

GEOLOGICAL SURVEY  
OF  
WESTERN AUSTRALIA  
REPORT 8

A STUDY OF LATERITE PROFILES  
IN RELATION TO BED ROCK  
IN THE DARLING RANGE NEAR PERTH, W.A.

by R. Davy



1979

## REPORT 8

vincentius 507 771 500221

John Andrew McFarland  
 Director

## by R. Davy

Issued under the authority  
of the  
Hon. Andrew Mensaros M.L.A.  
Minister for Mines

## FOREWORD

This report describes the chemical and mineralogical changes through laterite and bauxite profiles in the Darling Range near Perth. The purpose of the investigation was to determine whether the nature of the underlying bed rock could be recognized by sampling the surface laterite, and if so, to consider how this information could be used for prospecting purposes.

Though the conclusions are limited because of the small number of profiles samples, they suggest that it should be possible to distinguish dolerite and other mafic rocks from felsic granites and gneisses when the overlying laterites are residual, and study has suggested a number of elements which are of possible use to prospecting through laterite.

The study represents a significant contribution to the literature on laterites and on prospecting in lateritic terrains. It should provide a basis for exploration geochemistry programmes in this type of environment, particularly in the southwest of the State.

J.H. Lord  
DIRECTOR  
2 May 1979



## CONTENTS

Summary . . . . .	1
Introduction . . . . .	2
Usage of terms . . . . .	2
Choice of profiles . . . . .	3
Methods . . . . .	6
Collection of samples . . . . .	6
Sample treatment . . . . .	6
Mineralogical analysis . . . . .	6
Chemical analysis . . . . .	6
Results . . . . .	7
Residual laterite profiles . . . . .	7
Mafic rocks . . . . .	7
Granitoids . . . . .	8
Schists . . . . .	8
Metasediments and sedimentary rocks . . . . .	9
Heavy-mineral studies . . . . .	9
Transported laterite profiles . . . . .	10
Discussion . . . . .	10
Residual lateritic profiles . . . . .	10
Weathering and bed-rock type . . . . .	11
Soil pH . . . . .	11
Behaviour of elements and oxides in laterite profiles . . . . .	12
Oxide and element ratios . . . . .	13
Origin of exotic minerals . . . . .	14
Origins of the profiles . . . . .	14
Identification of bed rock below laterite . . . . .	15
Surface indications of bed rock mineralization . . . . .	17
Transported lateritic profiles . . . . .	17
Conclusions . . . . .	18
Acknowledgements . . . . .	19
References . . . . .	87

## TABLES

Table 1	Key to profiles sampled	5
2(a-r)	The chemical and mineralogical composition of samples, grouped by profiles	20-38
3(a-c)	Comparison of minerals obtained from heavy fractions	39-42
4	Correlation coefficients between constituents in residual cap rock and bed rocks, and their significance.	43
5	Table showing approximate enrichment factors from bed rock to cap rock in residual laterites, expressed as cap rock/bed rock ratios.	44

## ILLUSTRATIONS

Figure 1	Diagrammatic section to illustrate components in a residual laterite profile (GSWA 16947)	2
2	Localities of laterite profiles sampled (GSWA 16948)	4
3(a-r)	Geochemical profiles (GSWA 16949)	45-71
4(a-r)	Mineral profiles (GSWA 16950)	72-85
5(a-d)	Scatter diagrams (GSWA 16951)	86

# A STUDY OF LATERITE PROFILES IN RELATION TO BED ROCK IN THE DARLING RANGE NEAR PERTH, W.A.

## SUMMARY

Eighteen laterite profiles, some bauxitic, from the Darling Plateau east of Perth have been studied chemically and mineralogically.

The residual nature of fifteen has been confirmed, though exotic heavy minerals have been found in the cap rock of many profiles. The laterite in these profiles formed as part of a single, continuous, essentially isovolumetric replacement process. Local chemical and climatic variations, together with the nature of the parent rock, have played some part in determining whether iron-rich laterite or bauxite were formed. There was an almost complete leaching of  $\text{Na}_2\text{O}$  and  $\text{CaO}$ , partial leaching of  $\text{MgO}$  and  $\text{K}_2\text{O}$  (depending on whether muscovite and/or illite is retained in the profile) and considerable loss of  $\text{SiO}_2$  (particularly from aluminosilicates). Relative to the parent rock there was an absolute gain in  $\text{H}_2\text{O}$ , and apparent increases in  $\text{Al}_2\text{O}_3$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{TiO}_2$  and V in the laterite of all profiles. As, Mo, Nb, Sn, Th, and Zr are normally concentrated in the upper parts of the profiles. Ba, Sr, and Zn are commonly lost, whilst the behaviour of Cu, Co, Ni, and Pb, is variable in the different profiles.

The profiles show no condensed sequences, and individual rock types are traceable geochemically, but with increasing difficulty, from bed rock to the surface.

The proportion of residual quartz, together with absolute values for  $\text{Al}_2\text{O}_3$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{TiO}_2$ , Cu and V (and to some extent  $\text{SiO}_2$ ,  $\text{K}_2\text{O}$ , Th, and Zr), in the cap rock can be used to identify bed rock. It is feasible to distinguish mafic from felsic igneous rocks, but more difficult to separate profiles over felsic igneous rocks from profiles over gneisses and metasediments by use of these constituents.

The results suggest that As, Cu, V, Mo, Sn, and Nb are concentrated in the cap rock of residual laterites and can be used as indicators of mineralization.

Three profiles through transported laterite at the Lower Wungong dam site were studied from diamond-drill core. The transported part of the profile proved to be only 1 to 2 m thick, and the underlying weathered material was saprolite. The properties of the transported material conceal the nature of the bed rock, and the parameters of the surface material referred to above as indicating the nature of the bed rock do not apply.

In any attempt to identify bed rock by a study of surface laterite, a prior selection of residual laterite must be made.



Laterite and bauxitic laterite overlie and obscure bed rock in much of the South West Land Division of Western Australia. Few workers have attempted to predict the underlying bed rock in other than the most general terms. Most previous work on laterite profiles has been carried out by soil scientists and geomorphologists who have been more interested in the effects of lateritization on agriculture than in predicting the nature of the bed rock.

The present work aims to:

- present data on lateritic profiles in the vicinity of Perth,
- consider ways in which the nature of bed rock may be deduced from a study of residual laterite, and
- suggest suitable prospecting aids in lateritic terrain.

Geologists at the Alcoa mine sites at Jarrahdale and Del Park empirically use, on a restricted areal basis, the cap rock texture, and the presence or absence of visible residual quartz to differentiate between bauxite overlying dolerite and bauxite overlying granitic rocks. A relict doleritic fabric in the cap rock suggests underlying dolerite. Gibbsite pisoliths, residual quartz, and apparent feldspar pseudomorphs in the cap rock suggest underlying granitoids (A. Smurthwaite, pers. comm.). It was hoped that this study would identify general mineralogical and chemical parameters in the cap rock which would permit identification of a larger number of bed rock types over a wider geographic area.

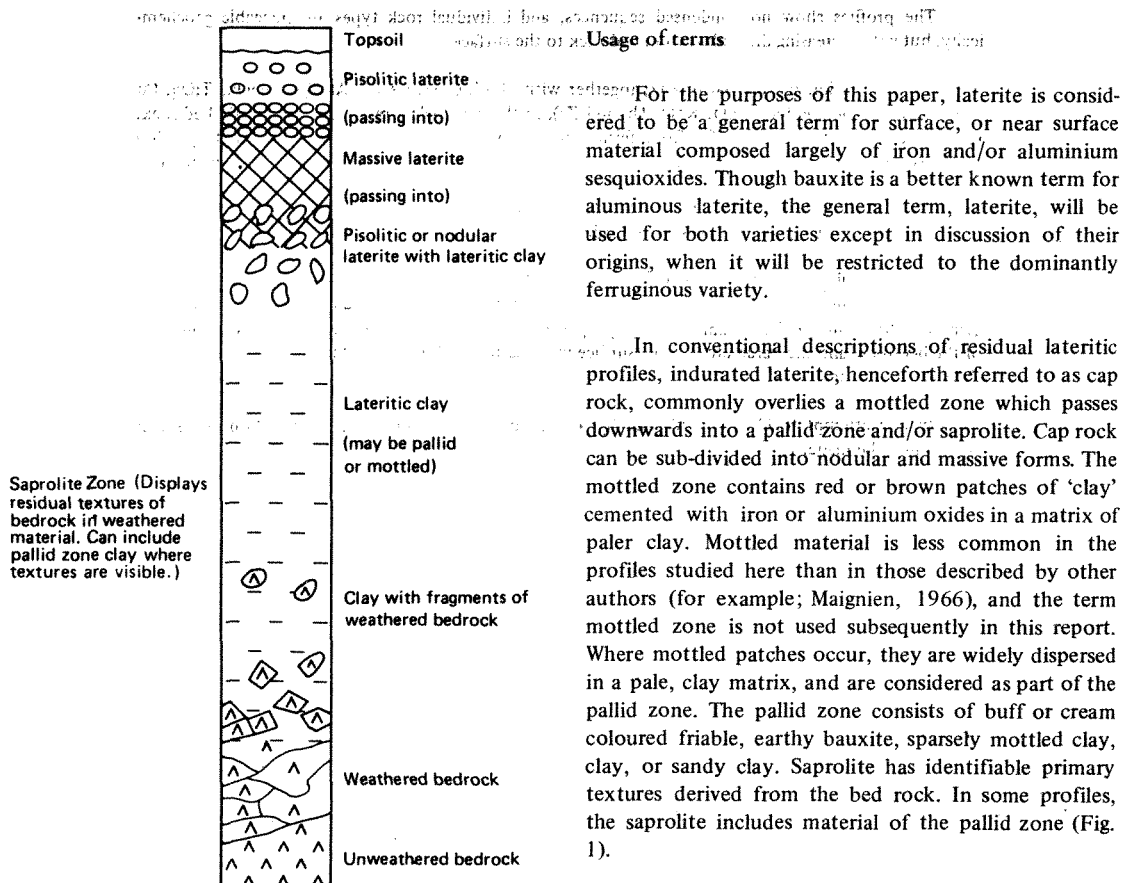


FIGURE 1: DIAGRAMMATIC SECTION TO ILLUSTRATE COMPONENTS IN A RESIDUAL LATERITE PROFILE

G.S.W.A. 16947

The differences between residual and transported laterites have not been adequately described, and differences between the two types are somewhat empirical.

For the purposes of this report transported and residual laterites were separated using the following criteria:

Residual laterite	Transported laterite
i) upland, flat lying or low slopes (to 10°)	steep slopes
ii) retention of (some) primary textures, structures or minerals	conglomeratic or brecciated, two or more phases of formation
iii) generally have massive zone	generally less massive, may have clay admixture from sub-laterite profile
iv) commonly overlie pallid or saprolite zone	may be over any subsurface material including fresh rock
v) limited stratification, relatable to pedogenetic processes	stratification, where present, relatable to creep and erosion

### Choice of profiles

The project was initially restricted to a study of residual lateritic profiles, but, for comparison, it was extended to include three profiles through transported laterite. In all, eighteen profiles over seven different bed rock types were sampled. The choice of profiles was restricted by the limited availability of complete profiles through residual laterite to bed rock.

The profiles sampled are identified in the attached table (Table 1). All are located on either the Perth or Pinjarra 1:250 000 sheets, (Fig. 2).

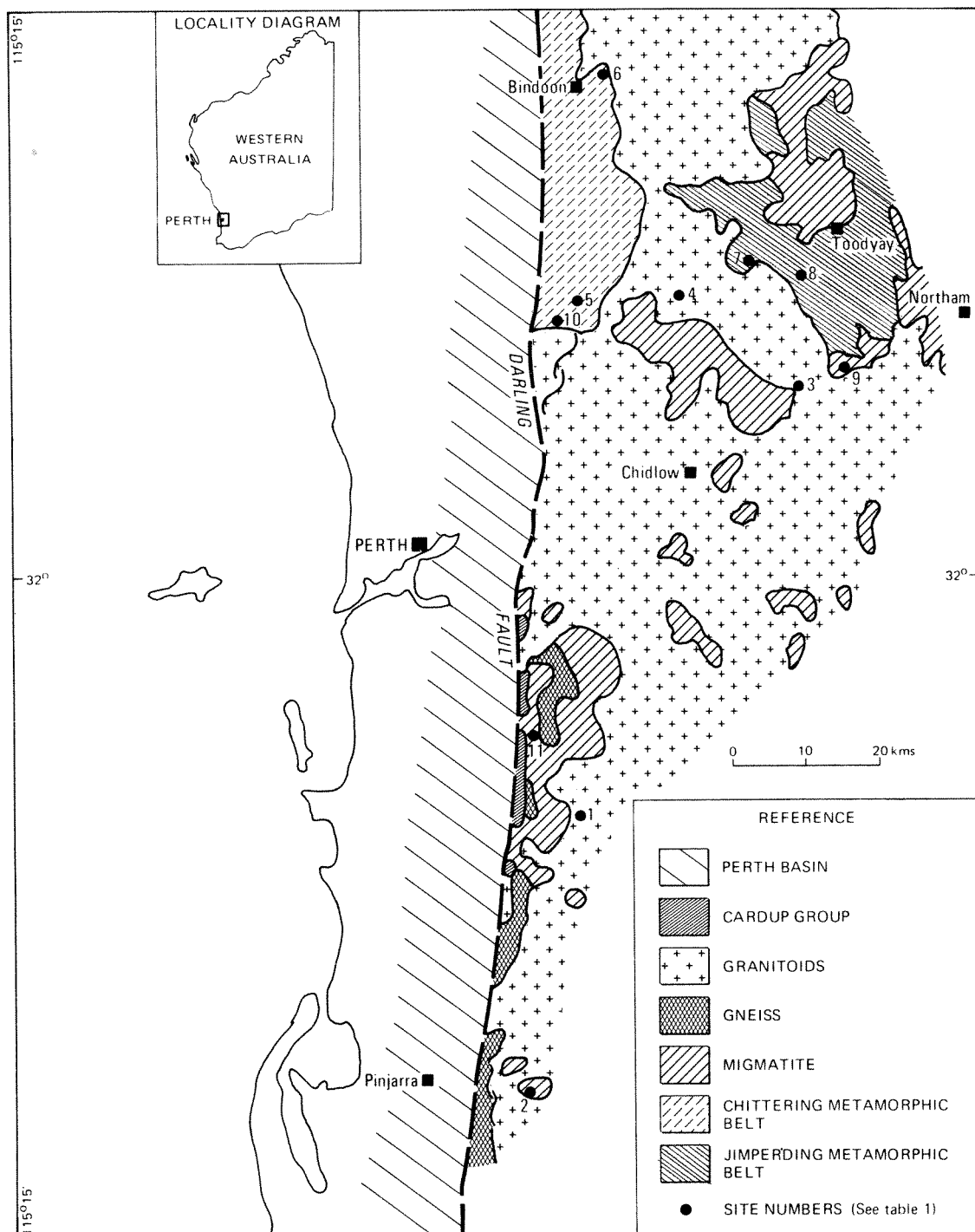


FIGURE 2: LOCALITIES OF LATERITE PROFILES SAMPLED

TABLE 1 Key to profiles sampled

Bedrock	Site Number	Site Name	Location A.T.M. Co-ordinates	Nature of profile	Designation of profile	Profile situation	Total Profile thickness (m)	Comments
Dolerite	1	Jarrahdale	4103 0048	Residual	A	Mine face	2.65	
	1	Jarrahdale	4125 0070	Residual	B	Mine face	1.8	Alcoa co-ordinates 2011
	1	Jarrahdale	4093 0066	Residual	C	Railway cutting	8.8	Alcoa co-ordinates 3939
	2	Del Park	4020 9655	Residual	D	Mine face	1.6	Alcoa co-ordinates 2732 Profile includes narrow oblique shatter zone
Gabbro	3	Coates Siding	4427 0734	Residual	E	Percussion cuttings	64	Peg 265, line 10800
Adamellite	1	Jarrahdale	4102 0048	Residual	F	Mine face	3.3	Alcoa : 52.3 m on bearing 271° from peg 3705
	1	Jarrahdale	4103 0047	Residual	G	Mine face	5.0	Alcoa : 85 m on bearing 261° from peg 4111
	4	Bald Hill	4268 0912	Residual	H	Breakaway	6.2	No exposure, pallid zone
Mica schist	5	Bowgale (Midland Brick Co. Chittering)	4078 0892	Residual	I	Quarry	5.05	
Mica schist	5	Bowgale (Midland Brick Co. Chittering)	4078 0893	Residual	J	Quarry	16.5	
Mica schist	6	Stephens Rd	4169 1192	Residual	K	Cliff face	32	Profile included lateritized dolerite dyke at 12 m
Andalusite—mica schist	7	Jimperding	4342 0916	Residual	L	Quarry	4.3	
Quartzite	8	Toodyay	4451 0932	Residual	M	Breakaway	0.65	Pallid zone absent
Banded Iron — Formation	9	Clackline	4510 0765	Residual	N	Hill outcrop	30—35	No exposure, pallid zone. Cap rock and bed rock offset
Silty Sandstone	10	Bullsbrook East	4047 0848	Residual	O	Road cutting	1	Pallid zone absent
Granitoid	11	Wungong	4070 0175	Transported	P	Diamond drill core	14.9	Diamond drill hole G. 44
	11	Wungong	4071 0177	Transported	Q	Diamond drill core	14.6	Diamond drill hole G. 58
Dolerite	11	Wungong	4063 0169	Transported	R	Diamond drill core	13.1	Diamond drill hole G. 111

## METHODS

### Collection of samples

Samples were collected from uncontaminated material at intervals in the profile corresponding to colour or textural changes. In the case of quarry faces, there was no difficulty in obtaining suitable material free from any contaminant. On natural faces and at profile C at Jarrahdale, soil and rock creep covered part of the profiles. In some cases (for example, at Bald Hill, Site 4) only cap rock and underlying bed rock could be sampled. Elsewhere, soil was cleared for a depth of up to 1 m before a sample could be selected.

Where rock types or bands inclined obliquely to the surface, the profile was sampled accordingly (up dip). This applied to the schist profiles (profiles I–L) and to the dolerite (profile C) in the Jarrahdale railway cutting.

One to two kilograms of material were collected from each sampling site in each profile, using composites of roughly equal-sized pieces of rock, or extended lateral channel-samples in the softer clays of the pallid zone.

### Sample treatment

A representative portion of each sample was split off and retained for reference purposes.

After surface-weathering and lichen had been cut from the more massive material, the remainder of each sample was dried at 40°C and put through a jaw crusher. The crushed pulp was coned and quartered until approximately 200 g of material was obtained. This portion was ground in a 'Rocklabs' ring mill for 20 seconds.

The ground material was split into four parts. One part was submitted for X-ray diffraction analysis, a second for X-ray fluorescence (XRF) and wet chemical analysis, and a third used for atomic absorption analysis; the fourth part was used to investigate the heavy mineral fraction.

### Mineralogical analysis

Sample material was submitted to the Western Australian Government Chemical Laboratories for X-ray diffraction analysis. Determinations (by L.V. Bastian) were carried out on a Philips PW 1130 generator and diffractometer using a scan speed of 2° per minute. A small number of samples were re-examined specifically for corundum (following Grubb 1971), but none was identified.

Samples from the cap rock and bed rock of each profile were subjected to heavy-mineral separation and examination. Each sample was deslimed by wet sieving. Plus 200-mesh material was dried and separated into a light and heavy fraction using bromoform (S.G. 2.89 at 20°C). The heavy fraction of the cap-rock material was strongly iron-stained and/or contained free iron (hydr)oxides. Magnetic material was removed with a hand magnet, and the remainder was boiled with 8N hydrochloric acid to facilitate examination of the transparent minerals. No attempt was made to compare the proportions of heavy minerals from the bed rock with those of the cap rock, because these procedures involved chemical dissolution.

### Chemical analysis

Most of the determinations were carried out by the Western Australian Government Chemical Laboratories, although Na<sub>2</sub>O, Cu, Pb, Zn, Ni, Co, Sr, and Ba were determined at the Geological Survey by atomic absorption analysis following an HF-HClO<sub>4</sub>-HCl acid extraction.

The Chemical Laboratories used conventional analytical techniques (mainly XRF) for the determination of major components, and As, Mo, Nb, Th, V, and Zr. FeO was determined by titration with potassium dichromate. Loss on ignition is reported as water since no trace of carbonate minerals was found. Ga, Y, La, and Ce, were determined spectrographically by the Chemical Laboratories but were not identified above their detection limits using this technique.

The pH of soil samples was determined with a Metrohm E280A pH meter, after stirring one part of the finely ground sample with five parts of distilled water for a standard period of one minute.

## RESULTS

The results of chemical analyses, pH determinations and mineralogical investigations are presented as individual profiles in Tables 2a–2r. Visual graphical portrayals of the same data are given in Figures 3a–3r and 4a–4r. Comparison data on the nature of heavy minerals present are given in Tables 3a–3c.

### RESIDUAL LATERITE PROFILES

#### Mafic rocks

**Dolerites:** In all four profiles in residual laterite over dolerite (Tables 1, 2a–d, Figs. 1, 3a–d, 4a–d), the mineralogy of the fresh rock is plagioclase and hornblende-tremolite-actinolite with subordinate quartz and accessory sphene or ilmenite. The chemistry of the dolerite is consistent with low-K tholeiitic mafic rocks categorized by Hallberg (1972), Hallberg and Williams (1972), and Davy (1978), for the eastern part of the Yilgarn Block.

The sodium content is normal for tholeiites, and is in the range of 2–3% Na<sub>2</sub>O. A figure of 2.1% Na<sub>2</sub>O for the dolerite of the railway cutting, Jarrahdale, (profile C), differs markedly from a figure of 6.2% given by Sadleir and Gilkes (1977) for rock from the same exposure.

The dolerites have higher vanadium contents than similar rocks in the Eastern Goldfields. Copper is very variable; 35 ppm was recorded in a dyke exposed in a roadside cutting on the South Dandalup to Dwellingup road (GSWA 42450, unpublished data), and 325 ppm in the rock sampled in profile A, at Jarrahdale.

The profiles over dolerite are characterised by a rapid change from bed rock to highly altered rock over a few millimetres. Weathering of dolerite tends to produce rounded, residual boulders of fresh dolerite in the weathered profile. The contact between fresh rock and weathered rock is sharp, and the rock appears to be fully altered within 5 cm, where all 'primary' minerals except quartz (and, in some places, ilmenite) have been lost. This abrupt transformation is apparently characteristic of mafic rocks, and was first noted by Harrison (1933).

Sadleir and Gilkes (1977) report that halloysite occurs with kaolinite in the weathered part of the profile over the dolerite in the railway cutting at Jarrahdale. Though there is no reason to doubt its presence in this, and other profiles, the Government Chemical Laboratories were unable to effect an identification of halloysite in the GSWA samples. This was probably due, in part, to the method of sample preparation.

Kaolinite (and halloysite) are absent from profile B, at Jarrahdale and the sesquioxides of the lateritic profile appear to have formed directly from the primary minerals without having passed through a clay stage.

The pH obtained from the dolerites was in the range 7.5–9.5. The greatest change takes place between the fresh dolerite and its weathered skin where there is a pH drop of the order of two units. Between the weathered skin and the cap rock, the pH decreases slightly, with a value of 5.2–5.5 in the cap rock. An exception occurs in profile D where the clay at 0.8–0.9 m depth has a pH of 6.1–6.2. Loose soil overlying the cap rock is usually more alkaline than the adjacent cap rock.

**Coates Siding gabbro:** The Coates Siding gabbro (Site 2, Fig. 2) ranges in composition from anorthosite to melanocratic, magnetite-rich gabbro (Baxter, in prep.). The profile sampled for this study overlies magnetite-free leucogabbro, and contrasts with the results for the magnetite-bearing gabbro and associated transported laterite reported by Hudson (1967).

The leucogabbro appears chemically related to the dolerites reported in the last section, though the mineralogy is markedly different (Table 2e, Figs. 3e, 3c). The vanadium content of the leucogabbro is low in contrast to the mean values for the mineralized melanocratic gabbro (0.54% V<sub>2</sub>O<sub>5</sub>) reported by Jones (1965, p. 155).

The profile was sampled through percussion hole cuttings. The hole, drilled in 1969, was sited at peg 265, line 10800 on the Garrick-Agnew exploration grid. The cuttings had been bagged in 3.1 m (10 ft.) lengths.

This lateritic profile, approximately 40 m to fresh bed rock, was the thickest sampled. The transition from fresh bed rock to secondary products is not as marked as for the dolerites.

## Granitoids

The bed rock below the three residual profiles over granitoids (Tables 1, 2f–h, Figs. 2, 3f–h, 4f–h) is adamellite, near the adamellite-granodiorite border.

The full lateritic profile seems to have developed over a vertical distance of up to two metres. This contrasts with the sharp change in the profiles over dolerite. Even in the freshest granitoid, there is minor alteration in the form of incipient kaolinization of feldspar and chloritization of biotite. The dominant control of weathering appears to be the presence of sheet joints. Below these joints, the rock is little altered, above, alteration is much more severe. Only one major sheet joint was visible at the sites sampled.

Detritus prevented collection of pallid zone material at Bald Hill (Site 4).

Kaolin-group minerals are absent from the two Jarrahdale profiles, (F and G) though a small proportion of these are present in the cap rock at Bald Hill. Alteration at Jarrahdale is apparently direct from feldspar to gibbsite, from biotite to goethite.

Relict quartz was identified in the hand specimens of all cap rock samples. Some vugs in nearby cap rock were lined with secondary quartz.

The pH of fresh granitoids is lower than that of the dolerites. These profiles show their most acid reaction in the pallid zone.

## Schists

Four profiles over mica schist were sampled (Tables 1, 2i–l, Figs. 2, 3i–l, 4i–l). The schist at Site 7 (Jimperding) contained prominent andalusite.

None of the schists sampled was entirely fresh. In all the bed-rock samples, kaolinite was present, and the profile appeared gradational over a distance of several metres, from schist through a pallid zone to cap rock. There appears to be no control by joints, and the permeability along cleavage or planes of schistosity probably controls the extent of weathering.

An occurrence of microcline near the top of profile I from 'Bowgale' (Site 5) is of particular interest. Its presence at that point is unusual when the degree of weathering in the profile is considered. The microcline may either be authigenic or may have had an exotic, detrital origin.

The lateritized dyke (sample GSWA 42388) in the profile at Stephens Road, Bindoon (Site 6), proved out of character with the rest of the profile (Table 2k, Figs. 3k, 4k) though consistent with the lateritized dolerites from Jarrahdale and Del Park. The lateritized schist profile above and below the dyke appears uncontaminated by the dyke.

The chemistry of the profiles over schist is less systematic than of those over mafic or felsic rocks, despite samples being collected in the same lithological unit, or, where clearly defined lithological units were not obvious, along narrow zones adjacent to a persistently recognisable plane of schistose foliation. This must be due in part to the lack of uniformity of the parent-rock chemistry; there are appreciable differences in the chemistry of the schists over small distances (Table 2k, GSWA nos. 42385, 42386).

The pH in the profiles over schist is more erratic than in those over dolerite or granitoid. The lateritized dolerite dyke at Bindoon has a pH one unit lower than adjacent, bleached, mica schists (Table 2k). The pH of 4.3 from a sample of the fresh schist from Bowgale (GSWA 42371B, Table 2i) is ascribed to the presence of small amounts of partly oxidized pyrite.

### Metasediments and sedimentary rocks

Profiles M and N (Table 1, Fig. 2) overlie metasedimentary rocks (quartzite and banded iron formation respectively) and profile O overlies unmetamorphosed Cretaceous, silty sandstone. Data obtained are presented in Tables 2m-o, and Figures 3m-o, 4m-o.

The quartzite and silty sandstone pass over approximately 1 metre, from bed rock to laterite. The quartzite displays abundant close-set joints which facilitate oxidation. It is considered that the fresh rock did not contain enough aluminosilicates for a conventional pallid zone to be formed. The sandstone contains kaolinite and the 'fresh' rock may be partly weathered. Within the small distances involved, the transformation to laterite seems gradual.

There were no means of assessing the control of weathering for the iron formation. The main mineralogical differences were that amphiboles in the bed rock were converted to sesquioxides in the cap rock. This is concomitant with a change from iron in its reduced (ferrous) state in the bed rock, to totally oxidized iron (ferric iron) in the cap rock. This is the one profile with little absolute change in the abundances of silicon or iron from the bed rock to the cap rock.

### Heavy-mineral studies

Heavy-mineral data for the residual profiles are given in Tables 3a and 3b. A comparison of the heavy minerals of the cap rock and of the bed rock is given in Table 3a. Heavy-mineral identifications through the whole of three profiles are given in Table 3b.

There is no evidence to suggest that the heavy minerals in the cap rock of profiles D, E and N have any origin other than in the bed rock beneath. However, there are enough differences between the heavy minerals of the cap rock and the bed rock of the remaining twelve profiles to suggest that there is some exotic material present. On the basis of the detailed study of the three profiles (Table 3b), this exotic material appears to be restricted to the cap-rock zone of the laterite.

Table 3a lists differences in the types of minerals found between the cap rock and the bed rock. It does not distinguish the profiles where different varieties of the same mineral occur.

Though none of the minerals identified in laterite over granitoid rocks is unusual for such rocks, the variety, particularly of zircons, is great. In the uppermost part of the cap rock of profile G (GSWA no. 42413A, see Table 2g) there are three distinct varieties of zircon:



- a) colourless, well rounded or broken rounded, unzoned, 0.1-0.2mm in diameter;
- b) almost opaque metamict grains with euhedral or subhedral bipyramid faces terminating prisms and 0.1 mm long
- and c) medium pink-brown, euhedral to partly rounded, zoned crystals, 0.05-0.3mm long.

The bed-rock adamellite contains only one variety, a dominantly subhedral, colourless, zoned zircon 0.1-0.2mm in diameter.

The heavy minerals in the cap rock and bed rock in the adamellite profile at Bald Hill (Site 4) are closely similar. However, rutile needles occur in profusion in the bed-rock muscovite, but are absent from the cap-rock muscovite.

In the andalusite schist at Jimperding, (Site 7), the cap-rock laterite contains sub-equant, sub-angular, pleochroic andalusite grains with inclusions. Approximately half the grains have colourless rodlike inclusions, and the remainder irregular opaque inclusions. The typical grain size is 0.5mm to 1mm. In the bed rock, opaque inclusions are less common, and occur in only 10-20% of the andalusite grains. The cap rock contains small grains, 0.05mm-0.1mm, of tourmaline, which is pleochroic from colourless to brown-green. Grains are either rounded or occur as euhedral prisms. No tourmaline was identified in the fresh rock.

The cap rock over the quartzite contains two types each of zircon and rutile: pink, and colourless zircon; deep brown, and yellow rutile. Neither zircon nor rutile was identified in the bed rock. Similarly the cap rock at Bullsbrook East (Site 10) contains well-rounded red and brown rutile grains; in the underlying sandstone the rutile is yellow and occurs in angular fragments.

## TRANSPORTED LATERITE PROFILES

Cores through profiles of transported laterite were taken at Site 11, the Lower Wungong dam site (Table 1, Fig. 2). Bed rock underlying profiles P and Q is granitic, that underlying profile R is dolerite though none of the cores terminated in fresh rock. In the latter case a dolerite cropping out subjacent to a drill hole was sampled as the presumed fresh parent rock. The cores passed through transported lateritic material, which was more nodular than massive, through a pallid zone into saprolite with residual textures of parent rock. Later excavations at the dam site have shown that the gneissic granitoids include patches essentially free of quartz; and that the saprolite zone extends to the top of the pallid zone (G. Marcos, pers. comm.). Transported material is restricted to the top 1 to 2 m of the profiles. Details of the geology of the dam site are given by Marcos (1974).

Data on these profiles are presented in Tables 2 p - r, 3c; and Figs 3 p - r, 4 p - r.

## DISCUSSION

### RESIDUAL LATERITIC PROFILES

The data presented here add to the limited data available on laterite profiles, and provide a basis for a scheme to identify bed rock underlying residual laterites by examination of the cap rock. The techniques used are not new. Heavy-mineral studies in the South West Land Division were first carried out by Carroll (1932; 1942; 1944a\*, b) and Carroll and Jones (1947). Terrill (1950) provided the first comparison, in Western Australia, of the major element chemistry of bedrock and laterite (for dolerite at Mount Helena and Parkerville).

This is the first time, however, that the cap rock of the laterite has been systematically studied for mineralogical and geochemical evidence concerning the underlying rock.

