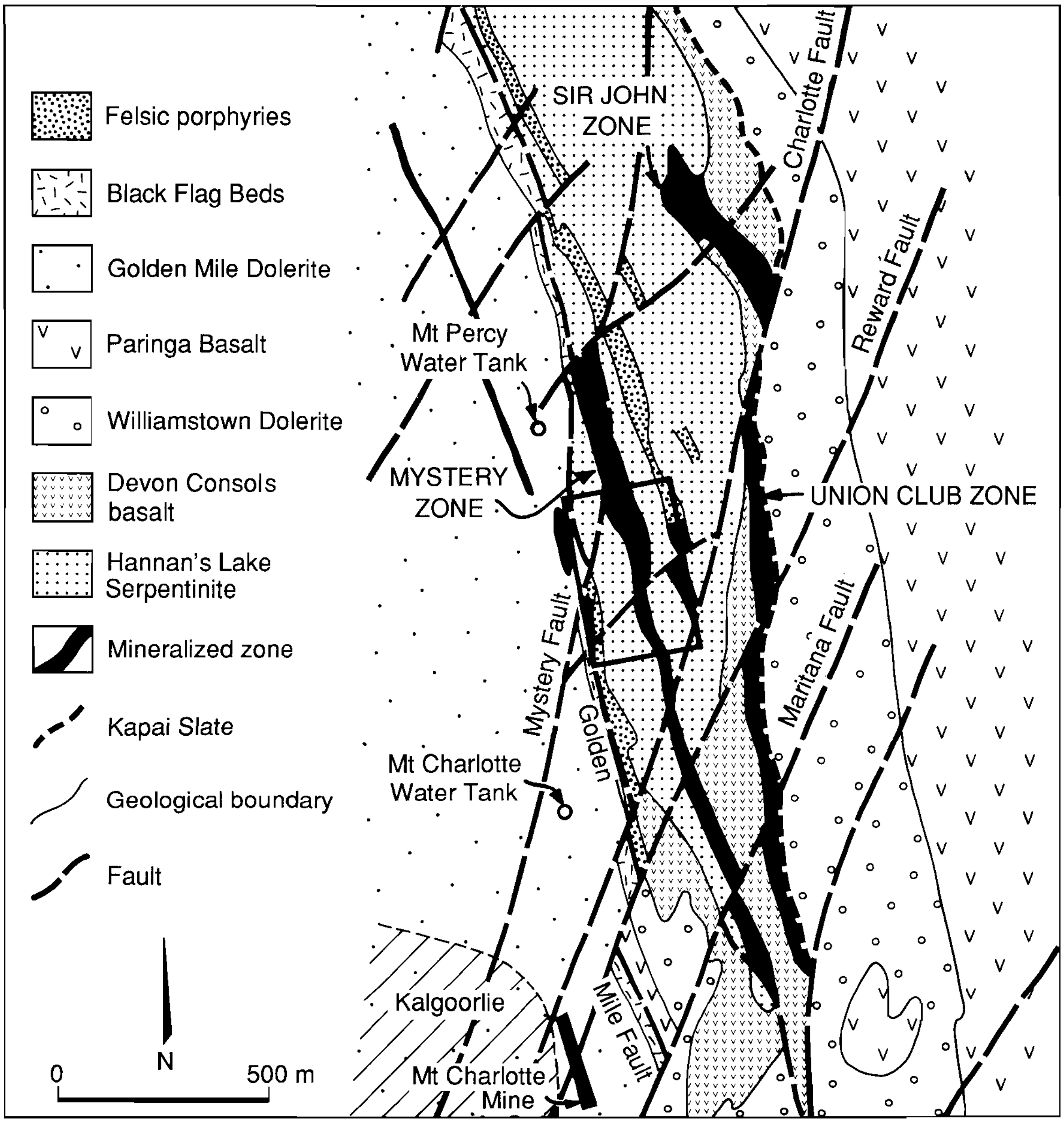


Figure 1. Regional geological setting of gold mineralization at Mt. Percy, Kalgoorlie, modified from Sauter et al., (1988). Box indicates location of detail shown in Figure 2.

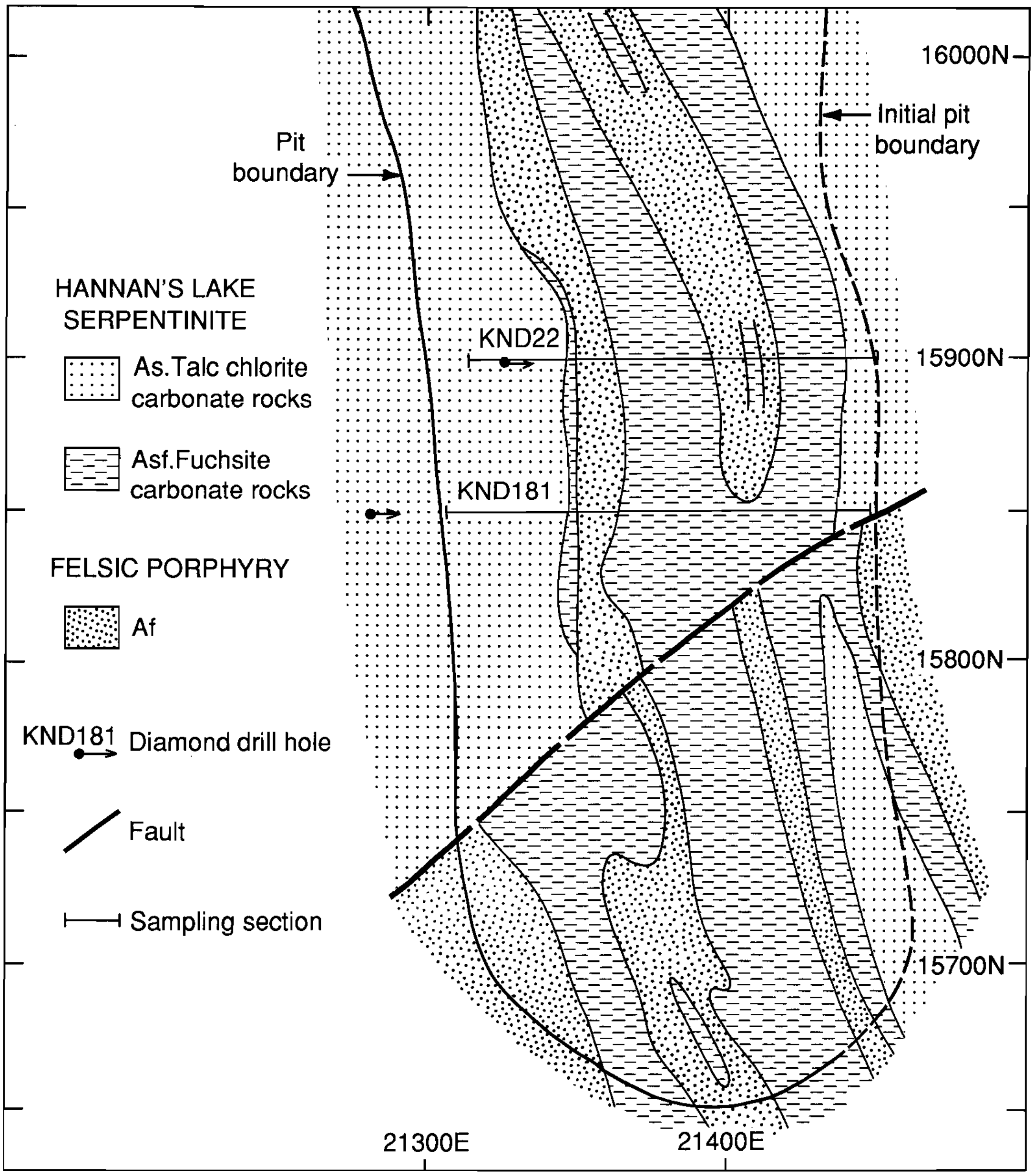


Figure 2. **Geology of the southern end of the Mystery Zone, Mt. Percy, projected to 400 m RL,** indicating the two sections selected for study. Information derived from pre-mine drilling, supplemented north of 15750N by in-pit mapping (T. Bradley, KCGM) and data from this study. Location of area shown in Figure 1.

3.2 Sample Preparation and Analysis

All samples selected for analysis were dried (40°C), a sub-sample taken for reference and the remainder jaw-crushed to 4 mm or smaller. The material was then riffle split and a minimum of 100 g extracted for grinding to less than 75 μm. Initially, samples were ground in an agate ring mill, but this proved very slow and the majority of samples were ground in a Mn steel mill.

Samples were analysed as follows:

A. Neutron activation analysis (INAA), 30 g sample (Becquerel Laboratories Pty. Ltd.):

Sb, As, Ba, Br, Ce, Cs, Cr, Co, Eu, Au, Hf, Ir, Fe, La, Lu, Mo, Rb, Sm, Sc, Se, Ag, Ta, Th, W, U, Yb, Zn.

B. X-Ray fluorescence (XRF) on pressed powders using a Philips PW1220C instrument by the methods of Norrish and Chappell (1977) and Hart (1989), with Fe determined for matrix correction (CSIRO):

Ba, Ce, Cu, Ga, Ge, Fe, Pb, Mn, Ni, Na_2O, Nb, Rb, Sr, S, TiO_2 , V, Y, Zn, Zr.

C. Inductively-coupled plasma emission spectrometry (ICP-ES) on a Hilger E-1000 following fusion of 0.25 g samples with Li metaborate and solution in dilute HNO_3 (CSIRO):

Al_2O_3, SiO_2, Fe_2O_3, TiO_2, CaO, MgO, Ba, Be, Cr, Cu, Mn, Ni, V, Zr.

D. Atomic absorption spectrometry (AAS) using solutions prepared for ICP-ES:(CSIRO):

K_2O, Na_2O. (Section 15900N and diamond drill samples only).

E. Inductively-coupled plasma mass spectrometry (ICP-MS), following digestion in $HClO_4$-HNO_3-HF acid mixture and solution in dilute HCl (Analabs Pty. Ltd):

Ag, Bi. (Selected samples only).

F. Atomic absorpton spectrometry, hydride generation (Analabs Pty. Ltd.):

Te. (Selected samples only).

The detection limits are listed in Table IV/1, Appendix IV. A number of elements were analysed by more than one technique (e.g., Ba, Cr, Ce, Fe, Rb, Zr) and others were at concentrations below detection limit in most, if not all, samples (e.g., Ag (by INAA), Ir, Se, Be). The duplicate sets of data were compared and, for the most part, there is satisfactory agreement between the methods, with the exception of Rb. Only the data from the method offering the greatest sensitivity and least scatter have been plotted and discussed in this report. These are listed in Appendix IV. However, all data are presented on the data disk. The suffixes ".x" and ".n" to the element symbols in Figures and Tables (e.g., Ba.x, Au.n) indicates analysis by XRF and INAA respectively. Where concentrations are below detection limit, a value of half detection limit has been used for statistical purposes. The precision of the data was monitored by replicate analyses of in house control samples introduced at a rate of about one control per 10 unknowns. The possibility of contamination of hard samples by W due to abrasion of tungsten carbide-faced tools during ripping and drilling has been discounted because samples collected independently give similar results (see section 5.2.3).

The mineralogy of selected samples was determined by X-ray diffractometry, using CuKα radiation and a graphite-crystal monochromator.

4.0 PRIMARY MINERALIZATION AND HOST ROCKS

The logged and interpreted geology of the two sections are shown in Figures 3 and 4. The petrology, mineralogy and geochemistry of the primary mineralization and its host rocks are the subject of another report (Binns, in preparation). However, the data are pertinent to an understanding of the characteristics and development of the regolith and are discussed briefly in this section. The lithological units have been given informal codes, defined in the text and Appendix V, for identification in some Figures, Tables and the data listings.

4.1 Petrography and mineralogy

Unweathered rocks from below the pit are represented by:

DDH KND 181: four samples derived from the percussion precollar, each representing 1 m, and 57 samples of quarter core, mostly representing complete intervals of 1 m between 90 and 180.7 m down hole. The core was continuously sampled from 131.00 to 167.00 m.

DDH KND 22: ten samples of quarter core, mostly of 1 m intervals, from depths between 74.00 and 167.00 m down hole.

There are two principal lithologies present in the cores, metamorphosed ultramafic rocks (Hannan's Lake Serpentinite; code As) and felsic porphyries (code Af). The ultramafic rocks are further altered to a green fuchsite-carbonate rock (code Asf), particularly at the contact with the porphyries, and xenoliths of the fuchsitic ultramafic rocks are present within the porphyries. Five ultramafic and three porphyritic units have been recognized. The mineralogy is summarized in Figure 10. The following descriptions are derived from observations by R.A. Binns (written communication, 1989).

4.1.1 *Hannan's Lake Serpentinite*

Biotitic talc carbonate rocks (Code Asb). These are the most western unit of the ultramafic rocks and consist of a fine, felted aggregate of talc and biotite, the latter intergrown with minor chlorite. In former A zone komatiites, patches of talc appear to have pseudomorphed olivines and biotite replaces matrix minerals. Porphyroblasts of magnesite and dolomite (1 mm) and albite (0.2 mm) are present throughout, with the carbonates locally coalescing into veinlets.

Talc chlorite carbonate rocks (Codes Ast; Asc). These are talc chlorite rocks, cross-cut by networks of coarse carbonate-albite and carbonate-quartz veins. Former spinifex and cumulate fabrics of A and B zone komatiites are partially destroyed by the veining and the superimposition of rhombic carbonate and anhedral albite porphyroblasts. Part of this unit has no talc and is identified by code Asc.

Fuchsite carbonate ultramafic rocks (Code Asf). These are moderately to strongly recrystallized komatiites, now composed predominantly of carbonate (dolomite and magnesite), quartz and fuchsite, with some chlorite, accessory rutile and, where mineralized, pyrite. These rocks are green, most conspicuously at the contact with the porphyries. The carbonates occur as coarse

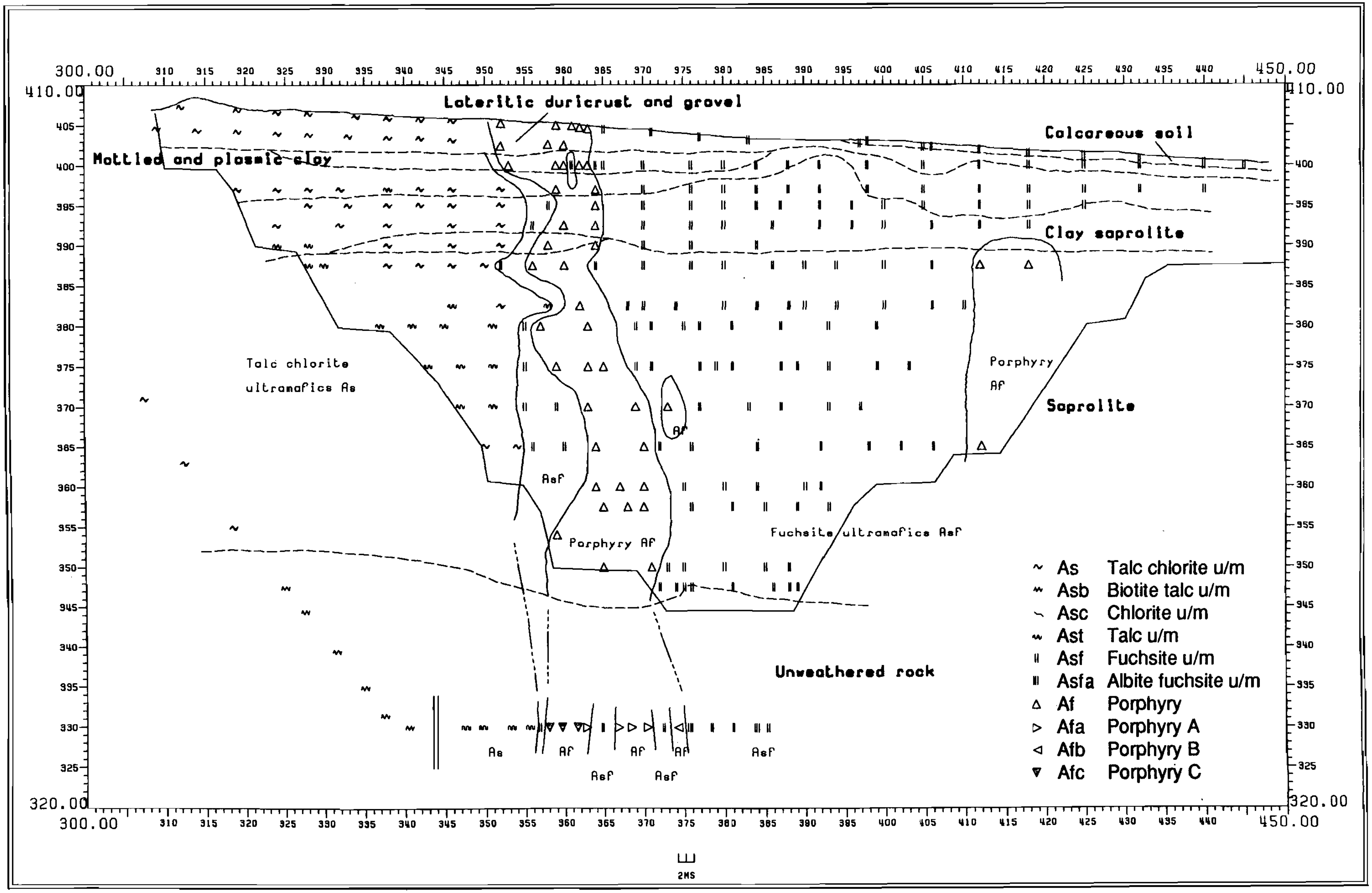


Figure 3. Logged and interpreted geology of Section 15850N, Mystery Zone, with regolith units superimposed. (N.B. Diamond drill core samples below RL 330 m are projected to 330 m. For clarity, not all core samples are shown).

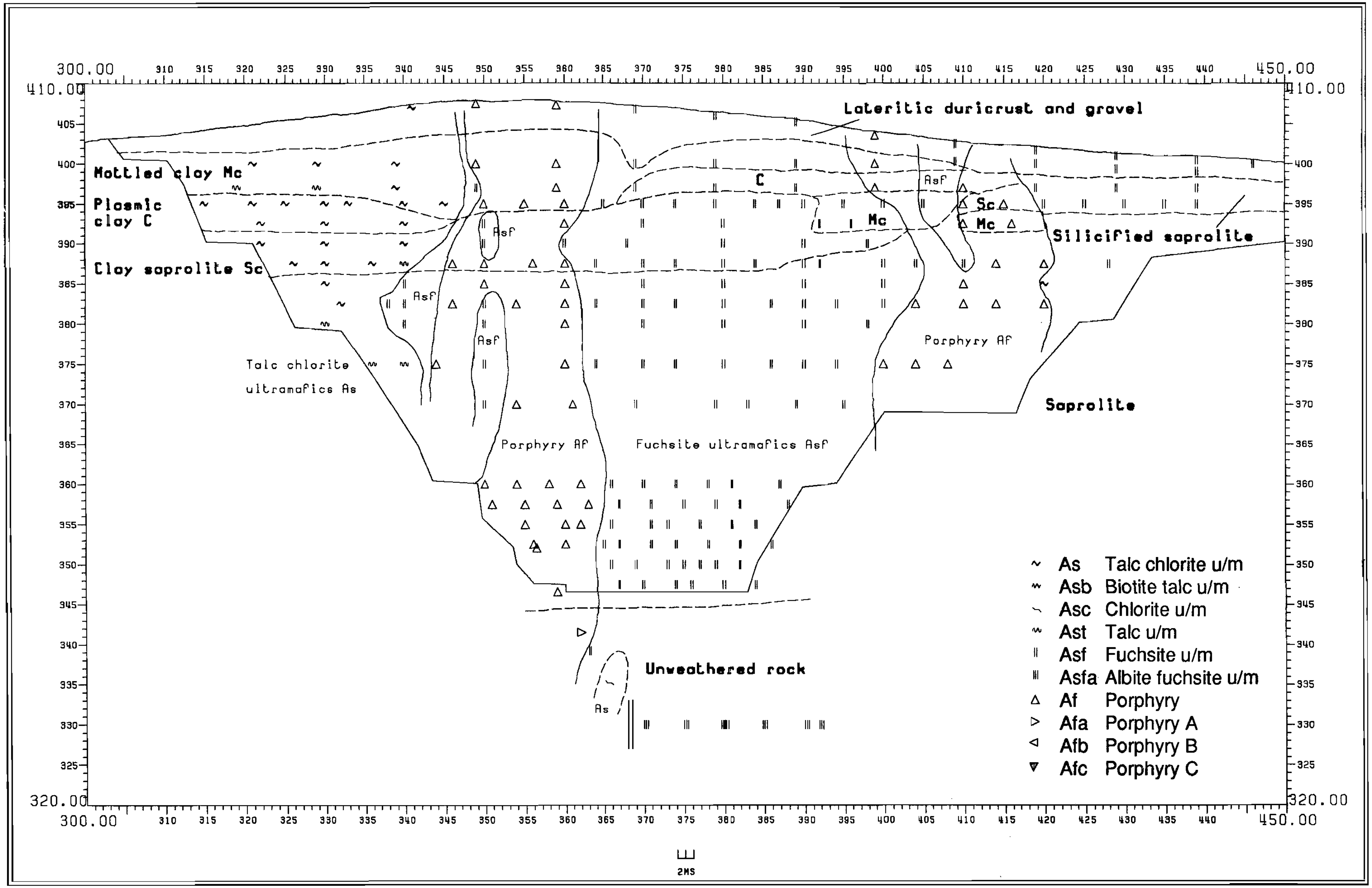


Figure 4. Logged and interpreted geology of Section 15900N, Mystery Zone, with regolith units superimposed. (N.B. Diamond drill core samples below RL 330 m are projected to 330 m).

(100-200 μm) rhombic porphyroblasts, as pseudomorphs after spinifex olivine blades, in quartz-carbonate veins and with very fine quartz (2 - 50 μm) in the matrix. Chromian muscovite (fuchsite) is present as coarse (50 μm) flakes, fine grained aggregates and as haloes around remnant chromite.

Fuchsite albite carbonate ultramafic rocks (Code Asfa). These rocks are broadly similar to the previous group but with albite occurring both in the matrix and in some veins. In some specimens, former olivines are replaced by carbonate, and pyroxenes by carbonate and chlorite. All fuchsitic ultramafic rocks are cross-cut by numerous carbonate ± quartz (± albite) veins. Some veins contain fuchsite and, in a few places, the dark green vanadiferous muscovite *roscoelite.*

4.1.2 *Porphyries*

Three sub-types of porphyry (A, B, C) have been recognized during mapping (P.C.C. Sauter, personal communication). All appear to be dioritic in origin and to have been subjected to carbonate alteration (dolomite and magnesite) and Si, K and S metasomatism. The differences may be due largely to the style of alteration.

Carbonated feldspar porphyry (A type; code Afa). These are pale grey to white rocks with green fuchsite-altered phenocrysts and fuchsitic xenoliths, the latter ranging in size from a few millimetres to several tens of centimetres or more. There are rare relict phenocrysts of feldspar, quartz and hornblende, the latter largely replaced by carbonate, chlorite and fuchsite. The groundmass is composed of albite (in part replaced by K feldspar), quartz, minor carbonate and muscovite, and accessory rutile, pyrite and other sulphides. The xenoliths consist of carbonates, fuchsite and quartz and appear to be derived from the ultramafic wall rocks.

Carbonated feldspar porphyry (B type; code Afb). These are pale buff and grey rocks, without visible phenocrysts of quartz or feldspar in either hand specimen or thin section. Mafic phenocrysts are represented by carbonates and fine-grained white micas, surrounded by rutile and sphene; fuchsite and chlorite are absent. The groundmass consists of carbonate, white mica, albite, quartz, rare laths of relict K-feldspar and accessory rutile and sphene.

Carbonated feldspar porphyry (C type; code Afc). These are pale grey rocks that commonly show bleaching adjacent to narrow cracks. Scattered phenocrysts of twinned plagioclase (now albite) and mafic minerals (probably hornblende but now carbonate, chlorite, mica and fine-grained opaque minerals) are set in a groundmass of fine albite, carbonates and quartz. Pyrite and other sulphides are locally abundant.

4.2 **Geochemistry**

4.2.1. *Lithogeochemistry*

Statistical data for each of the eight units are tabulated in Appendix III; mean compositions are given in Table 1. Only the three principal lithologies talc chlorite (biotite) carbonate rocks, fuchsite ultramafic rocks and porphyries can readily be distinguished in the regolith and a comparison of their mean compositions is summarized in Table 2. The porphyries are richer in Si, Al, Na, Ba, Sr, Zr, Hf, REE, Ga, Pb, Nb, Ta, Th and W, and poorer in Mg, Ca, Cr, Co, Fe, Sc, Ni, Mn and possibly Rb than the

Table 1. Mean compositions of principal lithological units sampled by DDH KND181 and KND22, Mystery Zone, Mt. Percy. (See Appendix III for greater detail).

	Lithology	N	SiO_2%	Al_2O_3%	MgO%	CaO%	Fe.n%
Asb	Biotite talc	8	39.27	7.03	20.09	6.78	6.72
Ast	Talc carbonate	8	37.71	4.96	21.53	6.25	6.52
Asc	Chlorite u/mafic	3	32.69	4.70	20.73	4.10	6.26
Asf	Fuchsite u/mafic	18	36.41	5.31	17.15	4.93	5.86
Asfa	Albite fuchsite	11	36.90	5.40	13.71	8.63	5.97
Afa	Porphyry A	12	62.14	13.05	3.97	3.55	2.36
Afb	Porphyry B	2	48.86	13.85	6.35	5.05	4.45
Afc	Porphyry C	8	61.83	12.06	3.58	3.04	2.29

	Lithology	N	TiO_2%	Na_2O ppm	K_2O ppm	LOI%	As.n ppm
Asb	Biotite talc	8	0.31	5175.00	12450.00	14.74	3.59
Ast	Talc carbonate	8	0.22	2321.88	225.75	18.10	45.14
Asc	Chlorite u/mafic	3	0.23	1246.67	863.00	25.47	205.33
Asf	Fuchsite u/mafic	18	0.24	1200.83	15182.22	25.25	291.33
Asfa	Albite fuchsite	11	0.25	7566.36	14985.45	24.55	25.17
Afa	Porphyry A	12	0.44	46650.00	15268.75	7.68	33.52
Afb	Porphyry B	2	0.83	32750.00	32800.00	12.30	1.00
Afc	Porphyry C	8	0.41	63925.00	4912.50	6.66	32.50

	Lithology	N	Au.n ppb	Ba.x ppm	Ce.n ppm	Co.n ppm	Cr.n ppm
Asb	Biotite talc	8	3.28	18.75	1.63	84.63	2230.00
Ast	Talc carbonate	8	3.33	8.50	1.00	94.50	2103.75
Asc	Chlorite u/mafic	3	16.47	12.33	1.50	90.00	1886.67
Asf	Fuchsite u/mafic	18	1299.09	299.72	1.47	82.72	1910.56
Asfa	Albite fuchsite	11	683.59	98.36	1.77	96.18	2017.27
Afa	Porphyry A	12	1537.00	692.08	45.92	15.00	175.00
Afb	Porphyry B	2	91.50	1475.50	110.00	26.00	19.00
Afc	Porphyry C	8	613.13	378.50	39.63	14.38	141.88

	Lithology	N	Cs.n ppm	Cu.x ppm	Eu.n ppm	Ga.x ppm	Ge.x ppm
Asb	Biotite talc	8	61.00	35.00	0.25	6.88	1.00
Ast	Talc carbonate	8	2.75	42.63	0.25	5.13	1.00
Asc	Chlorite u/mafic	3	0.70	32.33	0.25	4.67	1.33
Asf	Fuchsite u/mafic	18	2.28	51.33	0.25	7.11	1.72
Asfa	Albite fuchsite	11	2.92	45.18	0.25	6.09	2.00
Afa	Porphyry A	12	1.98	31.50	0.94	17.92	1.67
Afb	Porphyry B	2	5.00	66.50	2.55	17.50	3.00
Afc	Porphyry C	8	1.04	45.50	1.10	16.63	1.25

Table 1 (cont'd). Mean compositions of principal lithological units sampled by DDH KND181 and KND22, Mystery Zone, Mt. Percy.

	Lithology	N	Hf.n ppm	La.n ppm	Mn.x ppm	Nb.x ppm	Ni.x ppm
Asb	Biotite talc	8	0.50	0.94	1179.88	1.00	983.50
Ast	Talc carbonate	8	0.50	0.32	1082.38	1.00	356.13
Asc	Chlorite u/mafic	3	0.50	0.25	1202.67	1.00	1107.00
Asf	Fuchsite u/mafic	18	0.50	0.60	1001.11	1.00	879.22
Asfa	Albite fuchsite	11	0.50	0.29	1071.36	1.09	1176.82
Afa	Porphyry A	12	2.81	28.83	408.83	2.25	65.00
Afb	Porphyry B	2	3.80	63.25	724.00	5.50	59.50
Afc	Porphyry C	8	2.83	26.50	15.13	2.75	57.88

	Lithology	N	Pb.x ppm	Rb.x ppm	S.x %	Sb.n ppm	Sc.n ppm
Asb	Biotite talc	8	1.13	96.50	0.00	3.22	25.40
Ast	Talc carbonate	8	1.00	1.88	0.05	3.22	20.06
Asc	Chlorite u/mafic	3	2.00	2.33	0.04	3.80	19.93
Asf	Fuchsite u/mafic	18	10.89	43.83	0.44	6.21	19.58
Asfa	Albite fuchsite	11	1.45	49.09	0.57	5.06	20.99
Afa	Porphyry A	12	16.00	44.50	0.78	7.32	7.97
Afb	Porphyry B	2	4.50	99.50	0.20	7.35	14.40
Afc	Porphyry C	8	8.63	13.50	0.70	4.04	7.16

	Lithology	N	Sm.n ppm	Sr.x ppm	Ta.n ppm	Th.n ppm	V.x ppm
Asb	Biotite talc	8	0.81	64.88	0.41	0.25	156.25
Ast	Talc carbonate	8	0.58	128.50	0.25	0.25	120.75
Asc	Chlorite u/mafic	3	0.51	96.67	0.25	0.25	117.33
Asf	Fuchsite u/mafic	18	0.54	203.44	0.25	0.25	178.11
Asfa	Albite fuchsite	11	0.53	143.36	0.48	0.25	157.50*
Afa	Porphyry A	12	4.03	383.08	0.84	4.83	157.00
Afb	Porphyry B	2	10.50	299.50	0.25	7.70	156.00
Afc	Porphyry C	8	4.30	286.25	0.44	4.00	118.38

	Lithology	N	W.n ppm	Y.x ppm	Yb.n ppm	Zn.x ppm	Zr.x ppm
Asb	Biotite talc	8	1.00	7.13	0.77	65.38	19.75
Ast	Talc carbonate	8	1.16	4.88	0.44	59.50	11.63
Asc	Chlorite u/mafic	3	1.00	4.67	0.34	65.00	11.00
Asf	Fuchsite u/mafic	18	7.77	4.50	0.40	75.56	13.11
Asfa	Albite fuchsite	11	4.63	5.00	0.37	49.18	12.64
Afa	Porphyry A	12	21.67	5.92	0.33	48.50	127.83
Afb	Porphyry B	2	15.00	8.00	1.30	75.50	172.50
Afc	Porphyry C	8	23.88	7.38	0.29	42.38	130.13

* V data excludes roscoelite-bearing sample MW1838.

Table 2. Mean compositions of the major lithologies, DDH KND 181 and KND 22, Mystery Zone, Mt. Percy.

	Lithology	N	SiO_2%	Al_2O_3%	MgO%	CaO%	Fe.n%
As	Talc chlorite u/m	19	37.58	5.79	20.80	6.14	6.56
Asf	Fuchsite u/mafic	29	36.60	5.34	15.85	6.33	5.91
Af	Porphyry	23	60.57	12.68	4.13	3.59	2.52

	Lithology	N	TiO_2%	Na_2O ppm	K_2O ppm	LOI%	As.n ppm
As	Talc chlorite u/m	19	0.26	3353.42	5473.42	17.85	52.94
Asf	Fuchsite u/mafic	29	0.24	3615.34	15107.59	24.98	190.38
Af	Porphyry	23	0.46	52086.96	12658.48	7.87	30.27

	Lithology	N	Au.n ppb	Ba.x ppm	Ce.n ppm	Co.n ppm	Cr.n ppm
As	Talc chlorite u/m	19	5.38	13.42	1.34	89.63	2122.63
Asf	Fuchsite u/mafic	29	1065.63	223.34	1.59	87.83	1951.03
Af	Porphyry	23	1040.09	630.48	48.91	15.83	147.52

	Lithology	N	Cs.n ppm	Cu.x ppm	Eu.n ppm	Ga.x ppm	Ge.x ppm
As	Talc chlorite u/m	19	26.95	37.79	0.25	5.79	1.05
Asf	Fuchsite u/mafic	29	2.52	49.00	0.25	6.72	1.83
Af	Porphyry	23	1.87	39.65	1.14	17.22	1.61

	Lithology	N	Hf.n ppm	La.n ppm	Mn.x ppm	Nb.x ppm	Ni.x ppm
As	Talc chlorite u/m	19	0.50	0.57	1142.42	1.00	1159.89
Asf	Fuchsite u/mafic	29	0.50	0.48	1027.76	1.03	992.10
Af	Porphyry	23	2.88	30.80	449.43	2.70	63.17

	Lithology	N	Pb.x ppm	Rb.x ppm	S.x %	Sb.n ppm	Sc.n ppm
As	Talc chlorite u/m	19	1.21	41.79	0.03	3.32	22.29
Asf	Fuchsite u/mafic	29	7.31	45.83	0.49	5.78	20.12
Af	Porphyry	23	12.04	36.78	0.70	6.03	8.22

	Lithology	N	Sm.n ppm	Sr.x ppm	Ta.n ppm	Th.n ppm	V.x ppm
As	Talc chlorite u/m	19	0.66	96.68	0.32	0.25	135.16
Asf	Fuchsite u/mafic	29	0.53	180.66	0.34	0.25	298.28
Af	Porphyry	23	4.69	339.78	0.71	4.75	140.39

	Lithology	N	W.n ppm	Y.x ppm	Yb.n ppm	Zn.x ppm	Zr.x ppm
As	Talc chlorite u/m	19	1.07	5.79	0.56	62.84	14.95
Asf	Fuchsite u/mafic	29	6.58	4.69	0.39	65.55	12.93
Af	Porphyry	23	21.96	7.52	0.40	48.35	132.17

ultramafic rocks. These differences are as expected, reflecting the contrasting nature and primary mineralogy of these rocks. Among the ultramafic rocks, the fuchsitic units are enriched in K, Sr, Ba and possibly Pb and Ge compared to the talc chlorite carbonate rocks, but poorer in Mg and Cs. An apparent enrichment of V in the fuchsitic rocks is due to one sample containing 3870 ppm V, corresponding to the occurrence of roscoelite. This sample was omitted from the subdivision of the ultramafic rocks (Table 2). This subdivision shows that the biotitic unit is characterized by high K, Cs, Rb and, to a lesser extent, Al, Sc, Zr and REE contents; the abundance of K, however, is very similar to that in the fuchsitic rocks. The biotite and talc carbonate units are also more siliceous and are generally richer in Cr and Ca than the other ultramafic rocks, although the albite fuchsite rocks are the most calcic. Within the porphyries, the type B unit is quite distinctive, being relatively rich in Mg, Ca, Rb, K, Cs, Co, Cu, Mn, Zn, Sc, Ti, REE, Ge, Hf, Nb, Th and Zr and poor in Si, Na, Cr, Pb and Ta. The type A and type C porphyries are very similar, except for the much lower K_2O and Rb content and higher Na_2O contents of the type C unit.

4.2.2 *Gold mineralization*

Gold mineralization occurs principally in the fuchsitic ultramafic rocks and porphyry types A and C, with minor enrichment in porphyry B (90 ppb) and the chlorite carbonate ultramafic rocks (16 ppb) in contact with the fuchsitic rocks (Table 2). The porphyries and fuchsitic ultramafic rocks both have mean Au contents of approximately 1000 ppb, with some high grade zones (2000-13400 ppb) associated with quartz veining. The elements associated with primary mineralization appear to be S, Ag, W, As, Sb, Te and, possibly, Ba, K and Pb. These tend to be enriched in the porphyries and fuchsitic ultramafic rocks but, except for Ag and Te, for which only limited data are available, none has a very direct relationship with gold. Sulphur occurs principally in pyrite, with minor chalcopyrite, millerite and other sulphides. Silver and Te have broadly similar distributions to that of Au, and peak values of Au, Ag and Te occur together (Table 3). The Ag and Te concentrations are both in the range 0.24-19.0 ppm in the mineralized zone (i.e., higher than Au), with Ag/Au (and Te/Au) ratios mostly between 1 and 5 and Ag/Te ratios of approximately 1. The zone of W enrichment is approximately co-extensive with that of Au. Tungsten contents are markedly higher in the porphyries (means 15-24 ppm) compared to the fuchsitic rocks (means 5-7 ppm) and the other ultramafic rocks (<2 ppm). The Sb distribution is similar, but the contrasts are greatly reduced, with the mineralized rocks having a maximum enrichment factors of 1.5-2.0 compared to the biotite talc chlorite ultramafic wall rocks. The abundance of As is greater in the chlorite carbonate ultramafic rocks (205 ppm) than in either the albite fuchsite ultramafic rocks (25 ppm) or the porphyries (1-33 ppm). Thus there is an apparent dispersion halo extending about 2.5 m into the wall rock adjacent to the fuchsite-altered rocks. Arsenic is at low background abundances (<10 ppm) only in the biotite and (some) talc carbonate rocks and B-type porphyries. (The mean As content of the talc carbonate rocks is 45 ppm, contributed largely by one sample containing 317 ppm). The relationship of Ba with mineralization is a little difficult to assess, since a high background would be expected in the porphyries. However, the abundance of Ba is four- to ten-fold greater in the fuchsitic rocks compared to the other ultramafic rocks, with a very abrupt change at the contact.

Table 3. Silver, tellurium and gold contents of selected unweathered rocks, DDH KND 181, Section 15850N, Mt. Percy. (N.B. MW1838 from DDH KND22, Section 15900N).

Sample	Geology	Ag ppm	Te ppm	Au ppb
MW1770	Asb	0.05	<0.1	<5
MW1771	Asb	0.11	<0.1	<5
MW1776	Ast	0.13	<0.1	<5
MW1777	Ast	0.27	<0.1	<5
MW1778	Ast	0.16	<0.1	<5
MW1781	Ast	0.18	<0.1	<5
MW1784	Asf	0.63	0.1	140
MW1786	Afc	0.63	0.3	410
MW1791	Afc	2.82	1.5	1270
MW1794	Afc	1.26	0.5	620
MW1797	Afa	1.55	2.5	635
MW1800	Asf	0.48	0.2	77
MW1801	Asf	12.40	11.0	4240
MW1803	Afa	0.79	0.5	490
MW1804	Afa	2.98	0.2	4990
MW1806	Afa	0.90	0.3	290
MW1809	Afa	17.90	7.0	5450
MW1812	Asf	0.43	0.1	34
MW1815	Afb	0.51	0.4	150
MW1818	Asf	4.83	4.0	2090
MW1820	Asf	1.56	1.6	1240
MW1821	Asf	15.40	18.0	13400
MW1822	Asf	0.79	1.3	260
MW1824	Asf	0.23	0.3	44
MW1826	Asf	0.24	<0.1	18
MW1838	Asf	18.80	18.0	3670

4.2.3 *Lithological discrimination*

Only the principal lithological units, namely the talc chlorite carbonate rocks, the fuchsite carbonate rocks and the porphyries can be recognized with any certainty in the weathered zone and identification becomes increasingly difficult in the upper horizons. One of the objectives of the present study is to establish geochemical criteria for distinguishing between different lithologies. Successful lithological discrimination within the regolith depends strongly on the presence in the fresh rocks of distinctive concentrations or associations elements that are "immobile" or that are immobilized within resistant minerals. The most commonly used discrimination is that based on Ti/Zr ratios or Ti-Zr scattergrams, with Cr contents used to distinguish between mafic and ultramafic rocks. The Ti-Zr plot in Figure 5 shows a clear discrimination between unweathered porphyries and ultramafic rocks and indicates the distinctively high Zr and Ti contents of the B-type porphyries. Similar discrimination is possible using several other immobile elements, notably Hf (instead of Zr), Nb, REE, Ta and Th concentrated in the porphyries and possibly Cr and Sc within the ultramafic rocks. None of these is as useful as Ti and Zr, however, because their abundances are generally much lower. Discrimination based on Cr content is less likely to be satisfactory because the host minerals are chlorite and fuchsite, which are much less stable in the weathering environment than chromite, the usual host in ultramafic rocks. Thus, although Cr abundances remain high over the ultramafic rocks throughout much of the regolith, Cr is depleted in the lateritic duricusts and gravels (see section 5.2.7). The Ti-Zr plot shows a total overlap within the unweatheered ultramafic rocks and cannot be used for discrimination. Some discrimination is possible on plots between K, Ba and Zr (Figures 6 and 7) based on the contrasts described above, but there is an overlap in K contents between the biotitic and fuchsitic rocks. These elements may be of more use in the regolith, given the resistance of muscovite and barite to weathering compared to biotite. However, Ba may indicate mineralization, rather than being diagnostic of fuchsite-alteration. The inclusion of any Ba-rich porphyritic material can be recognized by a greatly increased Zr content. Of the other ore-related elements, W is probably the least mobile during weathering and has potential as a direct indicator of mineralization, whereas As and, to a lesser extent, Sb are relatively mobile during weathering.

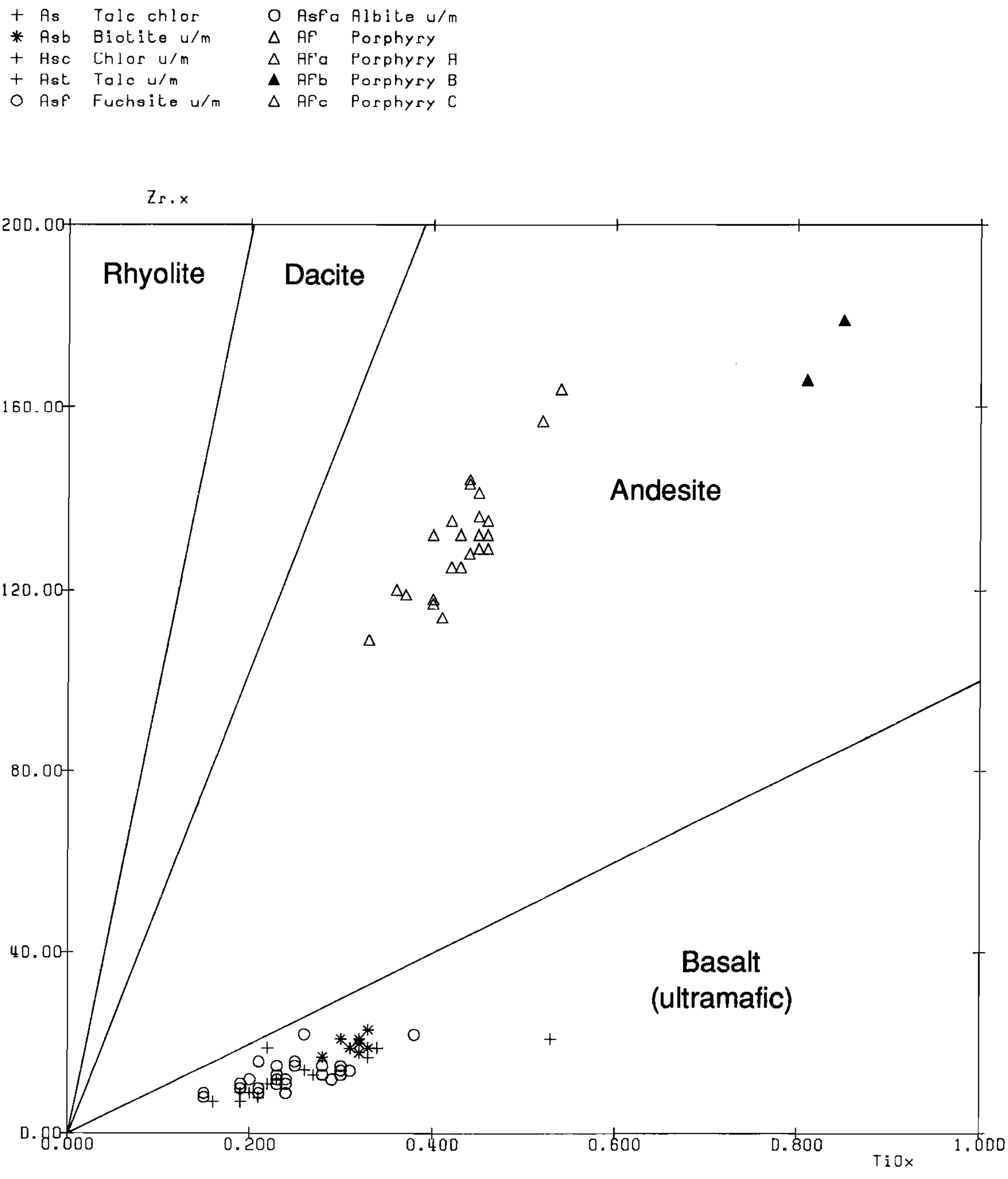


Figure 5. TiO_2-Zr plot for unweathered rocks from diamond drill core. Lithological fields from Hallberg (1984).