\*Carroll (1944a) studied heavy minerals, the copper content and pH of soils in the Bullsbrook East area, though her sample sites have not been related to the profile reported in this study.

It is recognised that with data from only fifteen profiles, over various types of rock, an infallible interpretation is not possible, but it is believed that a useful framework for further development is possible. The usefulness of any interpretation is restricted to parts of the Perth and Pinjarra Sheets. Extrapolation to other areas cannot be made without orientation investigations to see if the same criteria are likely to apply, though it is hoped that the results may prove usable throughout the high rainfall laterite areas of the South West (for example on the Collie and Pemberton Sheets).

### Weathering and bed-rock type

Though there are distinct differences in the cap rock of the various lateritic profiles, the lateritization process appears to have acted uniformly, producing, what appears at first inspection to be an assemblage of relict primary and stable secondary minerals that is independent of bed rock.

In detail, however, this does not apply, and variations are noted even over the same type of bed rock. This may be illustrated by the presence or absence of kaolinite type minerals (kandites) in the weathered zones adjacent to fresh dolerite. One hypothesis has been that clay minerals are a necessary intermediary between the breakdown of primary aluminosilicates and the formation of secondary sesquioxides. (Sivarajasingham and others, 1962). That this is a complex problem is shown in the data on the dolerite profiles in this report. In one dolerite profile (B), no kaolinite was detected at all. In another (profile A, also at Jarrahdale) traces of kaolinite were detected on the interface with fresh rock (5mm from fresh material but no higher in the profile). In yet another (profile D, Del Park), no kaolinite was identified in the first 2.5 cm of weathered rock, though it was consistently present further up the profile. In profile C at Jarrahdale kaolinite was abundant in the lower parts of the profile, in the uppermost part of the cap rock, but absent elsewhere.

There has been less discussion in the literature on the decomposition of granitic rocks, but the same problem applies. The kaolinite group of minerals was not recorded in profiles F and G over adamellite from Jarrahdale, but is present in profile H over adamellite at Bald Hill, and in the profiles over all other rocks.

The inference from these observations, particularly from the weathering skins of the dolerites is that in some cases clay is an intermediary in the formation of sesquioxides: in others it is not. Local conditions of weathering, as well as the parent rock, play major parts in determining the secondary minerals formed in the first stages of weathering. At the present time, these profiles are subject to the same overall climatic regime, and the pH pattern of the various profiles is similar.

### Soil pH

The purpose of measuring soil pH is to determine the probable acidity of pore water in contact with the soil. The pH values recorded above are consistent with values reported for surface soils in the South West Land Division by Carroll (1944a) and Turton and others (1962); for profiles at Del Park (Bestow, 1976) and for groundwaters at Del Park measured by Davy (1976).

Differences in pH values of soil are commonly ascribed to the presence of soluble salts and clays holding varying quantities of exchangeable cations (Russell 1973, Turton and others 1962). They are also dependent on the conditions of measurement. Russell (1973) noted that the pH of soil is very variable, changing over the year with differing proportions of soluble salts held in pore waters. He also noted that, even within the same paddock on the same day, 'appreciable' soil-pH variations can occur. These findings have been partly supported by Davy (1976), who showed that groundwater at Del Park may vary by as much as two pH units during the course of a year. Though relative differences revealed in the profiles are probably valid, absolute values must be treated with caution.

## Simplified summary of behaviour of elements and oxides during lateritization

*Oxides*

SiO <sub>2</sub>	depleted*
CaO, Na <sub>2</sub> O	almost completely removed
K <sub>2</sub> O, MgO	almost completely removed except when mica/illite is present
Al <sub>2</sub> O <sub>3</sub> , Fe <sub>2</sub> O <sub>3</sub> , TiO <sub>2</sub>	enriched, but Al <sub>2</sub> O <sub>3</sub> is depleted relative to Fe <sub>2</sub> O <sub>3</sub> in some profiles
MnO, P <sub>2</sub> O <sub>5</sub>	variable but generally depleted

*Trace Elements*

Ba, Sr	almost completely removed
Zn	depleted
As, Mo, Sn, V	enriched
Th, Zr	non-systematic, but usually enriched
Cu	variable, but usually depleted
Co, Ni, Pb	variable

\* Changes are expressed as a comparison of values in the cap rock with values in the bed rock.

Al<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub>, TiO<sub>2</sub> and V are the constituents which tend to remain as residual components. Each of these, however, has been mobile at some point during lateritization. Titanium commonly reaches a peak 1 to 2 metres below the top of the cap rock. This feature, and the transformation of ilmenite and sphene into finely dispersed anatase emphasize titanium's mobility, though it is recognised that the extent of the movement may be small. The retention of small amounts of ferrous iron in the highly oxidized profiles is a curious feature. This could be explained by the presence of small amounts of magnetite below the limits of detection by X-ray diffraction.

The interest in elemental mobility in this project lies in whether there is any consistent relationship between the composition of the cap rock and the bed rock. The profiles of Figure 3, show by the parallelism of the element concentration lines, which elements behave sympathetically. The study of correlation coefficients between caprock and bedrock (Table 4) indicates the presence of systematic changes.

The correlation coefficients have been calculated using the formula.

$$r = \frac{1}{N} \sum \frac{(\bar{x} - x)^2 (\bar{y} - y)^2}{s_x s_y}$$

where:-

- r = correlation coefficient
- N = number of samples
- x = individual values of one element
- $\bar{x}$  = mean values of x
- y = individual values for the other element
- $\bar{y}$  = mean values of y
- $s_x, s_y$  = standard deviation for x and y respectively

The large number of correlations significant at the 98% probability level indicates that the bed rock is reflected in the cap rock (Table 4). When the number of elemental correlations significant at the 90% level is considered the total number of significant correlations is exceptionally high. Therefore valid predictions of bed rock ought to be possible with a 90% confidence level at least. Table 4, however, gives an oversimplified picture. The values for some elements in the cap rock, especially alkalis, alkaline earths, P and Mn, are commonly so near the detection limit that some of the variation reported may be less accurate than is desirable. Zn and Pb are also low in the cap rock and can only be expressed in multiples of 2.5 or 5 ppm with a stepwise distribution, which may be important for low concentration levels, but unimportant at high (>100 ppm) levels. As and Mo are clearly recognisable in the cap rock but have very low values in most of the fresh rock and the apparent relations shown may not be real.

The following elements and oxides in the cap rock appear to provide criteria for the deduction of bed rock -  $\text{Fe}_2\text{O}_3$ ,  $\text{TiO}_2$ ,  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ , V and Cu at the 98% confidence level or better and  $\text{K}_2\text{O}$ , Nb, Th, and Zr at the 90% confidence level.

Table 5 shows approximate concentration (or depletion) factors for constituents, calculated as a ratio between values in the cap rock and values in bed rock. The factors are only tentative because of the heterogeneous nature of the laterite (and the metasedimentary bed rock), but supplement some of the correlations deduced earlier.

In quartz-poor parent rocks (mafic rocks), the relative  $\text{SiO}_2$  loss is much higher than in quartz-rich rocks. This suggests that aluminosilicate minerals have been attacked more readily than free quartz.  $\text{Al}_2\text{O}_3$  has a similar concentration factor for profiles over mafic and felsic igneous rocks but the factor is generally less for metasedimentary rocks. The oxides and elements ( $\text{Fe}_2\text{O}_3$ ,  $\text{TiO}_2$ , V), which tend to concentrate in surface zones with  $\text{Al}_2\text{O}_3$ , and which show similar correlation coefficients, have less consistent concentration factors.  $\text{Fe}_2\text{O}_3$  has a concentration factor of 2 to 3 over dolerite, 3 to 6.5 over granitoids, whilst there is no systematic pattern over the schists and metasedimentary rocks. (There is even a net loss in two profiles). The factor for  $\text{TiO}_2$  is about 2 at the top of the cap rock over dolerite (rather higher a few metres down), in contrast with a factor of 4 to 5 over the granitoids. This probably reflects the presence of the reactive sphene and ilmenite in the mafic rocks, with loss of  $\text{TiO}_2$  on weathering, compared with stable rutile in granitoids. The factor for  $\text{TiO}_2$  is lower over the metasedimentary and sedimentary rocks. V, similar to  $\text{TiO}_2$  in the dolerites, is relatively enriched over the granitoids, but behaves very irregularly over the metasedimentary rocks.

Factors for alkalis and alkaline earths are close to zero, though  $\text{MgO}$  and  $\text{K}_2\text{O}$ , owing to the overall stability of muscovite and/or illite, are partly retained in profiles over metasedimentary rocks and granitoids rather than over dolerites. As and Mo show marked surface enrichment. Since bed-rock values are so low, the factors given are inexact, but represent an enrichment of As of about one order of magnitude. The surface enrichment may be caused by absorption of As by sesquioxides, or by the formation of scorodite ( $\text{FeAsO}_4 \cdot 2\text{H}_2\text{O}$ ). For Mo, the factor is slightly lower, particularly over the metasedimentary rocks.

Nb, Th and Zr are usually enriched at the surface, and the factors are apparently more consistent than the correlation coefficients might imply. There are a few abnormal values of Th, but the normal factor over schists and metasedimentary rocks is in the range 1 to 4, and over igneous rocks 8 to 11. Nb lacks contrast between the rock types in absolute terms. Zr is more enriched over granitoids than over mafic rocks; it does not parallel  $\text{TiO}_2$  other than in very general terms. This contrasts with Gilkes and others (1973) who observed a very close relationship between these constituents with a correlation greater than 0.8 in a 'granitic profile' at Bakers Hill, 72km east of Perth.

Cu is consistently depleted in the profiles over mafic rocks. Its absolute value is so low over granitoids that the factor is effectively meaningless. The variation over schists and metasedimentary rocks is probably a function of a heterogeneous parent rock. Zn is depleted over most rocks. Ni and Co are depleted in the profiles over mafic rocks and most metasediments, but are enriched in cap rock over granitoids and some of the metasediments. This lack of consistency reduces the usefulness of these elements as indicators of the parent rock types.

#### Oxide and element ratios

Ratios have been examined in cap-rock material for those elements and oxides which have a high correlation between bed rock and cap rock.

The most useful has been V/Zr (Fig. 5a), where there is an apparent separation between the three fundamental types of rock.  $\text{Al}_2\text{O}_3/\text{Fe}_2\text{O}_3$ ,  $\text{Al}_2\text{O}_3/\text{SiO}_2$  and  $\text{TiO}_2/\text{SiO}_2$  diagrams (Figs. 5b, c, d) separate out mafic rocks but do not distinguish metasediments from felsic igneous rocks.

Use of these ratios offers promise in discrimination when coupled with absolute values.

## Origin of exotic minerals

The laterite appears to contain components not found in the bed rock, a feature also noted by Grubb (1971). The presence of two or three varieties of zircon, rutile or tourmaline in the cap rock, and the different proportions of some minerals together with differences in the nature and disposition of inclusions, indicate an exotic origin for at least some of the material. It is not possible in this study to do more than comment on the source of these minerals. Many probably originated nearby and were brought to their present position by wind action or soil creep (though the influence of this was minimized by the sampling procedures). Glassford and Killigrew (1976) have argued that desert conditions once existed in the South West Land Division and that the yellow sand prevalent over much of the Perth Basin originated then. If this is correct, wind-blown minerals may be expected over the whole of the South West Land Division. On the other hand, Grubb (1971) postulated that there was once a colluvial or fluvial mantle of coarse, feldspathic sediment, dating possibly from the Cretaceous, overlying basement Archaean rocks, and contributing material to the weathering profiles. There is no evidence to suggest that the cap rock represents a condensation of what was once a thick section of fresh rock (next section).

## Origins of the profiles

**The influence of bedrock and climate:** The nature of the end products of lateritization is controlled by the nature of the bed rock when climatic conditions are kept constant. This is clearly shown at Stephens Road, Site 6, where the lateritized dolerite dyke retains a distinct mineralogical and chemical character in the middle of a lateritized schist profile. It is probable that the absence of a pallid zone in the quartzite profile is a function of the parent rock, rather than a function of climatic change or of change in the nature of the lateritization process.

On the other hand, localized changes, possibly related to microclimatic changes, or changes in the degree of oxidation, do also produce diverse products from the same type of bed rock (viz. the dolerite discussed earlier).

**Volume changes during lateritization:** Residual boundaries to dykes (Sites 1, 2, and 6) and to quartz pegmatite veins (Site 1 near profile C) continue without alteration of the angle of contact or without change in the direction of veins as they pass from bed rock to the overlying saprolite zone. These features together with textures from the saprolite zone which are clearly relict from the parent rock lead to the conclusion that the dominant changes in the saprolite zones have been isovolumetric. Similar conclusions about saprolite zones have been deduced by previous workers (Millet and Bonifas, 1955; Valetton, 1972).

Some authors have assumed that the upper hard cap-rock portion of a lateritic profile is a condensed sequence, where the term 'condensed sequence' indicated that there has been the removal, by leaching, of the greater part of the constituents uniformly from a considerable thickness of rock. For example, Trendall (1962) suggested that 4 to 6 m (14 to 20 ft) of granitic rock may be consumed in the generation of 0.3 m (one foot) of laterite. The exotic minerals in the cap rock could be considered supportive of this hypothesis.

However, it is not believed that the cap rock is a condensed sequence of this order of magnitude. Evidence is provided in the railway cutting at Jarrahdale (profile C). Residual outlines of the sampled dyke are visible through the 'clay'-rich zones, but disappear in the cap rock, which is, however, visibly different over the projected extension of the dyke compared with that over the adjacent granitoid. Over the dyke, the cap rock is red brown and contains very little quartz. Over the granitoid, the cap rock is light brown with abundant visible quartz. The chemistry of the cap rock over the dyke is different from that over recognisable granitoids, and it has a composition consistent with lateritized dolerite. Sadleir and Gilkes (1977) consider that pegmatite veins outcropping in the same railway cutting can be followed from fresh rock right into the hard cap rock. The cap rock over the pegmatite is represented by bauxite material containing extremely coarse, angular quartz. In neither case is there a flattening of the dip of the projected line of contact of dyke with host rock, which would be expected if the caprock were part of a condensed profile. Terrill (1950) argued, on similar grounds, that there was no condensed profile over dolerite at Mount Helena and Parkerville. He pointed out that the  $\text{Al}_2\text{O}_3/\text{Fe}_2\text{O}_3$  ratio in laterite over dolerite at Parkerville remained constant from parent rock through to cap rock.

It is concluded that there has been no dramatic condensation of bed rock in the production of the cap rock, but that material has been introduced, with limited movement of iron and aluminium giving the present lithified, nodular, and/or colloform textures. The origins of the exotic material and the means of its incorporation into the cap rock have not been clearly identified.

**Chemical considerations:** Present conditions in the profiles appear to be oxidizing, with the pH of soil-water suspensions in the range 4-7. The pH of crushed fresh rock-water is higher : 6.5-9.5.

Studies have been made at Del Park (Bestow, 1976; Davy, 1976) of the groundwater in selected drill holes in the course of monitoring possible pollution caused by bauxite mining. Bestow reports 7 ppm silica in water from one of these bores (bore 2910, p. 27). Davy has confirmed that iron and aluminium are only present in the most acid solutions, which are rare and only occur at the close of the summer dry season.

Norton (1973) has provided an interpretation of these observations, based on the importance of pH and Eh in the formation of laterite and/or bauxite. Under the conditions observed, both iron and aluminium would be retained with no separation of iron from aluminium (p. 358). This, coupled with the presence of silica in the groundwaters (which are transporting it from the present near-surface profiles) suggest that laterite formation may be occurring at the present time.

The ratio of  $\text{Al}_2\text{O}_3/\text{Fe}_2\text{O}_3$  remains approximately the same through the laterite profiles, except in five profiles over schists and adamellite\* where iron is enriched with respect to aluminium in the cap rock compared with the bed rock. Iron-enrichment relative to aluminium has, therefore, taken place even in a sequence whose end product is bauxite. On the other hand, both bauxite and iron-rich laterite can maintain, in the cap rock, the  $\text{Al}_2\text{O}_3/\text{Fe}_2\text{O}_3$  ratio of the underlying bed rock suggesting that the same lateritization process is acting even though end results differ.

Schellman (1975) considers that a 7 ppm concentration of  $\text{SiO}_2$  in solution is too great for the formation of bauxite. He affirms that gibbsite can only be formed from kaolinite when the soil solutions/groundwaters contain no more than one ppm  $\text{SiO}_2$ .

It appears that conditions for the formation of sesquioxides are still present, but that, at Del Park at least, the present conditions favour the formation of combined iron-aluminium oxides rather than aluminium oxide alone.

#### Identification of bed rock below laterite

In usage of the following arguments, it must be remembered that the total number of profiles examined is small, and that those examined cover a wide variety of rock types. Conclusions are not statistically significant.

Oxides and elements present in the cap rock which are considered of greatest use in indicating bed rock are  $\text{Al}_2\text{O}_3$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{TiO}_2$ , V, and Cu. These constituents show a high degree of correlation between bed rock and cap rock.

\* Profiles F, G, H, K, and L

Other useful constituents for which correlations are lower but still significant include  $\text{SiO}_2$ ,  $\text{K}_2\text{O}$ , Th and Zr. The abundance of relict primary quartz is a usable mineralogical factor.

It has proved easy to distinguish mafic from felsic igneous bed rock using the following criteria of cap rock chemistry.

Component	Mafic	Felsic
Quartz (modal)	<10%	$\geq 20\%$
$\text{SiO}_2$	<15%	>20%
$\text{Fe}_2\text{O}_3$	$\geq 25\%$	5–20%
$\text{TiO}_2$	$\geq 2\%$	0.5–1%
V	$\geq 700$ ppm	<500 ppm
Cu	$\geq 30$ ppm	< 10 ppm
( $\text{K}_2\text{O}$ )	$\leq 0.02\%$	$\geq 0.1\%$
Colour	'dark' red or purple brown	'light' yellow or orange brown

The presence of dioritic rocks at Site 11 is a complicating factor. The proportion of modal quartz would be lower in these rocks than in true granitoids. No residual profiles over dioritic rock were obtained, but in such profiles an intermediate value of quartz (perhaps 10–20%) might be expected in the cap rock. Other features would be expected to be closer to the criteria listed for felsic rocks than for those of mafic rocks.

The situation is more complex for differentiating between felsic igneous bed rocks and felsic metasedimentary bed rock, but the same factors seem relevant.

Component	Felsic igneous (or gneissic)	Metasedimentary	
		Schists	Other
Quartz (modal)	20–30%	15–40%	50–70%
$\text{SiO}_2$	20–30%	20–50%	50–70%
$\text{Al}_2\text{O}_3$	40–45%	15–40%	2–20%
$\text{Fe}_2\text{O}_3$	8–12%	15–25%	8–40%
$\text{TiO}_2$	0.5–1%	0.5–2%	<1%
V	50–200 ppm	200–900 ppm	<200 ppm
Cu	<10 ppm	<25 ppm	<100 ppm

Examination of between one and three of the above factors will separate the two igneous groups. In the case of cap rock over felsic igneous or gneissic rocks compared with cap rocks on metasedimentary rocks, separation is more complex mainly because of the wide range of chemical composition of the metasediments. The results suggest that at least one of the above parameters will be outstanding enough to indicate a (meta)sedimentary origin. However, it may be necessary to carry out analyses for all these features to be sure of differentiating the two. All the siliceous sedimentary rocks (iron formation, quartzite, sandstone) have 50% quartz and/or silica in the cap rock, so that this could be a discriminator for these rocks. The schists are generally closer to the igneous rocks in both bed rock and laterite composition.

Element and oxide ratios give ready and effective separation of mafic and felsic igneous rocks, but there is a less clear separation of felsic igneous and metasedimentary rocks. The  $\text{Al}_2\text{O}_3/\text{Fe}_2\text{O}_3$  ratios plot in different positions and provide reasonable separations, but the best indicator is V/Zr which relies on the zircon being locally derived.

If it can be assumed that the exotic heavy minerals in the cap rock have travelled no great distance, it may be possible to use the heavy minerals of the cap rock to indicate bed rock. The cap rocks of three of the four schists examined contain metamorphic minerals such as staurolite, sillimanite, andalusite and kyanite; the fourth was disproportionately rich in muscovite, compared with those over gneisses which also contain some mica. As the heavy-mineral assemblages include exotic grains, it is not possible to use them to specifically identify the parent rock. Thus, though andalusite schist contributed only andalusite to the laterite, the laterite over the schists at Site 5 contained a larger variety of metamorphic minerals than were identified in the bedrock.

In summary, based on the limited data available, it appears relatively easy to separate felsic and mafic igneous rocks below residual laterite simply by analysis for a few key elements. It does not appear to matter whether the laterite is iron-rich or aluminium-rich. It is, however, more difficult to separate felsic igneous rocks from metasedimentary rocks. To do this, it is necessary to analyse for a larger number of elements, and to supplement the analyses by a study of the heavy minerals present.

#### Surface indications of bed rock mineralization

This discussion is largely theoretical because no sign of sulphide mineralization was identified except pyrite casts in the Coates Siding gabbro (profile E) and in profile I (schist, sample 42371B). Chalcopyrite, however, has been observed in small quartz pegmatite veins in the south wall of the Jarrahdale railway cutting (G.F.U. Baker 1976, Alcoa, (WA) Ltd., report ME/2/76, unpublished).

Arsenic is concentrated in cap rock with a very high enrichment factor, and appears to be the best indicator of sulphides; although it may not distinguish barren from useful sulphides. Arsenic is also well known as an indicator for gold (Mazzucchelli and James, 1966).

Though Cu and Zn are leached from the profiles, both show high correlations between cap rock and bed rock. They are apparently very low in laterite, and high values may reflect mineralization. This applies especially to Cu, because it is less mobile than Zn.

Co and Ni show erratic distributions but would be of interest if values reached 300 ppm or over.

Pb has conspicuously low values in the laterites examined. It may be expected to concentrate over mineralized areas, but the laterite values obtained are so low that no concentration may be observed.

V appears to be its own indicator, concentrating well in laterite. High values (probably >0.5%) indicate substantial amounts in the bedrock.

Sn, Mo and Nb are concentrated in laterite over granitoid rocks. Both Mo and Sn are commonly present in the laterite with values of approximately 10 ppm compared with levels near to, or below, detection (1–3 ppm) in the parent rock. It may confidently be expected that these elements will reflect mineralization. The concentration factor for Nb is somewhat lower, but this element is also concentrated in the laterite and would act as an indicator of tantalite mineralization. Ta was not included in the present study, but may itself behave like Nb.

#### TRANSPORTED LATERITIC PROFILES

The concentrations of elements and oxides, and the mineralogy of the pallid, saprolite zones are similar to those in profiles previously described given the appropriate parent rock. The main mineralogical difference is that the kaolinite group minerals occur through the whole profile, whereas gibbsite is significantly lower, or is absent.



The essential chemical and mineralogical similarities of the lower parts of the profiles suggest that weathering conditions at Wungong have been similar to those of the residual profiles and that the same chemical leaching and concentrating conditions have applied. Variations in the upper parts of the profile are primarily due to creep. One slight difference in the profiles is the presence of a brown, clay-rich zone carrying a small proportion of iron minerals near the base of the profiles over the granitoids. It is considered that this zone represents the site of a former sheet joint which has been a main channel for percolating groundwaters.

These profiles do not fit into the patterns suggested in the proceeding discussion for the identification of bedrock by sampling the upper part of the laterite. The table below shows the different values for the upper part of the laterite:

Component	Mafic rocks		Granitoids	
	Residual profile	Wungong profile	Residual profile	Wungong profile
Quartz (modal)	<10%	<10%	≥20%	20%
SiO <sub>2</sub>	<15%	36%	>20%	30-35%
Fe <sub>2</sub> O <sub>3</sub>	≥25%	14%	5-20%	25-33%
TiO <sub>2</sub>	≥2%	1.5%	0.5-1%	1-1.5%
V	≥700 ppm	350 ppm	<500 ppm	550-600 ppm
Cu	≥30 ppm	105 ppm	<10 ppm	20-90 ppm
K <sub>2</sub> O	≤0.02%	0.10%	≥0.1%	0.06-0.12%

The only similar component is that of modal quartz.

## CONCLUSIONS

Conclusions may be summarized as follows:

1. In any attempt to identify bed rock from a study of laterite, a distinction between residual and transported laterite must be drawn, and the study must be restricted to the residual laterite.
2. The profiles chosen as residual are indeed substantially residual, but an exotic heavy-mineral component has been identified in the cap rock of many of the profiles. The source of the exotic material has not been traced, but the nature of the introduced minerals suggests a local derivation.
3. The residual laterites show no indications of a condensed upper sequence. Residual structures and textures are readily identified in the saprolite, and are traceable in some instances into the overlying cap rock. The cap rock is now composed of secondary minerals with relict, primary heavy-minerals, but there is no major break in chemistry between the saprolite and the cap rock and trends are progressive up the profile.
4. The lateritic degradation (lateritization) of dolerite occurs over a very small distance (less than 5 cm). Degradation of granitoids occurs over approximately 2 m and of schistose metasedimentary rocks over a greater distance (up to 12 m).
5. Lateritization is characterized by an almost complete leaching of calcium and sodium, a less complete leaching of magnesium and potassium, and some leaching of silica. Magnesium and potassium are leached except when muscovite and/or illite is retained in the laterite profile. Quartz is less readily attacked than other silicates, and tends to remain as residual corroded grains. The leached ions are balanced by a large real increase of H<sub>2</sub>O<sup>+</sup>. Lateritization effects an apparent increase in the concentration of aluminium, iron, titanium, and vanadium. Interpretation of increases in thorium, niobium, and zirconium is complicated by the presence of the exotic heavy minerals. Cobalt, manganese and nickel, expected on the basis of laterite studies elsewhere to be retained in the profile, display inconsistent behaviour.

6. The lateritizing process appears uniform in the profiles studied. Local variations in pH and Eh, and in the composition of the parent rock determine whether iron-rich laterite or bauxite is formed in the residual profiles. The composition of groundwater at one site suggests that, at the present time, sesquioxides of both iron and aluminium are being retained and silica is being leached from the profile.

7. It is possible, in general terms, to identify the rock underlying residual laterite on the basis of colour, the proportion of residual quartz, and the following elements and oxides:  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{TiO}_2$ , Cu and V.  $\text{K}_2\text{O}$ , Th and Zr may be used to supplement the above. Separation of mafic from felsic rocks appears possible using only one or two of these factors, but separation of felsic igneous rocks from metasedimentary rocks appears to need a combination of factors with additional data on the heavy minerals.

The use of element ratios offers no real advantage in interpretation compared with use of the absolute amounts present.

8. Each profile at the lower Wungong damsite is largely residual, but at the top there is 1-2 m of transported material. The properties of the latter tend to conceal the nature of the bed rock, and the parameters of the cap rock for determining bed rock, suggested in conclusion 7 above, do not apply.

9. No mineralization (except vanadium) was identified, or is known, in the vicinity of the profiles studied. However, the following elements in the cap rock of residual profiles appear useful for routine prospecting purposes:

- i) arsenic — for sulphides
- ii) copper and vanadium — for base metals and vanadiferous rocks
- iii) tin, molybdenum and niobium — for mineralized granites

#### ACKNOWLEDGEMENTS

The analytical services of the Mineral Division of the Government Chemical Laboratories and discussions with, and guidance from, officers of Alcoa of Australia (WA) Ltd, in particular Messrs. A. Murray and A. Smurthwaite, are gratefully acknowledged.

TABLE 2

THE CHEMICAL AND MINERALOGICAL COMPOSITION OF  
SAMPLES, GROUPED BY PROFILES

OXIDES )  
 ) EXPRESSED IN PER CENT  
MINERALS )

TRACE ELEMENTS EXPRESSED IN PPM

MINERALOGY DETERMINED BY X-RAY DIFFRACTION

TABLE 2a. Profile A data

Sample No.	42419	42420	42421	42422	42423	42424	42425W	42425 I	42425UN
Depth (m)	0	0.3	1.0	1.6	2.1	2.6	-----	2.65	-----
SiO <sub>2</sub>	36.8	3.0	6.8	2.0	2.3	10.7	21.3	30.5	48.0
Al <sub>2</sub> O <sub>3</sub>	29.5	35.5	30.1	23.3	28.4	27.7	21.0	17.5	12.7
Fe <sub>2</sub> O <sub>3</sub>	17.2	31.0	34.2	46.2	40.6	31.9	24.5	16.7	3.6
FeO	3.0	1.7	2.5	2.7	2.1	2.9	5.8	8.6	12.3
MgO	0.05	0.04	0.01	0.07	0.01	0.04	2.7	5.1	6.1
CaO	0.04	<0.01	0.01	0.01	0.02	0.02	2.5	5.2	9.9
Na <sub>2</sub> O	<0.01	<0.01	0.01	0.06	0.06	0.10	0.10	1.0	2.4
K <sub>2</sub> O	0.12	<0.01	0.01	<0.01	<0.01	0.01	0.03	0.07	0.2
H <sub>2</sub> O	10.5	23.8	20.4	17.9	21.0	21.6	15.8	11.3	2.0
TiO <sub>2</sub>	2.1	4.0	4.9	5.6	4.5	4.7	5.0	4.1	2.4
P <sub>2</sub> O <sub>5</sub>	0.06	0.09	0.08	0.10	0.11	0.07	0.05	0.05	0.21
MnO	0.05	0.09	0.13	0.16	0.11	0.13	0.19	0.22	0.22
Total	99.4	99.2	99.2	98.1	99.2	99.9	99.0	100.4	100.0
As	7	16	7	6	8	10	<1	<1	2
Mo	5	5	2	1	2	1	<0.5	0.5	<0.5
Nb	33	22	20	16	15	13	13	13	9
Th	125	59	41	14	85	16	5	<2	3
V	420	1300	1300	1900	1500	1500	1100	1100	720
Zr	555	300	315	245	270	205	85	150	105
Sn	10	<10	<10	<10	<10	<10	<10	<10	<10
Cu	15	95	142	148	210	360	315	240	325
Pb	20	25	25	30	20	20	20	15	<10
Zn	22	38	45	75	72	55	105	128	150
Ni	32	42	45	68	50	78	100	102	228
Co	42	72	65	55	80	72	78	90	122
Sr	<5	<5	<5	<5	<5	<5	7	22	124
Ba	<10	<10	<10	<10	<10	<10	50	<10	50
pH	6.3	5.2	5.5	5.3	5.2	5.6	6.0	6.3	8.2
Quartz	35	5	<10	<5	2	10	10	10	5
Plagioclase	—	—	—	—	—	—	5	5	40
Hornblende	—	—	—	—	—	—	20	35	50
Ilmenite	—	5	5	>5	>5	>5	<10	5	5
Kaolinite	—	—	—	—	—	—	—	5	—
Gibbsite	30	55	>45	35	>45	<45	30	20	—
Boehmite	10	—	—	—	—	—	—	—	—
Goethite	5	25	25	30	35	35	25	20	—
Hematite	20	10	15	25	10	5	—	—	—
Al <sub>2</sub> O <sub>3</sub> /Fe <sub>2</sub> O <sub>3</sub>	1.4	1.1	0.82	0.47	0.67	0.79	0.68	0.67	0.74
Fe <sub>2</sub> O <sub>3</sub> /TiO <sub>2</sub>	9.8	8.2	7.5	8.8	9.5	7.5	6.2	6.4	7.1
10 <sup>4</sup> V/Fe <sub>2</sub> O <sub>3</sub>	20	40	35	39	35	43	36	42	42
TiO <sub>2</sub> /V	50	31	38	29	30	31	45	37	33
42419	Soil from surface. Small nodules (<3 mm) with humus, clay and sand.								
42420	Caprock. Dark red-brown vuggy, porous bauxite. No visible quartz.								
42421	Base of caprock. Friable bauxite. Deep rich red-brown nodules (to 2 cm) set in a brown clay matrix.								
42422	?Bauxite. Loose deep red brown vuggy nodules (to 5 cm) in a matrix of light brown clay.								
42423	Decomposed dolerite. Totally decomposed dolerite but retaining visible relict textures. Now represented by red-brown bauxite with ochreous interfaces.								
42424	Outer margin of dolerite boulder. Dark brown, irregular nodules of limonite/bauxite with lighter brown surface coating 5 cm from fresh dolerite								
42425	Dolerite.								
42425W	Deep brown and yellow brown porous crust. 1.5 cm from 42425UN.								
42425 I	Lighter brown with residual minerals from dolerite. Feldspar totally altered. 0.5 cm from 42425UN.								
42425UN	Fresh dolerite.								