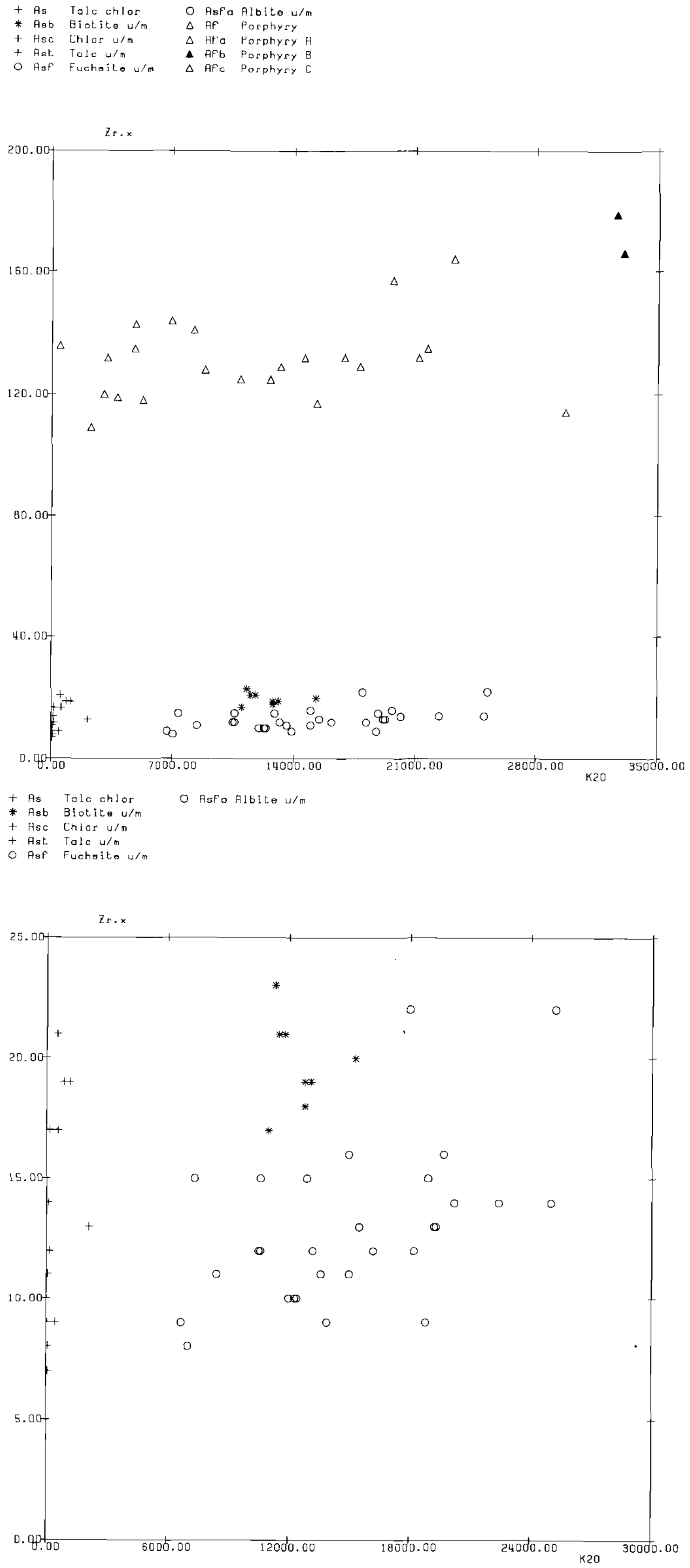


Figure 6. K_2O-Zr plot for unweathered rocks from diamond drill core, illustrating discrimination between felsic porphyries and ultramafic rocks, and between micaceous and non-micaceous ultramafic rocks.

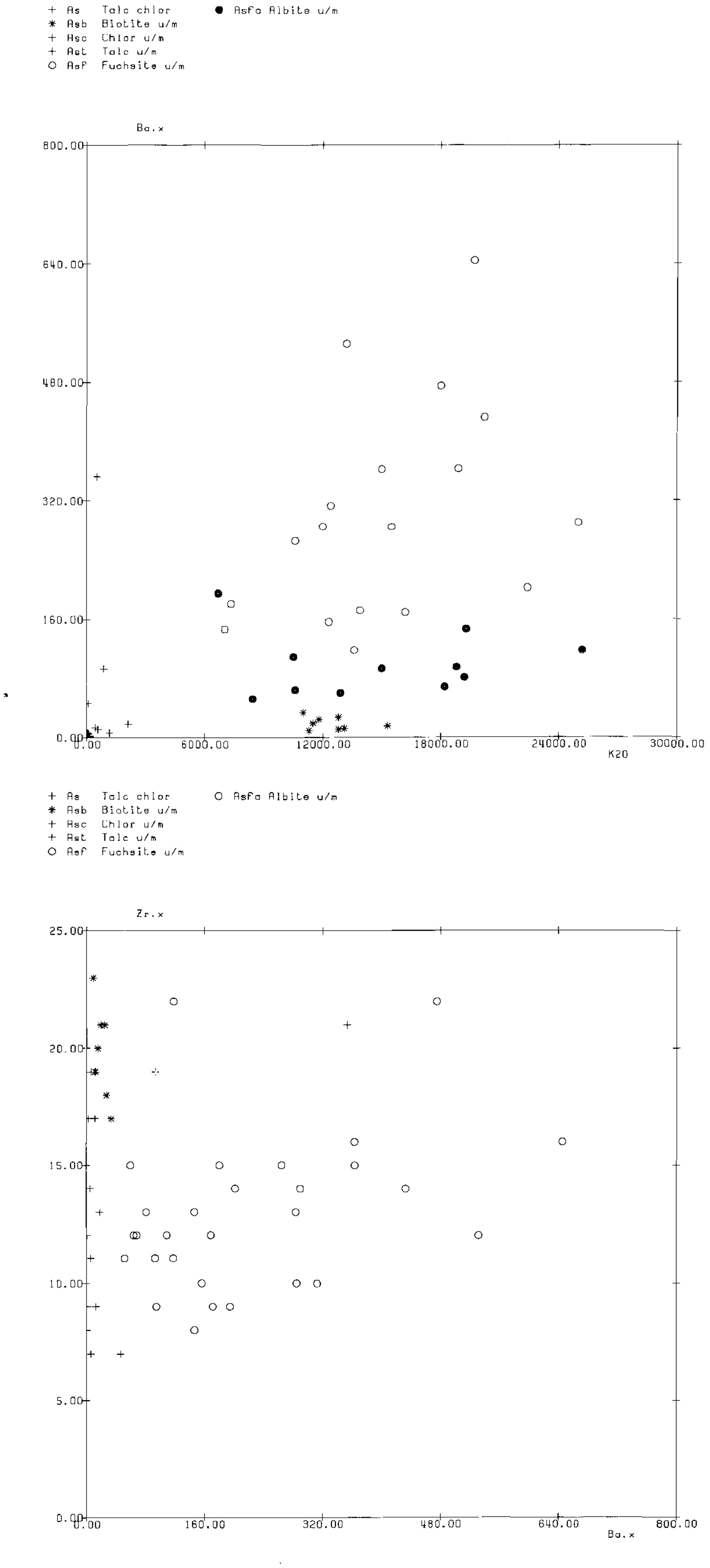


Figure 7. K_2O-Ba and Ba-Zr plots for unweathered rocks from diamond drill core illustrating partial disrimination between ultramafic rock units.

5.0 REGOLITH GEOCHEMISTRY

5.1 Regolith

Primary mineralization at Mt. Percy is overlain by an almost complete lateritic profile. Massive pisolitic cuirasse is well developed over the more ferruginous of the ultramafic units, such as the talc chlorite carbonate rocks of the Hannan's Lake Serpentinite in the western side of the Mystery pit, and these formed the higher elevations of the pre-mining landsurface. The depth of weathering is 50-60 m, with minor oxidation extending to 100 m or more along fractures. The principal regolith units present on the two sections across the Mystery Zone are shown on Figures 8 and 9 and on the element distribution plots. The regolith units have been given informal codes, defined in the text and Appendix V, for identification in some Figures, Tables and the data listings. The mineralogical changes within the profiles over the principal lithologies are shown on Figure 10.

Saprolite (Codes S, Sc, Ss). The saprolite forms a broad zone 40-50 m thick. The transition from unweathered to weathered rock (the weathering front) occurs within and beneath the deepest level sampled in the pit (i.e., below 60 m depth, RL 345-350m). The deepest rock drill samples in Section 15850N are only partly weathered: CaO concentrations of 2-5% are similar to those in the fresh rock, but it is probable that some of the sulphides have been oxidized. Accordingly, these may be classified as saprock, subject to a detailed mineralogical investigation. The saprolite becomes softer and increasingly clay-rich towards the surface (code Sc) and, as a result of settling, consolidation and the development of iron oxide segregations, the rock fabrics are destroyed and it merges with the plasmic and mottled clays at about 15 m depth. Locally, however, recognizable fabrics are preserved at depths as shallow as 3-4 m (e.g., 380-390 E, Section 15850N), where the saprolite over ultramafic rocks has been silicified (code Ss). Identification of the parent rock, at least into the three major lithological units, is possible throughout most of the saprolite and these are shown on Figures 3 and 4 and on the element distribution plots. The porphyries and fuchsitic ultramafic rocks tend to be bleached in the mid-saprolite (20-40 m), commonly emphasizing the green colour of the fuchsite; this is particularly evident along some ultramafic/porphyry contacts. Green colouration also becomes more evident towards the top of the saprolite, due to either to an originally greater abundance of fuchsite or, more probably, to the development of chromian clays during weathering. Chromium contents exceeding 1% are present over the talc chlorite ultramafic rocks, contained mainly in kaolinite. Use of the terms upper saprolite, mid saprolite and lower saprolite in the text is only descriptive; they are not formally defined.

Mottled and plasmic clay zone (Codes M, Mc and C). This zone is transitional between the saprolite and the lateritic duricrust and gravels. It consists of pale green-grey clays and silty clays, strongly coloured by secondary iron oxides. In the plasmic clays (code C), the iron oxides are present as diffuse impregnations throughout the matrix, whereas in the mottled clay (code Mc), they occur as secondary structures such as pisoliths and highly irregular nodules and aggregates.

Lateritic duricrust, cuirasse and gravels (Codes L, Lk, Lks). These were present as an almost continuous horizon over the deposit. It varied in thickness from about 5 m over the talc chlorite ultramafic rocks (e.g., 320 E, Section 15850N) to less than 1 m thick over some porphyries and fuchsitic ultramafic rocks, 70-80 m downslope to the east. The lateritic materials are pisolitic, nodular or, more rarely, vermiform, either strongly Fe oxide-cemented as the large cuirasse blocks over the talc chlorite rocks, or more weakly cemented as duricrusts and friable gravels elsewhere. Nodules, coatings and channel fillings of calcrete are common in the lateritic horizon

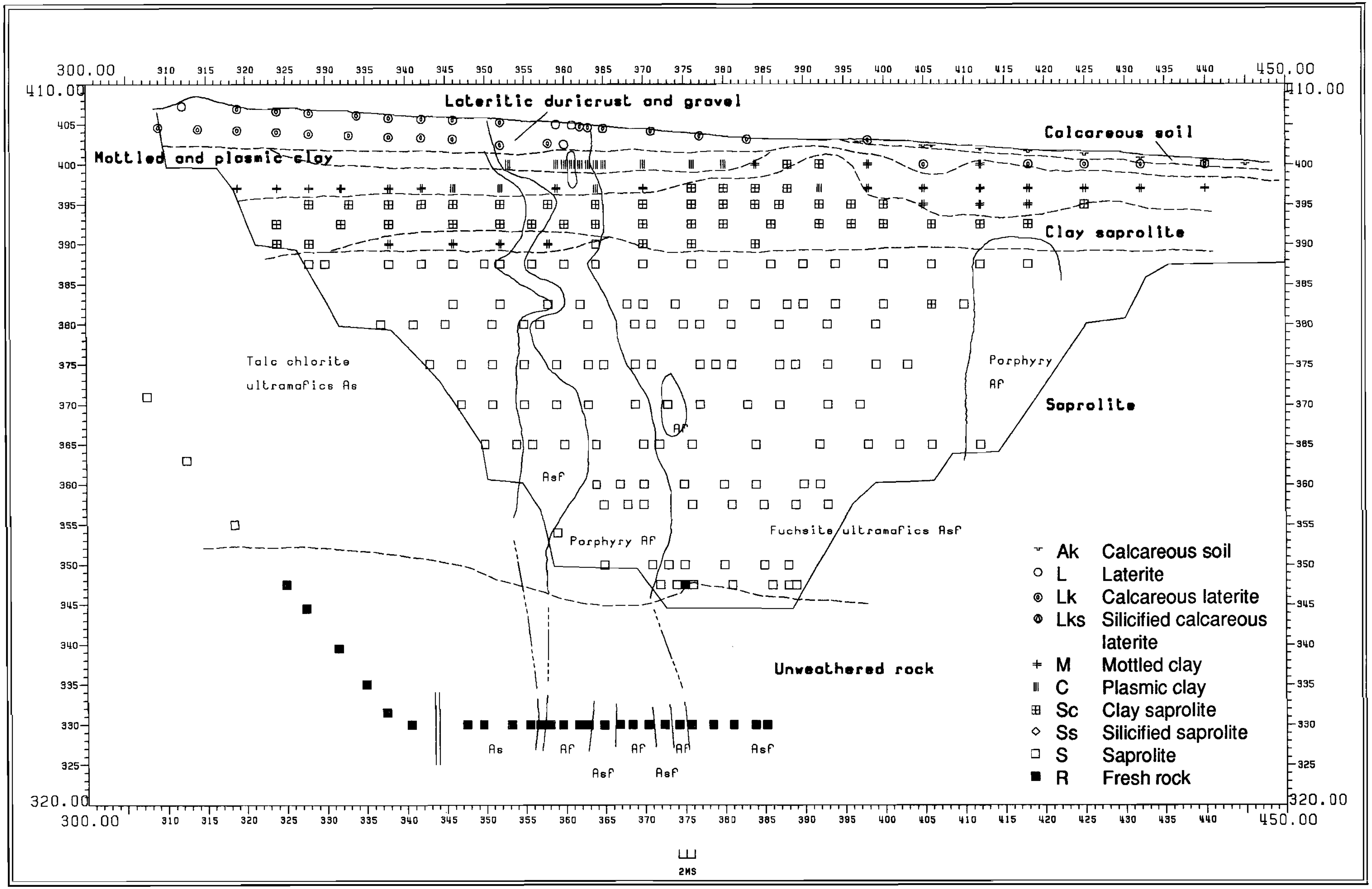


Figure 8. Main regolith horizons, Section 15850N, Mystery Zone, with geology superimposed. (N.B. Diamond drill core samples below RL 330 m are projected to 330 m).

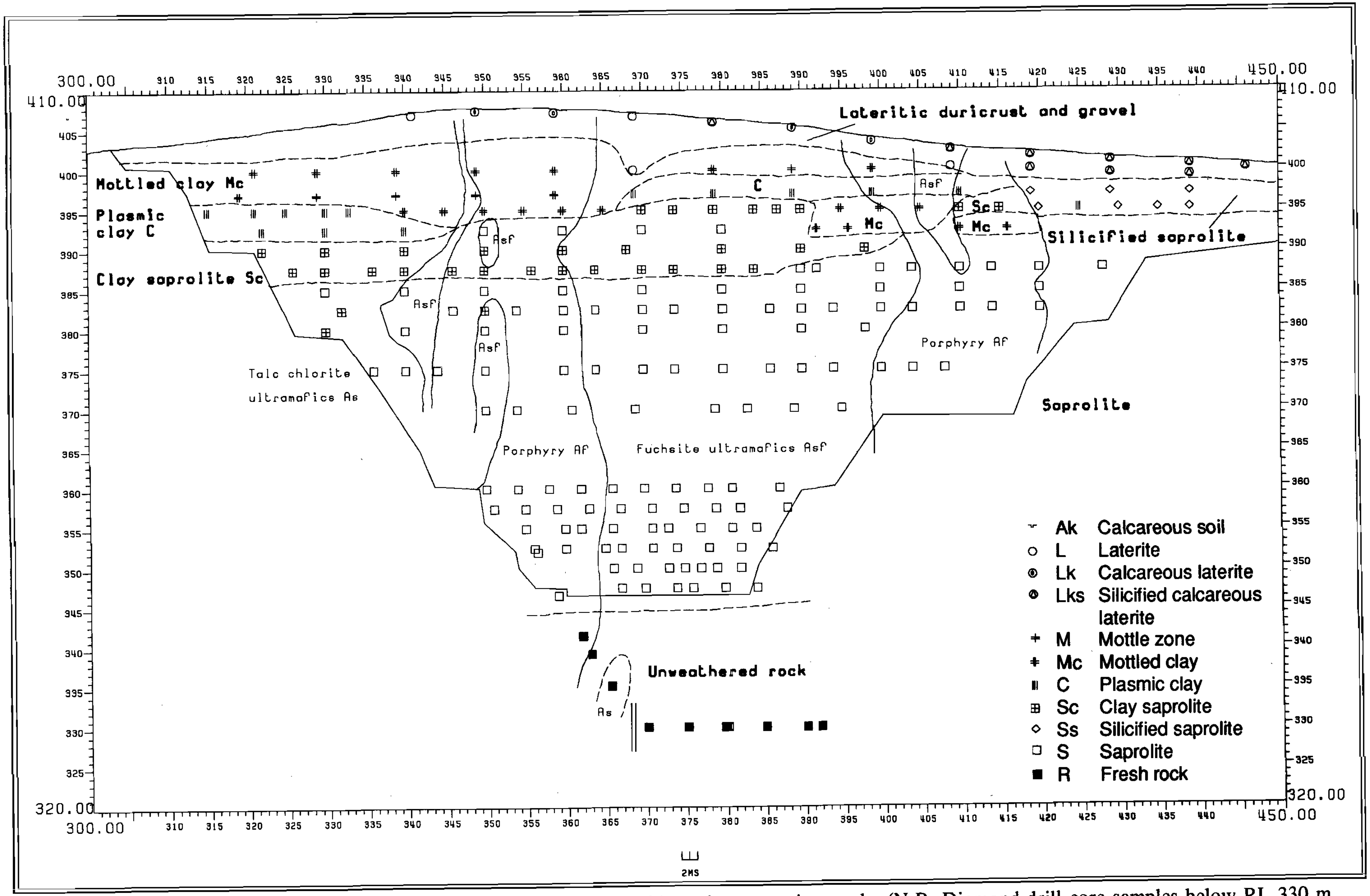


Figure 9. Main regolith horizons, Section 15900N, Mystery Zone, with geology superimposed. (N.B. Diamond drill core samples below RL 330 m are projected to 330 m).

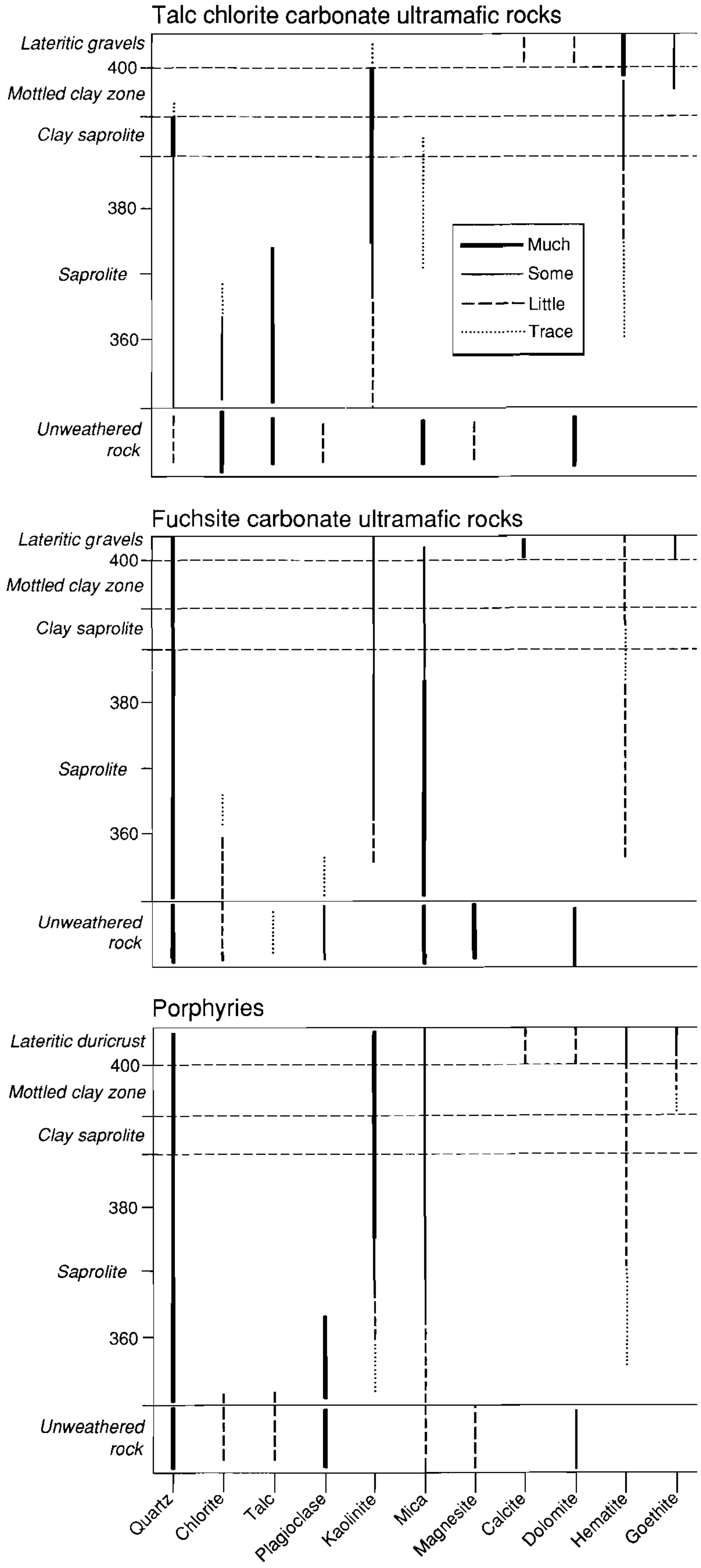


Figure 10. Mineralogy of the main regolith horizons over the three principal lithological units.