TABLE 2b. Profile B data

Sample No.	42449	42448	42447	42446	42445	42444	42443
Depth (m)	0–0.4	0.8–1.1	1.1–1.3	1.3–1.5	1.5–1.8	1.8	1.8
SiO <sub>2</sub>	3.7	2.3	3.1	4.5	5.9	12.2	48.5
Al <sub>2</sub> O <sub>3</sub>	31.3	28.2	36.0	29.6	32.1	27.4	12.2
Fe <sub>2</sub> O <sub>3</sub>	37.5	38.4	27.6	36.1	31.4	31.2	4.7
FeO	1.4	3.3	2.7	2.1	2.0	2.3	11.6
MgO	0.02	0.01	0.02	0.03	0.03	0.04	5.5
CaO	0.01	0.01	0.02	0.01	0.01	0.02	8.5
Na <sub>2</sub> O	0.01	0.01	0.03	0.06	0.04	0.01	2.4
K <sub>2</sub> O	0.01	0.01	0.01	0.02	0.01	0.01	0.21
H <sub>2</sub> O	21.6	20.6	24.6	22.3	23.3	22.0	3.5
TiO <sub>2</sub>	3.3	6.1	5.4	4.9	4.2	4.5	2.4
P <sub>2</sub> O <sub>5</sub>	0.06	0.08	0.06	0.16	0.15	0.06	0.14
MnO	0.08	0.18	0.15	0.13	0.13	0.14	0.23
Total	99.0	99.3	99.7	99.9	99.3	99.9	99.9
As	15	6	7	10	4	4	1
Mo	4	2	2	3	2	2	<0.5
Nb	16	21	17	20	16	14	11
Th	16	22	19	25	24	10	2
V	1200	1600	1400	1200	1000	1000	540
Zr	295	390	375	300	285	255	125
Sn	<10	<10	<10	<10	<10	<10	<10
Cu	80	35	35	130	220	245	175
Pb	20	10	10	10	10	15	10
Zn	50	55	45	50	35	45	155
Ni	45	55	60	45	65	70	90
Co	135	130	125	120	115	110	120
Sr	<5	5	5	<5	<5	<5	305
Ba	50	100	50	50	50	50	250
pH	5.5	5.8	5.8	6.0	6.0	6.2	7.5
Quartz	5	3	3	>5	5	<15	10
Plagioclase	—	—	—	—	—	—	25
Hornblende	—	—	—	—	—	—	60
Ilmenite	2	10	>5	5	<5	5	5
Gibbsite	<50	>40	55	>45	50	>40	—
Goethite	30	30	30	<40	40	40	—
Hematite	15	>15	5	5	—	—	—
Al <sub>2</sub> O <sub>3</sub> /Fe <sub>2</sub> O <sub>3</sub>	0.80	0.67	1.2	0.77	0.96	0.81	0.70
Fe <sub>2</sub> O <sub>3</sub> /TiO <sub>2</sub>	12	6.9	5.7	7.8	8.0	7.5	7.3
10 <sup>4</sup> V/Fe <sub>2</sub> O <sub>3</sub>	31	38	46	31	30	30	31
TiO <sub>2</sub> /V	28	38	39	41	42	45	44
42449	Cap rock: Red—brown fragmental bauxite with incipient pisolites.						
42448	Laterite and/or bauxite : Red—brown (purple—brown) massive to fragmental laterite containing black nodules to 0.5 cm.						
42447	Laterite: Greyish brown, friable.						
42446	Laterite: Purple(red)—brown, quartz free.						
42445)	Weathered dolerite : Successive sections of skin on fresh dolerite						
42444)	of 42443.						
42443	Dolerite: Fresh						

TABLE 2c. Profile C data

Sample No.	42434	42433	42432	42431	42430	42429	42428
Depth (m)	0	1.2	2.7	4.05	4.95	5.8	8.8
SiO <sub>2</sub>	6.6	7.8	13.2	9.8	16.1	23.3	51.1
Al <sub>2</sub> O <sub>3</sub>	39.9	39.3	33.2	35.9	30.3	28.1	14.1
Fe <sub>2</sub> O <sub>3</sub>	25.5	25.6	26.0	26.1	30.0	24.2	2.2
FeO	0.39	0.26	0.45	0.19	0.13	0.39	8.8
MgO	0.01	0.01	0.01	0.01	0.02	0.02	6.8
CaO	<0.01	<0.01	0.02	0.04	0.01	0.01	11.2
Na <sub>2</sub> O	0.01	0.03	0.05	0.06	0.06	0.17	2.1
K <sub>2</sub> O	0.01	0.02	<0.01	0.01	0.01	0.02	0.22
H <sub>2</sub> O	25.6	25.1	24.1	24.8	21.6	20.0	2.0
TiO <sub>2</sub>	1.7	1.9	2.7	2.7	1.4	3.2	1.2
P <sub>2</sub> O <sub>5</sub>	0.03	0.05	0.04	0.09	0.05	0.08	0.17
MnO	0.01	0.01	0.02	0.01	0.01	0.01	0.19
Total	99.8	100.1	99.8	99.7	99.7	99.5	100.1
As	15	15	<1	2	2	7	<1
Mo	5	3	1	1	1	1	0.5
Nb	12	11	19	12	4	10	9
Th	56	46	11	<2	10	17	3
V	740	720	730	730	510	1100	310
Zr	190	190	150	140	70	135	80
Sn	<10	<10	<10	<10	<10	<10	<10
Cu	42	145	165	100	98	65	152
Pb	20	20	15	15	20	15	<10
Zn	10	10	15	10	12	10	60
Ni	52	45	48	48	70	55	98
Co	42	55	50	42	45	35	65
Sr	<5	<5	<5	<5	<5	<5	122
Ba	<10	<10	<10	<10	<10	<10	<10
pH	5.4	5.7	5.6	5.9	6.0	6.0	9.5
Quartz	<10	<10	<15	10	10	10	<10
Plagioclase	—	—	—	—	—	—	35
Biotite	—	—	—	—	—	5	2
Hornblende	—	—	—	—	—	—	<55
Kaolinite	<5	—	—	—	20	20	—
Gibbsite	55	60	50	55	35	35	—
Goehite	25	>25	35	35	30	30	—
Hematite	5	5	—	—	5	—	—
Al <sub>2</sub> O <sub>3</sub> /Fe <sub>2</sub> O <sub>3</sub>	1.5	1.5	1.3	1.4	1.0	1.1	1.2
Fe <sub>2</sub> O <sub>3</sub> /TiO <sub>2</sub>	15	14	9.8	9.7	22	7.7	9.9
10 <sup>4</sup> V/Fe <sub>2</sub> O <sub>3</sub>	29	28	28	28	17	45	26
TiO <sub>2</sub> /V	23	26	37	37	27	29	39
42434	Cap rock: Massive cap rock with about 5% voids; greater proportion of deep red (brown) rather fragmental material; quartz apparently absent.						
42433	Cap rock: Vuggy (15-20% voids), deep-red rock with lighter brown 'veins' and void coatings.						
42432	Upper trench: Friable, deep, orange-brown, slightly nodular bauxite.						
42431	Lower trench: Friable, deep, orange-brown, 'clayey' bauxite.						
42430	Lower bauxite: Fragmental deep-red bauxite with small, irregular, black patches and zones of yellow to white clay.						
42429	Basal clay: Immediately above dolerite; deep red-brown, nodular, porous ?bauxite with lighter brown coating on and between nodules						
42428	Dolerite: fresh						

TABLE 2d. Profile D data

Sample No.	42435	42436	42437	42438	42442	42441	42440	42439W	42439
Depth (m)	0	0.5	0.85	0.9	1.53	1.53	1.53	1.53	1.6
SiO <sub>2</sub>	4.7	12.8	10.4	7.6	14.9	17.7	10.0	28.9	50.0
Al <sub>2</sub> O <sub>3</sub>	31.5	46.9	49.5	37.3	37.2	30.0	33.9	23.0	13.8
Fe <sub>2</sub> O <sub>3</sub>	37.2	8.5	9.0	25.9	20.2	26.4	28.4	18.3	2.8
FeO	1.0	0.39	0.45	1.1	0.64	0.90	0.51	3.7	9.5
MgO	0.02	0.02	0.02	0.02	0.02	0.02	0.01	3.4	7.8
CaO	0.01	0.01	0.01	0.02	0.02	0.04	0.01	3.4	11.1
Na <sub>2</sub> O	<0.01	<0.01	<0.01	0.01	0.02	0.01	<0.01	0.07	2.1
K <sub>2</sub> O	0.01	0.01	0.01	0.01	<0.01	0.02	<0.01	0.05	0.22
H <sub>2</sub> O	22.1	27.8	28.3	24.5	24.0	21.5	24.2	16.3	2.4
TiO <sub>2</sub>	2.6	2.7	2.2	3.1	2.8	2.8	3.0	2.4	1.2
P <sub>2</sub> O <sub>5</sub>	0.06	0.04	0.02	0.05	0.05	0.05	0.05	0.05	0.17
MnO	0.06	0.03	0.04	0.05	0.04	0.04	0.06	0.12	0.21
Total	99.3	99.2	100.0	99.7	99.9	99.5	100.1	100.3	99.3
As	13	4	12	16	5	6	1	<1	<1
Mo	4	4	7	8	3	2	1	0.5	<0.5
Nb	17	16	21	20	21	17	13	9	8
Th	31	25	57	19	27	11	12	3	<2
V	920	270	340	750	450	630	610	470	290
Zr	255	235	265	240	265	225	165	130	75
Sn	<10	<10	<10	<10	<10	<10	<10	<10	<10
Cu	65	10	5	55	45	85	140	155	85
Pb	10	10	<10	<10	15	10	<10	10	10
Zn	25	15	15	20	15	20	20	65	105
Ni	55	50	55	60	65	80	70	135	120
Co	95	80	80	100	95	105	100	100	120
Sr	5	5	<5	<5	<5	5	<5	60	195
Ba	<10	60	150	150	60	60	<10	150	350
pH	5.3	5.6	6.2	6.1	5.8	5.9	5.6	6.9	8.8
Quartz	5	10	>5	<10	>10	<20	10	15	10
Plagioclase	—	—	—	—	—	—	—	—	30
Hornblende	—	—	—	—	—	—	—	25	<60
Ilmenite	—	—	—	5	—	<5	<5	5	2
Kaolinite	<5	>10	>10	—	<10	>5	—	—	—
Gibbsite	>45	70	70	>55	55	40	>50	30	—
Anatase	—	2	—	—	—	—	—	—	—
Goethite	40	<10	5	30	25	>30	35	25	—
Hematite	5	—	5	—	—	—	—	—	—
Al <sub>2</sub> O <sub>3</sub> /Fe <sub>2</sub> O <sub>3</sub>	0.82	5.3	5.2	1.4	1.8	1.1	1.2	1.0	1.1
Fe <sub>2</sub> O <sub>3</sub> /TiO <sub>2</sub>	15	3.3	4.3	8.7	7.5	9.8	9.7	9.3	11
10 <sup>4</sup> V/Fe <sub>2</sub> O <sub>3</sub>	24	30	36	28	22	23	21	21	22
TiO <sub>2</sub> /V	28	100	65	41	62	44	49	51	41

42435	Cap rock: Massive; deep red-brown rock with small proportion of lighter brown veins and coatings to voids (which comprise some 5%).
42436	Sheared clay: Medium-brown clay-rich zone; some apparent vertical movement suggesting shear or crush zone.
42437	Sheared clay: Similar to 42436; brown clay.
42438	Clay: Similar to above but lacking indications of movement.
42442	Weathered skin on 42439: Similar to 42440. Primary texture still apparent, but primary mineralogy totally disappeared. (50 to 80 mm from fresh dolerite).
42441	Weathered skin on 42439: Similar to 42440 (25 to 50 mm from fresh dolerite).
42440	Weathered skin on 42439: Porous, brown, friable material retaining dolerite textures. (25 to 50 mm from fresh dolerite).
42439	Fresh dolerite: 42439W weathered-zone adjacent to fresh dolerite; feldspars totally altered.

TABLE 2e. Profile E data

Sample No.	42392A	42392B	42392	42393	42394	42395	42396	42397	42398	42399
Depth (m) *	0	0.3-3.0	9-12	21-24	30.5-33.5	33.5-36.6	36.6-39.6	39.6-42.7	45.7-48.8	61.0-64.10
SiO <sub>2</sub>	3.9	2.2	19.1	34.5	39.1	41.8	46.1	47.0	48.1	50.3
Al <sub>2</sub> O <sub>3</sub>	16.6	39.0	28.8	28.5	26.2	21.1	16.3	16.9	14.8	13.5
Fe <sub>2</sub> O <sub>3</sub>	55.6	31.5	29.0	19.0	16.5	14.4	11.1	8.6	4.9	2.9
FeO	2.4	0.30	0.90	0.64	0.71	2.4	3.9	4.4	6.8	8.0
MgO	0.05	0.02	0.13	0.20	0.93	3.3	4.3	5.5	6.9	7.9
CaO	0.03	0.02	0.06	0.04	0.12	1.8	4.4	6.0	8.8	10.5
Na <sub>2</sub> O	<0.01	<0.01	0.03	0.03	0.02	0.14	0.28	0.22	2.7	2.9
K <sub>2</sub> O	0.1	<0.1	0.11	0.10	0.21	0.51	0.60	0.40	0.32	0.21
H <sub>2</sub> O	13.90	23.50	17.90	15.27	14.18	13.37	11.60	8.80	4.47	2.46
TiO <sub>2</sub>	4.84	3.06	3.03	2.05	2.02	1.62	1.57	1.27	1.20	1.13
P <sub>2</sub> O <sub>5</sub>	0.09	0.01	0.05	0.05	0.02	0.08	0.08	0.07	0.12	0.15
MnO	0.11	0.04	0.08	0.05	0.05	0.12	0.28	0.18	0.19	0.19
Total	97.6	99.7	99.2	100.4	100.1	100.6	100.5	99.4	99.3	100.1
As	25	35	3	3	3	7	2	4	2	5
Mo	9	7	2	1	0.5	1	0.5	0.5	0.5	1
Nb	5	15	13	12	9	10	10	10	9	10
Th	3	10	4	10	5	3	2	12	10	3
V	4100	1400	850	430	740	460	410	350	350	320
Zr	90	210	145	150	100	90	90	75	75	75
Sn	not determined									
Cu	180	60	110	140	325	330	212	188	152	126
Pb	15	15	15	10	10	10	10	10	10	<10
Zn	80	10	45	40	90	230	290	240	410	600
Ni	25	10	105	105	215	310	315	275	245	220
Co	10	10	85	70	70	135	170	140	115	85
Sr	<5	<5	<5	<5	<5	50	160	165	260	275
Ba	50	25	25	25	50	100	160	250	125	140
pH	5.4	5.3	5.3	5.9	6.2	7.0	8.1	8.4	9.2	8.9
Quartz	5	<5	>5	<5	10	15	<10	10	<5	<10
Plagioclase	—	—	—	—	—	10	40	25	25	30
Mica	—	—	—	—	—	—	—	—	5	5
Chlorite	—	—	—	—	—	—	—	30	35	25
Amphibole	tr	—	—	—	—	10	25	30	30	30
Ilmenite	<5	5	—	—	—	—	—	<1	1	2
Kaolinite	>10	5	25	65	<70	>45	15	—	—	—
Gibbsite	<20	50	<30	>5	—	—	—	—	—	—
Anatase	—	—	—	—	2	—	—	—	—	—
Goethite	20	20	25	20	>15	<20	>10	5	—	—
Hematite	40	15	10	5	<5	—	—	—	—	—
Al <sub>2</sub> O <sub>3</sub> /Fe <sub>2</sub> O <sub>3</sub>	0.29	1.2	0.96	1.5	1.5	1.2	1.1	1.3	1.2	1.2
Fe <sub>2</sub> O <sub>3</sub> /TiO <sub>2</sub>	12	10	9.9	9.6	8.6	10.5	9.8	11	10	10
10 <sup>4</sup> V/Fe <sub>2</sub> O <sub>3</sub>	70	44	28	22	43	27	27	26	28	27
TiO <sub>2</sub> /V	12	22	36	48	27	35	38	36	34	35

42392A	Cap rock: Deep-brown, vuggy laterite (voids 20%) with buff coloured powder lining the voids.
42392B	Laterite: Nodular material from 1st bag of percussion cuttings; deep-red brown fragmental laterite.
42392	Red-brown laterite, powder and cuttings.
42393	Red-brown laterite, cuttings.
42394	Red-brown laterite, cuttings.
42395	Transitional to pallid zone; mid-brown clay, cuttings.
42396	Transitional to pallid zone; mid-brown clay, cuttings.
42397	Weathered gabbro: Small fragments with (weathered) residual gabbroic texture. Fines mainly clay, cuttings.
42398	Gabbro: Grey-green cuttings.
42399	Gabbro: Grey-green cuttings.

\*except 42392A drill cuttings bagged in 10-foot increments



TABLE 2f. Profile F data

Sample No.	42404	42405	42406	42407	42408	42409	42410	42411	42412
Depth (m)	0	0.1	0.6	1.0	1.4	2.3	2.7	3.15 *	3.3
SiO <sub>2</sub>	24.7	22.1	28.2	27.6	53.9	66.8	70.5	73.2	73.5
Al <sub>2</sub> O <sub>3</sub>	42.1	41.8	41.2	37.2	25.7	19.4	15.0	13.7	13.9
Fe <sub>2</sub> O <sub>3</sub>	13.5	10.7	7.2	11.4	3.7	2.1	2.8	1.3	0.9
FeO	1.5	0.39	0.32	0.32	0.32	0.26	0.84	1.0	0.71
MgO	0.05	0.06	0.05	0.06	0.05	0.06	0.15	0.27	0.22
CaO	0.01	0.01	0.01	0.01	<0.01	0.01	0.09	1.1	0.69
Na <sub>2</sub> O	0.02	0.03	0.05	0.03	0.05	0.12	0.57	2.5	2.1
K <sub>2</sub> O	0.40	0.46	0.52	0.56	2.4	2.7	4.3	5.0	5.3
H <sub>2</sub> O	16.36	23.44	21.84	21.64	12.84	7.82	5.66	1.09	1.5
TiO <sub>2</sub>	0.89	1.01	0.73	0.79	0.36	0.27	0.25	0.21	0.20
P <sub>2</sub> O <sub>5</sub>	0.03	0.02	0.02	0.04	0.04	0.03	0.03	0.04	0.03
MnO	0.01	0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.03	0.03
Total	99.6	100.0	100.1	99.6	99.4	99.6	100.2	99.7	99.1
As	13	13	10	14	7	<1	1	<1	<1
Mo	8	13	5	11	6	1	7	2	1
Nb	34	41	35	36	15	16	12	9	10
Th	252	285	312	553	178	112	143	64	76
V	210	150	45	90	30	20	20	10	10
Zr	610	610	505	660	340	290	290	205	150
Sn	10	10	10	10	<10	<10	<10	<10	<10
Cu	2	5	5	5	2	2	2	2	7
Pb	20	20	15	15	10	10	15	20	15
Zn	30	12	12	12	8	5	12	30	20
Ni	50	25	42	45	15	8	15	10	5
Co	50	55	25	30	18	10	5	5	2
Sr	<5	<5	<5	<5	<5	<5	5	90	90
Ba	100	50	50	25	425	650	900	780	860
pH	6.5	6.1	5.7	5.9	6.0	6.5	6.7	8.1	7.9
Quartz	>20	20	>25	25	45	50	55	>35	35
Plagioclase	—	—	—	—	—	—	<5	25	25
Microcline	—	—	—	—	15	25	25	<30	30
Mica	5	5	5	10	5	10	<10	10	10
Gibbsite	50	>55	<60	50	30	15	<10	—	—
Boehmite	10	5	—	—	—	—	—	—	—
Goethite	<10	<15	10	15	5	—	—	—	—
Hematite	5	—	—	—	—	—	—	—	—
Al <sub>2</sub> O <sub>3</sub> /Fe <sub>2</sub> O <sub>3</sub>	(2.8)	3.8	5.5	3.2	6.4	8.1	4.1	5.7	8.2
Fe <sub>2</sub> O <sub>3</sub> /TiO <sub>2</sub>	(17)	11	10	15	12	8.9	15	11	8.5
10 <sup>4</sup> V/Fe <sub>2</sub> O <sub>3</sub>	(14)	14	6.0	7.7	7.5	8.3	5.4	4.2	5.9
TiO <sub>2</sub> /V	(42)	67	162	88	120	135	125	210	200

42404 Topsoil with small nodules of laterite.

42405 Cap-rock bauxite: Cemented, variegated red to red-brown pisolites with abundant voids between pisolites; quartz visible.

42406 Cap-rock bauxite: Less massive than 42405, the colour is more reddish brown than red; very porous and vuggy; quartz visible.

42407 Nodular cemented bauxite: Vuggy cemented red-brown nodular bauxite with red clay partly filling voids between the nodules; quartz visible.

42408 Nodular bauxite: Loose nodules of red bauxite (0.2-0.8 cm in diameter) with a rim of mid-brown, fine-grained material in a matrix rich in clay; rare larger nodules reach 1.5 cm.

42409 Saprolite: Buff-coloured, sandy clay with residual textures of granite.

42410 Decomposed granite.

42411 Weathered granite: Above a sheet joint. Decomposition of feldspar, penetration of ?limonite along grain boundaries.

42412 Granite: Below sheet joint; feldspars partly kaolinized; some penetration of ?limonite.

TABLE 2g. Profile G data

Sample No.	42413A	42413B	42414	42415	42416	42417	42418
Depth (m)	0	0	0.75	0.2	1.75	3.25	5.0
SiO <sub>2</sub>	20.0	20.0	18.7	21.4	36.3	69.5	74.0
Al <sub>2</sub> O <sub>3</sub>	45.8	44.5	44.9	43.9	35.8	15.5	14.1
Fe <sub>2</sub> O <sub>3</sub>	7.9	9.0	9.0	9.1	6.7	1.9	0.80
FeO	0.26	0.13	0.32	0.39	0.19	1.8	0.64
MgO	0.02	0.02	0.02	0.02	0.01	0.4	0.09
CaO	0.01	0.01	0.01	0.01	0.01	1.8	1.1
Na <sub>2</sub> O	0.05	0.05	0.04	0.05	0.04	4.3	2.5
K <sub>2</sub> O	0.11	0.17	0.15	0.20	0.13	2.0	4.1
H <sub>2</sub> O	24.93	24.31	25.44	23.94	20.72	2.18	2.28
TiO <sub>2</sub>	0.47	0.56	0.64	0.72	0.44	0.32	0.11
P <sub>2</sub> O <sub>5</sub>	<0.01	0.02	0.04	<0.01	0.02	0.02	0.01
MnO	<0.01	<0.01	<0.01	0.01	<0.01	0.04	0.01
Total	99.5	98.8	99.2	99.7	100.4	99.8	99.7
As	16	24	19	25	10	3	<1
Mo	5	7	7	8	7	1	2
Nb	20	24	26	28	28	22	7
Th	255	252	174	185	317	25	23
V	90	90	140	130	65	20	5
Zr	410	425	430	450	400	180	60
Sn	<10	10	<10	<10	10	10	<10
Cu	4	5	3	3	4	3	3
Pb	15	10	15	15	15	25	35
Zn	10	10	10	10	8	40	18
Ni	22	20	22	32	35	12	8
Co	52	38	52	25	25	11	6
Sr	<5	<5	<5	<5	<5	92	40
Ba	<10	<10	<10	<10	<10	450	480
pH	5.3	5.2	5.3	5.5	5.3	7.4	7.0
Quartz	20	<20	>15	20	30	40	45
Plagioclase	—	—	—	—	—	35	<25
Microcline	—	—	—	—	—	>10	>25
Mica	—	3	1	5	tr.	<15	10
Gibbsite	70	>65	70	>60	<60	—	—
Goethite	>5	10	10	<10	<10	—	—
Hematite	<5	2	2	5	2	—	—
Al <sub>2</sub> O <sub>3</sub> /Fe <sub>2</sub> O <sub>3</sub>	5.6	4.9	4.8	4.6	5.2	4.0	9.7
Fe <sub>2</sub> O <sub>3</sub> /TiO <sub>2</sub>	20	16	15	13	16	12	14
10 <sup>4</sup> V/Fe <sub>2</sub> O <sub>3</sub>	11	9.8	15	14	9.4	5.1	3.3
TiO <sub>2</sub> /V	52	62	46	55	68	160	220

- 42413A Bauxite Cap-rock: Vuggy, cemented, nodular bauxite; red nodules (1-1.5 cm) cemented with lighter brown material, visible quartz.
- 42413B Bauxite Cap-rock: Similar material but larger nodules (to 3 cm); visible quartz.
- 42414 Lower part, cap-rock: Cemented, vuggy, red bauxite with light-brown surface coatings, visible quartz.
- 42415 Matrix bauxite: Pisolitic, brown-red bauxite with abundant interstitial material; visible quartz.
- 42416 Bauxite: Loose brown-red nodules (to 2 cm) with lighter brown skin set in red and brown sandy clay.
- 42417 Weathered granite: Above sheet joint; some feldspar kaolinized, incipient reddening of feldspars.
- 42418 'Fresh' granite: Granitoid with lightly kaolinized feldspar.

TABLE 2h. Profile H data

Sample No.	42355	42356	42357	42358	42359
Depth (m)	0	0	1.0	6.0	6.2
SiO <sub>2</sub>	30.1	25.8	28.4	72.1	72.7
Al <sub>2</sub> O <sub>3</sub>	43.0	41.0	40.3	15.7	14.7
Fe <sub>2</sub> O <sub>3</sub>	8.5	9.0	8.4	1.4	1.4
FeO	0.51	0.39	0.26	0.64	0.64
MgO	0.11	0.11	0.11	0.65	0.65
CaO	0.06	0.02	0.01	3.36	2.08
Na <sub>2</sub> O	0.03	0.02	0.03	3.00	3.68
K <sub>2</sub> O	0.11	0.05	0.31	3.86	3.38
H <sub>2</sub> O	17.6	23.0	22.1	1.32	0.96
TiO <sub>2</sub>	0.61	0.69	0.28	0.15	0.15
P <sub>2</sub> O <sub>5</sub>	0.03	0.02	0.02	0.03	0.05
MnO	0.01	0.01	0.02	0.07	0.06
Total	100.6	100.2	100.2	100.9	100.5
As	24	16	15	<1	<1
Mo	6	8	2	1	<0.5
Nb	18	18	10	10	10
Th	101	65	153	25	18
V	160	160	100	40	40
Zr	425	335	460	120	110
Sn	<10	<10	<10	<10	<10
Cu	8	6	12	5	4
Pb	20	20	10	20	25
Zn	20	20	20	75	95
Ni	70	80	45	15	10
Co	90	105	85	20	40
Sr	10	<5	<5	400	430
Ba	50	25	50	1250	1225
pH	6.2	6.1	6.1	8.1	7.9
Quartz	25	<25	25	40	40
Plagioclase	—	—	—	<30	35
Microcline	—	—	—	25	20
Mica	—	—	<5	>5	5
Kaolinite	10	>5	5	—	—
Gibbsite	45	60	<60	—	—
Boehmite	10	—	—	—	—
Goethite	5	>5	<10	—	—
Hematite	5	<5	—	—	—
Al <sub>2</sub> O <sub>3</sub> /Fe <sub>2</sub> O <sub>3</sub>	4.7	4.4	4.6	7.7	7.2
Fe <sub>2</sub> O <sub>3</sub> /TiO <sub>2</sub>	15	14	31	14	14
10 <sup>4</sup> V/Fe <sub>2</sub> O <sub>3</sub>	18	17	11	19	19
TiO <sub>2</sub> /V	38	43	28	38	38

42355	Laterite nodules: Dark red brown nodules, buff coloured skin, up to 3 cm in diameter. Broken surfaces show a fragmented texture.
42356	Massive laterite: This sample was taken from the first massive cap rock below the nodules; the rock has a rather fragmented texture with a small proportion of voids; slightly lighter in colour than 42355 with buff-coloured patches and abundant, angular quartz grains 1-2 mm in diameter.
42357	Massive laterite: Lighter brown than 42356; quartz is abundant; the texture is residual granitic.
42358	Weathered porphyritic granitoid: Red-stained, weathered granite; residual feldspar is now stained by hematite; original minerals recognizable.
42359	Fresh porphyritic adamellite: Phenocrysts (0.5 cm) of K-feldspar are set in a matrix of white-grey plagioclase, brown biotite and colourless quartz; there is incipient reddening of plagioclase in places.

TABLE 2i. Profile I data

Sample No.	42376	42375	42374	42373	42372	42371A	42371B
Depth (m)	0	0.5	1.9	2.5	4.0	4.85	5.05
SiO <sub>2</sub>	42.8	51.2	69.6	66.0	66.3	30.7	43.0
Al <sub>2</sub> O <sub>3</sub>	25.6	23.5	16.2	18.7	13.9	23.0	21.9
Fe <sub>2</sub> O <sub>3</sub>	18.7	11.7	5.4	5.9	12.6	30.5	22.7
FeO	0.77	0.26	0.39	0.13	0.19	0.19	0.26
MgO	0.27	0.33	0.27	0.15	0.08	0.17	0.38
CaO	0.09	0.04	0.05	0.03	0.02	0.03	0.02
Na <sub>2</sub> O	0.09	0.04	0.03	0.03	0.03	0.06	0.67
K <sub>2</sub> O	0.16	0.31	0.30	0.06	0.06	0.04	1.45
H <sub>2</sub> O	11.10	11.80	7.46	8.24	6.81	13.05	9.00
TiO <sub>2</sub>	0.81	0.83	0.65	0.76	0.54	2.33	0.71
P <sub>2</sub> O <sub>5</sub>	0.04	0.03	0.02	0.01	0.02	0.03	0.02
MnO	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02
Total	110.4	100.0	100.4	100.0	100.5	100.1	100.1
As	20	12	7	5	6	6	<1
Mo	11	9	4	8	9	3	4
Nb	36	54	56	50	46	23	25
Th	64	128	113	102	88	28	36
V	400	220	80	80	65	610	250
Zr	490	715	815	1105	705	170	145
Sn	<10	<10	<10	<10	<10	<10	<10
Cu	8	9	8	7	8	46	28
Pb	45	45	20	10	40	115	65
Zn	55	45	30	45	85	70	255
Ni	100	90	45	40	40	50	95
Co	55	35	10	15	30	130	70
Sr	<5	<5	<5	<5	<5	<5	<5
Ba	60	135	350	35	90	40	325
pH	6.1	6.1	6.3	6.1	5.7	5.6	4.3
Quartz	30	35	55	50	50	<10	15
Microcline	—	<5	—	—	—	—	—
Mica	—	—	—	—	—	—	20
Kaolinite	>30	>35	<40	<45	>35	55	40
Gibbsite	<20	10	—	—	—	—	—
Anatase	—	—	—	—	—	2	—
Goethite	10	<15	<5	—	—	<5	<5
Hematite	>10	—	<5	>5	<15	>20	30
Al <sub>2</sub> O <sub>3</sub> /Fe <sub>2</sub> O <sub>3</sub>	1.3	2.0	2.8	3.1	1.1	0.75	0.95
Fe <sub>2</sub> O <sub>3</sub> /TiO <sub>2</sub>	24	14	8.9	7.9	24	13	32
10 <sup>4</sup> V/Fe <sub>2</sub> O <sub>3</sub>	21	18	14	13	5.1	20	11
TiO <sub>2</sub> /V	20	38	81	95	83	38	28

- 42376 Top part ferruginized zone: Hard, red, brown, and cream nodules and fragments in a mid-brown 'clay' cement.
- 42375 Mid-part ferruginized zone: Yellow sandy clay with red patches.
- 42374 Lower part ferruginized zone: Buff-coloured, friable, sandy clay with siliceous nodules up to 1.5 cm in diameter.
- 42373 Upper part of mottled zone: White sandy clay with a larger proportion (5-10%) of red patches.
- 42372 Lower part of mottled zone: White, sandy clay with isolated red spots, some 1—3 cm across.
- 42371 Weathered schist:  
 A) A mixture of fine-grained, red, siliceous material and pale-cream clay  
 B) Similar to A, but muscovite visible on broken surfaces.