(code Lk), particularly in the upper, more friable material where it merges with the soil. Some lateritic materials over fuchsitic ultramafic rocks are also silicified (code Lks). Some samples of calcareous soil and lateritic gravel contain 20-35wt% $CaCO_3$. It is probable that the development of the calcrete contributes to the destruction of the lateritic horizon and the development of the soil both physically, by the crystal growth that accompanies precipitation of the carbonate, and chemically, by replacing pre-existing minerals.

Soil (Code Ak). A thin cover of red-brown loamy soil, containing abundant lateritic nodules and pisoliths, was present over most of the Mystery Zone, although boulders of lateritic cuirasse outcropped in places. The soil was calcareous, with fine grained calcium carbonate dispersed in the matrix and also present as calcrete nodules, fracture fillings, rhizomorphs and coatings.

5.2 Geochemistry

The element distributions are shown as symbol plots in Appendix I (Section 15850N) and Appendix II (Section 15900N). The plotting intervals were selected on the basis of the principal populations evident in the histograms and cumulative frequency graphs of the whole data set shown on Figures IV/1 to IV/10, Appendix IV. The log transformed data for each element are given in full in the histograms in Figures IV/1 to IV/5, whereas the histograms on Figure IV/6 to IV/10 are based on a trimmed set of untransformed data to show greater detail. Different aspects of the distributions of some elements (e.g., S) are shown by emphasizing different populations, and for these two symbol plots are included. Elements having similar geochemical affinities are described together. Comparative statistical data for each group of elements in the main regolith horizons over the principal lithological units are given in Tables IV/3 to IV/9, Appendix IV.

5.2.1 *Major elements: Fe, Si, Al*

These elements are commonly the principal residual products of deep chemical weathering, occurring as the oxides (e.g., goethite, hematite, gibbsite, quartz, hyalite) or as aluminosilicates (kaolinite, halloysite, allophane). Each is strongly enriched in the lower to mid saprolite, commonly by factors of two or more, due to residual concentration following the leaching of other components, particularly Mg and Ca. Remobilization and further concentration, probably in part absolute, takes place in some upper horizons. Due to closure, their abundances and distributions are generally inter-dependent. Comparative statistical data for these elements in the main regolith horizons over the principal lithological units are given in Table IV/3, Appendix IV.

Iron is present predominantly in ferromagnesian minerals in the unweathered rocks, with minor amounts in the sulphides associated with gold mineralization. Iron is strongly enriched towards the top of the regolith over all lithologies, being concentrated in the mottled zone and, particularly, the lateritic duricrust. In the upper saprolite and overlying horizons, it occurs initially as diffuse stains of secondary Fe oxides and subsequently as discrete segregations such as nodules, pisoliths, veins and void coatings; these consist predominantly of goethite and hematite, with some maghemite. The lower Fe content of the porphyries (means 2.3-4.4% Fe) compared to that of the ultramafic rocks (6.0-6.7%) is discernible throughout the regolith, and appears to be retained even in the duricrust. The highest concentrations occur over the talc chlorite rocks, with maximum values of 70-75% Fe_2O_3 (mean 45% Fe) in the massive boulder cuirasse (pisolitic duricrust) that formed the high ground on the western margin of the pit at 15850N. This cuirasse was similarly developed on 15900N but was not sampled. However, the underlying mottled zone is enriched in Fe oxides. The duricrust over the other lithologies is less indurated and less ferruginous (e.g., means 24 to 41%), even though the parent materials for much of it are fuchsitic ultramafic rocks that have mean contents of 6.0% Fe, only marginally lower than that of the talc chlorite rocks (6.5% Fe). The lower Fe abundances in the duricrusts are due in part to dilution by calcite and minor dolomite (as calcrete), silica (as silcrete) and kaolinite. The difference in the composition and physical nature of the lateritic duricrusts is probably related to the different porosities of the regoliths from which they have been derived. The massive Fe-rich cuirasse is developed over dense impervious clays whereas the more friable duricrusts overlie mica-rich clays, locally silicified, with a silty, porous texture. Because of their weaker cementation and open fabric, these friable duricrusts became suitable sites for calcrete precipitation which, by crystal growth, gradually fragmented them and left them more prone to erosion than the massive duricrusts.

Silica occurs principally as ferromagnesian- and alumino-silicate minerals in the unweathered rocks. Quartz is an important component of most lithologies present, including ultramafic rocks, in which it occurs as an alteration product; there are also numerous quartz veins associated with gold mineralization. The higher silica content of the porphyries is evident in the lower saprolite but becomes much less apparent above about RL 350 (50-57 m depth) and the differential tends to be reversed in the upper saprolite and overlying horizons. Some of the highest silica contents (70-85% SiO_2) are due to the presence of quartz veins but others are due to the silicification of weathered fuchsitic rocks. This takes the form of a weak, pervasive cementation of the rather porous clays of the upper saprolite, the precipitation of quartz in veins and voids or the development of massive silcrete, commonly with partial preservation of the lithic fabric. Some of the silcrete outcropped (e.g., at 430 to 440 E on Section 15900N) or was incorporated in the duricrust. Silicification, particularly as silcretes, of weathered ultramafic rocks in the Yilgarn Block and other deeply weathered terrains is particularly characteristic of dunites (e.g., Smith, 1977; Butt and Nickel, 1981), presumably because, in the absence of Al, the silica cannot form kaolinite. Rocks of possible dunitic composition have been recognized in unweathered drill core from DDH KND181 as the B zone of komatiitic flows, but the fabrics are generally poorly preserved and not readily identified in the upper horizons of the regolith. Apart from where there was outcropping silcrete, however, the silica content of the soils and duricrust is generally low (<30% SiO_2), due to the precipitation of, and possible replacement by, Fe oxides and pedogenic carbonates.

Aluminium is present in alumino-silicate minerals (e.g., feldspars, mica, talc) in the unweathered rocks, with higher concentrations in the porphyries (12.7% Al_2O_3) than the ultramafic rocks (5.5% Al_2O_3). It is enriched throughout the regolith compared to the bedrock, particularly over the ultramafic rocks. The higher Al content of the porphyries is reflected by strong kaolinization in the lower to mid saprolite but the distinction between the lithologies is lost in the upper saprolite, plasmic horizon and mottled zones. These horizons are all very clay-rich, particularly over the talc chlorite ultramafic rocks, and have mean Al_2O_3 contents of 18-22.5 wt%. The high concentrations overlying the ultramafic rocks are a little unusual, given the low initial abundance. They are probably largely residual, due to the loss of other components and settling and compaction of the clays, but there may be some absolute enrichment as a result of the release of Al as the clays are replaced and destroyed during the precipitation of Fe oxides and the formation of the lateritic duricrust. The Al_2O_3 content of the duricrusts is relatively low, being consistent with most Al being present as aluminous hematite or goethite rather than kaolinite.

5.2.2 *Alkaline earth elements: Mg, Ca, Sr, Ba*

Comparative statistical data for these elements in the main regolith horizons over the principal lithological units are given in Table IV/3, Appendix IV. Magnesium, Ca and Sr have a number of similarities in their weathering behaviour, namely that they are strongly leached at the onset of weathering and almost totally depleted from some horizons of the regolith, but are re-concentrated at or close to the surface as pedogenic calcrete. Barium behaves somewhat differently, being relatively enriched through most of the regolith, possibly being leached only very close to the surface; it reprecipitates as the sulphate (barite) rather than as a carbonate and so does not occur solely with the carbonates in the calcrete-bearing horizons. The downslope increase in the abundance of the calcretes is probably more a function of the greater porosity and friability of the host horizon than of lateral dispersion. The distribution of the alkaline earth elements throughout the regolith at Mt. Percy, particularly Ca, is characteristic of the region. It has particular significance given the association between carbonate alteration and mineralization in many Archaean Au deposits and the enrichment of gold in horizons containing pedogenic carbonate. Calcrete precipitation is also an important feature of the evolution of these regoliths since it is probably one of the principal processes capable of destroying lateritic duricrust, by either displacement or replacement of pre-existing minerals and cements.

Magnesium is abundant (means 15.8-20.8% MgO) in fresh ultramafic rocks, occurring predominantly as magnesite and dolomite, with lesser amounts in ferromagnesian silicates (e.g., chlorite, talc, biotite, amphobole); the abundance in the porphyries is much less (4.1% MgO), as dolomite, rare magnesite and rare ferromagnesian minerals. The carbonate minerals are the most susceptible to weathering, so that there is a marked reduction in MgO content in the lowest horizon of the saprolite. However, concentrations above 5% MgO are present at higher levels in some saprolite over ultramafic rocks, particularly the talc carbonates, due to the stability of talc and some other ferromagnesian minerals (e.g., hornblende) and, in places, the precipitation of secondary magnesite. Magnesium is strongly leached from the upper horizons of the regolith, with concentrations as low as 0.01-0.50% MgO in the clay-rich upper saprolite, plasmic horizon and mottled zone over all lithologies, but again particularly over the talc chlorite ultramafic rocks. Minor concentrations of Mg (mostly 0.8-2.0% MgO) are present in the lateritic duricrusts and gravelly soils, occurring as dolomite precipitated, with calcite, as pedogenic calcrete.

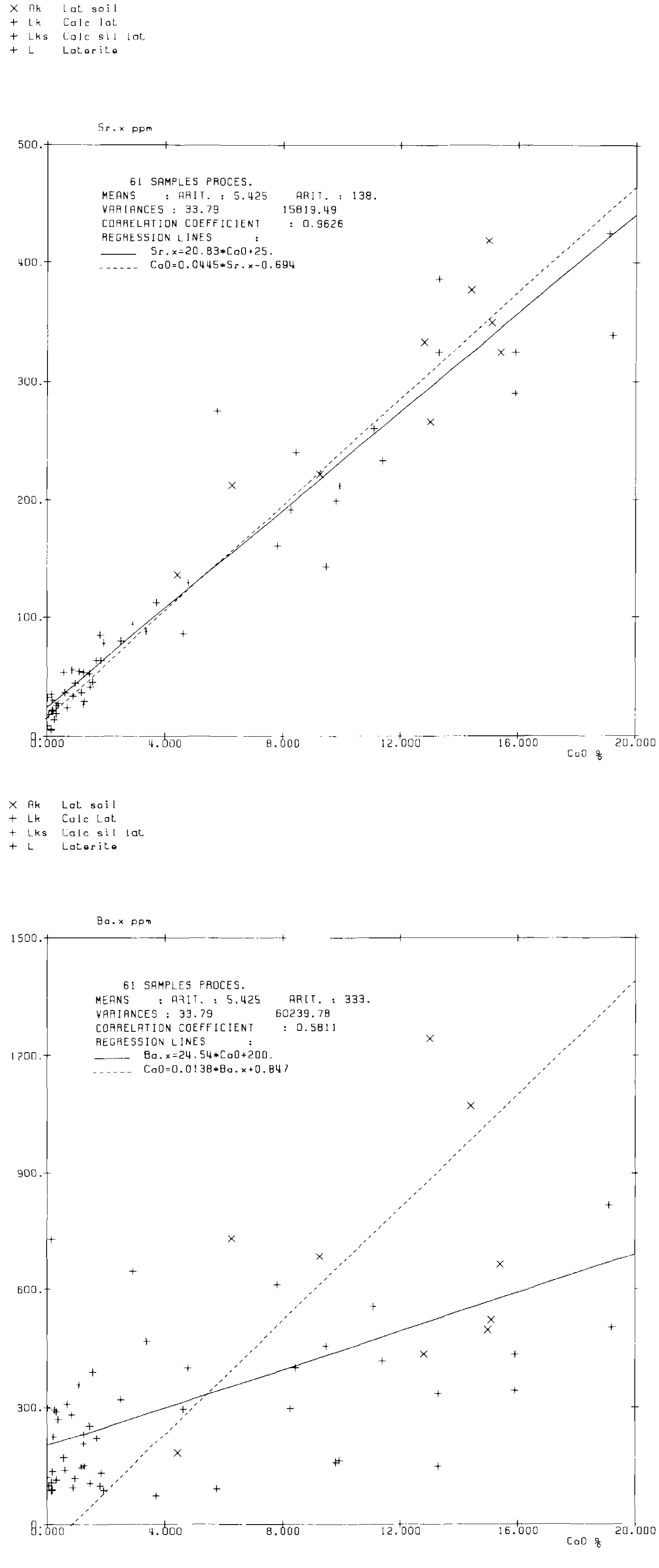
Calcium is hosted predominantly by dolomite and is enriched in the ultramafic rocks (mean 6.3% CaO) relative to the porphyries (3.6% CaO). In consequence, Ca is leached more strongly than Mg, which is present also in more resistant ferromagnesian minerals and is at concentrations below 0.1% CaO throughout much of the regolith, from RL 350 (50-57 m depth) to within 5 m of the surface. At the surface, however, Ca is precipitated in pedogenic calcretes, as calcite and, less commonly, dolomite, at concentrations of up to 10-19% CaO (18-34% $CaCO_3$). The calcretes occur as coatings on blocks and cobbles of cuirasse and silcrete, as rhizoconcretions (root casts), pendants, nodules and irregular masses, and as a friable matrix to lateritic gravels. These may be void infillings, or have displaced or replaced pre-existing material. The association between gold and pedogenic Ca carbonate is discussed in section 6.2.2. Gypsum is present as a trace to minor constituent in some surface materials; it is suspected to be aeolian in origin.

Strontium. The host minerals for Sr in the unweathered rocks have not been determined, but the associations with Ca and Ba suggest that Sr is present in dolomite and, in the porphyries, in feldspar. Similar to Ba, but in contrast to Ca and Mg, the Sr contents of the porphyries (means 285-385 ppm) are greater than in the fuchsitic (205 ppm) and talc chlorite carbonate (65-130 ppm) ultramafic rocks. In the regolith, Sr has a distribution pattern broadly similar to that of Ca. Like Ca, it is strongly leached even from the lowest horizon of the regolith developed on ultramafic rocks. Concentrations of less than 10 ppm Sr occur throughout the saprolite to mottled zones over talc chlorite rocks and in the lower saprolite of the fuchsite rocks, increasing to 10-40 ppm in the latter from the mid to upper saprolite. Over the porphyries, however, Sr is retained at concentrations of 200-300 ppm in the lower saprolite, although Ca is strongly leached at this level. The persistance of Sr corresponds to the presence of albite, which is more resistant to weathering than dolomite. Above RL 360 (45-47 m depth), Sr contents sharply decrease and remain less than 40 ppm almost to the surface. Strontium is strongly enriched with Ca and Mg in the pedogenic calcrete precipitated in the soils and lateritic duricrust, with maximum concentrations of 200-400 ppm. There is a very strong correlation ($r=0.96$) between Sr and Ca in the calcareous surface horizons (Figure 11) in which Sr probably occurs as a substitute for Ca in calcite; strontianite may be present but has not been observed.

Barium. Barium is strongly enriched in the B type porphyries (mean 1475 ppm), with lesser amounts in the A and C types (means 630 and 370 ppm). Moderate abundances are associated with the fuchsitic ultramafic rocks (mean 265 ppm) but it is only a trace constituent of the talc chlorite carbonate ultramafic rocks (mean <15 ppm). The probable host minerals are feldspar (albite) and barite. The differences in Ba contents of the principal lithologies is maintained almost throughout the regolith and is lost only in the lateritic duricrust. Initial inspection of the data from traverse 15850N suggests that Ba is indicating the location of weathered primary Au mineralization within the regolith; however, in Section 15900N, it is evident that the high Ba concentrations are related to the porphyry, for primary mineralization here occurs mainly in the fuchsitic ultramafic rocks. Concentrations are generally slightly enriched, probably relatively, in the saprolite compared to the parent rocks, particularly over the talc chlorite ultamafic rocks. High Ba concentrations (>1000-1715 ppm) are present in weathered porphyries except in the duricrust, where it declines to 250-500 ppm. Barium is probably present principally as barite in the regolith and traces of barite were seen by SEM in the heavy mineral fraction of duricrust samples. There is no noticeable change in Ba abundance above RL 360, where albite is replaced by kaolinite, implying that, as it is released from albite, it is immediately reprecipitated as barite. Apart from over the porphyries, Ba appears to be enriched with the other alkaline earths in pedogenic calcretes in the soils and the surface horizon of the duricrust. However, unlike Mg and, in particular, Sr, there is no close relationship between Ba and Ca (Figure 11), and Ba is not preferentially enriched in the carbonates in comparison to the ferruginous fraction. This is probably because it is present as barite, rather than as a carbonate or substituting for Ca.

5.2.3 *Elements associated with mineralization: Au, S, Sb, As, W, Ag, Te*

Comparative statistical data for these elements in the main regolith horizons over the principal lithological units are given in Table IV/4, Appendix IV. Primary gold mineralization is associated with the fuchsite-carbonate alteration of the ultramafic rocks and the porphyries which intrude them. The alteration zone is typically pyritic, and in



```
     61 SAMPLES PROCES.
MEANS     : ARIT. : 5.425    ARIT. : 138.
VARIANCES : 33.79            15819.49
CORRELATION COEFFICIENT     : 0.9626
REGRESSION LINES         :
______   Sr.x=20.83*CaO+25.
------   CaO=0.0445*Sr.x-0.694
```

```
     61 SAMPLES PROCES.
MEANS     : ARIT. : 5.425    ARIT. : 333.
VARIANCES : 33.79            60239.78
CORRELATION COEFFICIENT     : 0.5811
REGRESSION LINES         :
______   Ba.x=24.54*CaO+200.
------   CaO=0.0138*Ba.x+0.847
```

Figure 11. CaO-Sr and CaO-Ba plots for samples containing pedogenic carbonates.

addition to gold, is characterized by high abundances of S, Sb, As, Ag, Te and W. There is, however, no close correlation between gold and these elements within the alteration zone itself. Each of these elements behaves differently during weathering and has a distinctive dispersion pattern.

Gold. The distribution of gold in the regolith on both sections is characteristic of many deposits in the region. The distribution is typically patchy, even at the close (relative to exploration) sampling interval used in the study. This presumably reflects inhomogeneities in the occurrence of both primary gold and secondarily dispersed gold, as well the variable presence of coarse particulate gold. The principal features of the distribution patterns are as follows.

1. There is a widespread zone of gold enrichment close to the surface, within the lateritic duricrust and the overlying soil. Not all the gold is associated with the ferruginous material; a significant proportion is present in the pedogenic calcrete, which constitutes over 20% of some samples. The samples with the highest gold contents are generally the most calcareous. Analyses of the ferruginous and calcareous fractions of lateritic soils and gravels (Table 4) show that both components have high Au contents. The Fe oxides and the calcrete are very finely divided so that complete separation was not possible. However, it appears that Au does not consistently favour either component, which suggests that the concentration is related to by the environment rather than with to a specific mineral host. In one sample (MW0080), the ferruginous fraction is particularly Au-rich, but this is probably due to an isolated grain of free gold. These results are consistent with findings elsewhere in the southern Yilgarn Block, namely that pedogenic calcrete horizons are an important site for Au enrichment (Lintern, 1989). Neither these geochemical data, nor the results of panning (Gedeon and Butt, 1990), provide any evidence for the enrichments of gold sought by the early prospectors at the base of the lateritic duricrusts and gravels. It is not known whether the gold in these enrichments, or that recovered by dry blowing, was primary or secondary.

2. A leached and depleted zone (mostly < 100 ppb Au), 5 - 10 m thick is present just beneath the lateritic duricrust and gravels (below about 2-4 m). This corresponds approximately to the upper, clay-rich zones of the regolith, i.e., the mottled and plasmic zones and some upper saprolite; it also coincides with the zone of Br concentration. Sporadic samples rich in Au indicate the occurrence of quartz veins in which gold has been protected from weathering.

3. Possible supergene enrichment is present in a zone 10 - 15 m thick from a depth of about 17 m. The distribution suggests some homogenization and dispersion within the weathered porphyry and fuchsitic ultramafic rocks. The maximum enrichment is coincident with the presence of alunite (as indicated by the S distribution) in the upper saprolite but the gold is much more widespread.

4. There is only minor lateral dispersion of gold below about 30 m depth in the regolith. Although much of the gold is secondary, it appears to have remained within or close to the original host unit.

Table 4. Compositions of whole samples and hand-separated ferruginous and calcareous fractions of lateritic soils and gravels, Mystery Zone, Mt. Percy.

Sample	Au	Fe	CaO	SiO_2	Al_2O_3	MgO	Sr	Ba	Sb	As	W
	ppb	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm
MW0040											
Whole	1310	11.6	6.2	48.0	11.7	1.09	215	730	3.9	27	6.1
Ferruginous	2550	30.4	4.32	28.5	10.9	0.60	150	1245	7.3	40	20.0
Calcareous	2490	4.7	17.3	45.2	8.0	1.85	625	540	1.9	14	2.2
MW0080											
Whole	4560	22.0	11.9	27.8	9.5	0.83	225	390	4.9	51	19.0
Ferruginous	21300	40.5	0.3	19.5	8.3	0.38	20	395	8.4	83	31.0
Calcareous	3040	4.9	26.1	33.4	7.0	1.512	490	255	1.5	22	3.9
MW0100											
Whole	2730	28.7	2.8	23.0	15.3	0.61	85	630	8.9	120	25.0
Ferruginous	4690	42.9	0.35	8.8	10.6	0.28	35	480	13.0	170	45.0
Calcareous	2140	10.3	14.5	34.2	11.5	1.37	295	450	3.8	55	9.0
MW0115											
Whole	1410	10.5	18.7	30.8	9.4	0.87	345	620	5.1	51	8.2
Ferruginous	650	31.2	7.4	19.4	10.2	0.40	145	645	8.1	99	7.0
Calcareous	1380	8.4	19.7	32.5	9.2	0.99	360	350	4.6	47	6.5

Most of the gold in the regolith is presumed to be secondary, on the basis of its morphology and composition (Gedeon and Butt, 1990). Silver-bearing grains and gold tellurides were recovered from the lower saprolite (below RL 355), in one sample almost in equal numbers with Ag-poor grains; the shallowest sample with a Ag-rich grain was from 17 m, had probably been preserved in vein quartz. All grains above this level were of Ag-poor gold.