TABLE 2j. Profile J data

Sample No.	42383A	42383B	42382	42381	42380	42379	42378	42377	42384
Depth (m)	0	0	2.0	3.2	7.2	9.7	12.1	14.2	16.5
SiO <sub>2</sub>	45.2	44.3	39.9	65.9	61.4	56.7	53.4	55.2	63.9
Al <sub>2</sub> O <sub>3</sub>	22.5	19.5	26.1	23.0	25.3	19.3	16.6	19.1	14.4
Fe <sub>2</sub> O <sub>3</sub>	18.8	24.5	20.3	1.8	1.5	9.7	15.0	8.3	4.9
FeO	0.71	0.90	0.26	0.26	0.26	0.32	0.51	1.41	3.79
MgO	0.14	0.17	0.24	0.30	0.45	0.05	2.23	4.64	3.81
CaO	0.03	0.04	0.03	0.01	0.01	0.05	0.11	0.04	0.10
Na <sub>2</sub> O	0.04	0.07	0.06	0.07	0.06	0.53	0.37	0.45	0.31
K <sub>2</sub> O	0.07	0.13	0.54	0.27	0.03	1.57	1.93	3.08	2.25
H <sub>2</sub> O	10.70	9.04	11.60	7.95	10.90	10.70	9.40	7.10	6.05
TiO <sub>2</sub>	1.74	1.51	1.01	1.04	0.24	0.55	0.60	0.95	0.69
P <sub>2</sub> O <sub>5</sub>	0.02	0.03	0.01	0.01	0.01	0.03	0.13	0.06	0.04
MnO	0.02	0.02	0.01	0.02	<0.01	0.03	0.03	0.06	0.13
Total	100.0	100.2	100.1	100.6	100.2	99.5	100.3	100.4	100.4
As	20	13	3	<1	<1	<1	<1	1	1
Mo	5	5	1	1	1	1	1	3	3
Nb	23	20	23	19	9	13	14	20	22
Th	65	87	72	22	11	33	22	39	21
V	660	770	750	190	48	160	180	220	130
Zr	375	345	175	250	85	120	105	170	145
Sn	10	<10	30	<10	<10	<10	<10	<10	<10
Cu	12	12	28	13	20	95	155	150	98
Pb	35	50	60	20	<10	35	75	50	70
Zn	80	95	80	100	30	320	410	680	910
Ni	25	60	60	45	50	90	140	215	180
Co	155	50	35	25	20	25	45	60	45
Sr	<5	<5	<5	10	5	10	15	10	10
Ba	<25	50	160	150	110	450	550	1100	450
pH	6.1	6.3	6.2	4.9	4.7	4.4	6.0	5.4	6.4
Quartz	<35	30	20	<40	35	>30	30	30	45
Mica		<5	5	5	>5	<20	<25	>30	30
Kaolinite	30	>25	>40	>55	<60	<35	20	25	20
Chlorite	—	—	—	—	—	5	10	5	—
Gibbsite	>15	<15	10	—	—	—	—	—	—
Goethite	5	5	<15	—	—	>10	>15	<10	—
Hematite	15	>20	10	—	—	—	—	—	5
Al <sub>2</sub> O <sub>3</sub> /Fe <sub>2</sub> O <sub>3</sub>	1.2	(0.77)	1.3	11	14	1.9	1.1	1.9	1.6
Fe <sub>2</sub> O <sub>3</sub> /TiO <sub>2</sub>	11	(17)	20	2.0	7.5	18	28	10	13
10 <sup>4</sup> V/Fe <sub>2</sub> O <sub>3</sub>	34	(30)	36	90	27	16	12	22	14
TiO <sub>2</sub> /V	26	(20)	13	55	50	34	33	43	53

42383A Nodular laterite: Pisolitic brown and red-brown nodules.

42383B Soil with small ironstone concretions subadjacent to 42383A.

42382 Clay zone: Buff coloured clay below laterite. Contains quartz grains up to 3 mm diameter.

42381 Clay zone: Brown clay containing relatively abundant sand-sized quartz.

42380 Uppermost weathered schist: Grey-cream decomposed schist, now almost wholly clay.

42379 Weathered schist: A mixture of grey-green and red-brown, clay-rich schist; mica is visible on the grey-green surfaces, but not on the red-brown surfaces.

42378 Weathered schist: Brown and greenish-grey clay-rich weathered mica schist.

42377 Weathered schist: Dark-grey, clay-rich, weathered mica schist.

42384 Weathered schist (base of profile). Grey to buff mottled clay-rich mica schist.

TABLE 2k. Profile K data

Sample No.	42391	42390	42389	42388	42388A	42387	42386	42385
Depth (m)	0	0	2	12	12	22	32	32
SiO <sub>2</sub>	49.6	54.1	62.8	33.4	78.3	75.0	79.8	76.0
Al <sub>2</sub> O <sub>3</sub>	18.0	15.6	13.6	16.7	12.1	11.2	12.1	11.2
Fe <sub>2</sub> O <sub>3</sub>	21.3	16.6	11.9	36.6	0.9	6.9	0.8	5.5
FeO	0.77	2.1	0.45	0.71	0.05	0.32	0.58	0.51
MgO	0.48	0.46	0.89	0.27	0.50	0.74	0.60	0.31
CaO	0.04	0.07	0.03	0.02	0.02	0.03	0.01	0.04
Na <sub>2</sub> O	0.02	0.08	0.09	0.03	0.08	0.02	0.21	0.45
K <sub>2</sub> O	0.75	0.43	0.52	0.09	3.4	2.6	2.90	2.5
H <sub>2</sub> O	8.60	10.33	7.75	10.68	2.80	3.53	3.11	3.47
TiO <sub>2</sub>	0.79	0.79	0.65	2.3	0.25	0.29	0.30	0.28
P <sub>2</sub> O <sub>5</sub>	0.03	0.03	0.02	0.06	0.01	0.03	0.03	0.02
MnO	0.01	0.01	0.01	0.02	<0.01	0.01	<0.01	0.01
Total	100.4	100.6	98.7	101.0	98.9	100.7	100.5	100.3
As	13	11	8	4	5	<1	<1	<1
Mo	3	3	3	1	<0.5	<0.5	1	<0.5
Nb	23	23	23	10	35	28	32	29
Th	94	76	70	18	20	69	80	109
V	380	350	250	1600	25	25	25	10
Zr	400	380	365	130	350	380	410	360
Sn	<10	<10	10	<10	10	10	10	10
Cu	8	6	6	170	<5	35	11	86
Pb	30	35	15	10	5	15	<10	<10
Zn	10	15	15	20	5	15	10	30
Ni	60	55	55	40	<5	15	20	25
Co	60	35	30	65	95	20	15	15
Sr	<5	15	<5	<5	12	15	15	25
Ba	160	150	175	60	1400	1500	1200	1250
pH	5.9	5.6	5.9	5.9	6.9	7.2	6.5	6.3
Quartz	40	<50	>50	15	55	60	65	60
Mica	>5	2	5	—	30	>20	>20	25
Kaolinite	20	20	25	>40	15	10	<15	<10
Gibbsite	<10	>10	5	—	—	—	—	—
Anatase	—	—	—	2	—	—	—	—
Goethite	—	—	<5	<20	—	<10	—	—
Hematite	25	<20	10	<25	—	—	—	>5
Al <sub>2</sub> O <sub>3</sub> /Fe <sub>2</sub> O <sub>3</sub>	0.81	0.83	1.1	0.45	13.2	1.6	8.6	1.9
Fe <sub>2</sub> O <sub>3</sub> /TiO <sub>2</sub>	28	24	19	16	3.8	25	4.7	21
10 <sup>4</sup> V/Fe <sub>2</sub> O <sub>3</sub>	17	19	20	43	26	3.5	18	1.7
TiO <sub>2</sub> /V	21	23	26	14	100	116	120	280

- 42391 Loose nodules: Loose nodules (up to 2 cm) immediately below 42390. The nodules are porous, light brown and rather fragmental, not pisolitic.
- 42390 Soil with small nodules ( <3 mm) of laterite, including brown 'humic' clay and sand.
- 42389 Nodular laterite: Brown pisolitic nodules to 3 cm.
- 42388 Massive laterite: A buff coloured fragmental laterite with clay partly filling voids.
- 42388A Weathered schist: A pale-grey clay-quartz rock derived from schist.
- 42387 Weathered schist: Red-brown hardened schist still retaining traces of muscovite.
- 42386 Weathered schist: Creamy grey, clay-rich schist, outcrop in creek bed.
- 42385 Weathered schist: Red rock, a weathered schist, from outcrop in creek bed; a muscovite schist with a dusting of hematite.

TABLE 21. Profile L data

Sample No.	42351	42352	42354	42353
Depth (m)	0	1	4	4.3
SiO <sub>2</sub>	23.4	21.6	57.1	59.9
Al <sub>2</sub> O <sub>3</sub>	38.4	33.8	30.7	26.2
Fe <sub>2</sub> O <sub>3</sub>	15.9	24.0	0.3	0.6
FeO	0.39	0.45	0.26	0.19
MgO	0.08	0.17	0.14	0.75
CaO	0.01	0.03	0.04	0.06
Na <sub>2</sub> O	0.02	0.02	0.08	0.14
K <sub>2</sub> O	0.10	0.34	0.13	3.98
H <sub>2</sub> O	20.00	17.80	10.6	8.01
TiO <sub>2</sub>	1.57	1.46	0.76	0.74
P <sub>2</sub> O <sub>5</sub>	0.04	0.02	0.03	0.03
MnO	0.03	0.03	0.01	0.02
Total	99.9	99.7	100.2	100.5
As	86	267	4	8
Mo	10	6	2	8
Nb	22	11	12	12
Th	103	109	21	27
V	900	520	130	160
Zr	355	220	175	185
Sn	10	10	<10	<10
Cu	25	18	5	3
Pb	38	75	15	5
Zn	40	30	20	15
Ni	160	210	60	35
Co	160	130	75	30
Sr	<5	<5	<5	30
Ba	25	115	50	550
pH	6.4	6.6	6.9	7.0
Quartz	15	>5	>20	<30
Mica	—	2	5	30
Andalusite	>5	—	<10	—
Kaolinite	15	30	65	>40
Gibbsite	<45	<35	—	—
Anatase	2	1	—	—
Goethite	<20	<20	—	—
Hematite	—	<10	—	—
Al <sub>2</sub> O <sub>3</sub> /Fe <sub>2</sub> O <sub>3</sub>	2.4	1.4	51	33
Fe <sub>2</sub> O <sub>3</sub> /TiO <sub>2</sub>	10	17	0.8	1.1
10 <sup>4</sup> V/Fe <sub>2</sub> O <sub>3</sub>	55	21	217	200
TiO <sub>2</sub>	17	28	58	46
42351	Caprock: Pale buff, massive to nodular laterite with small (≤0.5 cm), rounded, residual quartz grains; dispersed irregular cavities up to 1 cm long by 3 mm wide.			
42352	Laterite nodules and fragments: Medium buff to red fragments displaying quartz on broken surfaces, mixed with lighter brown nodules having vague indications of concentric structures; the fragmental material contains about 5% irregular cavities; the nodules are less cavernous.			
42354	Weathered mica schist: Pale-buff mica schist with some liminotic staining; small grains of quartz are visible, but the micaceous sheen has largely disappeared.			
42353	Mica schist: Fresh, grey mica schist having a silvery sheen on broken surfaces; sparse pink spots identified as andalusite.			

TABLE 2m. Profile M data

Sample No.	42360	42361	42362
Depth (m)	0	0.3	0.65
SiO <sub>2</sub>	68.9	93.6	97.2
Al <sub>2</sub> O <sub>3</sub>	13.3	2.8	0.9
Fe <sub>2</sub> O <sub>3</sub>	7.8	0.9	0.2
FeO	0.51	0.45	0.77
MgO	0.15	0.04	0.03
CaO	0.04	0.02	0.32
Na <sub>2</sub> O	0.06	0.03	0.03
K <sub>2</sub> O	0.17	0.08	0.15
H <sub>2</sub> O	8.37	1.74	0.51
TiO <sub>2</sub>	0.85	0.27	0.18
P <sub>2</sub> O <sub>5</sub>	0.06	0.01	0.09
MnO	0.04	<0.01	0.02
Total	100.3	99.9	100.4
As	15	1	5
Mo	9	4	2
Nb	15	4	3
Th	18	<2	<2
V	180	60	60
Zr	295	80	55
Sn	<10	<10	<10
Cu	8	1	3
Pb	<10	<10	<10
Zn	40	15	15
Ni	55	15	<10
Co	90	55	25
Sr	15	<5	<5
Ba	120	60	25
pH	6.0	5.3	6.5
Quartz	>65	>90	>95
Mica	—	2	<5
Kaolinite	5	<5	—
Goethite	10	—	—
Hematite	—	—	—
Gibbsite	<20	<5	—
Al <sub>2</sub> O <sub>3</sub> /Fe <sub>2</sub> O <sub>3</sub>	1.6	2.1	0.90
Fe <sub>2</sub> O <sub>3</sub> /TiO <sub>2</sub>	9.8	5.2	5.6
10 <sup>4</sup> V/Fe <sub>2</sub> O <sub>3</sub>	22	43	60
TiO <sub>2</sub> /V	47	45	30
42360	Laterite: Light-buff massive laterite with localized red-brown patches; quartz is abundant; fractures (?joints) run from laterite down to bedrock.		
42361	Partly ferruginized quartzite: Quartzite with light-buff, powdery joint-faces; rare dark areas occur in the quartzite.		
42362	Quartzite: 'Fresh' quartzite with faint reddish-brown tinge. Rare ferruginous stain on partings.		



TABLE 2n. Profile N data

Sample No.	42363	42364	42365
Depth (m)	0	5	30-35
SiO <sub>2</sub>	52.6	57.4	47.5
Al <sub>2</sub> O <sub>3</sub>	2.8	3.8	2.0
Fe <sub>2</sub> O <sub>3</sub>	39.5	32.3	18.6
FeO	0.71	0.58	24.9
MgO	0.05	0.05	3.1
CaO	0.04	0.08	1.6
Na <sub>2</sub> O	0.01	0.01	0.18
K <sub>2</sub> O	0.01	<0.01	0.06
H <sub>2</sub> O	4.25	5.47	2.71
TiO <sub>2</sub>	0.06	0.09	0.08
P <sub>2</sub> O <sub>5</sub>	0.18	0.32	0.09
MnO	0.02	0.02	0.74
Total	100.2	100.1	101.6
As	10	9	1
Mo	2	6	1
Nb	2	4	4
Th	22	14	10
V	25	40	35
Zr	5	<5	15
Sn	<10	<10	<10
Cu	98	218	38
Pb	10	25	10
Zn	75	210	250
Ni	60	95	55
Co	130	135	225
Sr	<5	10	50
Ba	15	<15	85
pH	4.6	5.3	6.4
Quartz	>50	>55	20
Hornblende	—	—	20
Grunerite	—	—	60
Gibbsite	—	<5	—
Boehmite	<25	25	—
Goethite	25	15	—
Al <sub>2</sub> O <sub>3</sub> /Fe <sub>2</sub> O <sub>3</sub>	0.07	0.12	0.04
Fe <sub>2</sub> O <sub>3</sub> /TiO <sub>2</sub>	672	366	575
10 <sup>4</sup> V/Fe <sub>2</sub> O <sub>3</sub>	0.62	1.22	0.76
TiO <sub>2</sub> /V	24	23	23
42363	Laterite cap rock: Dark brown, vuggy ironstone containing both colourless and yellowish quartz up to 5 mm in diameter.		
42364	Laterite: Medium dark-brown ironstone carrying a proportion of glassy quartz; the rock is mainly massive, but contains 5-10% yellow ochreous patches.		
42365	Banded iron formation: A banded rock with macrobands 0.5-1 cm thick. Fresh surfaces are brownish black and contain an abundance of glistening ?colourless needles.		

TABLE 2o. Profile O data

Sample No.	42368	42369	42370
Depth (m)	0	0	1
SiO <sub>2</sub>	64.3	78.7	82.5
Al <sub>2</sub> O <sub>3</sub>	17.0	11.6	9.7
Fe <sub>2</sub> O <sub>3</sub>	7.9	3.2	2.1
FeO	0.39	0.26	0.32
MgO	0.09	0.13	0.23
CaO	0.02	0.03	0.05
Na <sub>2</sub> O	0.03	0.05	0.06
K <sub>2</sub> O	0.04	0.08	0.21
H <sub>2</sub> O	4.89	5.50	4.64
TiO <sub>2</sub>	0.71	0.29	0.34
P <sub>2</sub> O <sub>5</sub>	0.02	0.02	0.01
MnO	0.01	<0.01	<0.01
Total	100.4	99.9	100.2
As	26	14	4
Mo	4	3	2
Nb	15	7	8
Th	3	26	23
V	160	70	50
Zr	310	100	120
Sn	<10	<10	<10
Cu	4	5	10
Pb	30	<5	<5
Zn	10	5	10
Ni	50	20	15
Co	45	35	60
Sr	15	25	30
Ba	40	25	100
pH	5.7	6.0	6.4
Quartz	>55	>60	65
Microcline	—	—	5
Kaolinite	15	<35	30
Gibbsite	<20	—	—
Boehmite	—	—	—
Goethite	10	5	—
Al <sub>2</sub> O <sub>3</sub> /Fe <sub>2</sub> O <sub>3</sub>	2.1	3.3	4.0
Fe <sub>2</sub> O <sub>3</sub> /TiO <sub>2</sub>	12	12	7.1
10 <sup>4</sup> V/Fe <sub>2</sub> O <sub>3</sub>	19	20	21
TiO <sub>2</sub> /V	44	41	68

42368 Nodular laterite : Nodules and fragments of buff to dark-red laterite; there is abundant visible quartz 1-2 mm in diameter.

42369 Lateritized sediment: Buff and red mottled sandstone.

42370 Clay-rich sandstone: Friable quartz grains up to 2 mm in diameter are set in a buff-coloured, clay-rich matrix.

TABLE 2p. Profile P data

Sample No.	42601	42602	42603	42604	42605	42606	42607	42609	42608
Depth (m)	0-0.3	0.3-0.6	1.3-1.6	3.1-3.4	6.1-6.4	7.8-8.1	9.4-9.7	11.0-11.3	14.6-14.9
SiO <sub>2</sub>	34.8	32.9	48.8	45.5	56.3	47.0	42.7	52.9	63.4
Al <sub>2</sub> O <sub>3</sub>	17.9	17.0	32.4	35.9	28.0	34.1	32.8	29.6	22.1
Fe <sub>2</sub> O <sub>3</sub>	32.9	37.3	2.5	2.1	2.5	3.1	7.8	4.1	3.2
FeO	0.71	0.39	0.13	0.13	0.39	<0.01	<0.01	<0.01	0.19
MgO	0.10	0.05	0.13	0.51	0.17	0.14	0.25	0.52	0.63
CaO	0.04	0.01	0.03	<0.01	0.01	0.01	0.01	0.01	0.02
Na <sub>2</sub> O	0.03	0.07	0.10	0.07	0.10	0.06	0.12	0.19	0.13
K <sub>2</sub> O	0.06	0.05	0.12	0.04	0.05	0.03	0.12	0.41	0.95
H <sub>2</sub> O	11.5	10.7	15.1	15.8	12.3	14.9	15.8	12.9	9.3
TiO <sub>2</sub>	1.1	0.55	0.36	0.52	0.37	0.42	0.40	0.29	0.23
P <sub>2</sub> O <sub>5</sub>	0.03	0.03	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
MnO	0.03	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Total	99.2	99.1	99.8	100.6	100.2	99.8	100.0	100.9	100.2
As	3	9	2	<1	2	<1	<1	<1	<1
Mo	1	2	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Nb	10	9	13	19	12	10	13	11	9
Th	11	40	22	12	14	18	9	21	15
V	580	740	55	35	25	30	30	50	50
Zr	115	100	95	195	140	185	160	140	110
Sn	<10	<10	<10	<10	<10	<10	<10	<10	<10
Cu	90	42	20	15	10	10	10	20	25
Pb	<10	10	<10	10	10	20	10	15	15
Zn	20	13	13	14	12	14	14	15	16
Ni	40	35	35	40	30	25	25	20	20
Co	40	45	30	40	20	35	35	35	20
Sr	5	<5	<5	<5	<5	<5	<5	<5	<5
Ba	<10	<10	<10	<5	<10	<10	<10	100	250
pH	5.7	5.8	5.6	4.3	5.2	5.0	5.0	4.9	5.7
Quartz	20	<25	<10	—	20	5	tr	15	30
Plagioclase	—	—	—	—	—	3	—	—	—
Mica	—	—	—	—	—	2	—	5	10
Kaolin	35	>25	80	>90	80	90	<95	80	60
Illite/Montmorillonite	—	—	<5	<10	—	—	—	—	—
Gibbsite	5	10	>5	—	—	—	—	—	—
Goethite	10	10	2	—	—	—	>5	—	—
Hematite	30	30	—	—	—	—	—	—	—
Al <sub>2</sub> O <sub>3</sub> /Fe <sub>2</sub> O <sub>3</sub>	0.53	0.45	12	16	9.7	11	4.2	7.2	6.9
Fe <sub>2</sub> O <sub>3</sub> /TiO <sub>2</sub>	31	69	7.5	4.3	7.8	7.4	20	14	14
10 <sup>4</sup> V/Fe <sub>2</sub> O <sub>3</sub>	17	20	20	16	8.6	9.7	3.9	12	16
TiO <sub>2</sub> /V	19	7.4	65	149	148	140	133	58	46

42601 Dull, dark grey-brown nodules and soil; visible quartz.

42602 Red-brown nodules up to 3 cm in diameter; nodule-skin pale fawn.

42603 Transition from lateritic zone to upper part of pallid zone; creamy fawn clay with rare, red nodules.

42604 White clay, quartz free pallid zone.

42605 Friable white sandy clay pallid zone.

42606 White clay, essentially quartz free.

42607 Rather nodular zone with brown limonitic coatings over 'pebbles' of grey clay; quartz free.

42609 Pink (flesh-coloured) clay with quartz and red to red-brown nodules; suggestion of a granitic texture.

42608 Quartz fragments and rare ferruginous nodules in white clay; relict granitic texture, true saprolite.

TABLE 2q. Profile Q data

Sample No.	42610	42611	42612	42613	42614	42615	42616	42617	42618	42619	42620	42621
Depth (m)	0-0.3	0.3-0.6	1.6-1.9	2.4-2.7	4.0-4.3	5.2-5.5	7.3-7.6	7.9-8.2	10.4-10.7	12.5-12.8	14.0-14.3	14.3-14.6
SiO <sub>2</sub>	29.8	36.3	29.2	43.8	46.9	45.6	45.2	45.3	53.2	37.9	37.0	38.2
Al <sub>2</sub> O <sub>3</sub>	29.4	29.3	42.3	38.4	36.9	37.9	36.7	37.6	31.6	32.1	38.5	41.3
Fe <sub>2</sub> O <sub>3</sub>	25.3	17.4	6.2	1.3	1.0	1.4	2.4	1.3	1.3	14.7	4.7	0.72
FeO	1.5	0.84	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.26	<0.01
MgO	0.07	0.08	0.05	0.07	0.09	0.06	0.10	0.07	0.18	0.36	0.07	0.11
CaO	0.09	0.06	0.01	0.02	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Na <sub>2</sub> O	0.06	0.02	0.05	0.05	0.05	0.05	0.09	0.01	0.03	0.19	0.06	0.03
K <sub>2</sub> O	0.12	0.16	0.07	0.10	0.26	0.11	0.26	0.15	1.3	0.10	0.28	0.60
H <sub>2</sub> O	12.2	14.7	21.8	16.2	14.8	15.2	14.9	15.2	11.9	15.0	18.7	19.0
TiO <sub>2</sub>	1.4	1.2	0.48	0.51	0.40	0.42	0.46	0.41	0.11	0.16	0.25	0.12
P <sub>2</sub> O <sub>5</sub>	0.06	0.04	0.02	<0.01	0.01	<0.01	<0.01	0.01	<0.01	0.06	0.06	0.04
MnO	0.03	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Total	100.0	100.1	100.2	100.5	100.4	100.7	100.1	100.1	99.6	100.6	100.8	100.1
As	15	19	6	<1	3	<1	<1	<1	<1	<1	<1	<1
Mo	4	3	1	<0.5	<0.5	<0.5	<0.5	<0.05	<0.05	<0.05	<0.5	<0.5
Nb	19	22	12	20	22	16	20	19	8	6	13	2
Th	41	26	25	14	11	11	21	17	22	5	21	14
V	570	620	180	50	10	10	20	5	5	150	60	20
Zr	325	370	130	175	155	170	195	175	130	55	110	90
Sn	10	10	10	10	10	10	10	10	<10	<10	10	10
Cu	20	10	20	10	10	10	13	20	5	35	73	42
Pb	10	35	15	15	22	20	20	25	15	<10	25	20
Zn	22	22	12	14	13	13	21	18	17	12	10	6
Ni	40	45	45	40	30	30	40	45	30	35	75	50
Co	45	50	40	40	25	35	40	45	30	35	40	40
Sr	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	5	5
Ba	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
pH	6.0	6.0	5.5	5.3	4.9	4.9	4.2	4.5	4.8	4.0	4.5	5.2
Quartz	20	25	<5	tr	>5	<5	2	tr	15	1	5	15
Mica	—	—	—	—	—	—	1	tr	10	3	10	15
Kaolin	>15	>30	>50	95	>90	90	>95	<100	75	>80	60	30
Illite/Mont.	—	—	—	—	—	<5	—	—	—	—	—	—
Gibbsite	<30	<30	40	5	2	2	—	—	—	—	20	40
Boehmite	<10	—	—	—	—	—	—	—	—	—	—	—
Goethite	—	—	5	—	—	—	—	—	—	—	5	—
Hematite	>25	15	—	—	—	—	—	—	—	15	—	—
Al <sub>2</sub> O <sub>3</sub> /Fe <sub>2</sub> O <sub>3</sub>	1.1	1.6	6.8	30	37	27	15	29	24	2.2	7.7	57
Fe <sub>2</sub> O <sub>3</sub> /TiO <sub>2</sub>	19	15	13	2.6	2.5	3.3	5.2	3.2	12	92	20	6.0
10 <sup>4</sup> V/Fe <sub>2</sub> O <sub>3</sub>	21	34	29	39	10	7.1	8.3	3.9	1.3	10	5.0	28
TiO <sub>2</sub> /V	25	19	27	102	400	420	230	820	220	11	42	60
42610	Grey brown earth; soil, and red brown nodules up to 1 cm in diameter with a thin, pale, grey-brown skin.											
42611	Medium brown nodular 'earth': quartz is visible in the earthy material; the nodules are red brown with no visible quartz; they are up to 1.2 cm in diameter.											
42612	Equivalent in position to 42603, yellow-brown quartz-free clay, with isolated dark red nodules.											
42613	Creamy clay, no quartz.											
42614	Off-white clay: Red brown, limonitic, dusting on some partings.											
42615	Off-white to cream clay with some quartz.											
42616	Reddish grey friable rubbly clay.											
42617	Very similar to 42616 but slightly lighter in colour.											
42618	White clay with some quartz.											
42619	Red stained sandy clay with irregular patches of pale clay, possibly containing less quartz.											
42620	White clay with brown coated partings.											
42621	Saprolite with granitic texture. Off white clay (feldspar) with quartz and small brown patches (oxidised ferromagnesian minerals).											

TABLE 2r. Profile R data.

Sample No.	42622	42623	42624	42625	42626	42627	42628	42629	42451
Depth (m)	0.6-0.9	2.1-2.4	3.7-4.0	6.1-6.4	9.8-10.1	11.0-11.3	12.5-12.8	12.8-13.1	0
SiO <sub>2</sub>	35.5	36.2	44.3	44.2	33.8	42.5	44.2	38.9	49.2
Al <sub>2</sub> O <sub>3</sub>	29.3	26.5	27.8	25.5	20.0	23.9	24.0	21.9	12.8
Fe <sub>2</sub> O <sub>3</sub>	14.3	18.2	11.1	13.4	29.9	16.6	13.1	20.9	3.8
FeO	0.51	0.51	0.39	0.39	0.39	0.45	0.64	0.58	11.4
MgO	0.10	0.10	0.15	0.20	0.19	0.22	0.50	0.87	6.3
CaO	0.03	0.02	0.02	0.01	0.01	0.01	0.04	0.04	9.9
Na <sub>2</sub> O	0.03	0.02	0.03	0.12	0.02	0.03	0.04	0.10	2.5
K <sub>2</sub> O	0.10	0.02	0.01	0.02	0.02	0.03	0.30	0.73	0.22
H <sub>2</sub> O	17.6	15.9	14.1	13.5	13.3	13.4	13.9	13.8	2.0
TiO <sub>2</sub>	1.5	2.0	2.5	2.6	2.2	2.8	3.1	2.6	1.9
P <sub>2</sub> O <sub>5</sub>	0.08	0.09	0.04	0.05	0.10	0.06	0.12	0.21	0.22
MnO	0.03	0.03	0.03	0.03	0.05	0.05	0.07	0.08	0.22
Total	99.1	99.6	100.5	100.0	100.0	100.1	99.6	100.7	100.5
As	<1	1	<1	1	<1	6	2	<1	<1
Mo	0.5	<0.5	<0.5	<0.5	0.5	<0.5	<0.5	<0.5	<0.5
Nb	15	14	19	19	19	22	22	24	6
Th	9	11	6	<2	13	5	9	12	4
V	350	440	400	370	680	700	460	550	480
Zr	135	140	200	200	155	205	220	205	80
Sn	<10	<10	<10	<10	<10	<10	<10	<10	<10
Cu	105	122	71	78	205	125	118	148	65
Pb	25	10	10	<10	<10	<10	<10	<10	<10
Zn	18	22	26	35	65	42	57	68	140
Ni	65	50	55	60	50	50	60	60	110
Co	45	45	45	40	55	55	55	50	115
Sr	<5	<5	<5	<5	<5	<5	<5	<5	1500
Ba	<10	<10	<10	50	<10	<10	100	200	165
pH	5.9	5.6	5.2	5.4	3.8	4.1	5.3	6.1	8.5
Quartz	<10	10	15	>15	10	15	20	15	>5
Plagioclase	—	—	—	—	—	—	—	—	40
Hornblende	—	—	—	—	—	—	—	—	50
Ilmenite	—	—	—	—	—	<5	<5	<5	<5
Mica	—	—	—	<5	5	1	5	5	—
Kaolin	>60	55	>70	<65	50	60	55	>50	—
Illite	—	5	—	—	—	—	—	—	—
Gibbsite	>10	<10	—	—	—	—	—	—	—
Goethite	<20	>20	<15	>15	35	20	>15	25	—
Al <sub>2</sub> O <sub>3</sub> /Fe <sub>2</sub> O <sub>3</sub>	2.0	1.4	2.4	1.9	0.66	1.4	1.7	1.0	0.79
Fe <sub>2</sub> O <sub>3</sub> /TiO <sub>2</sub>	9.9	9.4	4.6	5.3	14	6.1	4.5	8.3	8.6
10 <sup>4</sup> V/Fe <sub>2</sub> O <sub>3</sub>	24	24	35	27	22	41	33	26	29
TiO <sub>2</sub> /V	43	45	63	70	32	40	67	47	40

42622 Rich brown, apparently quartz free clay; rather friable as collected. Red brown nodules present.

42623 Rich brown friable loamy clay with a significant number of small (0.5 cm) red brown nodules.

42624 Light brown porous clay with both red-brown and off white patches.

42625 Medium brown clay.

42626 Light brown clay with relict textures after dolerite.

42627 Similar to 42626. Doleritic texture.

42628 Friable light brown clay with lighter coloured 'fragments'. Probably relict dolerite.

42629 Rich brown clay, partly apparently fragmental, partly with relict doleritic textures.

42451 Fresh dolerite

TABLE 3a Comparison of minerals obtained from heavy fractions (S.G. &gt;2.89): cap rock and bed rock in residual profiles

		Minerals																			
Profile	Sample No.	Rock type	Fresh or Laterite	Opaques	Bio-tite	Musco-vite	Chlorite	Epi-dote	Green amphi-boles	Zircon	Mona-zite	Rutile	Sphene	Anda-lusite	Stauro-lite	Silli-manite	Kyanite	Garnet	Tour-maline	Tremo-lite	Other
A	42420		L	D	T	—	—	—	—	T	T	—	—	—	—	—	—	—	—	—	—
	42425		F	A	—	—	—	R	D	—	—	—	T	—	—	—	—	—	—	—	—
B	42449	Dolerite	L	D	—	—	T	T	—	T	—	—	—	—	—	—	—	—	—	—	—
	42443		F	A	T	—	?T	—	D	—	—	—	T	—	—	—	—	—	—	—	—
C	42434		L	D	R	—	R	—	—	R	—	—	R	—	?T	—	—	—	—	—	—
	42428		F	R	R	—	R	—	D	—	—	—	R	—	—	—	—	—	—	—	—
D	42435		L	D	—	—	—	—	—	—	—	—	A	—	—	—	—	—	—	—	Brown clay A
	42439		F	R	T	—	T	—	D	—	—	—	—	—	—	—	—	—	—	—	—
E	42392A	Gabbro	L	D	R	—	—	—	R	—	—	—	R	—	—	—	—	—	—	—	Cummingtonite R
	42399		F	R	R	—	A	—	A	—	—	—	R	—	—	—	—	—	—	—	Cummingtonite M
F	42405	Adamellite	L	A	?A	—	—	—	—	T	—	—	—	—	—	—	—	—	—	—	Brown clay/biotite
	42412		F	T	A	—	—	A	—	A	R	—	—	—	—	—	—	—	—	—	—
G	42413A		L	D	—	T	—	—	—	T	—	T	—	—	—	—	—	—	—	—	—
	42418		F	T	A	A	—	—	—	T	—	—	—	—	—	—	—	—	—	—	—
H	42355		L	A	M	T	—	T	—	T	T	—	—	—	—	—	—	—	—	T	Spinel T
	42359		F	T	A	M	—	R	—	T	T	—	—	—	—	—	—	—	—	—	—

D = Dominant (over 60% of heavies)  
 M = Major (>40% of heavies)  
 A = Abundant (>20% of heavies)  
 R = Rare (<20% of heavies)  
 T = Trace (1 — few grains)

No attempt has been made to give more than a qualitative visual estimate of the proportion of heavy minerals.