Sulphur. Sulphur in the unweathered, mineralized porphyries and fuchsitic ultramafic rocks is present mainly in pyrite; arsenopyrite, chalcopyrite, galena, millerite, pyrrhotite and barite occur as accessory minerals. The sulphide minerals appear to be the most susceptible to weathering, possibly more so than the carbonates, and S contents are generally less than 0.125% throughout the lower to mid-saprolite. However, in the upper saprolite, there is a zone of pronounced S enrichment, with maximum concentrations of 1.0 - >5.0%. The lower boundary of this S-rich zone is quite sharply defined and corresponds most closely to the appearance of clay-rich saprolite. The S probably occurs principally as alunite (potassium aluminium sulphate), although other S species, such as barite and gypsum, may also be present. The zone of S (or alunite) enrichment seems to be confined mainly to the weathered fuchsitic ultramafic rocks and concentrations decline sharply over the porphyries and talc chlorite ultramafic rocks. Nevertheless, the clay-rich saprolites derived from the latter are S-rich compared to overlying and underlying horizons. The alunite zone appears to overlie primary mineralization but the relationship between this secondary S enrichment and the underlying sulphides is uncertain. The relationship between the alunite and the secondary gold mineralization is also unclear. The alunite zone is partly coincident with the centre of the poorly-defined supergene enrichment of gold in the upper saprolite. However, Au is present below the alunite zone and, conversely, alunite extends above the zone of Au enrichment into the mottled and plasmic clays which are leached and depleted in gold. Some secondary gold grains recovered from this part of the profile are embedded in alunite (Gedeon and Butt (1990), Figures 18 and 19) and it is thus presumed that, at least in part, alunite precipitation post-dates that of Au.

Sulphur contents of the lateritic duricrust are commonly <0.125%, but a few samples contain 0.5-1.0%. Gypsum was observed in the duricrust prior to mining and is the probable host mineral. Some S is also present as barite.

Antimony. The mean Sb content of the primary mineralization is 6 ppm in both the porphyries and the fuchsitic ultramafic rocks, compared to 3 ppm in the talc chlorite ultramafic rocks. Apart from isolated maxima of 17 and 34 ppm in two of the most Au-rich samples (13.4 and 5.5 ppm Au respectively), there is little variation in the abundance of Sb and there is no direct correlation with the distribution of gold. The Sb content of regolith materials is generally greater than that of the unweathered rocks, particularly over the fuchsitic ultramafic rocks. An increase to 10-16 ppm Sb is apparent even at the lowest level studied in the pit (RL 345-360) in both sections. This increase is coincident with the trend of weathered Au mineralization, with little lateral spread. Higher in the regolith, however, Sb becomes more widely dispersed and increases further in concentration. The highest mean Sb contents (10-20 ppm, with maxima of 20-30 ppm) occur in the most clay-rich horizons, i.e the zone leached and depleted in gold. Although this widespread dispersion and enrichment in Sb is probably secondary, sporadic maxima >50 ppm probably relate to the occurrence of quartz veins; the sample with the peak concentration (285 ppm Sb) also contains 32 ppm Mo and 110 ppm Cu. Other Sb-rich samples are also enriched in W. In contrast, the Sb contents of the duricrust and soils are broadly similar to those of the unweathered rocks (< 10 ppm) and Sb is concentrated in the ferruginous fraction (Table 4). High values are present in the duricrusts overlying the talc chlorite ultramafic rocks. These duricrusts are enriched in a number of other, mostly "immobile", elements and are discussed further below.

Arsenic. Primary mineralization is characterized by moderate enrichment in As, with mean concentrations of 30 ppm in the porphyries and 185 ppm in the fuchsitic ultramafic rocks. Some, but not all, of the highest concentrations occur adjacent to lithological contacts and As enrichment extends beyond other alteration effects associated with mineralization into the talc chlorite ultramafic wallrocks. The As content increases from a background of 1-5 ppm in the talc chlorite rocks to over 250 ppm within 2.5m of the contact with the fuchsite-altered rocks. There is, however, no particular association with gold. Like Sb, As has restricted dispersion in the lower part of the regolith but becomes more widely dispersed in the upper saprolite. However, this dispersion appears to be less homogeneous than that for Sb and there is much less overall enrichment. Peak As contents (>300 ppm) in any horizon generally occur in the more ferruginous samples. Arsenic has been leached from the clay-rich and mottled horizons of the regolith but, unlike Au, some high As values are retained, particularly in Fe-rich materials, on the presumed projection of primary mineralization at this level. The lateritic duricrusts and soils have As contents similar to or slightly lower than that of the primary mineralization, with some lateral dispersion, particularly over the talc chlorite ultramafic rocks. Arsenic is preferentially concentrated in the ferruginous fraction (Table 4).

Tungsten. Tungsten is consistently enriched throughout the primary mineralization, particularly on 15850N, with concentrations of 18-28 ppm over the porphyries and 4-10 ppm in the fuchsitic ultramafic rocks, compared to <2 ppm in the unmineralized talc chlorite ultramafic rocks. Tungsten is probably present as scheelite, although this was not identified in heavy mineral concentrates. The abundance of W is slightly greater in the regolith, particularly over the ultramafic rocks, and the distribution is generally more homogeneous, suggesting some dispersion during weathering. Such dispersion is most evident in the clay-rich horizon over the talc chlorite ultramafic rocks on 15850N, which contains 5-15 ppm W up to 20 m from the contact with the fuchsitic rocks and the porphyry. The W distribution is less homogeneous on Section 15900N, which is characterized by a number of sporadic high values (>40 ppm W), particularly close to porphyry-fuchsite ultramafic contacts (e.g., 400-420 E, RL 380-400), and within the fuchsitic ultramafic rocks at 370E (RL 380-405). Some of the W-rich samples (60-100 ppm W) have high concentrations of one or more other elements (Sb, Au, Cu) but, in the majority, W is the only anomalous ore-associated element.

An important feature of the W distribution is its retention in the lateritic duricrusts and soils, in which it is present within the ferruginous fraction (Table 4). Tungsten thus gives a widespread surface anomaly, broadly coincident with that of gold. The duricrusts over the talc chlorite ultramafic rocks are strongly enriched in W (25-60 ppm), especially on Section 15850N, extending the lateral dispersion evident in the underlying mottled clays. These duricrusts are enriched in a number of other, mostly "immobile", elements and are discussed further below. Over the porphyries and fuchsitic ultramafic rocks, however, the W contents are similar to those of the underlying regolith; this implies some mobility and loss of W, for if it were immobile, some residual enrichment would be expected.

The possibility that W is a contaminant due to abrasion of tungsten carbide-faced tools during ripping, drilling and preparation for analysis has been discounted. Independently-collected samples from the duricrust and saprolite have similar W contents (range 7-40 ppm) to near-by grade-control samples, and the unweathered rocks were sampled by diamond drilling. The cleaning and crushing equipment contained no tungsten carbide.

Silver and *Tellurium*. The Ag and Te contents of the mineralized zone are both in the range 0.24-19.0 ppm (i.e., higher than Au) with Ag/Au (and Te/Au) ratios mostly between 1 and 5, and Ag/Te ratios of approximately 1. From limited data on Section 15850N (Table 5), it appears that these relative abundances are maintained in the lower saprolite, below RL 360, implying that there has been little or no remobilization of any of these elements. Above RL 360, however, there is some preferential loss initially of Ag and, above RL 380, of Te. Complex mixed grains of Au, Ag and/or Te, both elemental and as chlorides and bromides, were found in concentrates at RL 357.5 (Gedeon and Butt, 1990), possibly marking the onset of substantial secondary mobilization. (N.B. RL 360 is the level at which the rock hardness increases, necessitating a change in sampling procedure from ripping to drilling.) The abundances of Ag and Te are both below detection limit from R.L 380 to the surface (Ag <0.4 ppm, Te <0.1 ppm; 18 samples), although it is possible that they may be preserved locally in vein quartz in this upper part of the regolith.

5.2.4 *Alkali metals: Na, K, Rb, Cs*

Comparative statistical data for these elements in the main regolith horizons over the principal lithological units are given in Table IV/5, Appendix IV. Only incomplete data sets are available for Na and K. All samples were analysed for Na by XRF on pressed powders, but results above about 4% are unreliable. More reliable data for these metals were obtained for the diamond drill core and samples from Section 15900N by analysis by AAS after fusion with lithium metaborate.

One of the most important features of the distribution patterns is the association between K, Rb and Cs and the alteration zone. On Section 15900N, there appears to be a close relationship between these elements and the primary Au mineralization itself, which is here mainly within the fuchsitic ultramafic rocks. The relationship is less evident on Section 15850N, where mineralization is strongest in the porphyritic rocks, although present also in the mineralized ultramafic rocks. This association of alkali metals represents the occurrence of micas in the alteration zone and is retained throughout much of the regolith, being lost only in the lateritic duricrusts. A similar association of these alkali metals is present in the biotitic talc carbonate rocks, which are unmineralized and outside the alteration zone. In these rocks, the association is with biotite rather than muscovite (fuchsite) and the Rb and, particularly, Cs contents are very much higher (61 ppm Cs, compared to less than 6 ppm Cs in all the other unweathered rocks). Furthermore, assuming that these rocks are represented in the samples collected from the regolith, biotite has been weathered and the alkali metals have been leached from the saprolite and overlying horizons. In comparison with the other alkali metals, there is no obvious Na enrichment associated with mineralization and Na has been leached from much of the regolith.

Table 5. Silver, tellurium and gold contents of selected saprolite samples, Section 15850N, Mt. Percy. N.B. Above RL 380, Ag and Te contents are below detection limits (0.4 Ag, 0.1 ppm Te).

Sample	Geology	RL m	Ag ppm	Te ppm	Au ppb
MW1533	Asf	380	0.16	22.0	1450
MW1722	Af	360	0.55	0.6	915
MW1728	Af	360	0.84	3.0	1180
MW1734	Af	360	0.66	0.3	2090
MW1744	Asf	360	1.96	1.4	480
MW1754	Asf	360	0.50	<0.1	77
MW1758	Asf	360	0.41	0.2	100
MW1764	Asf	360	0.95	0.7	58
MW1766	Asf	360	1.07	1.8	120
MW1866	Af	350	0.63	1.5	600
MW1870	Asf	350	0.55	0.6	925
MW1874	Asf	350	2.82	0.3	420
MW1884	Asf	350	0.99	0.9	360
MW1894	Asf	350	0.54	0.5	270
MW1900	Asf	350	1.63	1.5	795
MW1937	Af	350	0.57	0.7	515

Sodium. Sodium is present in albite in unweathered rocks and the highest concentrations are accordingly found in the porphyries (5.20% Na_2O) and some adjacent albite-bearing fuchsitic ultramafic rocks. These higher Na contents are retained in the lower saprolite, to RL 360, above which Na is mostly leached. This distribution is very similar to that of Sr, which also appears to be hosted by albite. From RL 360 to the surface, the Na_2O content is generally in the range 0.10-0.30% over all lithologies, with a number of sporadic higher values (0.5-1.3% Na_2O), mainly in the middle saprolite (RL 370-385). The minerals hosting Na in the regolith have not been identified, but halite is known to be present. Many of the higher concentrations occur in the alunite zone.

Potassium. The K distribution is controlled by the presence of micas, principally chromian muscovite (fuchsite) and biotite, and their relative resistance to weathering. Potassium feldspar is only a minor component, in the fuchsitic rocks. The presence of muscovite characterizes the alteration associated with mineralization, and this is reflected by high K contents in the fuchsitic ultramafic rocks (1.51% K_2O) and porphyries (1.26% K_2O). The unaltered biotitic talc carbonate rocks also have high K contents (1.25% K_2O), but these are distinguished by their high Cs contents (61 ppm). The muscovite persists to the mottled zone and is indicated throughout the regolith to this level by concentrations of 1.0-2.0% K_2O. The K_2O content of the lateritic duricrusts is rather lower (0.5-1.0%), but nevertheless appears to give surface expression to the alteration. In contrast, the K-enrichment due to biotite probably does not persist into the regolith. No K data are available on Section 15850N where the biotitic rocks are well represented, but as neither Cs nor Rb are retained, it is assumed K is leached also; Cs and Rb remain with K where it is in muscovite.

The K distribution in the lower saprolite (below RL 360) in Section 15900N seems to indicate a particularly strong enrichment associated with the projection of the Au mineralization itself. This distinction is lost higher in the regolith, possibly due to some remobilization of K and its precipitation as alunite. Above the alunite-bearing horizons, the K content may again more specifically reflect the distribution of muscovite.

Rubidium. The Rb distribution closely follows that of K and is largely controlled by the occurrence of micas. The highest concentrations occur in the biotitic rocks. Where muscovite is the host mineral, Rb, like K, is retained in the regolith to the mottled zone and is similarly reduced in abundance in the lateritic duricrust. Unlike K, however, Rb does not appear to be redispersed in the alunitic horizons. Some high Rb concentrations (80-125 ppm) occur in saprolitic and mottled clays between 385E and 400E on 15850N, below 3m depth. These clays also have high Cs contents. The origin of these enrichments is not clear, particularly in the absence of data for K, but they possibly represent an increase in the abundance of muscovite.

Caesium. The Cs distribution closely follows those of K and Rb and hence mica. There is no clear association with primary Au mineralization in the unweathered rocks, but there is an increase in Cs abundance (8-12 ppm) where drilling on 15900N intersected weathered mineralization in the lower saprolite (below RL 360). Caesium is strongly enriched in the biotitic rocks (52-79 ppm), from which it is leached during weathering. Like Rb, it is not obviously redispersed in the alunitic horizon and it is enriched with Rb in mottled and saprolitic clays between 385 and 400E on 15850N. It is possible that there is a zone of weak Cs accumulation (15-20 ppm) in the clay-rich horizons, particularly in 15900N.

5.2.5 *Halogens: Br*

Bromine was the only halogen determined. Comparative statistical data for Br in the main regolith horizons over the principal lithological units are given in Table IV/5, Appendix IV. The Br content is below detection limit (2 ppm) in the unweathered rocks, but the abundance increases steadily through the regolith to 20-30 ppm (maximum 64 ppm) in the clay-rich upper horizons. Complex bromides and chlorides of Ag, Au and Te were observed in heavy mineral concentrates from the saprolite at RL 357.5, but these and halite were the only halide minerals observed. A probable explanation for the distribution pattern is that Br is providing a measure of either the clay content or the moisture content - the latter itself reflecting the clay content of water-unsaturated regolith materials. The clay-rich zones in which Br is most strongly concentrated are those leached or depleted in gold. Since the Br distribution probably reflects that of Cl, there is possibly a causal link between the halogen and Au distribution patterns, i.e., Au mobilization as halide complexes. Alternatively, the presently observed Br distribution may post-date Au mobilization and simply reflect a suitable host environment for accumulation. The Br is probably derived from the ocean and has been concentrated by evaporation during prolonged periods of aridity.

5.2.6 *Base and transition metals: Pb, Cu, Zn, Co, Ni, Mn*

Comparative statistical data for these elements in the main regolith horizons over the principal lithological units are given in Table IV/6, Appendix IV. They are considered together because the base metals (Pb, Zn, Cu) are associated with some primary Au mineralization and because the transition metals (Mn, Co, Ni, Cu and Zn) have many similarities in chemical behaviour in the weathering environment. Nevertheless, there is no obvious enrichment of base metals with the primary Au mineralization at Mt. Percy. Pyrite is the most abundant sulphide mineral and only a few grains of other sulphides (e.g., galena, chalcopyrite, sphalerite, arsenopyrite, millerite) were recovered in the heavy mineral concentrates or seen in polished section. The abundance of Pb is mostly very low and its distribution, particularly on Section 15850N, is similar to that of Zr and other immobile elements associated with the porphyries. The distribution patterns of Mn, Co, Ni, Cu and Zn have a number of similarities. They all tend to be leached under acid, reducing conditions and precipitated under more alkaline, oxidizing conditions, with the behaviour of Mn being the most strongly influenced by redox changes. All are leached from the upper horizons of the regolith and are patchily enriched, together or separately, deeper in the regolith. The closest associations are between Zn, Ni and Co; coprecipitation of Co and Ni with secondary Mn oxides is a common feature in many lateritic profiles developed over ultramafic rocks, but is not observed here. Some enrichment of Cu and Zn partly overlaps the alunite zone as depicted by the S distribution.

Lead. The Pb abundance is very low both in the unweathered rocks and the regolith. Some isolated high values (maxima 30 ppm, 110 ppm) in the mineralized zone contribute to the higher mean Pb contents of the porphyries and fuchsitic ultramafic rocks. Lead tends to behave as an immobile element but, because of its low abundance, the distribution pattern in the regolith is indistinct, particularly on Section 15900N. The Pb distribution on Section 15850N indicates the position of the mineralized porphyry and adjacent fuchsitic wall rocks. Lead is weakly concentrated in the lateritic duricrusts, particularly over the talc chlorite ultramafic rocks, a feature common to all elements in resistate minerals.

Copper and *zinc*. Zinc and Cu are probably hosted by ferromagnesian silicate minerals and perhaps spinels in the unweathered rocks. Sphalerite and chalcopyrite are very rare. Both metals are weakly concentrated in the lower saprolite, particularly on Section 15900N; similar patterns in Si, Fe, Cr and Ni suggest that this reflects the relative accumulation of the host minerals due to the preferential weathering of less stable phases such as dolomite. Above this level, these minerals are themselves weathered and Zn and Cu are released. The distribution pattern shows that they are largely leached from the lateritic duricrust and the clay-rich mottled zone and upper saprolite, with patchy accumulation in the middle to lower saprolite, with concentrations in the range 250-450 ppm Zn. On Section 15900N, some of the higher Zn and Cu values occur in the alunite-rich upper saprolite, but on Section 15850N, the accumulation is at a deeper level. Enrichments of the two metals are generally not coincident, so that a common host mineral is unlikely.

Cobalt and *nickel*. Cobalt and Ni have very similar distribution patterns to that of Zn. However, Co in particular appears to have been more strongly leached from the upper horizons, except over the talc chlorite rocks, and the higher concentrations are largely confined to the mid- to lower saprolite. The regolith over the porphyries is enriched in both metals compared to the unweathered rock, presumably due to lateral dispersion from the ultramafic wallrocks.

The accumulation of Ni (and Co) in the lower saprolite over the ultramafic rocks is in some respects typical of a lateritic nickel deposit in which there has been post-lateritic reworking of the regolith. Under favourable conditions (humid, tropical environments in which such reworking is caused by uplift), much of the Ni leached from Fe oxides in upper horizons is reprecipitated in secondary Mg silicates ("garnierite") and Fe-Mn oxides at the base of the profile. These Ni-enriched saprolites have Ni contents 8-10 times those of the parent material. The silicates are derived from the continued weathering of the primary ferromagnesian minerals, which also contribute Ni. At Mt. Percy, however, reworking of the lateritic regolith has occurred during increasingly arid conditions under which weathering has slowed and there is little, if any, secondary silicate mineralization of Ni. The Ni content of the mid- to lower saprolite over ultramafic rocks is mostly 1500-2300 ppm, i.e., about twice that of the parent rock, with relatively few samples containing more than 1900 ppm. Much of the Ni now present in this saprolite is thus probably retained within relict ferromagnesian minerals or within clays and Fe oxides derived from them. Nickel derived from higher in the regolith has not been strongly concentrated and appears to have been leached.

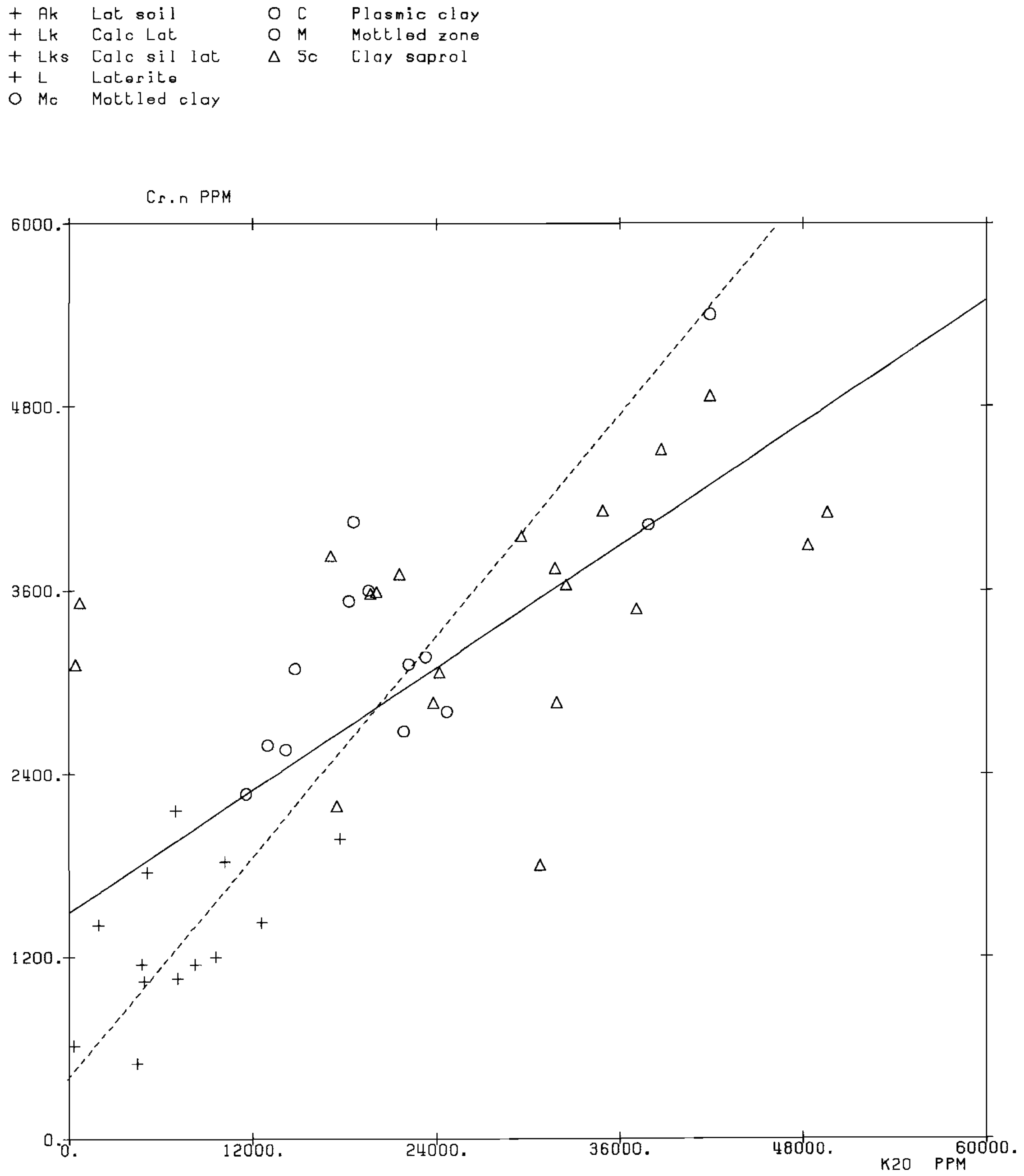
Manganese. Unlike the other transition metals, the Mn content of the regolith is much lower than that of the parent material. Manganese is retained in the lower saprolite, particularly below RL 350, at concentrations similar to those in the unweathered rocks, but above this level it is strongly leached. There is a close similarity between the distributions of Mn and Mg deep in the profile, implying that these metals are hosted by the same primary minerals, i.e., ferromagnesian minerals and dolomite, and are released together on weathering. It is deduced that much of the Mn that has been leached was probably that originally present in dolomite. The Mn distribution in the remainder of the regolith is similar to that of the other transition metals, particularly Co. It has been strongly leached from the upper saprolite and clay-rich horizons of the regolith, particularly over the porphyries and fuchsitic ultramafic rocks, with some patchy reprecipitation lower in the profile. There are, however, no sites in the regolith at which there has been significant concentration of Mn as secondary oxides (i.e., 0.2->1.0% Mn) so that coprecipitation with or adsorption to such oxides has not led to significant enrichments of elements such as Co and Ni. It is possible that there is some minor accumulation of Mn and Co between RL 355-360, especially on Section 15900N (i.e., where the rock hardness increases), and locally in the upper saprolite of the talc chlorite ultramafic rocks. There is also minor concentration of Mn (and Co) in the duricrusts and calcareous soils. In places, this is visible as surface coatings and dendrites of Mn oxides and is similar to the more abundant Mn oxide coatings seen in red-brown hardpans.