TABLE 3a (Continued). Comparison of minerals obtained from heavy fractions (S.G.&gt; 2.89): cap rock and bed rock in residual profiles

Profile	Sample No.	Rock type	Minerals																			
			Fresh or Laterite	Opaques	Bio-tite	Musco-vite	Chlorite	Epi-dote	Green amphi-bole	Zircon	Mona-zite	Rutile	Sphene	Anda-lusite	Stau-ro-lite	Silli-manite	Kyanite	Garnet	Tour-maline	Tremo-lite	Other	
I	42376	Schist	L	A	A	R	—	—	T	A	T	T	—	—	A	R	R	—	—	—	—	
	42371A		F	D	A	R	—	—	—	T	—	—	—	—	—	T	—	—	—	—		
J	42383A		L	—	A	—	—	—	—	R	T	—	—	—	D	R	A	—	—	—	—	
	42377		F	R	A	A	—	—	—	—	—	—	—	—	M	M	?T	T	—	—	—	
K	42391		soil	L	D	A	A	—	—	T	R	—	T	—	—	—	—	—	—	—	—	
	42390			D	A	—	—	—	—	R	T	R	T	—	T	—	—	—	—	—	—	
	42385			F	R	—	D	—	—	—	R	—	—	—	—	—	—	—	—	—	—	
L	42351		Quartzite	L	A	A	R	—	—	—	R	—	R	—	M	—	—	—	—	R	—	—
	42354			F	R	T	R	—	—	—	—	—	R	—	M	—	—	—	—	—	—	
M	42360	L		A	—	A	—	—	—	M	—	A	—	—	—	—	—	—	—	—	—	
	42362	F		T	D	R	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
N	42363	B.I.F.		L	D	—	—	—	—	T	—	—	—	—	—	—	—	—	—	—	—	
	42365			F	R	R	—	—	—	—	M	—	—	—	—	—	—	—	—	—	—	Grunerite M
O	42368	Silty Sandstone		L	A	M	A	—	—	T	A	R	R	—	—	R	T	T	T	T	—	Spinel T
	42370			F	A	T	—	—	—	T	R	T	T	—	T	R	T	—	—	—	—	—

TABLE 3b Comparison of minerals obtained from heavy fractions (S.G. &gt;2.89)

Profile	Sample No.	Rock type	Fresh or Laterite	Opaques	Minerals																
					Bio-tite	Musco-vite	Chlorite	Epi-dote	Green amphibole	Zircon	Mona-zite	Rutile	Sphene	Andalusite	Staurolite	Sillimanite	Kyanite	Garnet	Tourmaline	Tremolite	Other
B	42449	Dolerite	L	D	—	—	T	T	—	T	—	—	—	—	—	—	—	—	—	—	—
	42448			D	—	—	T	T	—	T	—	T	—	—	—	—	—	—	—	—	—
	42447			D	T	—	—	—	—	T	—	—	T	—	—	—	—	—	—	—	—
	42446			D	T	—	T	—	T	—	—	—	—	—	—	—	—	—	—	—	—
	42443		F	A	T	—	?T	—	D	—	—	—	T	—	—	—	—	—	—	—	—
G	42413A	Adamellite	L	D	—	T	—	—	—	T	—	T	—	—	—	—	—	—	—	—	—
	42414			D	—	T	T	—	—	R	T	T	—	—	—	—	—	—	—	—	—
	42415			D	T	T	—	T	—	R	—	—	—	—	—	—	—	—	T	—	—
	42416			D	—	T	—	—	—	R	R	—	—	—	—	—	—	—	—	—	—
	42417		F	R	A	A	—	—	—	R	—	—	—	—	—	—	—	—	—	—	—
	42418			T	A	A	—	—	—	T	—	—	—	—	—	—	—	—	—	—	—
I	42376	Schist	L	A	A	R	—	—	T	A	T	R	—	—	A	R	R	—	—	—	—
	42375			D	R	A	—	T	T	A	R	—	—	—	R	R	—	—	—	—	—
	42374			D	R	R	—	—	—	A	R	—	—	—	—	T	—	—	—	—	—
	42373			D	—	T	—	—	—	M	T	—	—	—	—	T	—	—	—	—	—
	42372		F	D	—	T	—	—	—	M	?T	—	—	—	—	T	—	—	—	—	—
	42371A			D	A	R	—	—	—	T	—	—	—	—	—	T	—	—	—	—	—



TABLE 3c Minerals obtained from heavy fractions of cap rock (S.G. >2.89) from transported laterite

Profile	Sample	Hole	Presumed Parent Rock	Mineral								
				Opagues	Biotite	Muscovite	Chlorite	Zircon	Rutile	Tourmaline	'Brown Clay'	
P	42601	G44	Granitoid	M	T	—	T	—	—	—	M	
Q	42610	G58	Granitoid	D	—	T	—	—	—	—	A	
R	42622	G111	Dolerite	D	—	—	T	R	R	T	—	

TABLE 4. Correlation coefficients between constituents in residual cap rock and bed rocks, and their significance

Oxide	Correlation coefficient	Significance level %	Element	Correlation coefficient	Significance level %
SiO <sub>2</sub>	+0.58	98	(As	+0.73	90 )
Al <sub>2</sub> O <sub>3</sub>	+0.60	98	(Mo	+0.46	90 )
*Fe <sub>2</sub> O <sub>3</sub>	+0.63	99	Nb	+0.47	90
MgO	-0.44	90	Th	+0.49	90
CaO	-0.44	90	V	+0.60	98
Na <sub>2</sub> O	-0.32	—	Zr	+0.46	90
K <sub>2</sub> O	+0.48	90	Cu	+0.60	98
TiO <sub>2</sub>	+0.90	99.9	Pb	+0.46	90
P <sub>2</sub> O <sub>5</sub>	+0.40	—	Zn	+0.67	99
MnO	+0.25	—	Ni	-0.31	—
			Co	+0.23	—
			(Sr	+0.02	— )
			(Ba	+0.46	90 )

15 pairs of data

\*All iron expressed as ferric oxide

Significance levels taken from Fisher and Yates

'Statistical Tables for Biological, Agricultural and Medical Research'

Publ. Oliver and Boyd, Ltd, Edinburgh.

Data for elements in brackets was obtained by ascribing value of half the minimum detectable value where analysis is below the detection limit.

TABLE 5 : Table showing approximate enrichment factors from bed rock to cap rock in residual laterites, expressed as cap rock/bed rock ratios

Rock type	Dolerite	Gabbro	Granitoid	Schist	Quartzite	Iron formation	Sandstone
No. of Samples	4	1	3	4	1	1	1
Element/oxide							
SiO <sub>2</sub>	0.06–0.13	0.06	0.27–0.41	0.4–1.0	0.71	1.1	0.78
Al <sub>2</sub> O <sub>3</sub> <sup>t</sup>	2.3–2.8	(1.2–2.9)	2.9–3.3	1.2–1.6	14.8	1.4	1.8
Fe <sub>2</sub> O <sub>3</sub> <sup>t</sup>	1.9–2.9	(2.5–5.0)	3.3–6.5	0.85–20	8.4	0.9	3.5
MgO	0.00–0.01	0–0.01	0.17–0.22	0.04–1.6	5	0.02	0.39
CaO	(0.00)	0	0.01–0.03	0.17–4.5	0.13	0.03	0.4
Na <sub>2</sub> O	(0.00)	0	0.01–0.1	0.04–0.14	2	0.06	0.5
K <sub>2</sub> O	0.00–0.05	0–0.05	0.03–0.08	0.03–0.30	1.1	0.17	0.2
TiO <sub>2</sub>	1.4–2.2	(2.7–4.3)	4.1–5.1	1.1–2.8	4.7	0.75	2.1
P <sub>2</sub> O <sub>5</sub>	0.19–0.43	(0.07–0.60)	0–1	0.5–2.0	0.67	2.0	2.0
MnO	0.05–0.35	(0.21–0.58)	0–0.3	0.15–1.5	2.0	0.03	(2)
As	(8–15)	5–7	(13–24)	11–20	3	10	6.5
Mo	(8–10)	7–9	2.5–13	1.3–2	4.5	2	2
Nb	1.3–2.5	0.5–1.5	1.8–4.1	0.8–1.8	5	0.5	1.9
Th	8–31	1–3.3	3.8–11	0.9–3.8	18	2.2	1.4
V	1.8–3.2	(4.4–13)	4–18	1.6–5.6(–38)	3.0	0.71	3.2
Zr	2.4–3.4	(1.2–2.8)	3.9–6.8	1.1–3.4	5.4	0.3	2.6
Cu	0.28–0.76	(0.48–1.4)	0.3–2	0.09–2.9(8.3)	2.7	2.5	0.4
Pb	(1–5)	(3)	0.4–1.3	0.5–7.6	0	1.0	(6)
Zn	0.17–0.32	0.02–0.13	0.2–0.6	0.09–.33(–2.7)	2.7	0.30	1.0
Ni	(.18–)0.46–0.53	0.05–0.11	2.7–8	0.14–4.6	(11)	1.1	3.3
Co	0.6–1.1	0.12	2.3–25	0.8–5.3	3.6	0.58	0.75
Sr	(0)	0	≤0.02	(0)	(30)	<0.1	0.5
Ba	(0)	(0.18–0.36)	≤0.12	<0.05–0.22	4.8	0.18	0.4

Fe<sub>2</sub>O<sub>3</sub><sup>t</sup> is total iron expressed as ferric oxide.

The use of brackets means that these figures are only approximations because of i) wide variations between samples or ii) one factor in the ratio is near or below the lower limit of detection.

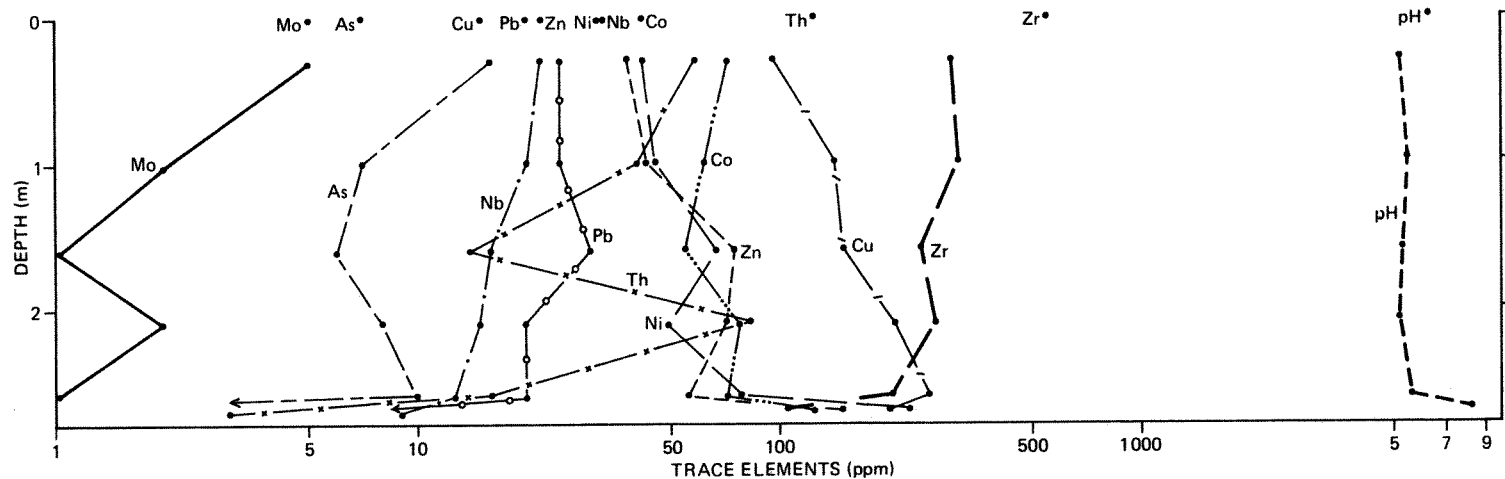
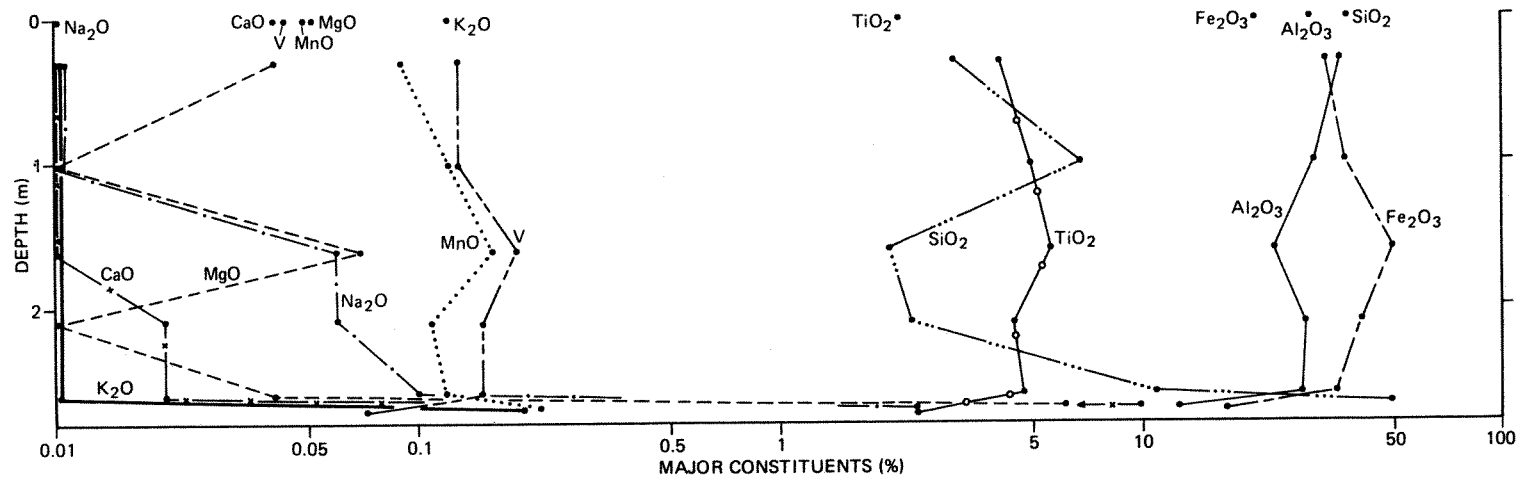


FIGURE 3a: DOLERITE, PROFILE A, JARRAHDALÉ  
42419-25

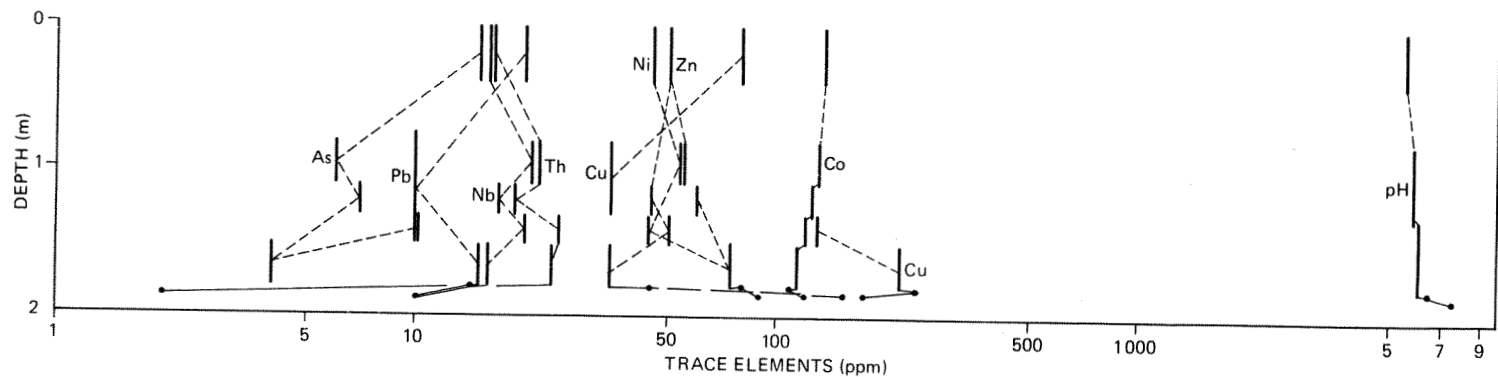
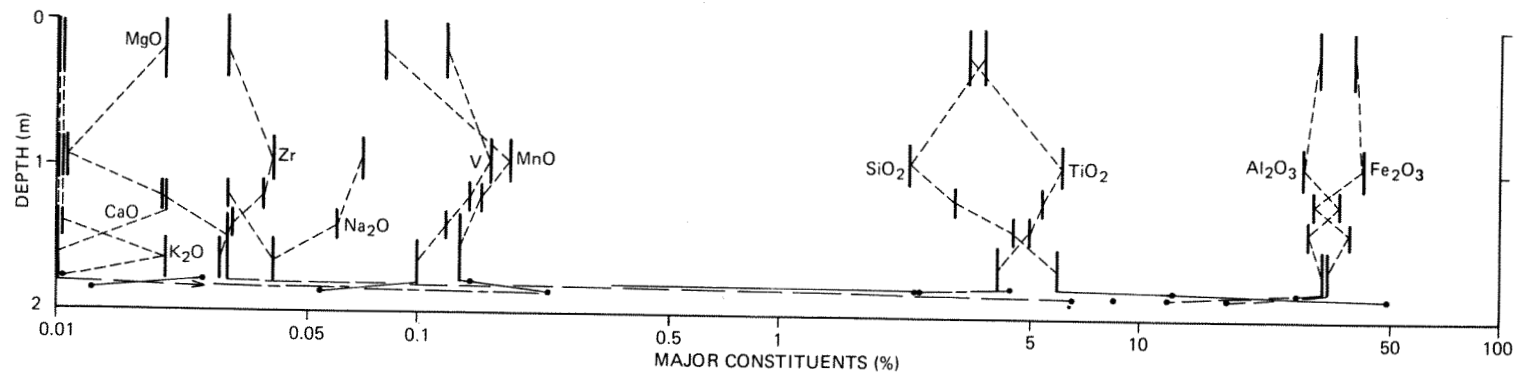


FIGURE 3b: DOLERITE, PROFILE B, JARRAHDALÉ  
42443-09

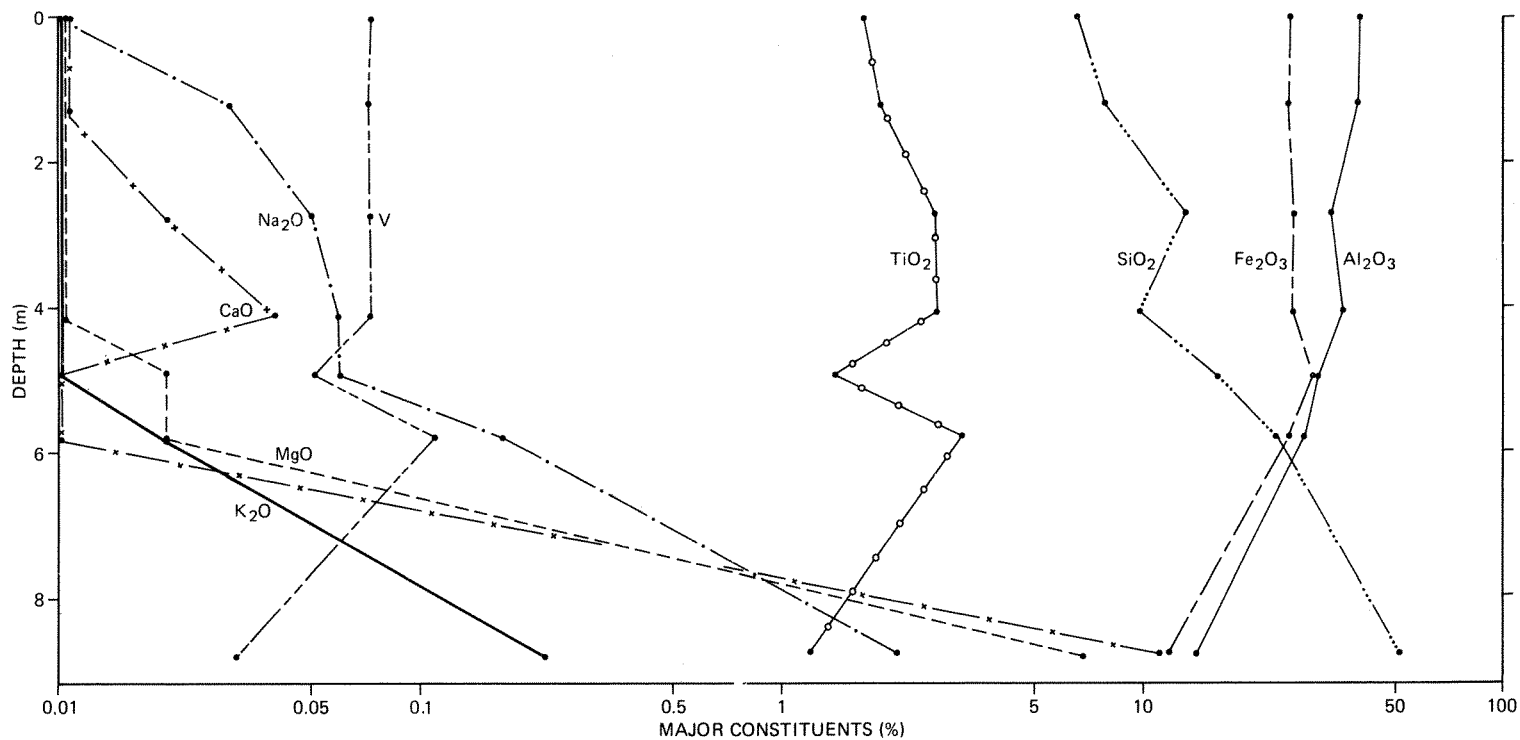


FIGURE 3c(i): DOLERITE, PROFILE C, JARRAHDALE  
42428-35

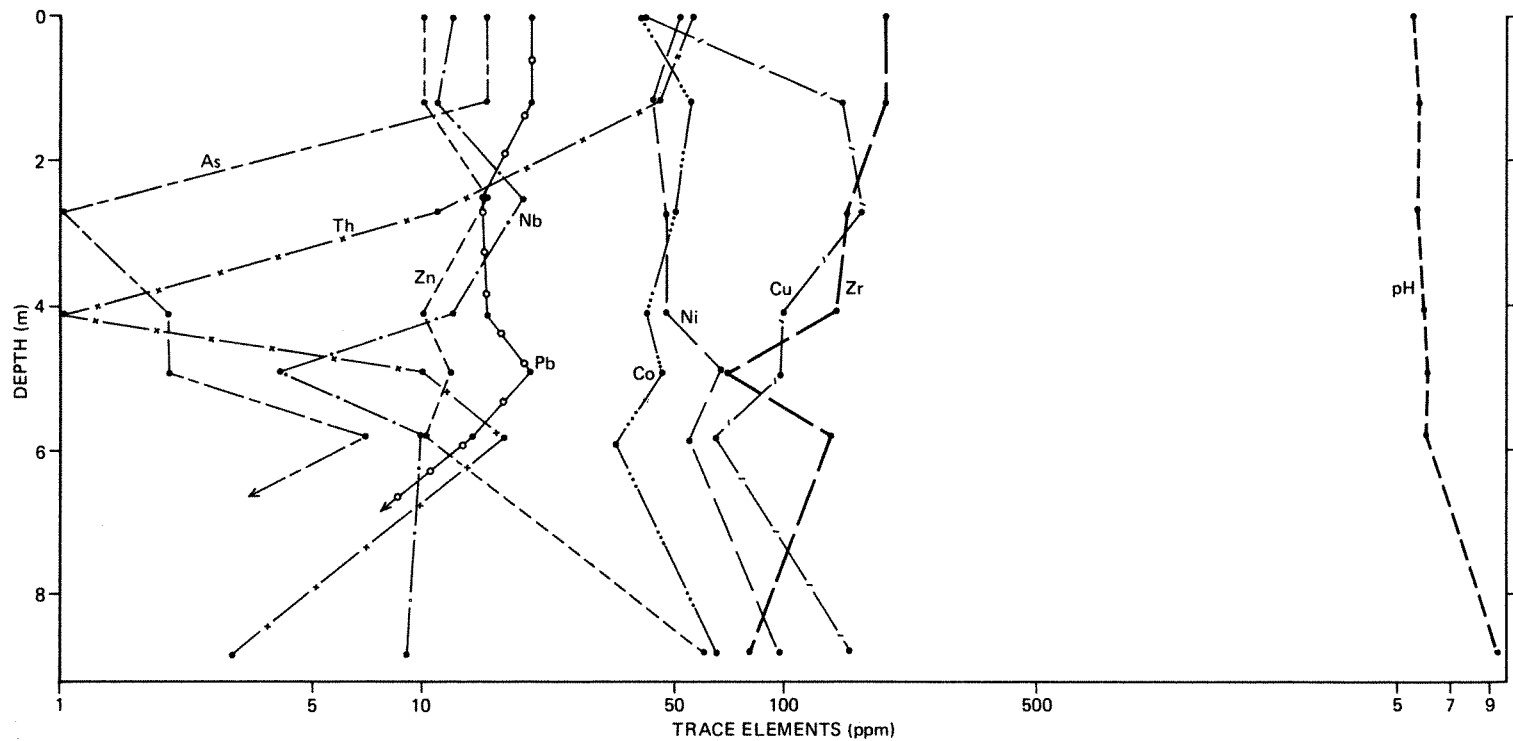
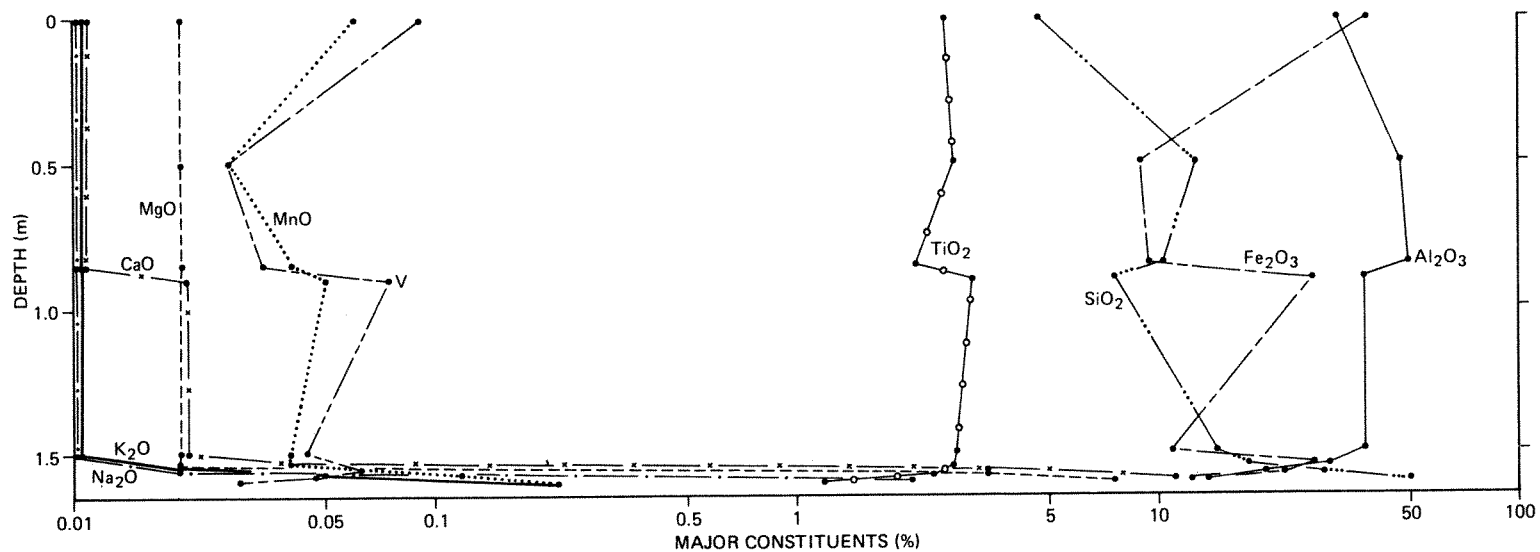


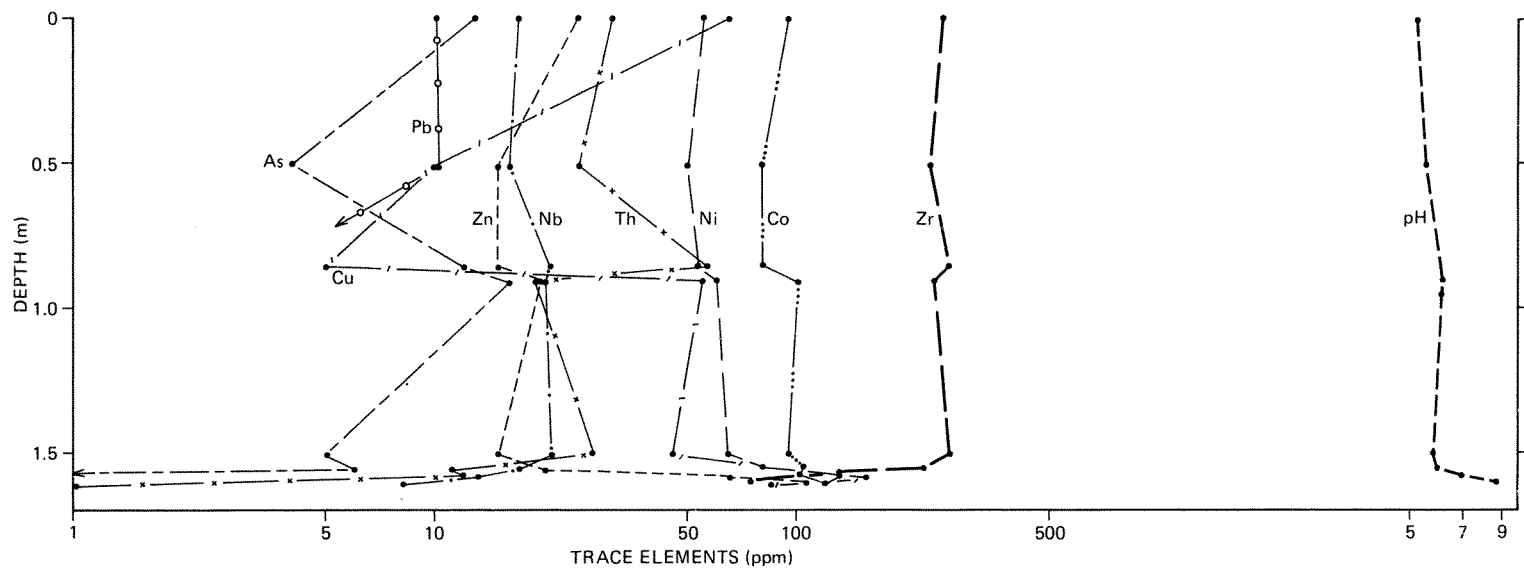
FIGURE 3c(ii): DOLERITE, PROFILE C, JARRAHDAL  
42428-35