5.2.7 *Lithophile transition elements: Cr, Sc, Ti, V*

Comparative statistical data for these elements in the main regolith horizons over the principal lithological units are given in Table IV/7, Appendix IV. These elements commonly accumulate in lateritic regoliths, particularly in the ferruginous horizons. The concentrations are largely residual, being due to the loss of other components. At Mt. Percy, this appears true of Ti and V, but the distribution of Cr is unusual in that it is concentrated in the upper, clay-rich saprolite, the plasmic horizon and mottled clay zone and is at anomalously low concentrations in the lateritic duricrust and gravels. The Sc distribution is similar to that of Cr. Each of these elements has been concentrated two- to four-fold in the saprolite and clay-rich horizons but, whereas Fe, Ti and V are further concentrated in the lateritic duricrust, the abundances of Cr and Sc, particularly over the ultramafic rocks, are similar to or less than those in the unweathered rocks.

Chromium. The Cr distribution in lateritic regoliths is strongly influenced by its host mineral in unweathered rocks. In many ultramafic rocks, most Cr is hosted by chromite, which is generally resistant to weathering. Chromium thus tends to accumulate in the duricrust, commonly to concentrations of 1.0-5.0% (e.g., Smith, 1977). At Mt. Percy, however, chromite is uncommon and most Cr in the unmineralized talc chlorite ultramafic rocks is present in ferromagnesian minerals, principally chlorite. These minerals are less abundant in the fuchsitic ultramafic rocks, but the fuchsite (chromian muscovite) itself is a host to some Cr. It is not certain whether this is the principal host mineral in the unweathered rocks, but residual fuchsite is significant in the clay-rich and ferruginous upper horizons of the regolith, in which there is a close correlation between the Cr and K_2O contents (r=0.74; Figure 12), with abundances of both elements decreasing towards the surface.

The unweathered ultramafic rocks have mean Cr contents of approximately 2000 ppm; that of the porphyries is much lower (150 ppm). Chromium is concentrated in the saprolite and clay-rich horizons, remaining within relict ferromagnesian minerals, fuchsite or becoming incorporated within (poorly crystalline) secondary Fe oxides or in clays. A striking feature of the Cr distribution is the high concentration (means 4050-4725 ppm, max. 10000 ppm) in the saprolitic, plasmic and mottled clays over the talc chlorite rocks. These horizons are also unusually Al-rich (mean 18.5-21.2% Al_2O_3), presumably in part due to absolute enrichment by Al released from clays during the precipitation of Fe oxides and the formation of the overlying lateritic duricrust. Chromium is probably released from the clays and recrystallizing Fe oxides in the same process, becoming incorporated in neo-formed clays (dominantly kaolinite) and Fe oxides in the underlying horizons. The clays are green, due to the presence of Cr. The equivalent horizons on the fuchsitic ultramafic rocks are coarser grained and more porous and have lower Al and Cr contents (means 12.8-18.0% Al_2O_3; 2030-3920 ppm Cr). These characteristics reflect the presence of residual fuchsite in the latter, which has retained and immobilized much of the



```
    46 SAMPLES PROCES.
MEANS     : ARIT. : 20176.    ARIT. : 2841.
VARIANCES :
CORRELATION COEFFICIENT     : 0.7439
REGRESSION LINES        :
______  Cr.n=0.0667*K20+1496.
------  K20=8.300*Cr.n-3405.
```

Figure 12. Plot illustrating the correlation between K_2O and Cr in the upper horizons of the regolith over fuchsite carbonate ultramafic rocks.

Al and Cr. The correlation between Cr and K_2O (Figure 12) in the upper regolith further suggests the importance of residual fuchsite as the mineral dominating Cr distribution in these horizons. Deeper in the saprolite, however, the correlation is poorer; some Cr is held by ferromagnesian minerals and their weathering products and K is also present as alunite. The weathered porphyries are strongly enriched in Cr, particularly in the clay-rich horizons. Although these rocks contain minor ferromagnesian minerals and xenoliths of fuchsitic ultramafic rocks, the enrichment is largely absolute, with Cr being derived from the duricrusts and clays of the adjacent ultramafic rocks.

The Cr contents of the lateritic duricrusts developed over the ultramafic rocks are unusually low and indicate that Cr abundance alone cannot be used to distinguish lithology. The low Cr abundance is largely a consequence of its occurrence in weatherable minerals such as chlorite, rather than in chromite. The higher Cr content of the lateritic duricrusts over the fuchsitic ultramafic rocks reflects the greater stability of fuchsite, although this too has been partly destroyed.

Scandium. Scandium concentrations in igneous rocks generally increase with decreasing contents of SiO_2, with the exceptions of olivine- (and nepheline-) rich rocks (Frondel, 1978). This is broadly evident at Mt. Percy, where the Sc contents of the unweathered ultramafic rocks (mean 21 ppm) are much greater than that of the porphyries (8 ppm). More important, however, is the very strong correlation between Sc and Cr, which suggests that Sc is hosted by the same minerals as Cr, e.g., chlorite and fuchsite. Similarly, in the regolith, there is generally a close parallel between the distributions of Sc and Cr, with both elements being concentrated in the clay-rich horizons of the ultramafic rocks and strongly enriched throughout the profile on the porphyry. The principal difference is that Sc is much less depleted than Cr in the lateritic duricrust and some of the highest concentrations over the fuchsitic rocks occur in this material. This is presumably due to sorption of Sc by Fe oxides and the replacement of the Fe^{3+} ion by Sc^{3+}. Indeed, ScO(OH) forms structural analogues of goethite and lepidocrocite (Frondel, 1972), hence Sc becomes more firmly bound to the Fe oxides than Cr. Because Sc is retained in the Fe oxides as well as fuchsite, the correlation between Sc and K_2O in the upper horizons is weaker than for Cr.

Titanium. Ilmenite and rutile are present in the unweathered rocks, and Ti may be hosted also by spinels and ferromagnesian minerals. The Ti content of the porphyries (mean 0.46% TiO_2) is almost double that of the ultramafic rocks (mean 0.26% TiO_2). Titanium has only restricted mobility during weathering; many of its host minerals are resistant and Ti is chemically mobile only in very acid environments ($pH < 4.0$) (Baes and Mesmer, 1976). Titanium thus tends to accumulate residually in the regolith and this is shown by the steady increase in Ti content upwards through the profile. The increase is greater over the ultramafic rocks, so that the discrimination between the porphyries and the ultramafic rocks is reduced in the saprolite and commonly absent in the saprolitic, plasmic and mottled clay zones. Unlike Cr and Sc, however, Ti is strongly concentrated in the lateritic duricrusts, with a number of samples containing over 10% TiO_2. Titanium is also strongly concentrated relative to Zr (see section 6.1.4), so that lithological discrimination based on Ti-Zr plots is not possible. Much of this concentration appears to be due to the residual accumulation of Ti as rutile or secondary anatase, or in Fe oxides derived from ilmenite. However, it is possible that there has been some absolute accumulation of Ti derived in solution or as fine particulates. The very high concentrations present in some samples (maximum 31.7% TiO_2) may reflect very localized high abundances in the original bedrock, rather than being due solely to accumulation during weathering. The enrichment in the highly ferruginous cuirasse duricrust on the talc chlorite ultramafic rocks is discussed below (Section 6.1.4).

Vanadium. The only V mineral specifically identified in the unweathered rocks is the vanadian muscovite, roscoelite, which is present in one sample (MW1838) of the fuchsitic ultramafic rocks in DDH 22 on 15900N. In other samples, V is probably hosted by the same minerals as Ti. However, whereas the Ti content of the porphyries is nearly double that of the ultramafic rocks, the V contents of the major lithological units (excluding the roscoelite-bearing sample) are similar (135-145 ppm V). This must reflect the occurrence of a relatively V-poor Ti-bearing mineral in the porphyries. Within the regolith, V has a very similar distribution to Ti (Figure 13), with both elements increasing steadily in abundance towards the surface. Both are strongly enriched in the lateritic duricrust, and concentrated relative to Zr, particularly over the talc chlorite ultramafic rocks. Samples containing 300-320 ppm V, compared to adjacent materials with 240-270 ppm V, may be delineate specific units within the fuchsitic ultramafic rocks in the lower saprolite on Section 15900N, but this is not confirmed by the distributions of other elements.

5.2.8 *Immobile elements: Zr, Hf, Th, Nb, Ta*

Comparative statistical data for these elements in the main regolith horizons over the principal lithological units are given in Table IV/8, Appendix IV. These elements generally exhibit little chemical mobility in the weathering environment and follow this behaviour at Mt. Percy. Zirconium, Hf, Nb and Ta are all members of the second and third transition series and have very similar chemical characteristics. In particular, the chemical behaviours of Zr and Hf are almost identical, and Nb and Ta almost invariably occur together. Thorium is an actinide element but it has chemical characteristics similar to Hf. Zircon is probably the principal host mineral for each of these elements and hence the stability of zircon determines their distribution and dispersion in the regolith. Some Th may be present as monazite, but if so it is present at very low abundances and has not been detected in the heavy mineral concentrates.

With the exception of Zr, the abundances of each of these elements is below analytical detection limits in the ultramafic rocks, apart from a few sporadic Ta values. They are detectable only in the porphyries, at very low concentrations. The Zr, Hf and Th contents increase upwards through the regolith, even over ultramafic rocks, and all five elements are enriched in the lateritic duricrusts and soils. The greater abundance of Zr, Hf and Th in the porphyries compared to the ultramafic rocks discriminates the porphyries quite clearly in the unweathered rocks and throughout the regolith except for the upper lateritic horizons. The location of the porphyry is readily seen from the distribution of these three elements, even in the clay-rich horizons. A similar discrimination is shown by Nb, but its concentrations are close to the detection limit and the contrast is only weak. Tantalum concentrations are generally too low in the fresh rocks, saprolite and clay-rich horizons to show a significant distribution pattern. However, on Section 15900N, Ta contents of 0.6-3.5 ppm delineate the porphyries in the lower saprolite below RL 360.

One of the most significant features of the distributions of these elements is their accumulation in the lateritic duricrust, particularly over the talc chlorite rocks. The highest concentrations of each of these elements, together with those of Fe, TiO_2, V, W and some REE, are present in the massive cuirasse on these rocks on Section 15850N. The cuirasse has relatively low Cr contents, as discussed in Section 5.2.7, so that its trace element composition indicates a felsic rather than an ultramafic rock, although major

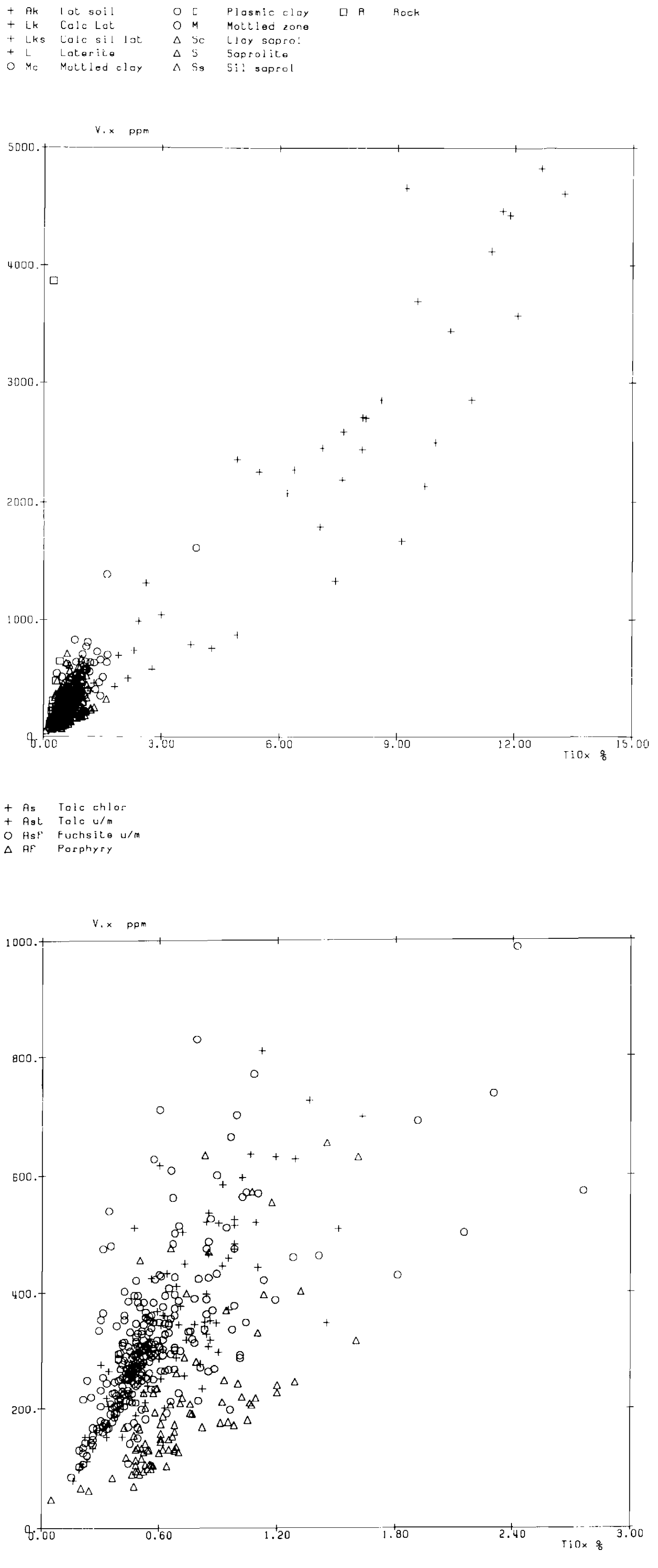


Figure 13. TiO_2-V plots illustrating their close correlation and concentration in the regolith and the poor discrimination between different lithologies.

element composition, especially the Fe content, relates to an ultramafic parent material. The porphyries are the probable source of the immobile elements, which now form a residual accumulation. A curious feature of the accumulation is that it is mainly upslope of the subcrop of the porphyry. The distribution patterns suggest that this may have been caused by the apparent flattening of the dip of the porphyry, brought about, for example, by landscape reduction during weathering. The possible mechanism is discussed further in section 6.1.4. There is, however, some downslope dispersion, shown by enrichments in the soil and the uppermost duricrust horizons. The enrichments are less pronounced on Section 15900N, partly because the talc chlorite ultramafic rocks are less well represented on the section. On Secction 15900N, the maximum Ta contents in the lateritic duricrusts directly overlie the porphyry which, as noted above, is also weakly delineated by its Ta content in the lower saprolite.

The enrichments of the immobile elements in the upper saprolite and clay-rich horizons may be due to either of two processes:

1. residual, or *relative*, accumulation, as the result of the leaching of other, more mobile components;

2. *absolute* accumulation, by illuviation of host minerals. Such illuviation may involve the translocation of fine zircon grains (e.g $<5\mu$m) down cracks and fissures by infiltrating waters, or the movement of coarser particles in root channels and larger fractures. Infilled roots and fractures have been observed to depths of >20 m at Mt. Percy. In some locations in the Mystery Zone, such infillings apparently occupy as much as 5% by volume - readily visible as red-brown earths in the bleached upper saprolite of the porphyries and fuchsitic ultramafic rocks.

5.2.9 *Rare earth elements: Y, La, Ce, Sm, Eu, Yb, Lu*

Comparative statistical data for these elements in the main regolith horizons over the principal lithological units are given in Table IV/9, Appendix IV. Yttrium is considered with the rare earth elements (REE) because of its similar chemical behaviour, particularly to the "heavier" REE. The distributions of these elements have a number of general characteristics in common, with some differences corresponding to whether they are "light" or "heavy". Except for Yb, the REE concentrations in the unweathered rocks are highest in the porphyries, the relative enrichment being greatest for the lighter REE (La, x55; Ce, x30; Sm, x7). There is little difference between the ultramafic rocks, with several REE being below detection limit. The host minerals for the REE have not been determined, but presumably include feldspars. However, resistant accessory minerals such as xenotime, monazite or zircon are probably not very important at Mt. Percy as the REE distributions in the regolith do not have the same characteristics as those of Zr and Th, namely persistance in the host unit throughout the regolith. The discrimination between the porphyritic and ultramafic rocks is maintained in the saprolite, below RL 390, but above this level, the lighter REE are leached. In contrast, Y and the heavier Lu and, particularly, Yb become concentrated over the ultramafic rocks. These distributions do not correspond to known variations in the mineralogy. However, a plot of La versus Ba in the porphyries (Figure 14) suggests a relationship between these two elements in the saprolite below about RL 390 in which the maximum La content is determined by the concentration of Ba. Both elements probably have a common host mineral (albite) and

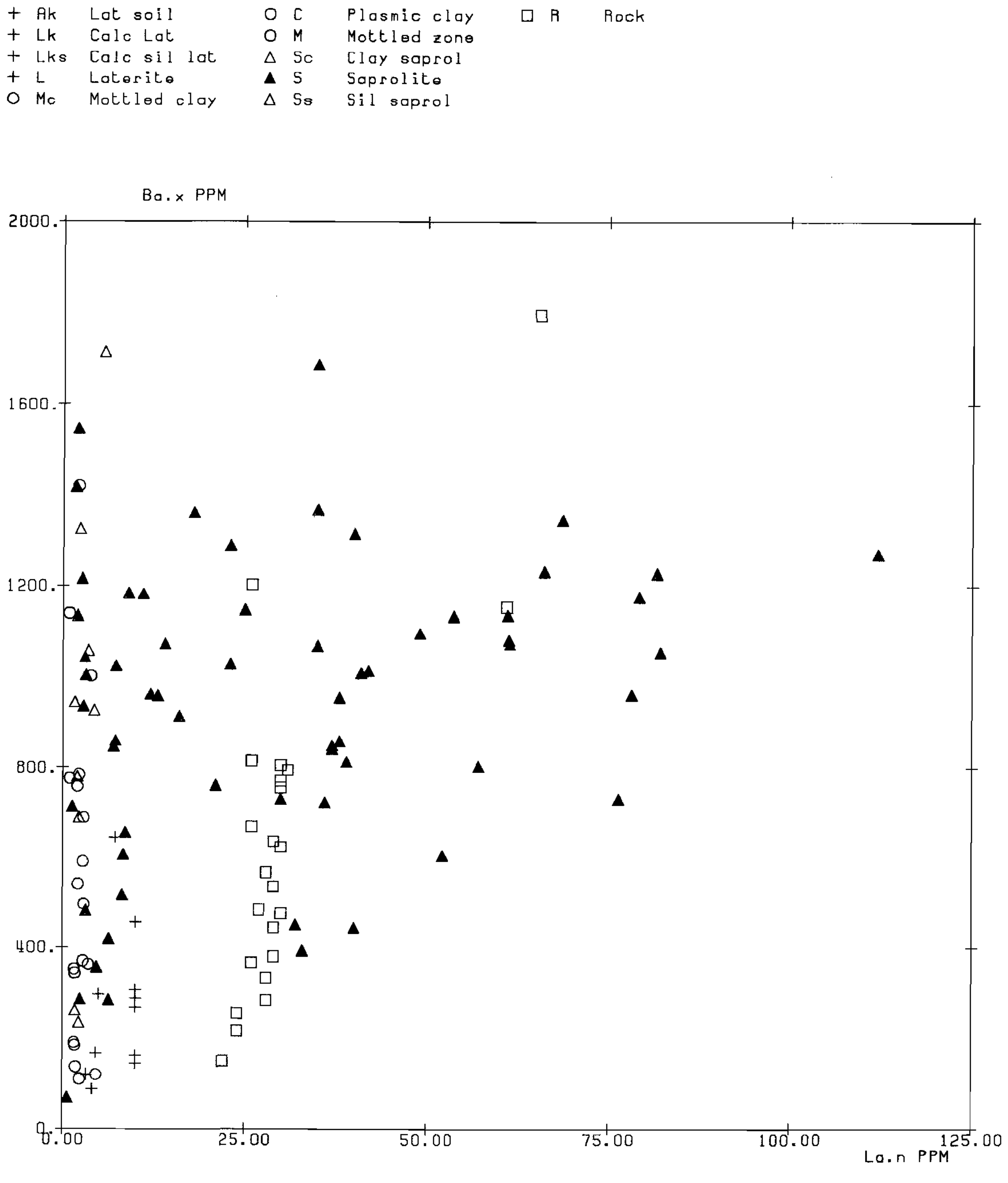


Figure 14. Plot suggesting that the abundance of La in weathered porphyries is related to a minimum concentration of Ba. The wide scatter of La contents in the regolith reflects enrichment in the lower saprolite and leaching from upper horizons.

remain in association through much of the saprolite, even though the albite itself has been altered to kaolinite.