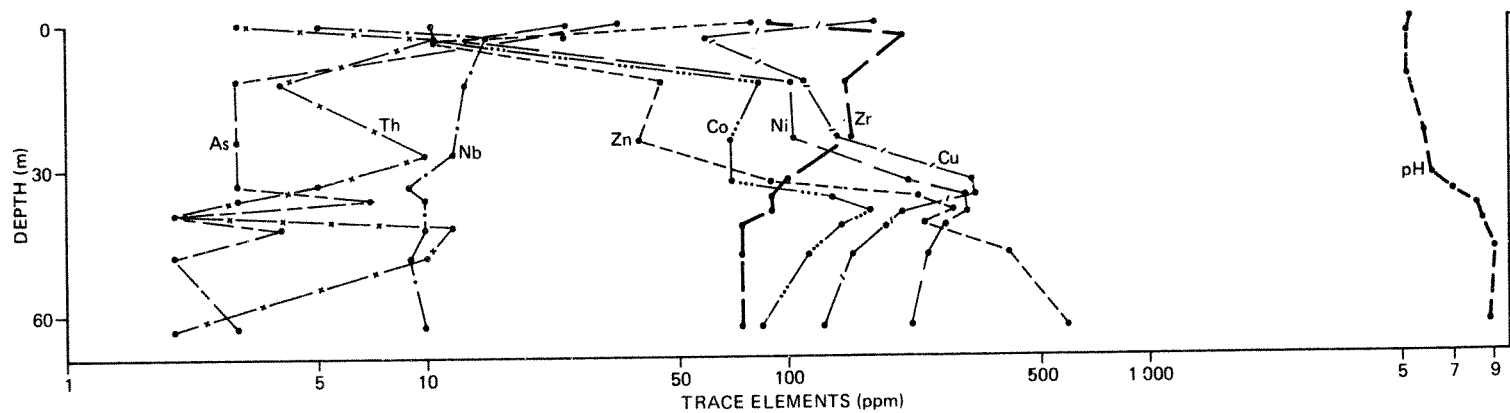
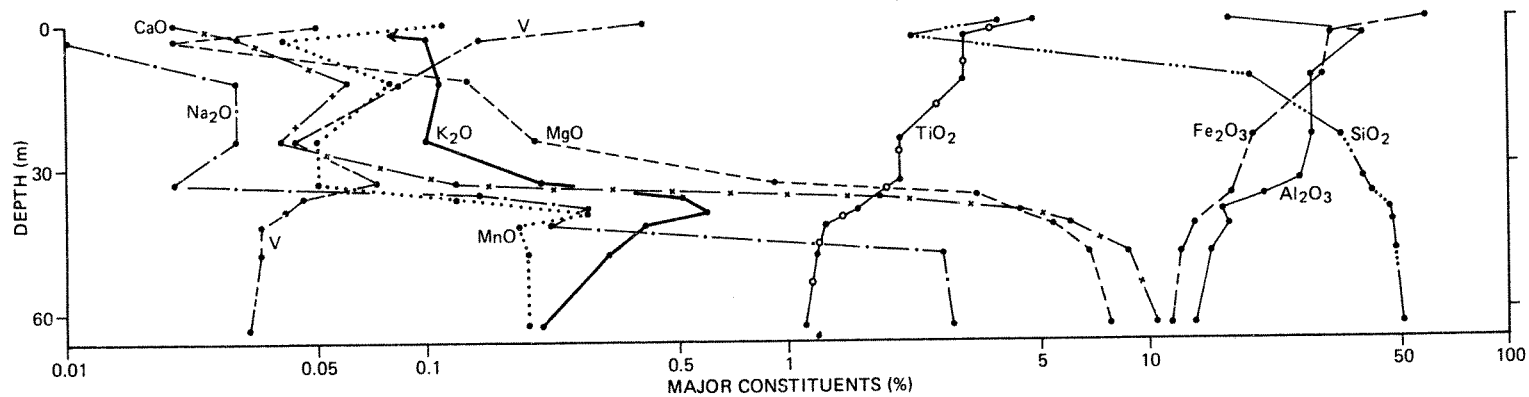


Crush or fault zone depth 0.5–0.85 m  
FIGURE 3d(i) DOLERITE, PROFILE D, DEL PARK  
42435–42

G.S.W.A. 16949







Percussion cuttings  
 FIGURE 3e: GABBRO, PROFILE E, COATES SIDING  
 42392-99

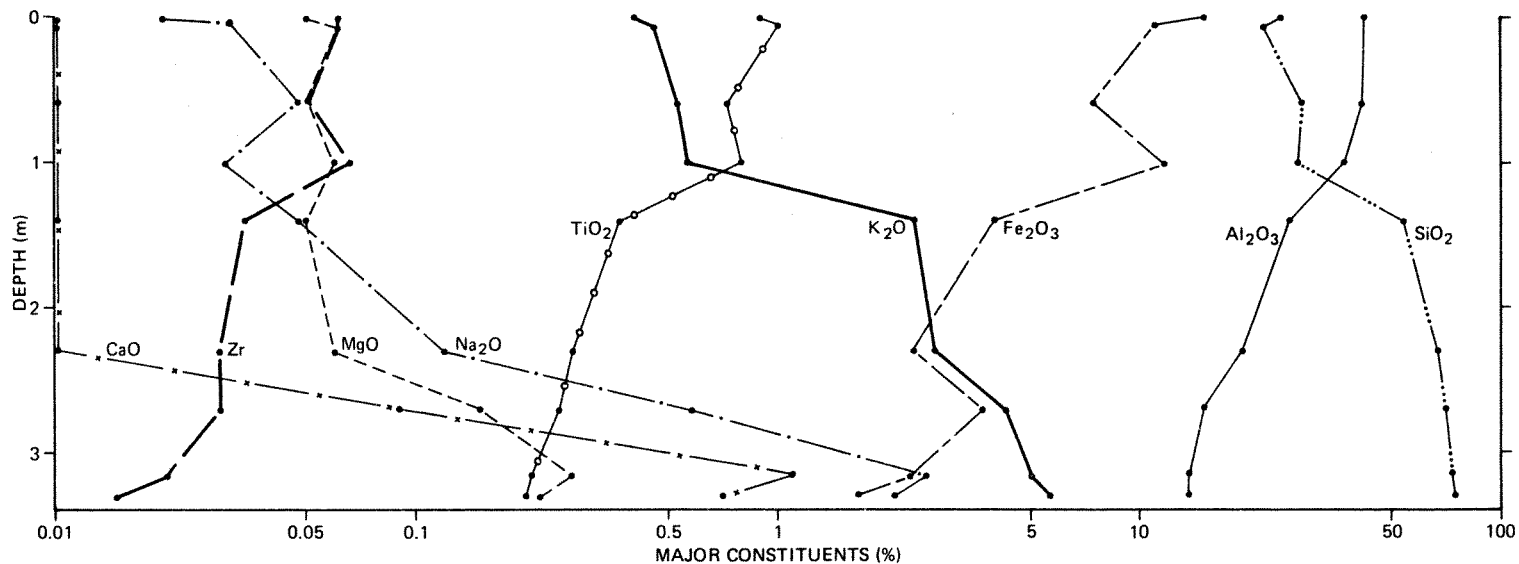


FIGURE 3f(i): ADAMELLITE, PROFILE F, JARRAHDALE  
42404-12

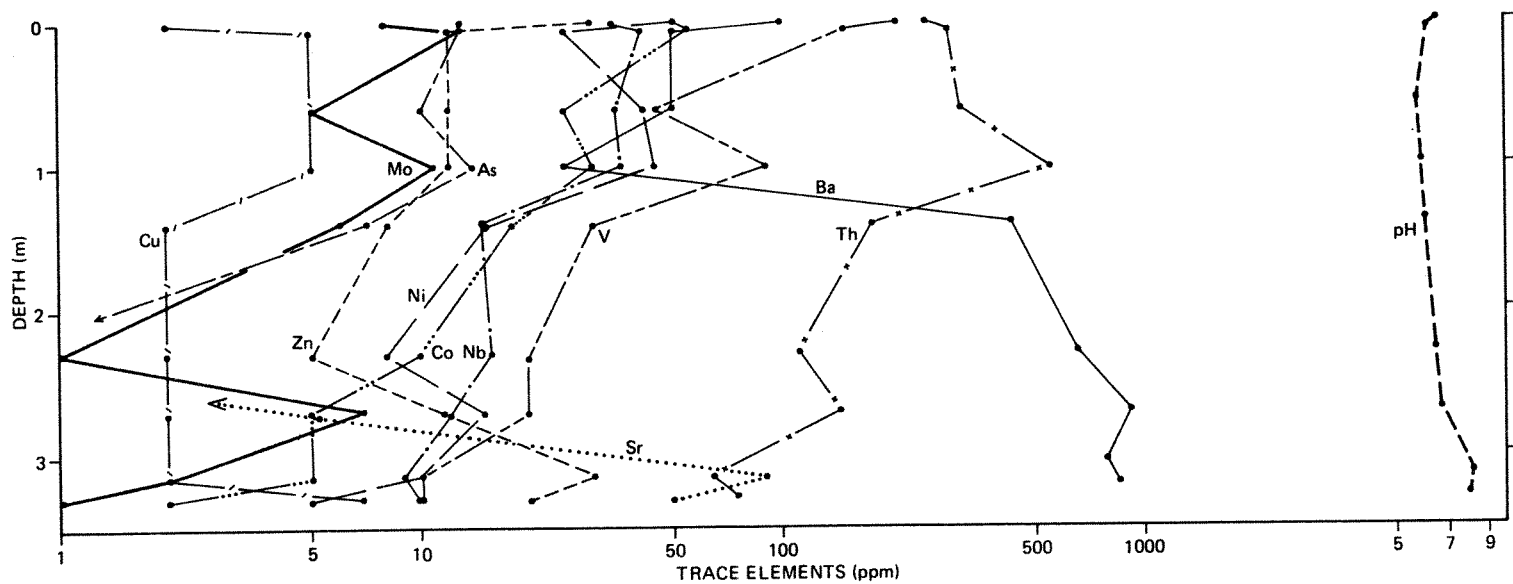


FIGURE 3f(ii): ADAMELLITE, PROFILE F, JARRAHDAL  
42404-12

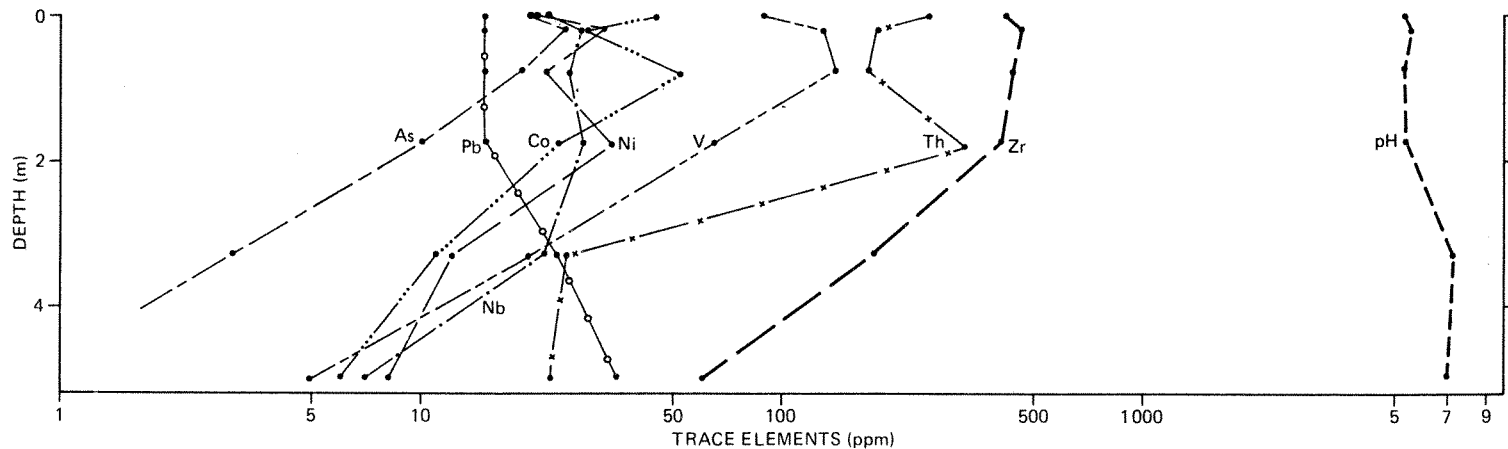
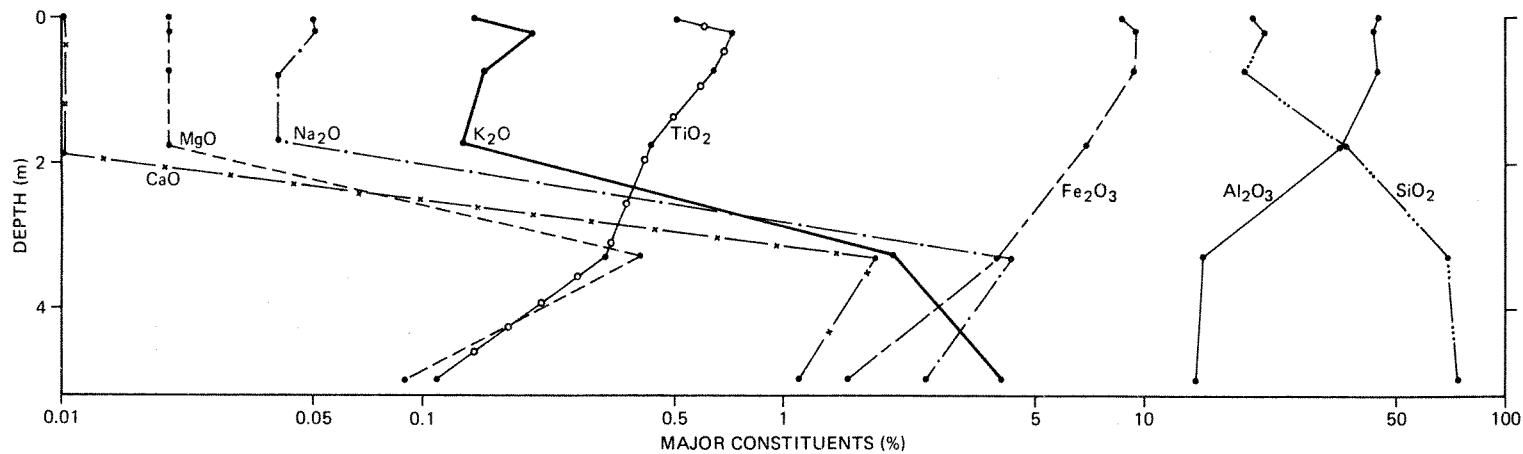


FIGURE 3g: ADAMELLITE, PROFILE G, JARRAHDAL  
42413-18

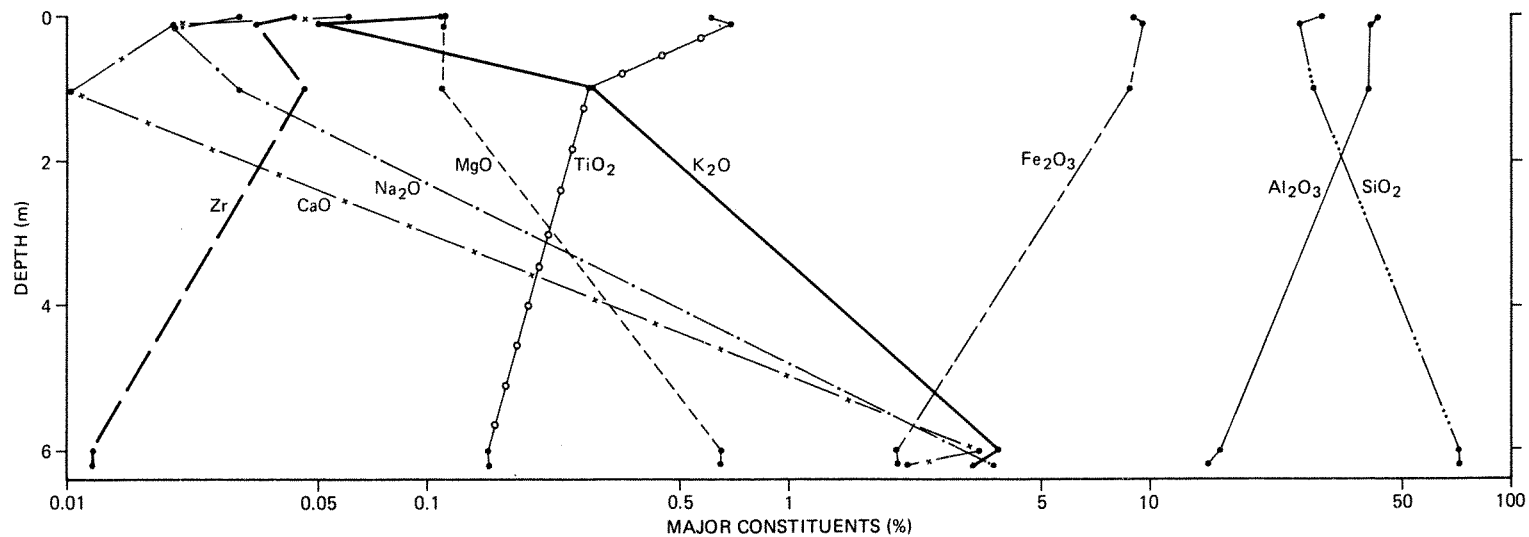


FIGURE 3h(i): ADAMELLITE, PROFILE H, BALD HILL  
42355-59

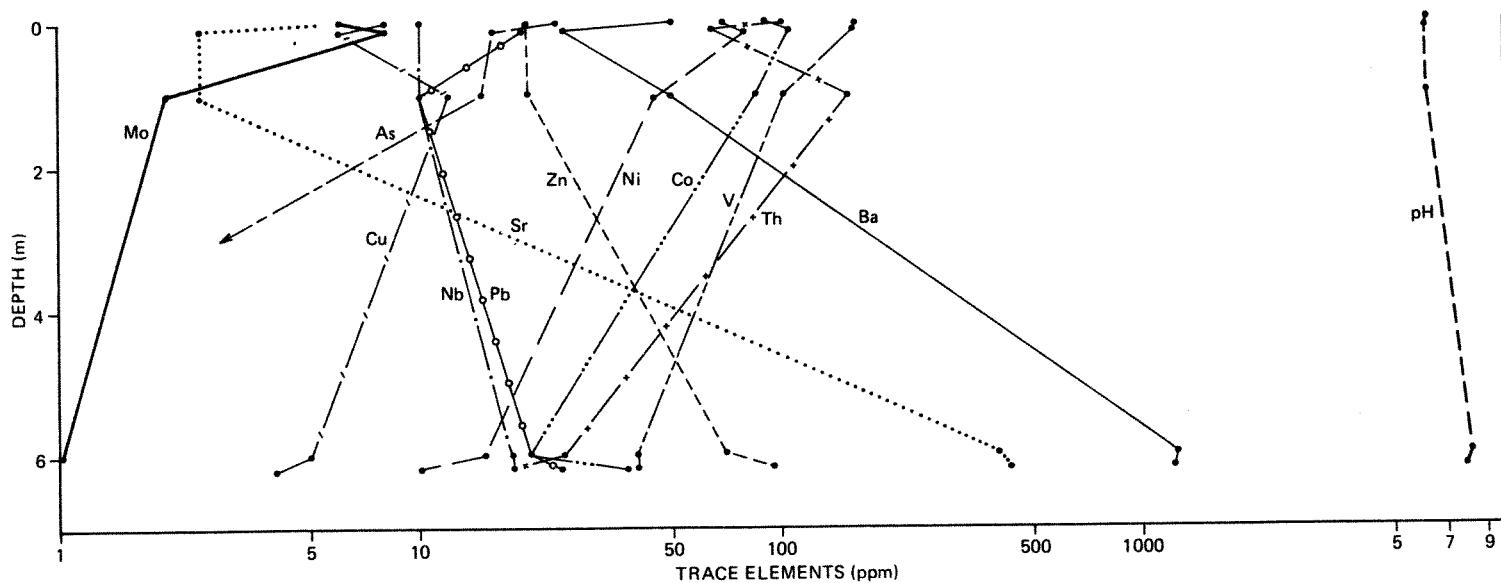


FIGURE 3h(ii) ADAMELLITE, PROFILE H, BALD HILL  
42355-59

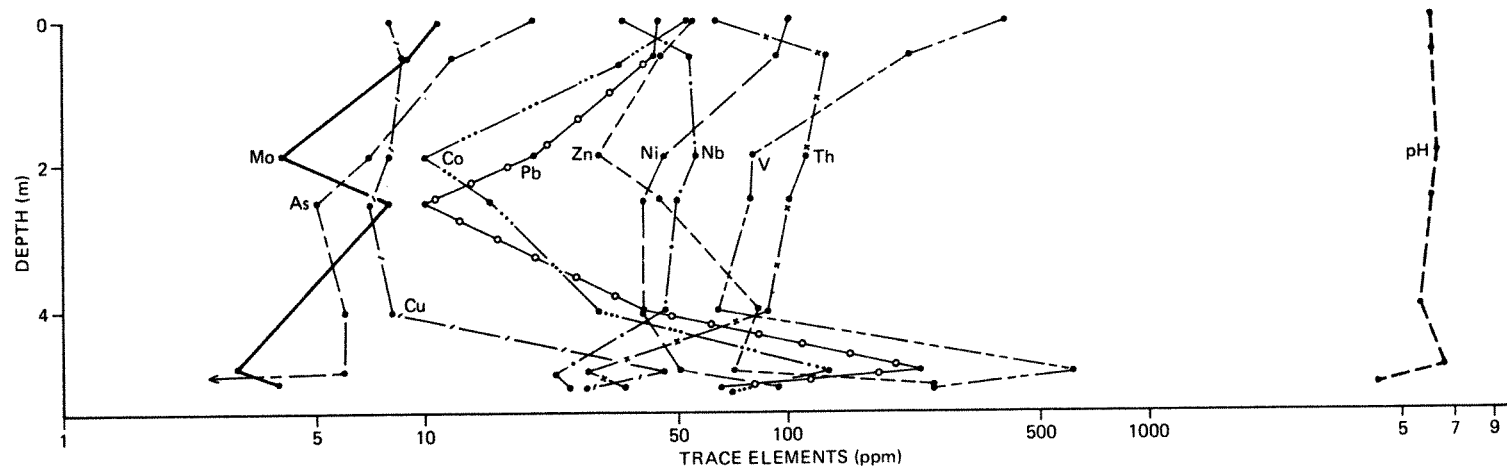
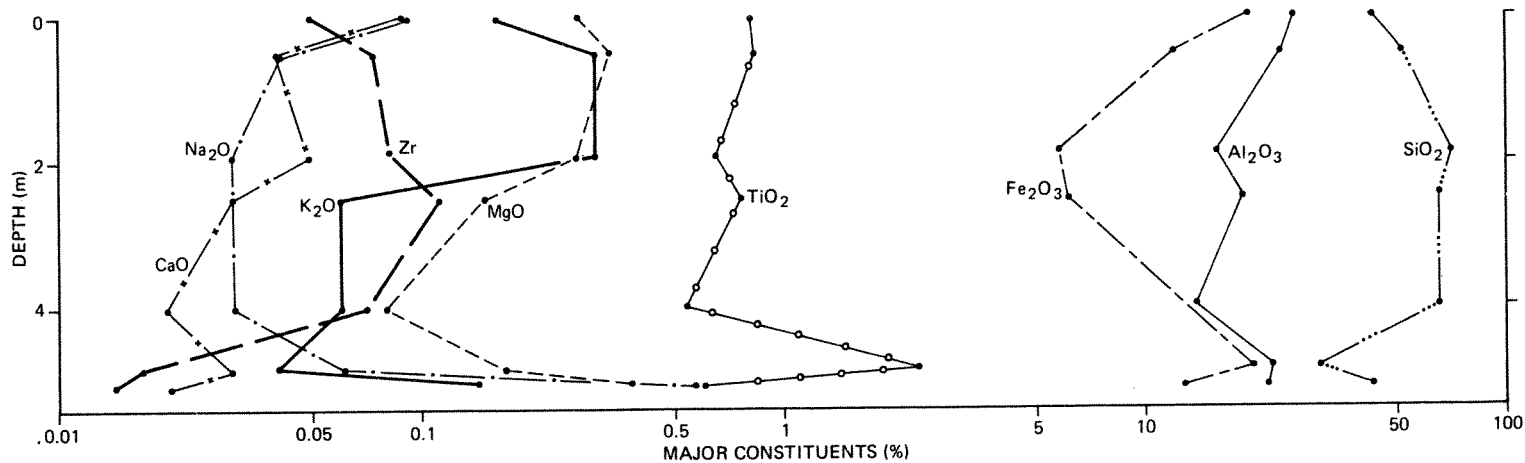


FIGURE 3i: MICA SCHIST, PROFILE I, 'BOWGALE' MIDLAND BRICK QUARRY, CHITTERING  
42371-76



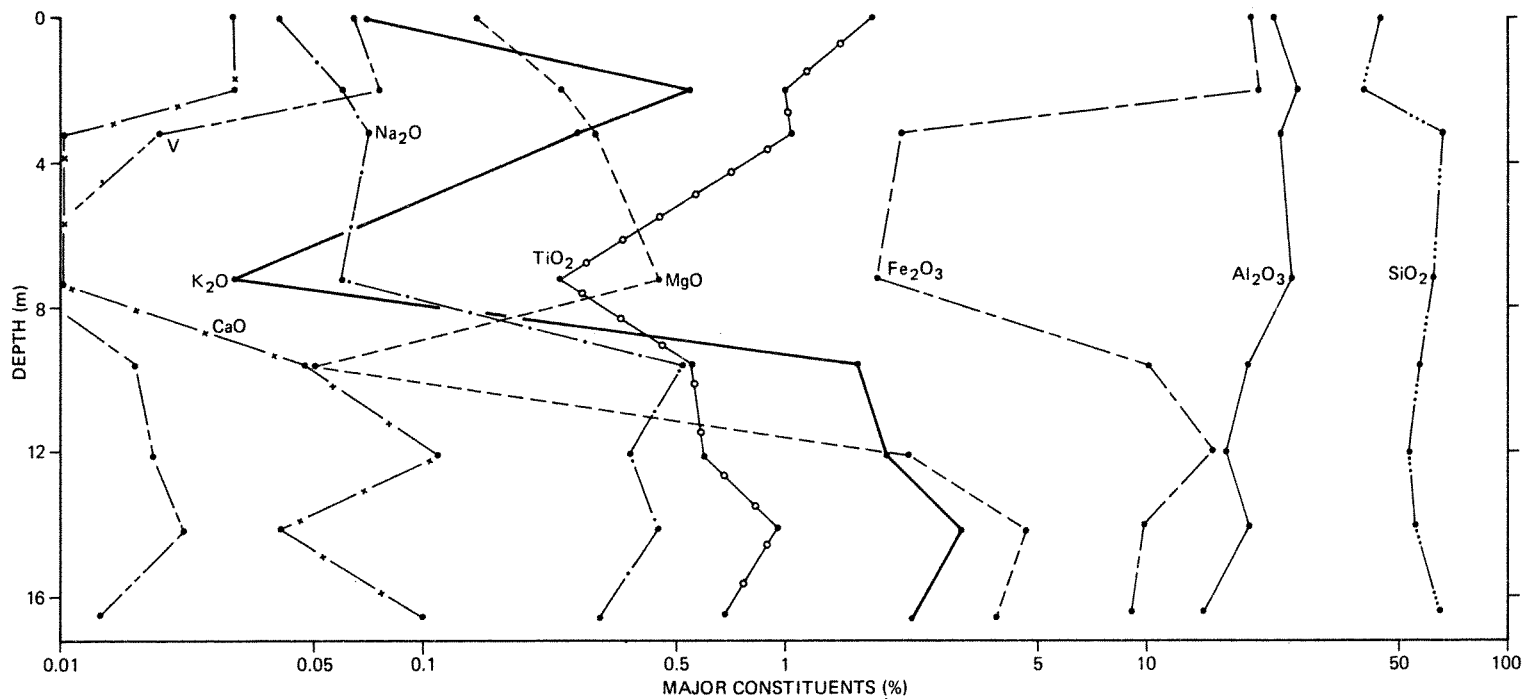


FIGURE 3j(ii): MICA SCHIST, PROFILE J, 'BOWGALE' MIDLAND BRICK QUARRY, CHITTERING  
42377-84

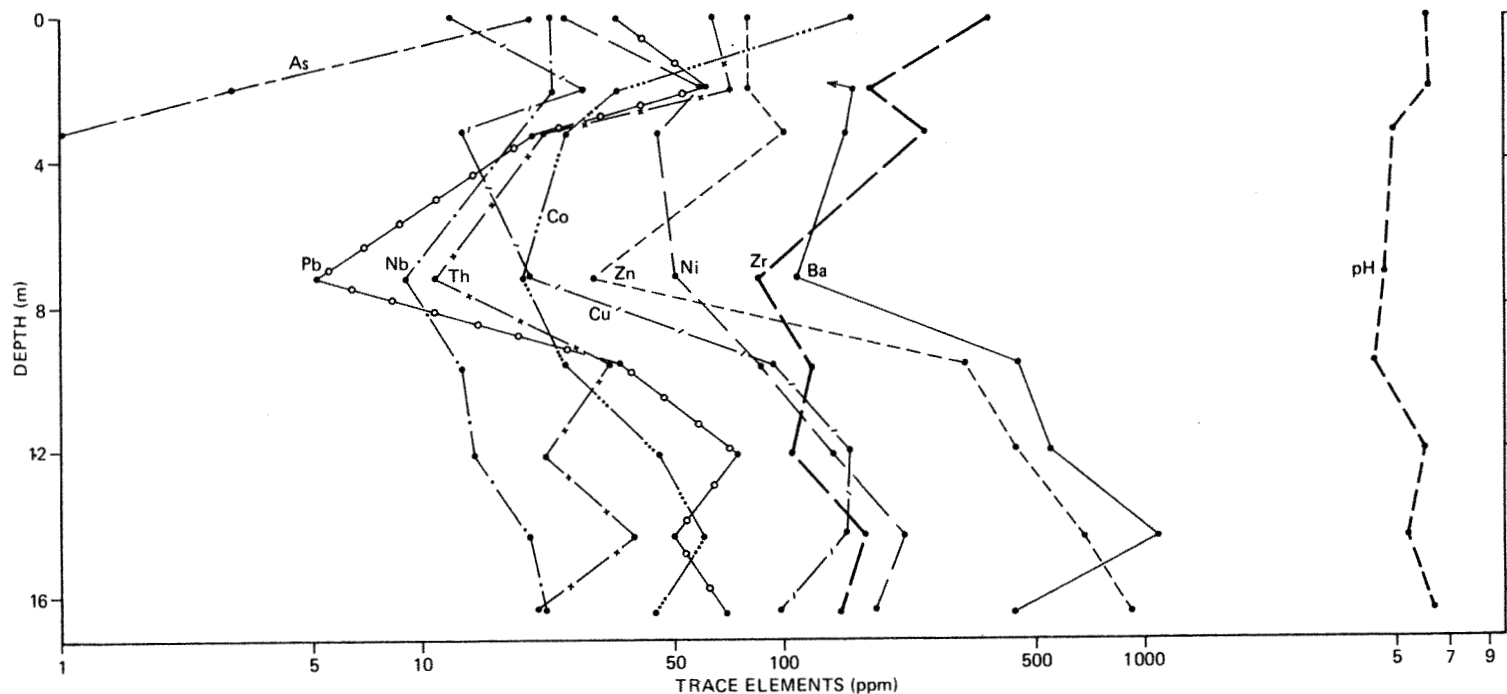
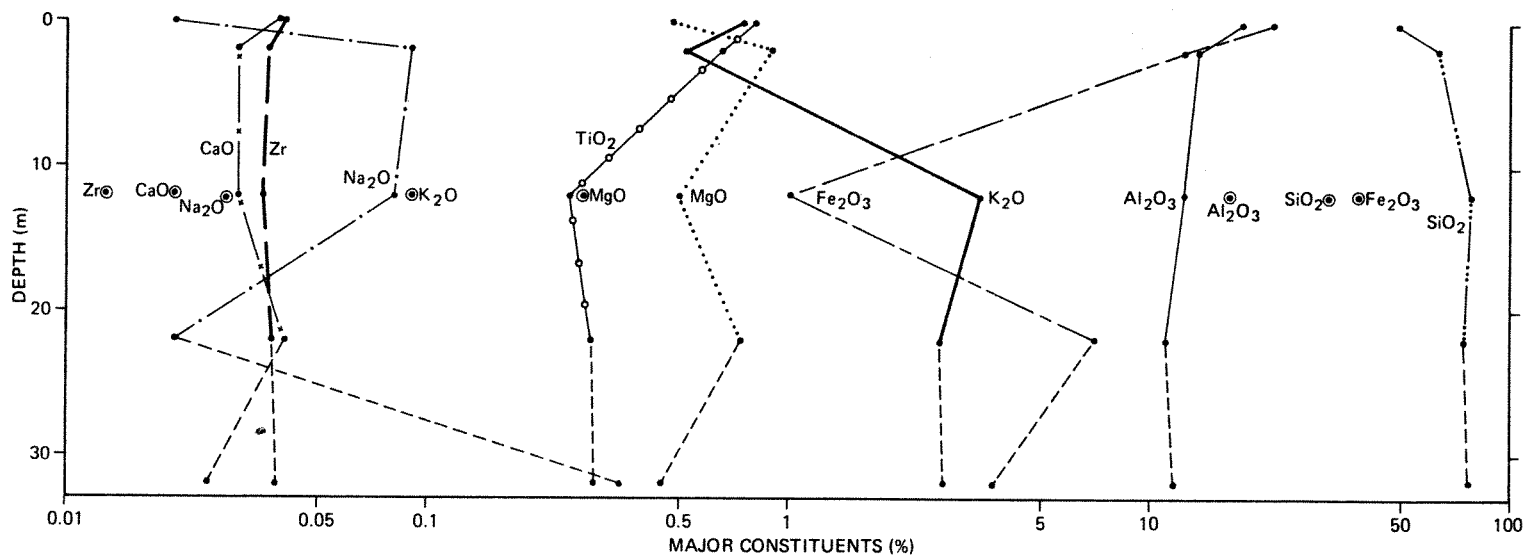
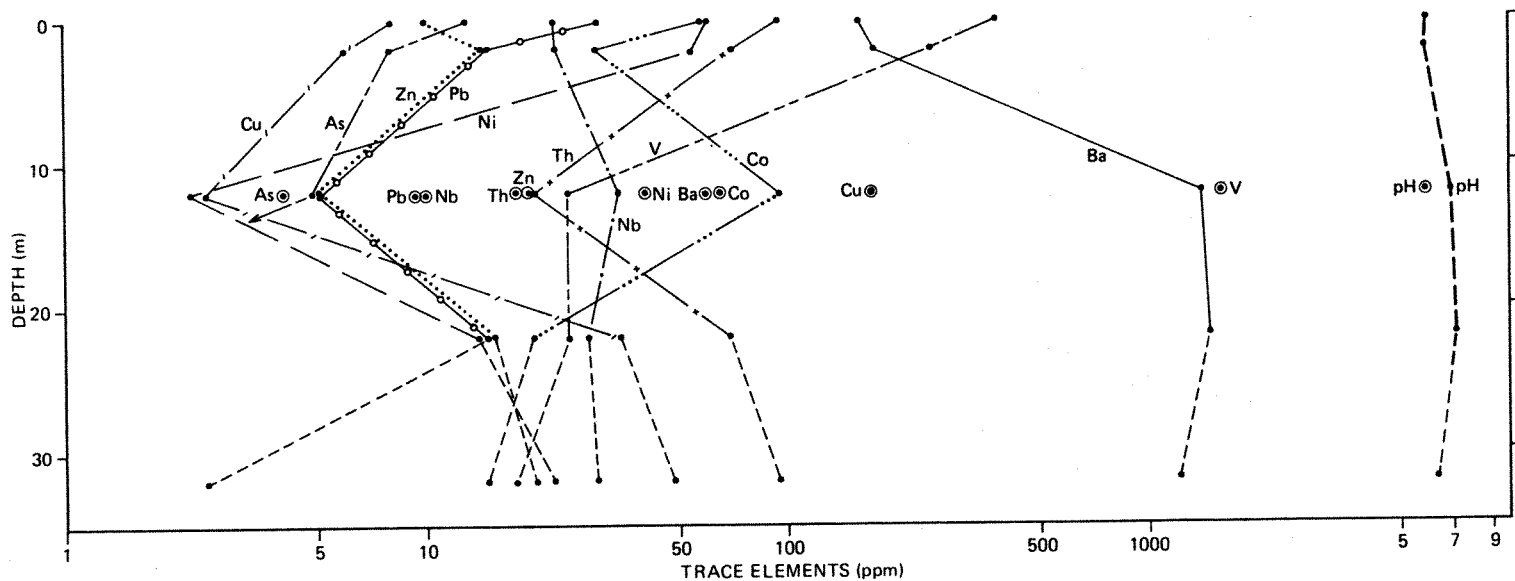