An important feature of the distributions of all these elements is an enrichment in the lower saprolite on both sections, particularly between RL 360 and 350. This corresponds the increase in the hardness of the regolith that led to the change from rip-sampling to drilling. Independently-collected samples, similarly enriched, eliminate contamination as a cause. The highest concentrations of the light REE are found at this level (e.g., 80-110 ppm La, 80-130 ppm Ce, 10-22 ppm Sm and 2-5 ppm Eu) but, although these maxima occur in the weathered porphyries, the enrichment also extends laterally into the weathered ultramafic rocks. The concentrations of Y, Yb and Lu are also elevated in the lower saprolite, especially over the ultramafic rocks, although the maxima are in the lateritic duricrusts. The minerals hosting these enrichments have not been determined.

All of the REE are enriched in the soils and lateritic duricrusts compared to the immediately underlying horizons. The effect is far greater for the heavier REE, which reach their highest concentrations in the cuirasse over the talc chlorite ultramafic rocks. The distributions of Y, Yb and Lu in the regolith over these rocks is quite different both from their distribution over much of the fuchsitic ultramafic rock and the distributions of the light REE. Their concentrations increase progressively upwards through the profile, but the overall abundances remain low, with mean maxima of 30 ppm Y, 3.3 ppm Yb and 0.64 ppm Lu. This distribution, which resembles that of V, indicates residual accumulation, either in resistant primary phases, or in secondary phases (e.g., Fe oxides) to which they are firmly bonded. Similar residual accumulation is evident in some fuchsitic ultramafic rocks on Section 15900N, possibly in one specific unit. Nevertheless, the enrichment of Y, Yb and Lu in the lower saprolite is evidence that they are neither hosted only by resistant phases, nor that they are immobile during weathering.

The behaviour of the REE in lateritic environments is not well understood, but two important features concerning the evolution of the regolith emerge from a preliminary study of these data:

1. The distributions of the light REE resemble those of gold in that they are enriched in the lateritic duricrusts, leached from the upper, clay-rich horizons and are retained in the saprolite, with some concentration and lateral dispersion at a position related to a presumed past water-table or redox front. The source and relative concentration of the REE, and the location of the saprolitic enrichment, differ from those of gold, but it is possible that they are due to the same general events in the evolution of the regolith and are due to some of the same processes of weathering.

2. The concentration of Y and the heavy REE in the cuirasse duricrusts on the talc chlorite ultramafic rocks may be evidence for the duricrusts being at least partially residual. Nevertheless, the concentration factor is much the same as for elements such as Zr which appear to be derived from the porphyries.

5.2.10 *Other elements: Ga, Ge*

Comparative statistical data for these elements in the main regolith horizons over the principal lithological units are given in Table IV/8, Appendix IV.

Gallium. The occurrence and distribution of Ga generally follow those of Al and Fe^{3+}. Thus, in unweathered igneous rocks, Ga is concentrated particularly in feldspars, some amphiboles, chlorites and micas, substituting for Al, and in magnetite and titanomagnetite, substituting for Fe^{3+}. This behaviour is evident at Mt. Percy, with Ga contents being greater in the more aluminous porphyritic rocks (mean 17 ppm) than the ultramafic rocks (6-7 ppm). The distribution through much of the regolith is also similar to that of Al with a close correlation between these two elements. Concentrations gradually increase upwards, with a marked enrichment in the clay-rich horizons, especially in the talc chlorite ultramafic rocks, that largely eliminates the differences in abundance between the main lithologies. Unlike Al, however, Ga has accumulated in the lateritic duricrusts, especially in the cuirasse over the talc chlorite rocks. This accumulation is of the same order as that of several other elements, including Zr, Ti, V and the heavy REE, and can be correlated with them. It is probably due to the preferential retention of Ga compared to Al in recrystallizing Fe oxides, possibly with some Ga retained in resistant minerals such as magnetite. This distribution is somewhat different from that in other lateritic regoliths; in bauxites, for example, Ga is commonly depleted relative to Al.

Germanium The Ge contents in the unweathered rocks and the regolith at Mt. Percy are very low. There is a weak, probably residual, concentration in the regolith derived from the fuchsitic ultramafic rocks, but this generally does not persist into the lateritic duricrust or the soil.

6.0 DISCUSSION AND CONCLUSIONS

6.1 Element Distributions and Regolith Evolution

6.1.1 *Introduction*

The geochemical data presented in this study are consistent with many of the general features established for the evolution of the regolith in semi-arid regions of the southern Yilgarn Block. The regolith is considered to have developed over a very long period, probably since at least the mid-Mesozoic, during which it has been subjected to several major changes of climate. Two climatic episodes have been of particular importance. These were, firstly, the humid, warm to tropical climates of the Cretaceous to mid-Miocene and, secondly, the drier climates since the Miocene. The former humid climates were probably equivalent to those prevailing in the present wetter savannas and gave rise to extensive, deep lateritic weathering. The later arid to semi-arid climates, which still prevail, have resulted in a general lowering of water-tables and changes to, and slowing of, chemical weathering.

The distribution of each element in the regolith is related to the different weathering processes that prevailed during the principal climatic regimes. In general, only the processes that refer to past regimes of long duration or to extreme or recent regimes have had a significant effect and this is evident in the data from Mt. Percy. Thus, many of the dominant geochemical (and mineralogical) characteristics of the regolith can be related to the development of the lateritic profile under humid conditions of higher water-tables, whereas others are due to later events related to more arid environments with lower water-tables and may still be active. The features produced by these later events appear as modifications of the pre-existing lateritic profile and tend to be reflected more by the minor components of the regolith.

6.1.2 *Lateritic weathering under humid tropical climates*

The characteristics commonly associated with lateritic weathering are:

1. Oxidation of sulphide minerals

Sulphur is strongly leached from the deepest levels of the regolith at Mt. Percy and appears to be the element most susceptible to weathering. This observation is consistent with conclusion that sulphides are some of the most unstable minerals in humid, oxidizing environments, rarely persisting into the weathering zone except as supergene phases such as marcasite, chalcocite and violarite, none of which has been observed at Mt. Percy. Nevertheless, some sulphide minerals (principally pyrite) were recovered high in the profile by panning (Gedeon and Butt, 1990); these are presumed to have been preserved within vein quartz and liberated by crushing. The other elements released by oxidation of the sulphides (Fe, Cu, Zn, Pb) may be either leached or retained in secondary minerals such as Fe oxy-hydroxides. However, other minerals also act as primary hosts of these metals, so the fate of the sulphide-derived components cannot readily be determined.

2. Strong leaching of alkali and alkaline earth metals

This applies particularly to Na, Ca and Sr, which are hosted mainly by the readily weatherable minerals albite (Na, Sr) and dolomite (Ca, Sr), so that they are reduced to very low concentrations throughout most of the regolith. The other alkali metals (K, Rb, Cs) are generally less strongly leached because they are hosted principally by a very resistant mineral, muscovite, which becomes appreciably weathered only in the lateritic duricrust. However, where the host mineral is weatherable, e.g., biotite, Cs and Rb are strongly leached. Similarly, Mg, held within dolomite, is leached, but it is also present in more resistant ferromagnesian minerals such as chlorite and is retained in the lower to mid saprolite. Accordingly, the Mg content only falls to very low levels ($<0.5\%$ MgO) in the upper saprolite and clay-rich horizons where the ferromagnesian minerals have been weathered. Barium, like K, is retained in a stable mineral and is only partly leached in the duricrust. However, whereas K is hosted by a primary mineral, it is probable that the much of the Ba is derived from albite and has been immediately reprecipitated as secondary barite.

3. Retention of less mobile major elements as stable secondary minerals

One of the principal characteristics of lateritic weathering profiles is the tendency for their chemical and mineralogical compositions to be dominated by the three elements Si, Al and Fe in the form of kaolinite, quartz, iron oxides (hematite and goethite) and, in places, gibbsite. These phases dominate the secondary mineral assemblages at Mt. Percy over all lithologies. The distributions of several minor and trace elements (e.g., Cr, Sc, Ga, V, As and, possibly, Au) are controlled wholly or in part by the distributions of these major elements. In addition, many resistate and immobile elements also tend to accumulate with Fe oxides in the lateritic horizons although, for most, no chemical interactions are involved.

The saprolites are increasingly kaolinized towards the surface, most strongly over the felsic porphyritic rocks but also very strikingly in the upper saprolite developed on the talc chlorite ultramafic rocks. The latter appears to be due to the introduction of Al, presumably an iterative accumulation that occurs as kaolinite is replaced during the precipitation of the Fe oxides that form the ferruginous lateritic horizon. Quartz is present as a residual, resistate mineral, principally over the porphyries, but it is also derived from quartz veins in the fuchsitic rocks. Secondary quartz is also present, particularly over the fuchsitic rocks, usually as a partly or massively silicified saprolite. Such silicification is typical of Al-poor ultramafic rocks in which silica released during weathering has insufficient Al available to precipitate as kaolinite.

The ferruginous horizon is particularly strongly developed over the talc chlorite rocks, where it occurs as a massive, strongly cemented, pisolitic lateritic duricrust or cuirasse. This cuirasse, which is present in part as large rounded boulders up to 2m in diameter, is typical of the duricrusts formed over ultramafic rocks. The duricrust is thinner over the other lithologies, less ferruginous and less strongly cemented. In part, this may be due to the slightly lower Fe content of the fuchsitic and porphyritic rocks, with a greater friability due to the the presence of quartz and muscovite and a later influx of secondary carbonates. Possible geomorphological influences are discussed in section 6.1.4.

The distributions of Cr, Sc and Ga are closely interrelated with those of Al and Fe. In unweathered rocks, Cr and Sc occur together (and with Fe in ferromagnesian minerals), and Ga is associated closely with Al. On weathering, these associations are retained, with each element concentrating in the kaolinitic clay-rich horizons, particularly over the talc chlorite rocks. However, some differentiation occurs with the development of the ferruginous horizon. Chromium appears to be released to accumulate with Al in the clay-rich horizons, whereas Sc and Ga tend to be retained with Fe in the ferruginous horizon. The distributions of As and Au are partly related to that of Fe; arsenic occurs preferentially in the ferruginous fractions of the lateritic soils and gravels and the higher As concentrations are found in more ferruginous samples deeper in the regolith. Gold occurs as a widespread halo in the ferruginous horizons, a common feature in lateritic terrains. However, in part, this is also due to concentration in pedogenic carbonates and in that sense is coincidental. Vanadium is strongly controlled by Fe oxides and as such it has a distribution similar to that of elements in resistant minerals.

4. Retention and accumulation of immobile elements and stable minerals

The distributions of K, Zr, Hf, Th, Nb, Ta, W, REE, Ti and V relate wholly or in part to their inertness during weathering, which is due to their chemical immobility (e.g., V, Ti) and/or to the stability of their host minerals (e.g., Zr and Hf in zircon, Ti in rutile and anatase). Their abundances tend to increase upwards through the profile due to the gradual loss of other components, with marked accumulation in the ferruginous lateritic horizon, within which lateral dispersion by colluvial action has taken place during the course of profile evolution. Vanadium and some Ti are released during weathering but become immobilized by precipitation with Fe oxides (V) or as anatase. Of these elements, the distribution of the REE has also some "chemical" component, but this is probably related to post-lateritic events. The implications of the very strong concentration of all of these elements in the lateritic cuirasse over the talc chlorite rocks is discussed in Section 6.1.4.

The distributions of the remaining elements, particularly Co, Cu, Pb, Mn and Ni, are also characteristic of lateritic environments in that they have been strongly leached from the upper horizons of the regolith.

6.1.3 *Weathering under semi-arid and arid climates*

Characteristics commonly associated with weathering under arid conditions are those related to the excess of evaporation over precipitation, which result in the accumulation of otherwise soluble weathering products within the regolith. The most important of these are the alkali and alkaline earth metals, which concentrate in groundwaters and the precipitate as carbonates, sulphates, halides and other salts. In lateritic profiles, this results in the paradoxical accumulation of these highly mobile components in an otherwise highly leached regolith. This is well exemplified at Mt. Percy, where there is a marked concentration of Ca, Sr and, to a lesser extent, Mg and Ba as pedogenic carbonates and minor sulphates in the near-surface horizons and the presence of alunite in the upper saprolite. In addition, groundwaters are saline, halite is present as a trace constituent throughout the regolith and Br is concentrated in the clay-rich horizons.

The presence of smectitic clays as intermediate weathering products are also typical of arid environments but are not well defined at Mt. Percy. Although secondary silicification is considered characteristic of arid environments, that occurring over ultramafic rocks, typically dunites is also known in humid tropical terrains (e.g., in India and Brazil). Thus, the silicification of the saprolite over the fuchsitic ultramafic rocks may not be related to aridity.

The distribution of Au (and Ag) at Mt. Percy has several characteristics that can be attributed to processes occurring under post-lateritic, probably arid conditions. These include:

1. a zone of leaching and depletion in some clay-rich upper horizons;

2. lateral dispersion in the mid to upper saprolite;

3. occurrence as Ag-poor secondary particles, particularly in the saprolite;

4. the occurrence of silver as secondary halides;

5. concentration of gold in pedogenic calcretes.

Items 1 to 4 are typical of those ascribed to mobilization of metals as halide (principally chloride) complexes under acid, oxidizing conditions in arid climates (Mann, 1984; Butt, 1989). They have not been reported in lateritic regoliths that have evolved only in humid environments. The accumulation of gold in pedogenic carbonates is a phenomenon as yet only reported from Western Australia (e.g., K. Schulz, personal communication, 1986; Butt, 1987; Lawrance, 1988; Glasson et al., 1988; Lintern, 1989; Lintern and Scott, 1990) but which is probably characteristic of arid zones elsewhere. The phenomenon seems to be related to cycling of Au and Ca by vegetation (Butt, 1987; Lintern, 1989).

The absolute enrichment of the REE in the lower saprolite is an unusual feature that, by analogy with the distribution of gold, may be ascribed to mobilization under arid conditions, with reprecipitation at a water-table level, or a redox front or porosity barrier related to a water-table. The REE probably occur as phosphates, but only one REE phosphate mineral grain was recorded during the examination of panned concentrates.

6.1.4 *Regolith evolution*

The principal stages in the evolution of the regolith at Mt. Percy can be summarized as follows:

1. Lateritic weathering under warm humid conditions.

    a. progressive weathering of sulphides, carbonates, feldspars and ferromagnesian minerals and the leaching of their mobile constituents (S, Na, Cs, Ca, Mg, Sr, Mn, Co, Ni, Cu, Zn).

    b. retention of less mobile constituents in secondary minerals, principally kaolinite and Fe oxides (Si, Al, Fe, Ba, Cr, Ti, V, As, Sb, Sc, Ga, Mn, Cu, Ni).

    c. dissolution or replacement of secondary minerals (e.g., kaolinite, barite) and some resistant primary minerals (e.g., muscovite) during the formation of the ferruginous horizon. This was accompanied by remobilization and some loss of constituents (Si, Al, Cr, Ba, K, Rb) and the recrystallization and accumulation of Fe oxides in secondary structures. Primary gold was probably dissolved from the ferruginous horizon by complexation with organic ligands in neutral to acid conditions, and reprecipitated as fine grained particles, probably with secondary Fe oxides.

    d. accumulation of immobilized elements in resistant primary minerals (e.g., Zr, Hf in zircon; K, Rb in muscovite; Ti in rutile; REE, Ta, Nb, Th, W) or in stable secondary minerals (Ti in anatase; V in Fe oxides).

2. Weathering under warm, semi-arid conditions.

    a. decline of the water-table, with arid conditions leading to vegetation changes which in turn induced instability of the landsurface and possibly initiated minor erosion. Slow weathering continued, mainly at the base of the profile. The gradual accumulation of the dissolved weathering products brought about as evaporation exceeded precipitation and by the development of an internal drainage, together with the accession of marine salts associated with rain fall, resulted in progressive salinization of the groundwater.

    b. dehydration and hardening of lateritic duricrusts, especially those derived from the talc chlorite ultramafic rocks.

    c. mobilization of Au and Ag, particularly in the near-surface, as halide complexes. Mobilization has probably continued intermittently to the present day, with progressively lower water-tables, with Au precipitation occurring close to the water-table or at redox fronts beneath and related to it.

    d. precipitation of alunite, probably under acid conditions with relatively high water-tables, apparently post-dating at least some Au mobilization.

Precipitation of silica, introduced into the profile or derived from dissolving clay minerals, in saprolites of fuchsitic ultramafic rocks, under similar conditions.

e. continued leaching of base and transition metals (Cu, Co, Pb, Mn, Ni) with minor precipitation in the mid to lower saprolite.

f. dissolution of primary minerals containing REE and the precipitation of REE as absolute accumulations at a probable porosity barrier in the lower saprolite. The barrier may mark a past water-table, or underlie a perched water-table.

g. release of soluble alkaline earth metals at the weathering front and their transport to the surface, probably by evaporation and/or evapotranspiration; vegetative cycling of these elements and gold has led to their gradual accumulation in the near-surface horizons.

The general preservation of the regolith at Mt. Percy implies that there has been little erosion at the site. Nevertheless, some features of the distributions of the immobile elements in particular suggest there may have been sufficient erosion to cause local topographic inversion. In addition to iron oxides, Ga, Nb, Ta, Th, Ti, V, W, Y, REE, Zr and Hf (but not Au) are all strongly concentrated in the massive cuirasse duricrusts developed on the talc chlorite rocks. Although accumulations of Fe and V are expected over ultramafic rocks, the other elements are more characteristic of felsic lithologies such as the porphyries: the distributions on Section 15850N strongly indicate these rocks to be the source. The cuirasses are all upslope from the projected outcrop of the porphyries on 15850N and 15900N, although other porphyries intrude the talc chlorite rocks 50-100 m south, at about 310E, and are also present in lower ground to the west. If the present topography is similar to that prevailing in the past, these elements can only have concentrated by the gradual residual accumulation of resistant minerals released from the porphyries by landsurface reduction during lateritization, with little or no downslope dispersion having taken place. This is a feasible but improbable mechanism, for the steepness of the dip of the porphyry and the high degree of enrichment suggest that a reduction of several tens of metres would be necessary to reach these concentrations, during which lateral dispersion would be inevitable. Alternative explanations are:

1. the presence of a flat-lying porphyry overlying the talc chlorite rocks, now weathered and destroyed except for the resistant minerals. Such porphyries do occur in the Mystery Zone.

2. the talc chlorite rocks once occupied lower ground and the porphyries and fuchsitic ultramafic rocks higher ground. The resistant minerals released from the porphyries were transported downslope to accumulate in the lower ground over the talc chlorite rocks; some chemically mobilized Fe was also precipitated at this site. Preferential erosion of the softer upper horizons of the regolith developed on the porphyries and fuchsitic ultramafic rocks has led to topographic inversion.

The hypothesis of topographic inversion is supported by evidence for localized partial truncation of the regolith. Compared to the talc chlorite rocks, the lateritic and clay-rich horizons on the porphyries and fuchsitic rocks are thin, with silicified saprolite at or close to the surface in some places. This truncation may have been due, in part, to these horizons being more friable and less indurated, thereby increasing their vulnerability to weathering. Truncation to the saprolite over these rocks is evident in the south wall of the Mystery Pit at 15650N and has also occurred over sedimentary rocks of the Black Flag Beds exposed in the west wall at RL 400 at about 16050N and over other units west of the pit. Conversely, an almost complete profile is present on Mt. Percy itself (16200N), which has massive cuirasse duricrust developed on Golden Mile Dolerite, and was also present on other talc chlorite units that formed the eastern margin of the Mystery Zone. The northern wall of the pit also may have a reasonably complete profile, but recent exposure suggests that this may have been cross-cut by a drainage channel, now infilled by lateritic gravels. The evidence thus points to a complex sequence of erosional and perhaps depositional events occurring during and after lateritic deep weathering that have affected the composition and structure of the near-surface horizons. If truncation has occurred, however, it brings into question the apparently residual nature of the lateritic gravels present over the porphyries and fuchsitic ultramafic rocks.

6.2 Implications for Exploration

6.2.1 *Introduction*

The multi-element dispersion patterns revealed by this study have several implications for exploration for gold, as well as providing some ancillary data of relevance to exploration for other commodities. Some aspects of the data are a little difficult to assess in the absence, at this stage, of appropriate values for the background abundances of the elements associated with the mineralization. This is being addressed by study of some almost barren fresh and weathered porphyries and ultramafic rocks in a similar geological setting about 1 km N of the Mystery Pit.

In general, the data presented in this report support the contention that at local to sub-regional scales, gold itself is one of the best indicators of gold mineralization, despite (or perhaps because of) its chemical mobility during weathering. The principal proviso to this observation is that sampling must take into account the distribution of gold in the regolith as exemplified by Mt. Percy and numerous other sites in the Yilgarn Block. In particular, the accumulation of gold in calcareous and ferruginous surface horizons and its depletion for 5 to 20 m below them, implies that sampling has to be carefully directed.

6.2.2 *Soils and lateritic materials*

Primary and saprolitic Au mineralization at Mt. Percy is indicated by a broad superjacent Au anomaly in the soils and lateritic horizons. This anomaly is comprised of gold (i) associated with Fe oxides and presumably accumulated during lateritic weathering and (ii) associated with pedogenic carbonates and accumulated during more recent arid phases, continuing to the present. The distribution of the gold, its partition between the ferruginous and calcareous fractions and the non-recovery of particulate primary gold from these materials (Gedeon and Butt, 1990) suggest that the gold precipitated in more recent calcareous environments is quantitatively more important than that accumulated earlier during lateritization. The absence of a gold enrichment in the massive cuirasse over the talc chlorite ultramafic rocks lends further support to this interpretation. Tungsten and, to a lesser extent, Sb, presumed to be hosted by detrital resistant minerals derived from the mineralized porphyry have accumulated in this cuirasse and any primary gold would be expected to accumulate also. Mt. Percy thus represents another example of the surface expression of Au mineralization being enhanced by the association of Au with pedogenic carbonates. These sites, mostly investigated during the course of this Project, include:

1. Full profile preserved: Bardoc (Freyssinet and Butt, 1988); Callion (Glasson et al., 1988; Llorca, 1989); Mt. Percy (this report); Mulline (Lintern and Butt, 1991).