FIGURE 3j(ii) MICA SCHIST, PROFILE J, 'BOWGALE' MIDLAND BRICK QUARRY, CHITTERING  
42377-84

G.S.W.A. 16949



Figures in circles at 12 m are from a laterized dolerite dyke  
 Dashed lines to mean value of two at 32 m  
 FIGURE 3k(i): MICA SCHIST, PROFILE K, STEPHENS ROAD, BINDOON  
 42385-91



Figures in circles at 12 m are from a laterized dolerite dyke  
Dashed lines to mean value of two at 32 m

FIGURE 3k(ii): MICA SCHIST, PROFILE K, STEPHENS ROAD, BINDOON  
42385-91

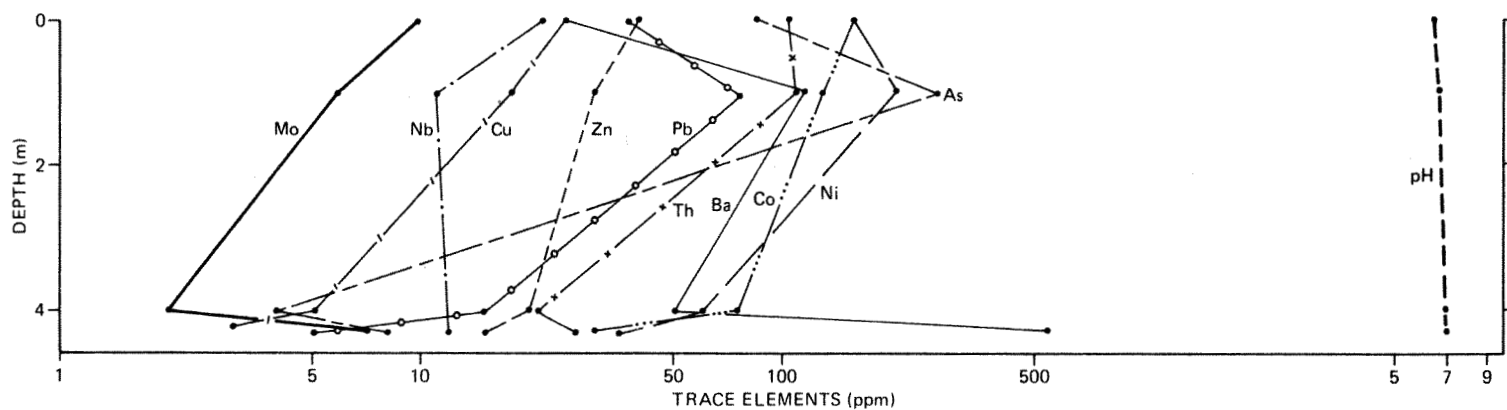
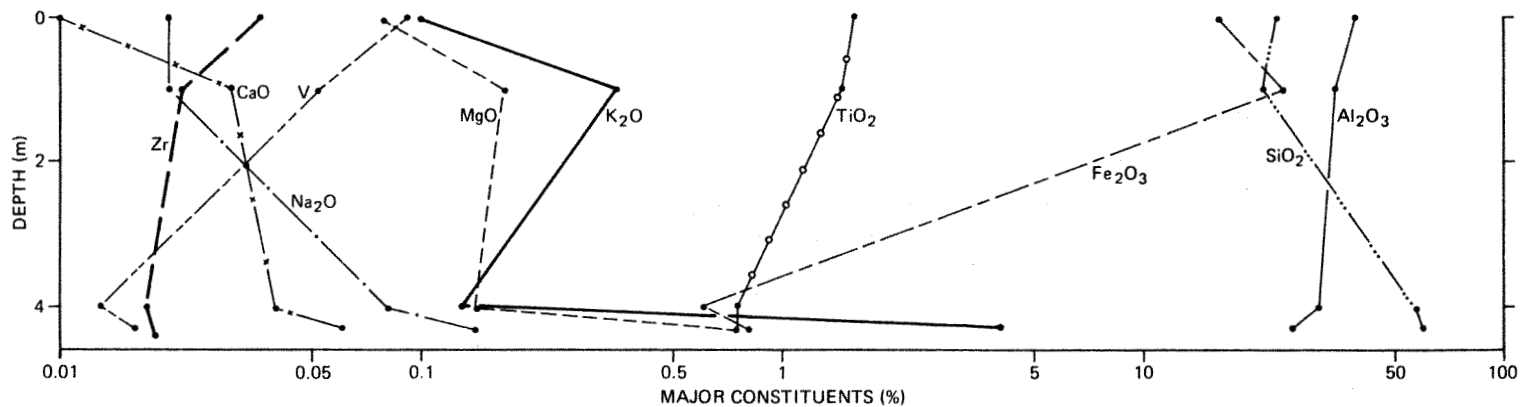


FIGURE 3I: ANDALUSITE MICA SCHIST, PROFILE L, JIMPERDING AREA  
42351-54

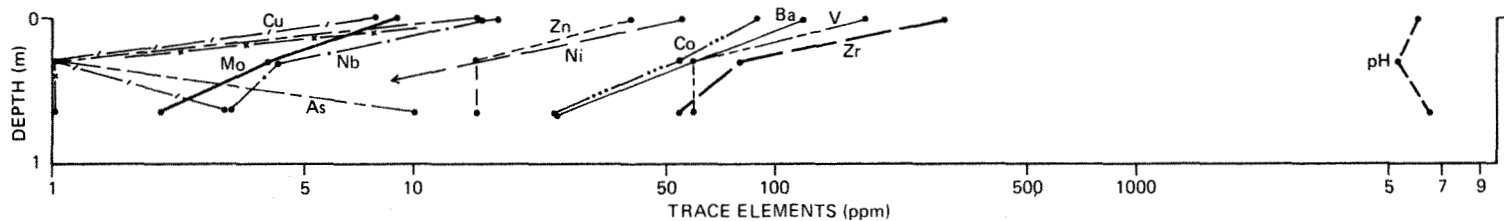
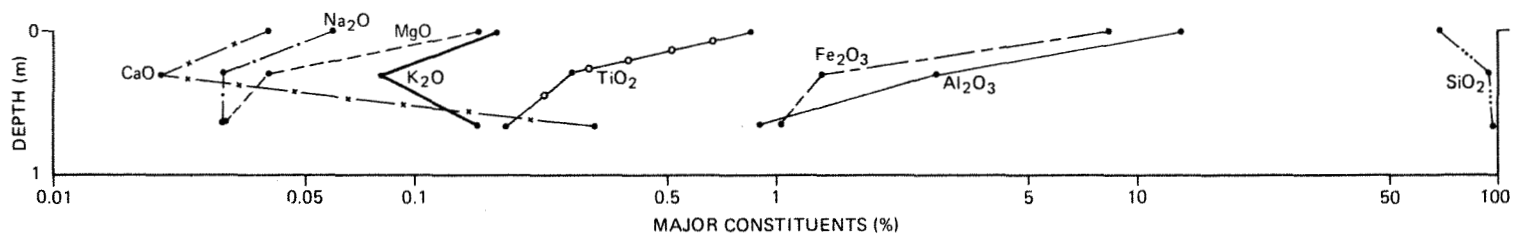


FIGURE 3m: QUARTZITE, PROFILE M, NORTH OF TEN MILE HILL, TOODYAY  
42360-62

G.S.W.A. 16949

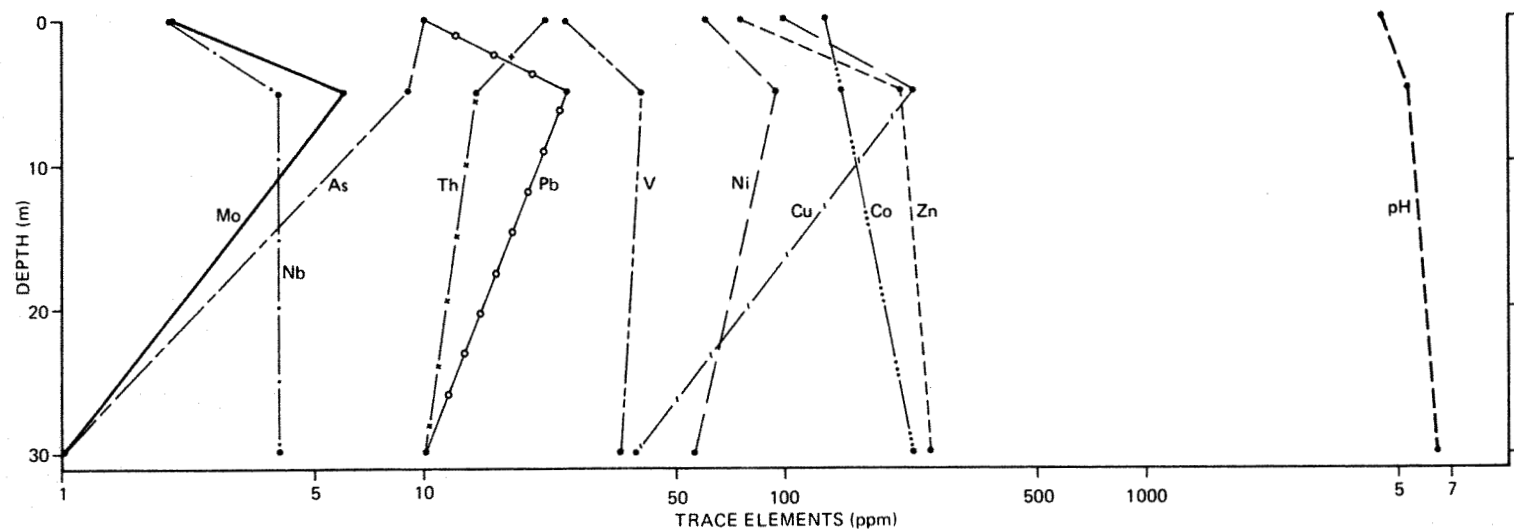
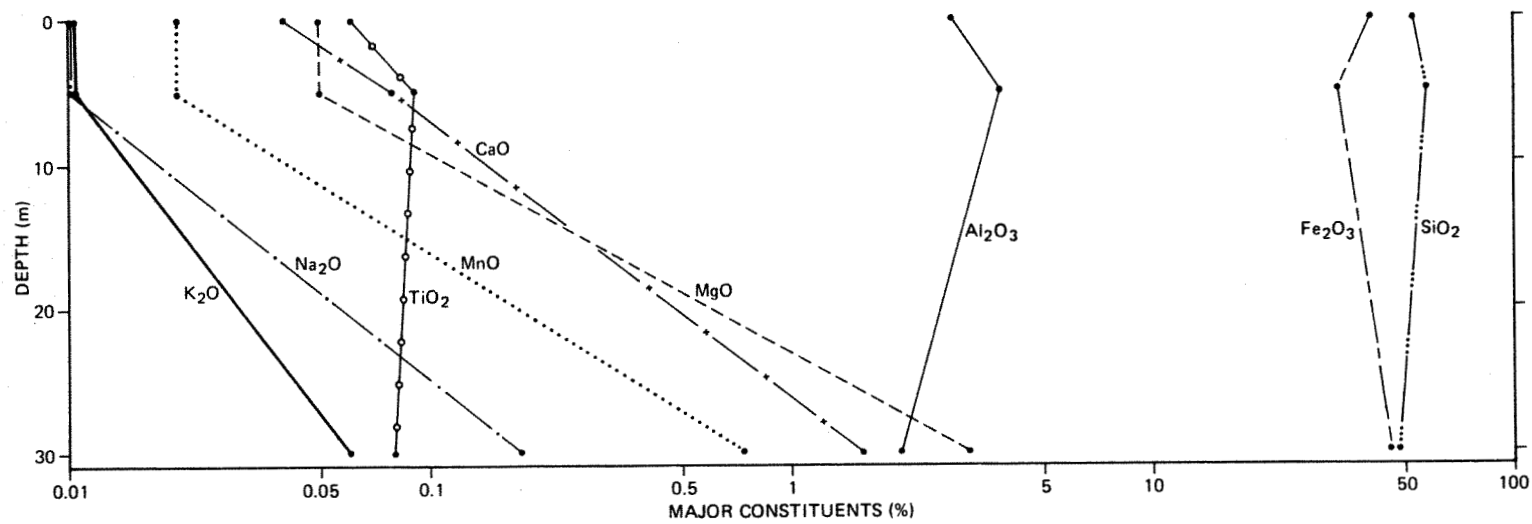


FIGURE 3n: IRON FORMATION, PROFILE N, CLACKLINE  
42363-65

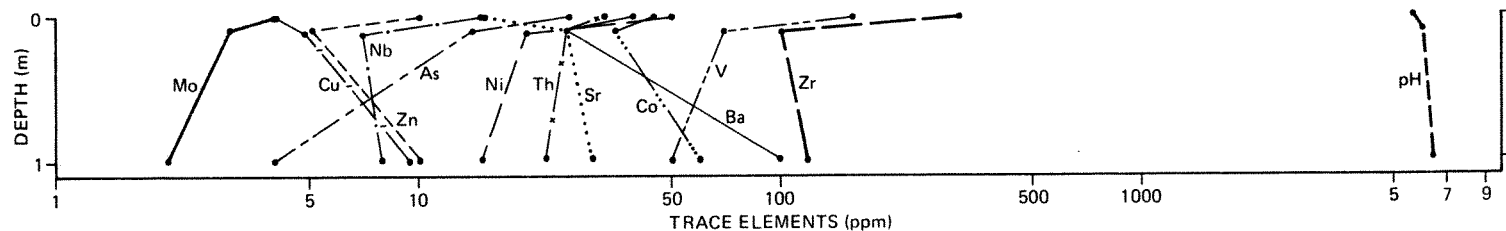
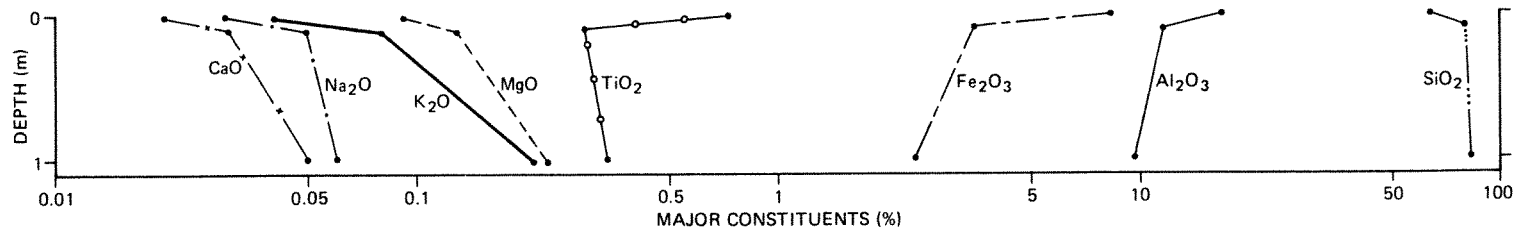