2. Profile partly truncated: Bounty (Lintern, 1989); Panglo (Lintern and Scott, 1990).

3. Profile truncated and overlain by transported overburden: Mt. Pleasant (Lawrance, 1988); Panglo (Lintern and Scott, 1990).

This association between Au and surficial, pedogenic carbonates seems to be prevalent throughout the southern Yilgarn Block, south of the "Menzies Line" (Butt et al., 1977).

Mineralization is also indicated by high concentrations of other ore-associated elements in the surface horizons, principally W, Sb, and As. These are all present at concentrations similar to those in laterites at some other deposits (e.g., Mt. Gibson) but do not appear to have wider or more consistent dispersion haloes than Au. From the limited data available, it appears that K contents give a surface expression to the alteration zones, commonly wider targets than mineralization itself, and also offer potential for detection by radiometric surveys.

6.2.3 *Mottled and plasmic clay zones*

These are the horizons with the lowest Au contents and contain the "depleted zone" present over most Au deposits in the Yilgarn Block. The thickness of the depletion is less than in many other deposits, in which it extends deep into the saprolite, but the presence of the depletion illustrates the care that must be taken when sampling the top 3-20 m of the regolith - i.e. in the mottled and plasmic clays and the upper saprolite. Gold contents in the depleted zone are generally < 100 ppb, even where there are quartz veins, and give little indication of the underlying mineralization. However, it is important to note that the other ore- and alteration-associated elements Sb, W and, to a lesser extent, As are anomalous through the zone. Similarly, high Ba concentrations are maintained through the clay-rich horizons; although, here, the distribution of Ba reflects that of the porphyries, it will be retained similarly where it is associated with mineralization. These data have particular significance when applied to areas in which the lateritic regolith has been partially truncated and soils are developed on clays and saprolites depleted in gold. Antimony, W, As, K and Ba would be expected to be anomalous even if Au contents have been depleted to near background values. If pedogenic carbonates are present, of course, the depletion may be offset by some surface enrichment.

6.2.4 *Clay saprolite and saprolite*

Gold is present throughout the saprolite at abundances broadly similar to those in the fresh rock. Some concentration and possible lateral dispersion, particularly in the clay saprolite, enhances the weathered expression of the primary mineralization and, of course, has been an exploitable resource in its own right. "Refining" of Au by the loss of Ag during weathering has increased the value of this supergene mineralization. The distributions of the other ore-associated elements generally show greater consistency in the saprolite than in fresh, mineralized bedrock, the homogenization being due to chemical dispersion during weathering. Dispersion is greatest in the mid to upper saprolite and clay saprolite, with the most pronounced effects and greatest concentration shown by Sb. The sample distribution does not permit proper assessment of the extent of lateral dispersion within the saprolite. However, As, Sb and K are homogenized over 5-10 m in the mineralized porphyries and fuchsitic ultramafic rocks, and high Sb and W concentrations extend up to 35 m and 15 m, respectively, into the clay saprolites developed over the talc chlorite ultramafic rocks.

The precipitation of alunite in the mid to upper saprolite is a feature that has possible exploration significance. As indicated by the S distribution, it occurs directly above the sulphidic mineralization in the porphyries and fuchsitic ultramafic rocks. Sulphur, and therefore alunite, is at low concentrations (0.125-0.25% S) in equivalent horizons over the unmineralized, sulphide-free, K-poor, talc chlorite rocks. This distribution thus suggests a genetic link between alunite and underlying primary sulphides, analagous to that between pedogenic carbonates and Ca-rich bedrock, but the mechanism involved, and the timing, are not known. However, sulphur is a very labile component in the present environment. Sulphur accession is presumed to occur in the form of aeolian gypsum, probably derived from the deflation of playas, and thin gypsiferous horizons are present in many soils in the region. It is possible, therefore, that S in the alunite also has an exotic source and its presence and location in the regolith are related to factors such as permeability, availability of K, depth of water-table and redox conditions, now or in the past, rather than to the presence of sparse disseminated sulphides at depth. This question may be resolved by study of the background area north of the Mystery Zone and data from equivalent sites elsewhere, and possibly by determination of sulphur isotope ratios.

6.3 Lithological Discrimination

The identification of the fresh parent rocks from their weathering products by geochemical means depends largely on the presence of diagnostic immobile elements, or elements immobilized in resistant minerals. Ratios and plots of Ti, Zr and Cr contents are commonly effective in discriminating between the major lithological groupings, whether fresh or moderately weathered, although distinctions *within* the groups may have to rely on some specific geochemical characteristics. This is the situation at Mt. Percy. Fresh porphyries and ultramafic rocks are readily distinguished on Ti-Zr plots (Figure 5), by high concentrations in the porphyries of several minor and trace elements, including Ba, Hf, Nb, Ta, Th and REE, and by high concentrations in the ultramafic rocks of Cr, V and Sc (see section 4.4). These characteristics are retained throughout most of the regolith, excluding the ferruginous lateritic horizons and soils, although dispersion of the REE in the lower saprolite suggests that these elements may not always be reliable for rock identification. The Ti-Zr plots show increasing abundances of both elements over all lithologies higher in the regolith, reflecting their relative accumulation during weathering (Figure 15).

Discrimination between different unweathered ultramafic rocks is less readily made; there are complete overlaps in plots of Ti, Zr and Cr, and between the K contents of the biotitic and fuchsitic rocks. However, in the regolith, the relative resistance of fuchsite (chromian muscovite) compared to biotite results in K content being diagnostic. The fuchsitic rocks generally contain more than 5000 ppm K_2O (Figure 16); the initial abundance will have been dependent on the degree of alteration, so there is no absolute minimum value.

Lithological discrimination is far less distinct in the upper regolith. The scatter in the Ti-Zr plots is greater in the mottled and plasmic clays over the porphyries than in the ultramafic rocks, presumably due to chemical and physical mixing in these upper horizons, perhaps coupled with greater initial heterogeneity due to ultramafic xenoliths. Discrimination is more difficult still in the lateritic gravels, duricrust and massive cuirasse, and the soils derived from them. This is seen in the Ti-Zr and V-Zr plots in Figures 15 and 17, which demonstrate a marked increase in Ti and V contents and Ti/Zr and V/Zr ratios in these materials, especially over the porphyries and talc chlorite rocks. The allocation of the parent rock to these materials was based largely on their position relative to the upward projection of the unit and may be in error. However, it does not appear that the poor discrimination is due only to mis-allocation. Possible explanations include one or more of: mixing during profile evolution and erosion, coincidentally localized high initial abundances of Ti and V, preferential relative or absolute accumulation and retention of Ti and V compared to Zr, or preferential loss of Zr.

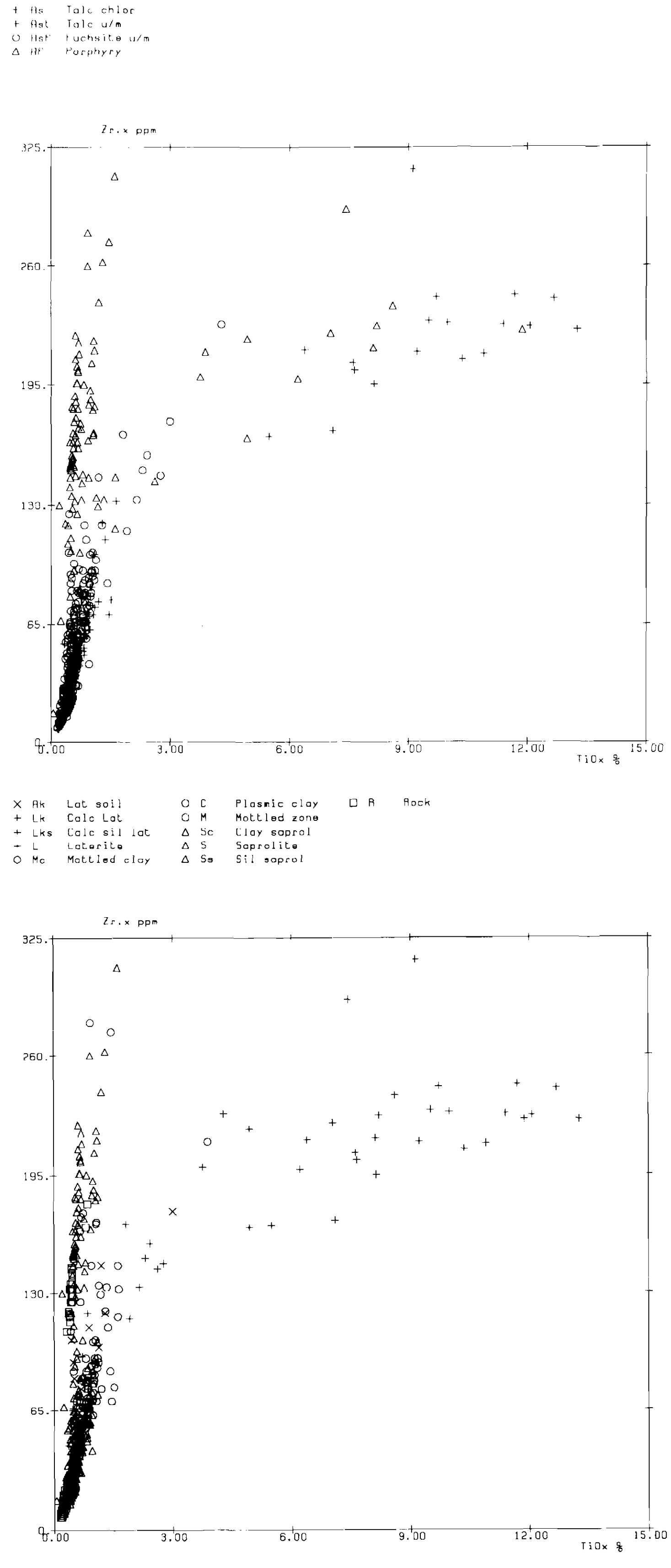


Figure 15. TiO_2-Zr plots illustrating TiO_2 enrichment and loss of discrimination between porphyries and ultramafic rocks in lateritic duricrusts, gravels and soils.

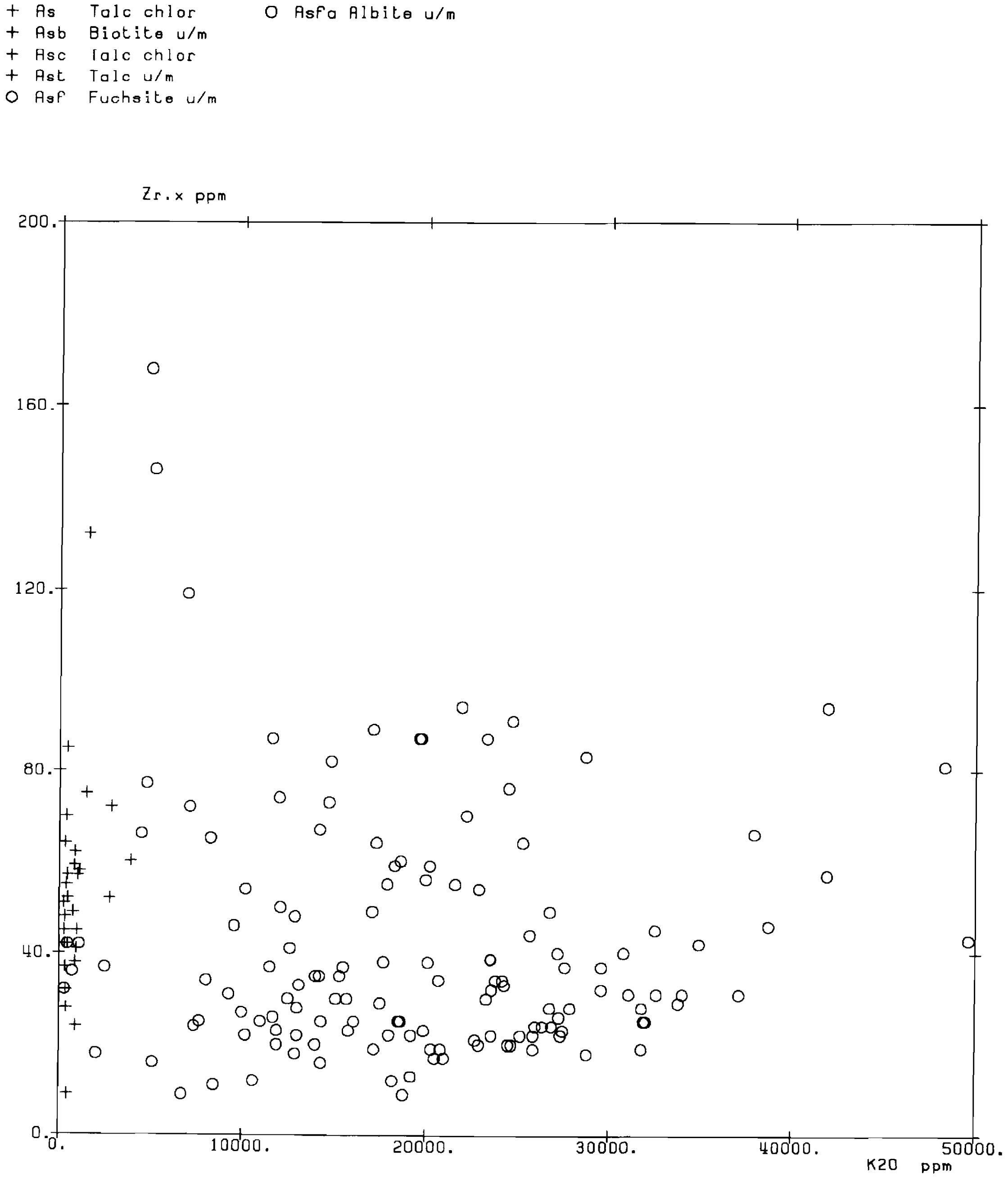


Figure 16. K_2O-Zr plot illustrating disrimination between talc chlorite ultramafic rocks and fuchsite-altered ultramafic rocks in the regolith (data from Section 15900N only).

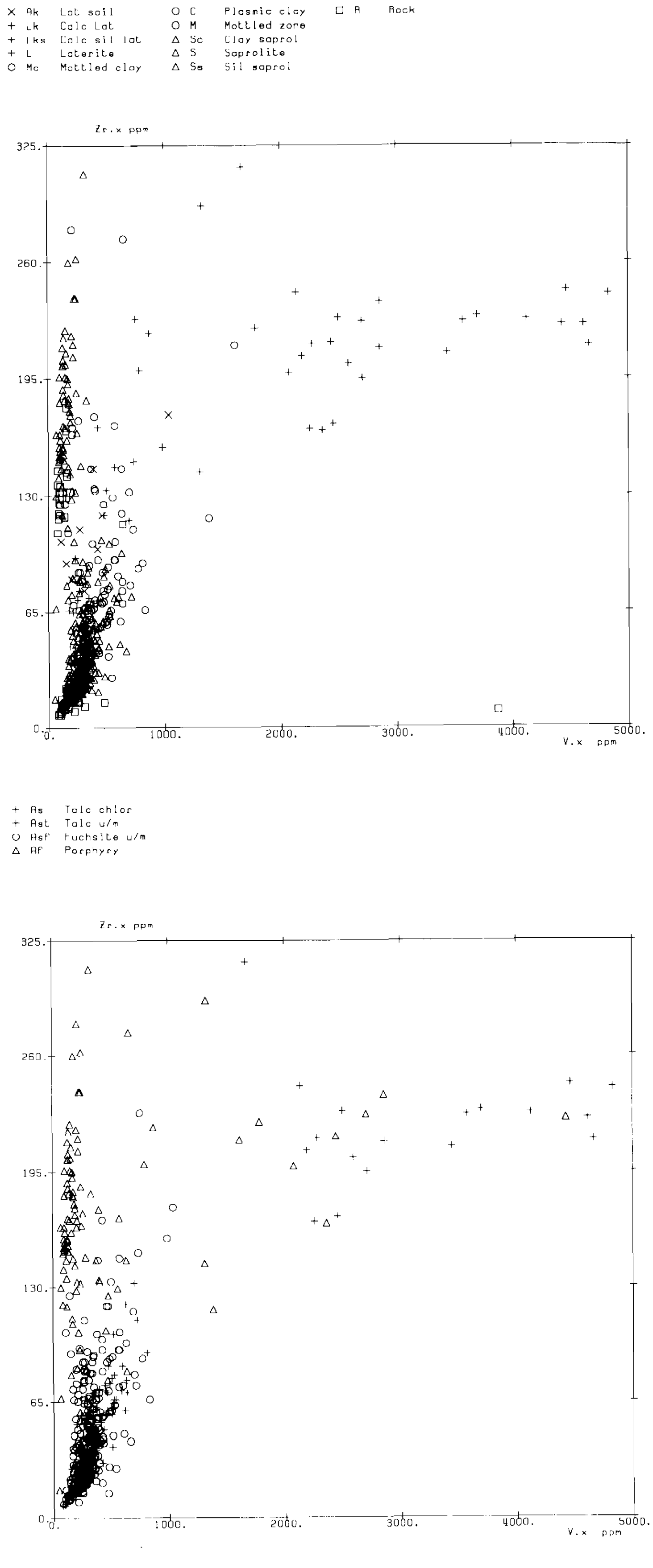


Figure 17. V-Zr plots illustrating V enrichment and loss of partial discrimination between porphyries and ultramafic rocks in lateritic duricrusts, gravels and soils.

7.0 ACKNOWLEDGEMENTS

The research was only possible with the assistance and advice of P.C.C. Sauter (KCGM), in particular for his careful supervision of sample collection. Sample preparation was by G.D. Longman, R.J. Bilz, and J.F. Crabb. XRF analyses were performed by M.K.W. Hart, with assistance from I.D.M. Robertson, ICP analyses by J.E. Wildman and G.D. Longman and AAS analyses by K.A. Howe and M.J. Willing. XRD data were collected by M.K.W. Hart and A. Horne. Much of the data processing and plotting has been carried out using a demonstration copy of the GDM program, supplied by the BRGM, Orleans, France. The assistance of D.J. Gray, A.Z. Gedeon and the BRGM in the implementation and use of this software is acknowledged. Additional drafting and artwork was by A.D. Vartesi. I.D.M. Robertson is thanked for valuable discussion during the course of the research and for his comments on the manuscript. J.J. Porter assisted with formatting the final document.

REFERENCES

Baes C.F. and Mesmer R.E., 1976. The hydrolysis of cations. John Wiley, New York, 487 pp.

Butt, C.R.M., 1987. Dispersion of gold in the weathered zone, Yilgarn Block, Western Australia. In: Meaningful sampling in gold exploration. Bulletin 7. Australian Institute of Geoscientists, pp. 27-53.

Butt, C.R.M., 1989. Genesis of supergene gold deposits in the lateritic regolith of the Yilgarn Block, Western Australia. In: R.R. Keays, W.R.H. Ramsay and D.I. Groves (Editors), The geology of gold deposits: the perspective in 1988. Economic Geology Monograph 6, Economic Geology, New Haven, pp. 460-470.

Butt, C.R.M., Horwitz, R.C.H. and Mann, A.W., 1977. Uranium occurrences in calcretes and associated sediments in Western Australia. Report FP16. CSIRO Australia, Division of Mineralogy, Perth, pp. 67.

Butt, C.R.M. and Nickel, E.H., 1981. Mineralogy and geochemistry of the weathering of the disseminated nickel sulfide deposit at Mt. Keith, Western Australia. Economic Geology, 76: 1736-1751.

Freyssinet, P. and Butt, C.R.M., 1988. Morphology and geochemistry of gold in a lateritic profile, Bardoc Mine, Western Australia. Restricted Report, MG 59R. CSIRO Australia, Division of Exploration Geoscience, Perth, 19 pp. (Unpublished).

Frondel, C., 1978. Scandium. In: K.H. Wedepohl, Handbook of Geochemistry, Volume II-2, Section 21. Springer-Verlag, Berlin.

Gedeon, A.Z. and Butt, C.R.M., 1990. Morphology and geochemistry of particulate gold in the lateritic regolith, Mystery Zone, Mt. Percy, Kalgoorlie, Western Australia. Restricted Report, 124R. CSIRO Australia, Division of Exploration Geoscience, Perth, 41 pp. (Unpublished).

Glasson, M.J., Lehne, R.W. and Wellmer, F.W., 1988. Gold exploration in the Callion area, Eastern Goldfields, Western Australia. Journal of Geochemical Exploration, 31: 1-19.

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

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

Lintern, M.J., 1989. Study of the distribution of gold in soils at Mt. Hope, Western Australia. Restricted Report, 24R. CSIRO Australia, Division of Exploration Geoscience, Perth, 17 pp. (Unpublished).

Lintern, M.J. and Butt, C.R.M., 1991. The distribution of gold and other elements in soils at Mulline, Western Australia. Restricted Report 159R. CSIRO Australia, Division of Exploration Geoscience, Perth, 58 pp. (Unpublished).

Lintern, M.J. and Scott, K.M., 1990. The distribution of gold and other elements in soils and vegetation at Panglo, Western Australia. Restricted Report, 129R. CSIRO Australia, Division of Exploration Geoscience, Perth, 50 pp. (Unpublished).

Llorca, S.M., 1989. Mineralogy and geochemistry of the Glasson gold deposit, Callion, Yilgarn Block, Western Australia. Restricted Report, 58R. CSIRO Australia, Division of Exploration Geoscience, Sydney, 21 pp. (Unpublished).

Mann, A.W., 1984. Mobility of gold and silver in lateritic weathering profiles: some observations from Western Australia. Economic Geology, 79: 38-49.

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

Sauter, P.C.C., Hyland, S.J. and Bradley, T., 1988. The Mount Percy gold mine. In: D.I. Groves, M.E. Barley, S.E. Ho and G.M.F. Hopkins (Editors), Western Australian Gold Deposits. Bicentennial Gold 88 Excursion Guidebook. Geology Department and University Extension, Publication No.14. University of Western Australia, pp. 84-86.

Smith, B.H., 1977. Some aspects of the use of geochemistry in the search for nickel sulphides in lateritic terrain in Western Australia. In: C.R.M. Butt and I.G.P. Wilding (Editors), Geochemical exploration 1976. Journal of Geochemical Exploration, 8: 259-281.

Travis, G.A., Woodall, R. and Bartram, G.D., 1971. The geology of the Kalgoorlie goldfield. In: J.E. Glover (Editor), Symposium on Archaean Rocks. Special Publication 3. Geological Society of Australia, Sydney, pp. 175-190.