FIGURE 3a: SILTY SANDSTONE, PROFILE O, BULLSBROOK EAST  
42368-70

G.S.W.A. 16949



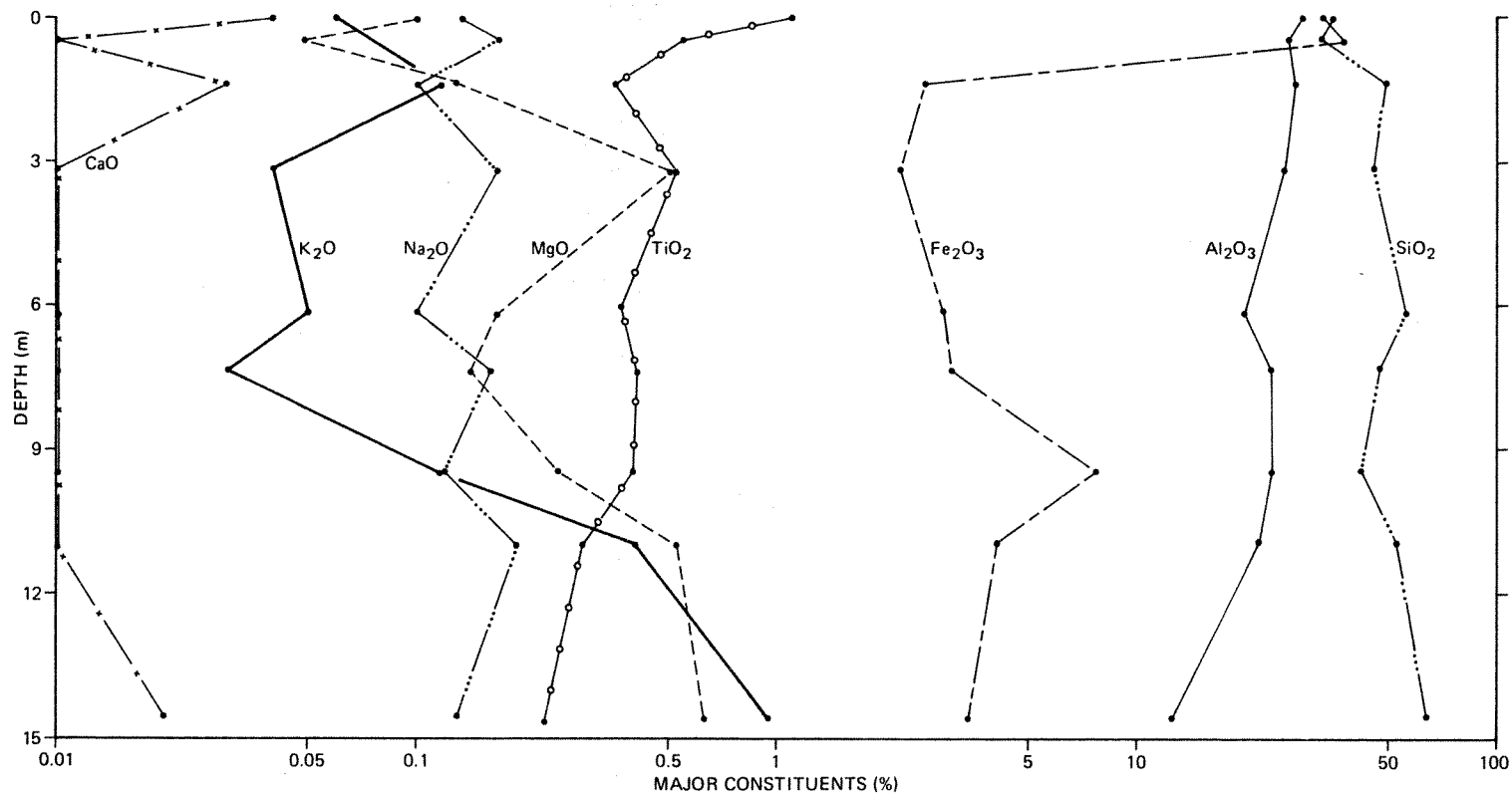


FIGURE 3p(i): GRANITOID, PROFILE P, LOWER WUNGONG DAMSITE  
42601-09

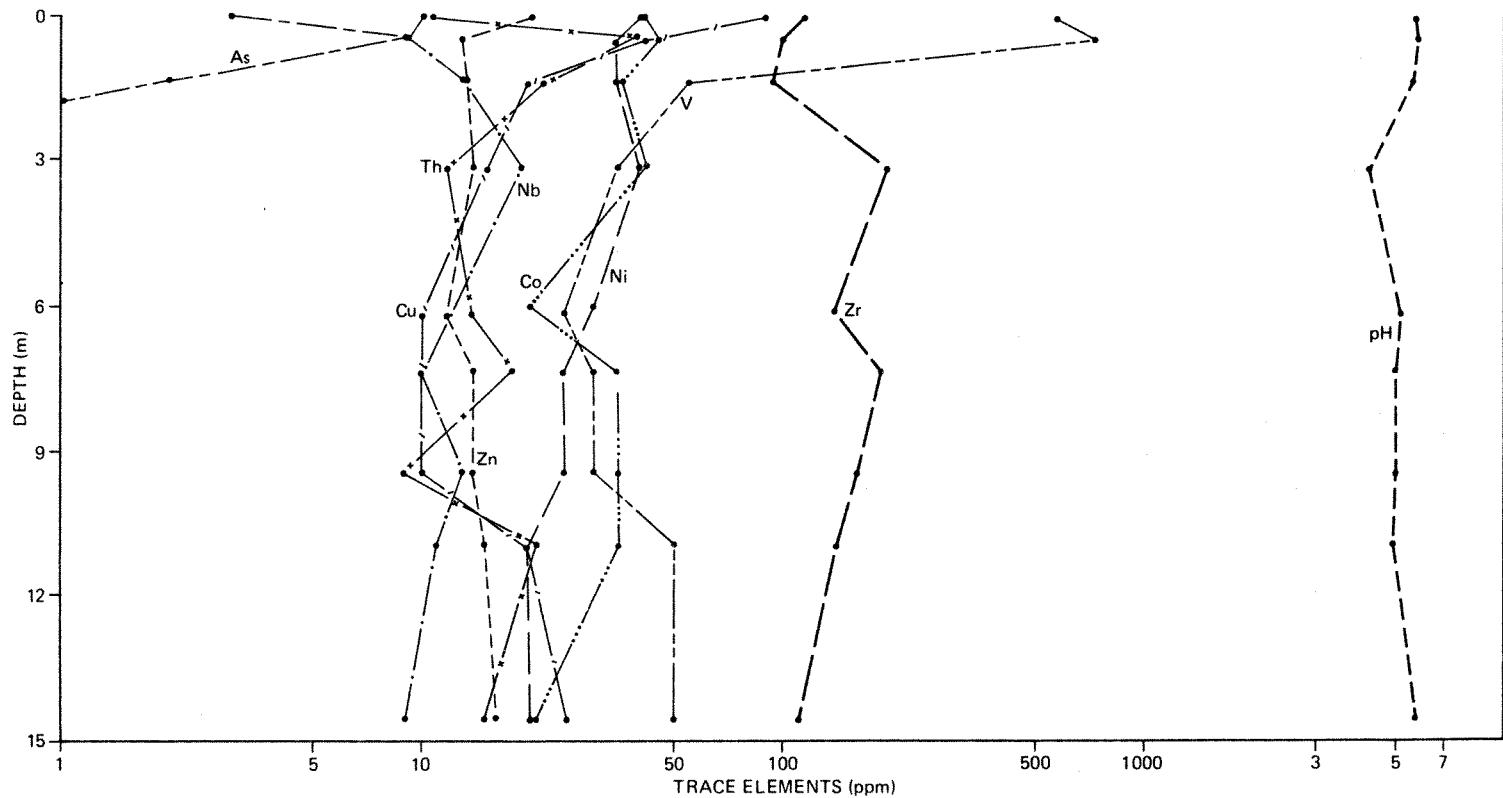


FIGURE 3p(ii): GRANITOID, PROFILE P, LOWER WUNGONG DAMSITE  
42601-09

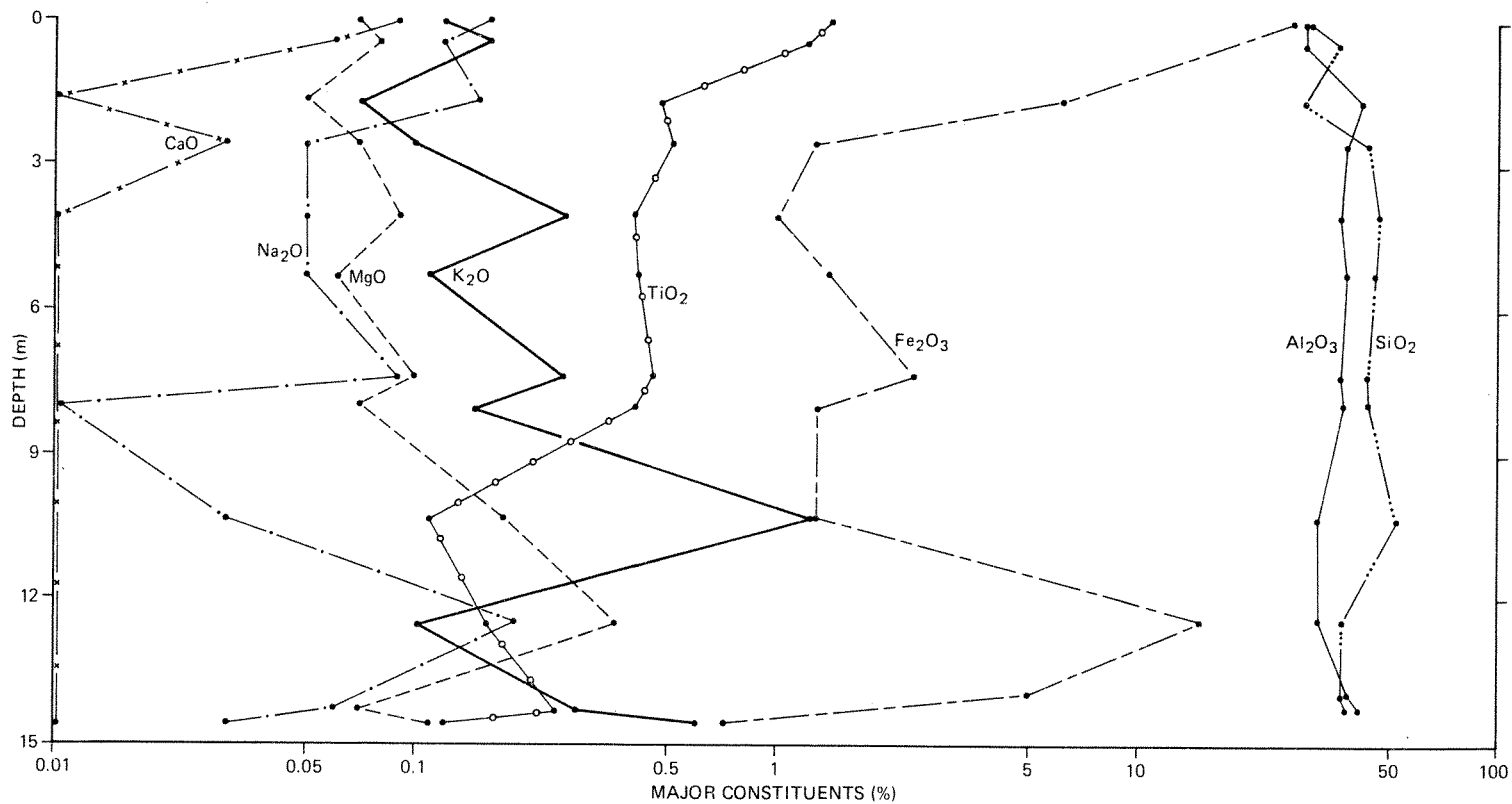


FIGURE 3q(i): GRANITOID, PROFILE Q, LOWER WUNGONG DAMSITE  
42610-21

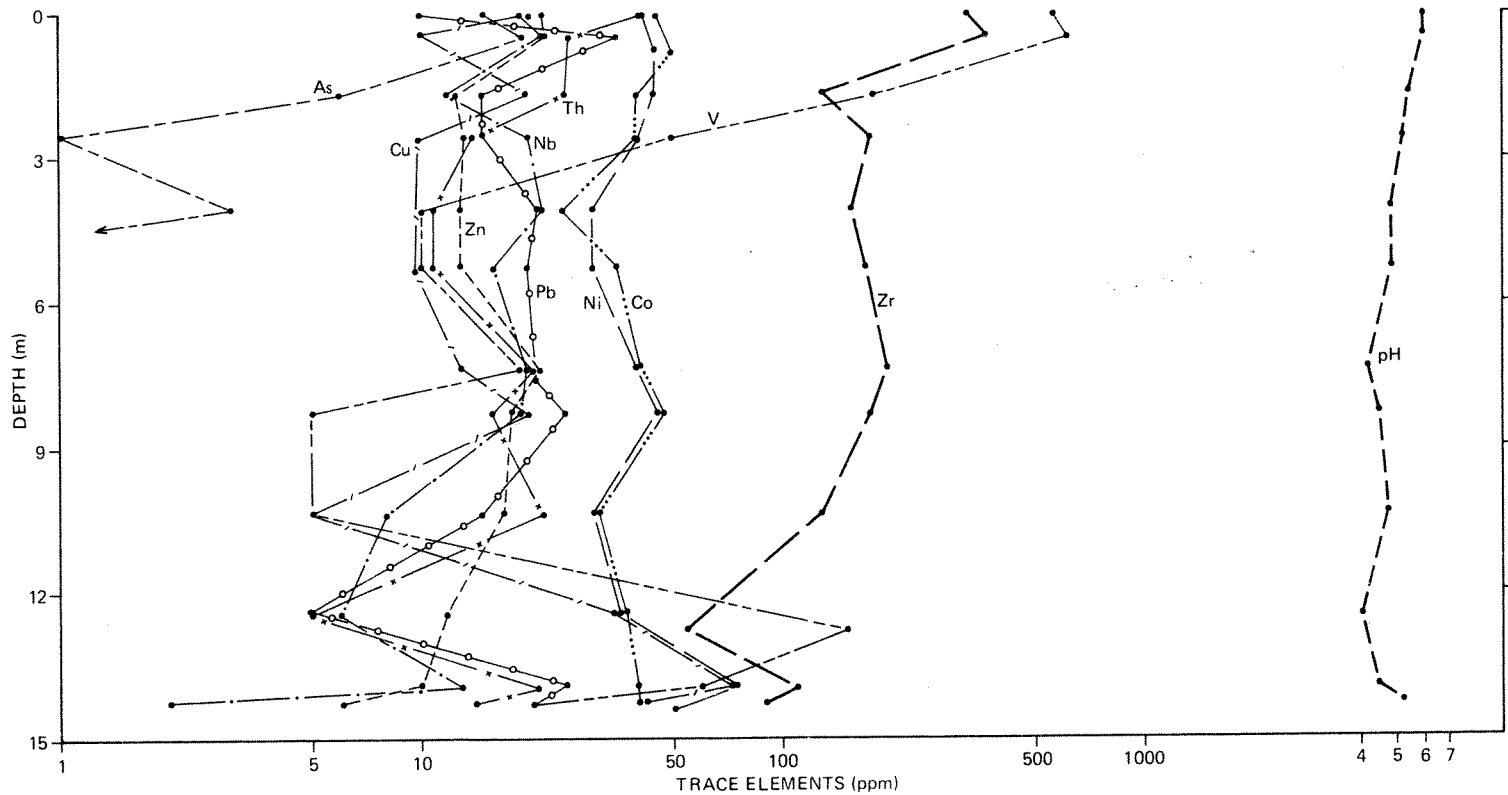


FIGURE 3q(ii): GRANITOID, PROFILE Q, LOWER WUNGONG DAMSITE  
42610-21

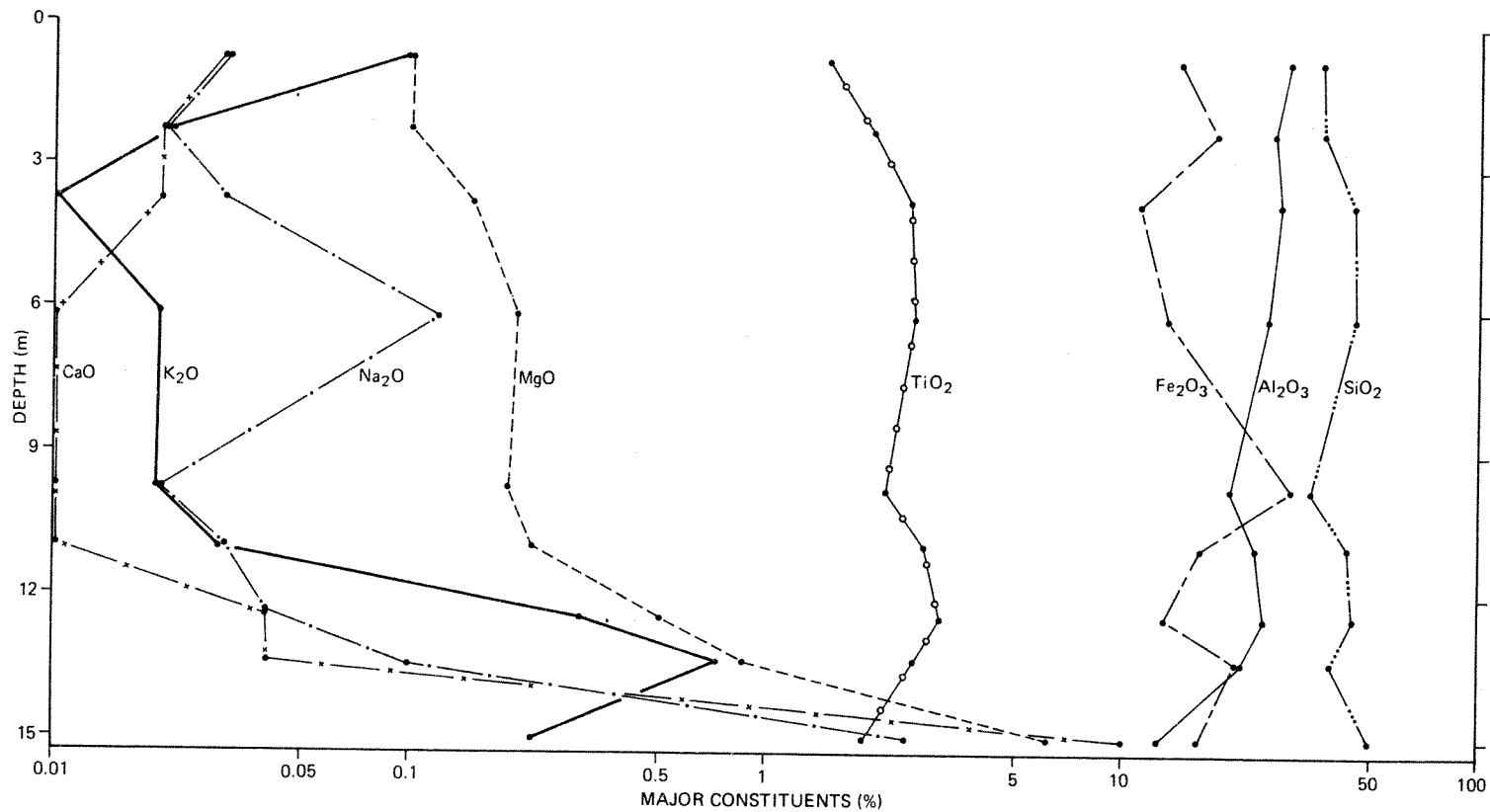


FIGURE 3r(i): DOLERITE, PROFILE R, LOWER WUNGONG DAMSITE  
42622-29, 51

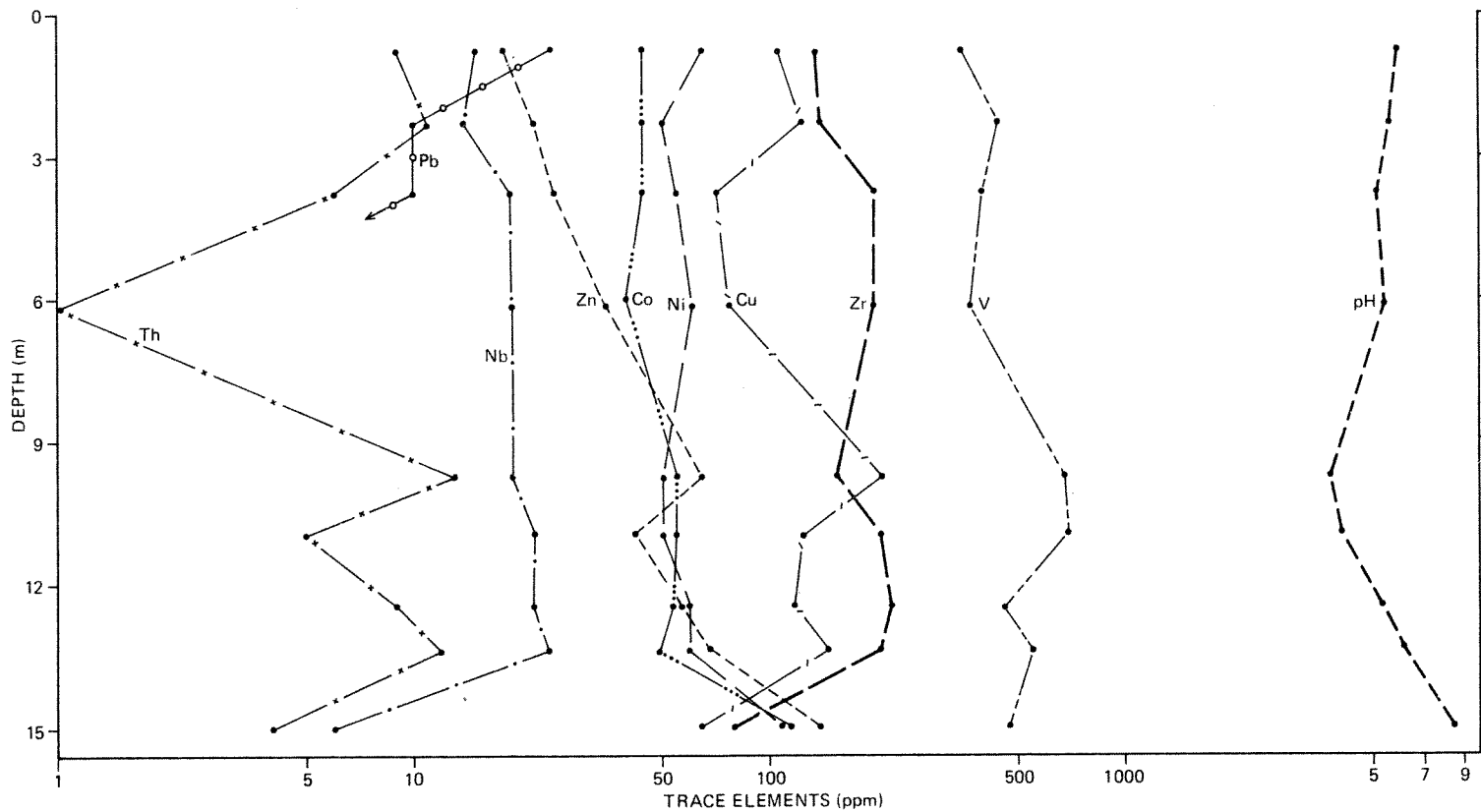


FIGURE 3r(ii): DOLERITE, PROFILE R, LOWER WUNGONG DAMSITE  
42622-29, 51

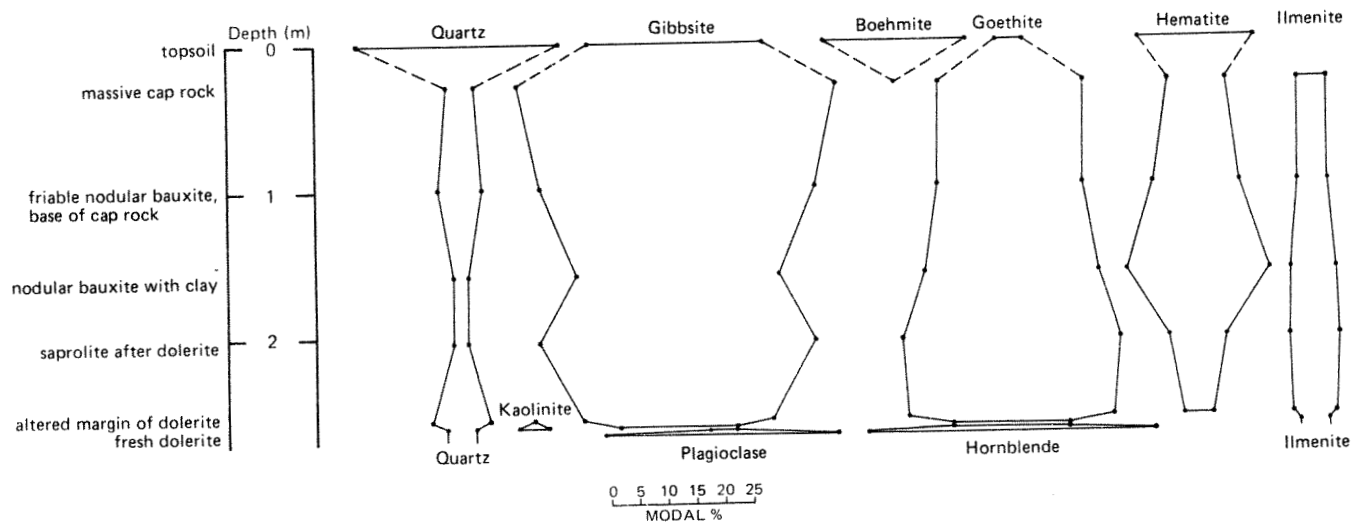


FIGURE 4a: DOLERITE, PROFILE A, SITE 1  
42419-25

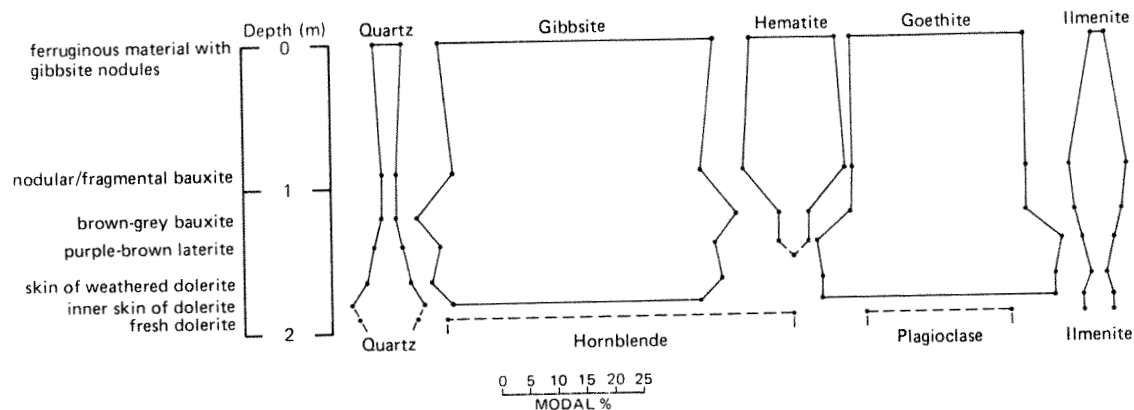


FIGURE 4b: DOLERITE, PROFILE B, SITE 1  
42443-49

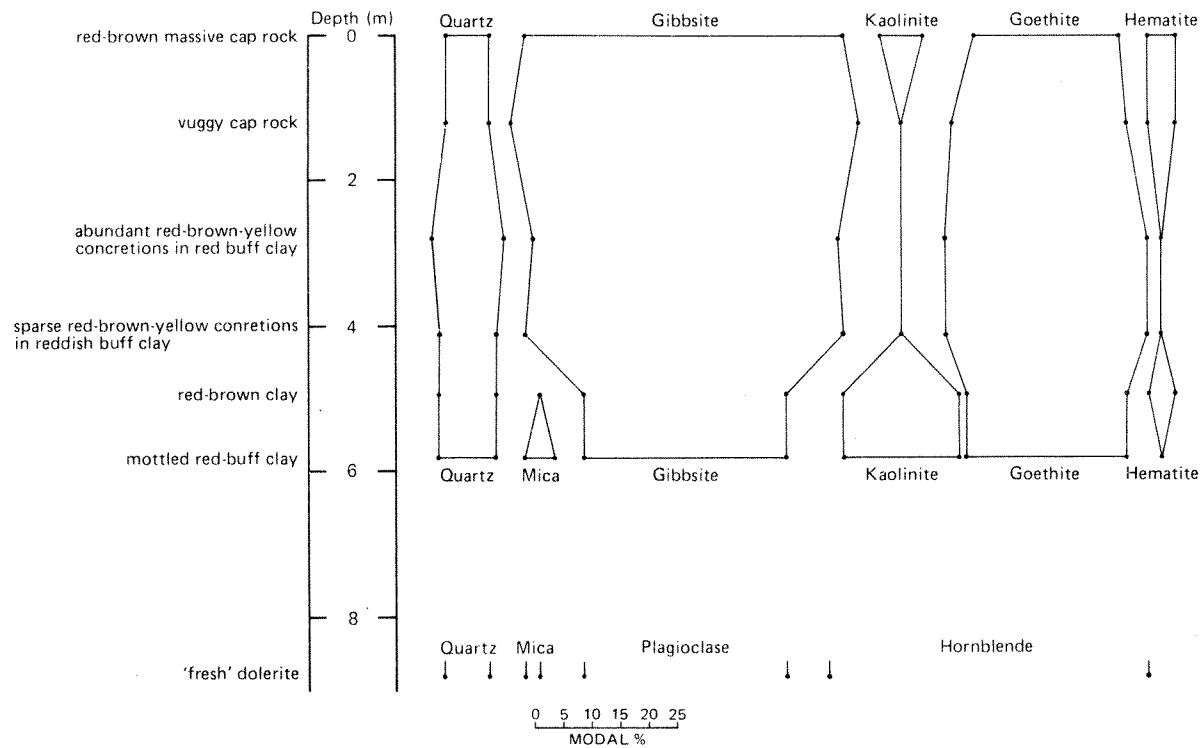


FIGURE 4c: DOLERITE, PROFILE C, SITE 1  
42428-34

G.S.W.A. 16950



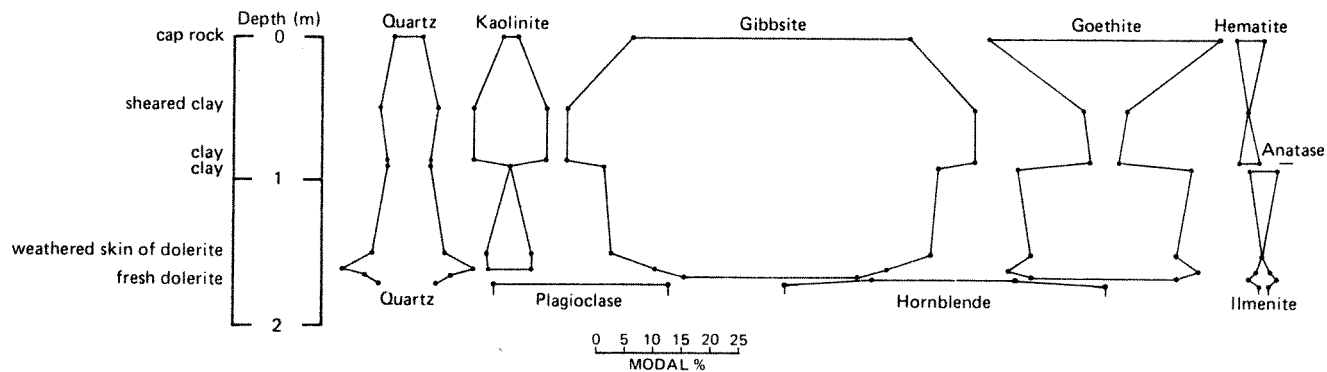


FIGURE 4d: DOLERITE, PROFILE D, SITE 2  
42435-42

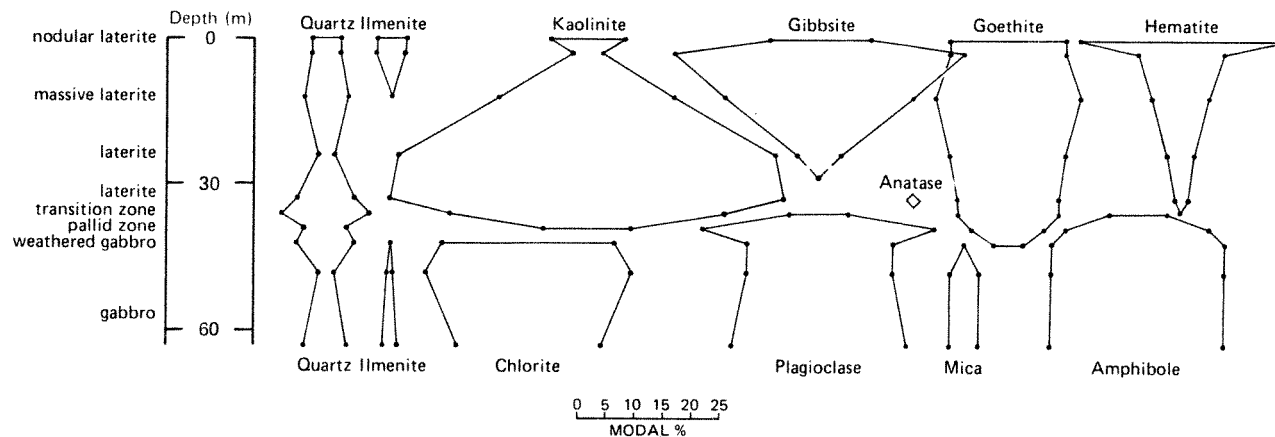


FIGURE 4e. GABBRO, PROFILE E, SITE 3  
42392-99

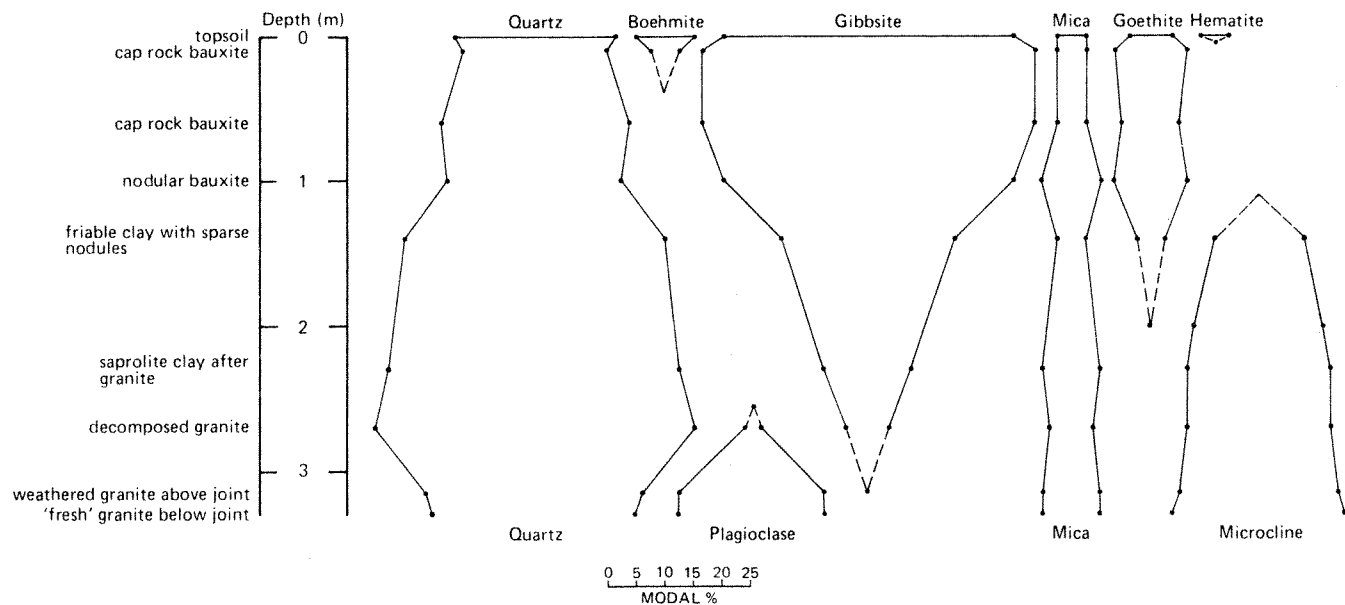


FIGURE 4f: ADAMELLITE, PROFILE F, SITE 1  
42304-412

G.S.W.A. 16950

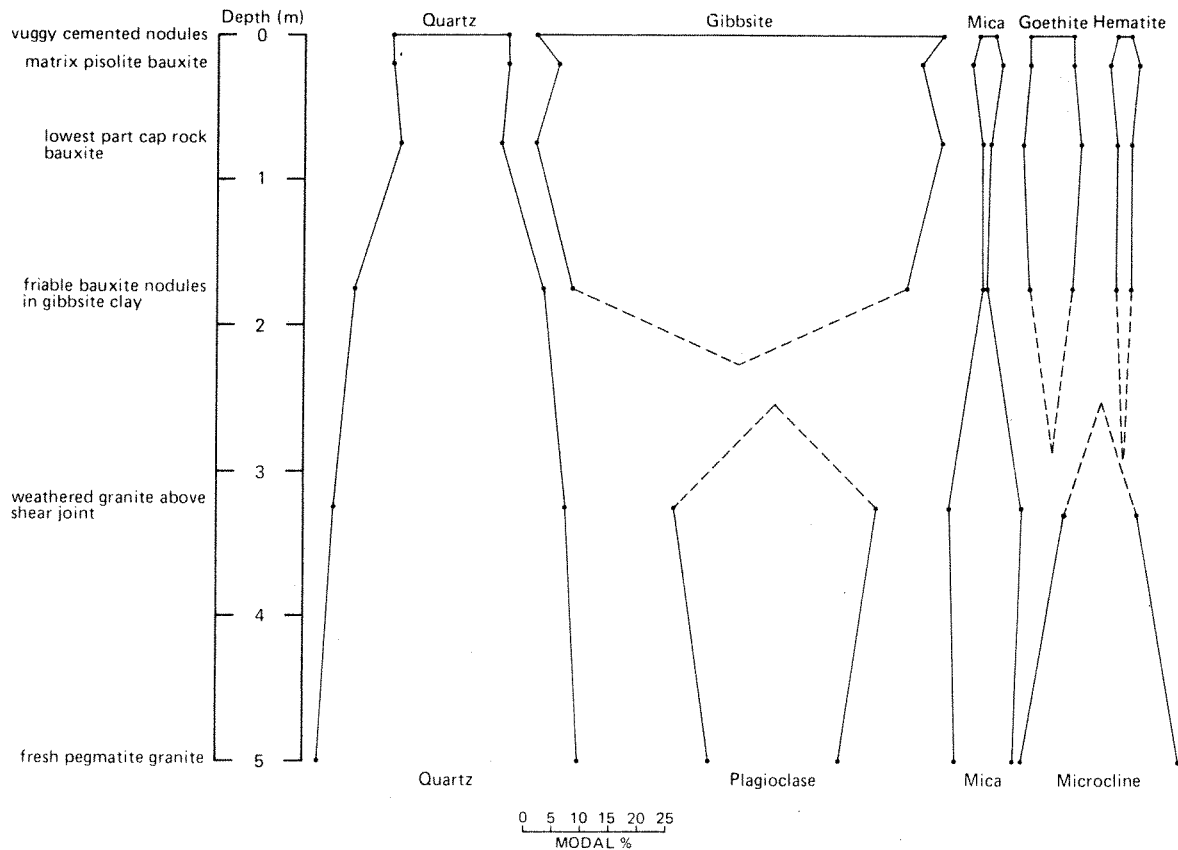


FIGURE 4g: ADAMELLITE, NEAR GRANODIORITE, PROFILE G, SITE 1  
42413A--18

G.S.W.A. 16950

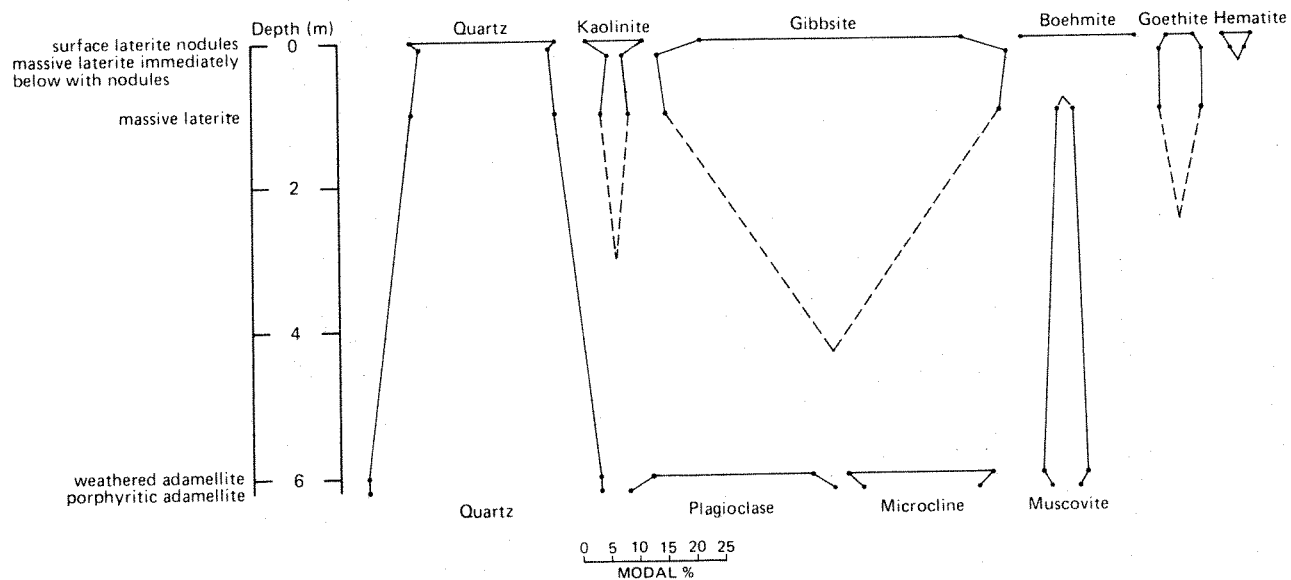


FIGURE 4h: ADAMELLITE, PROFILE H, SITE 4  
42355-59

G.S.W.A. 16950

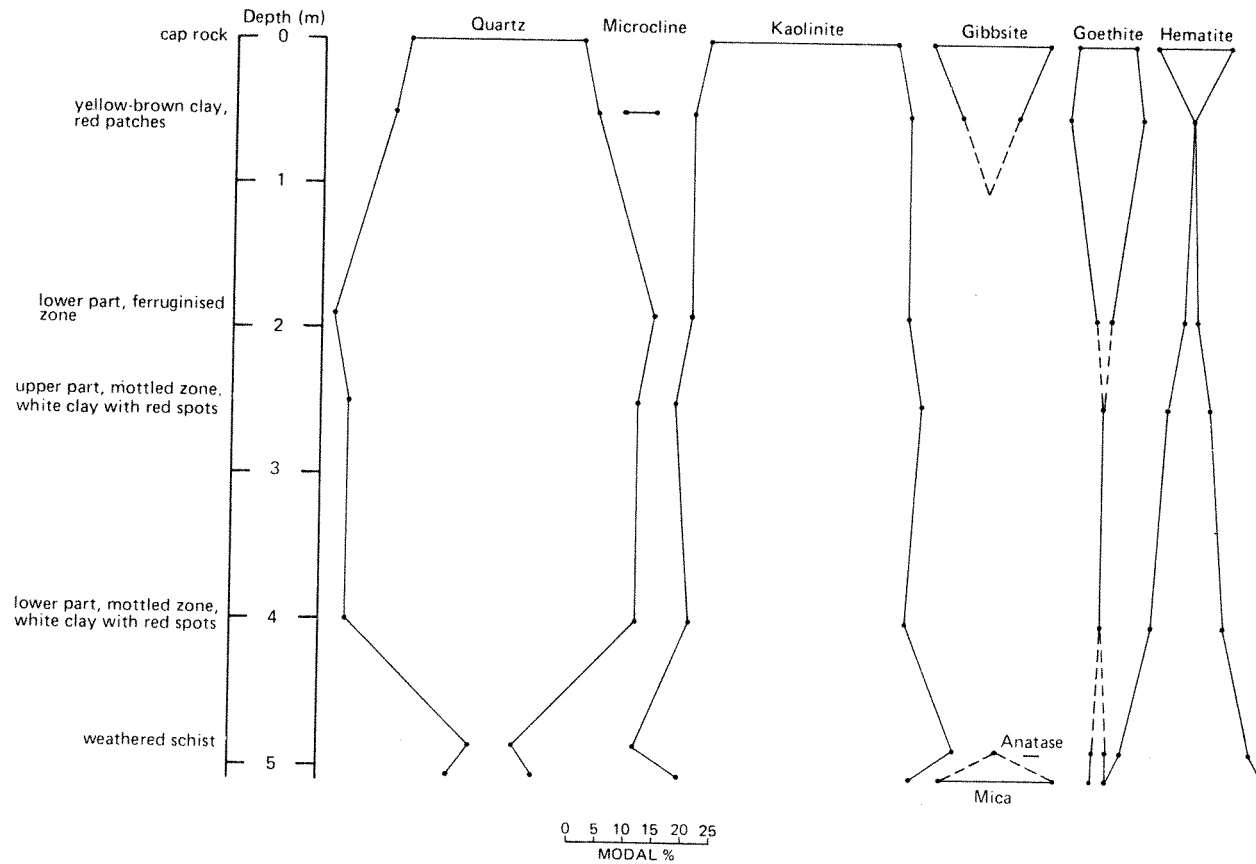


FIGURE 4i: MICA SCHIST, PROFILE I, SITE 5  
42371-76

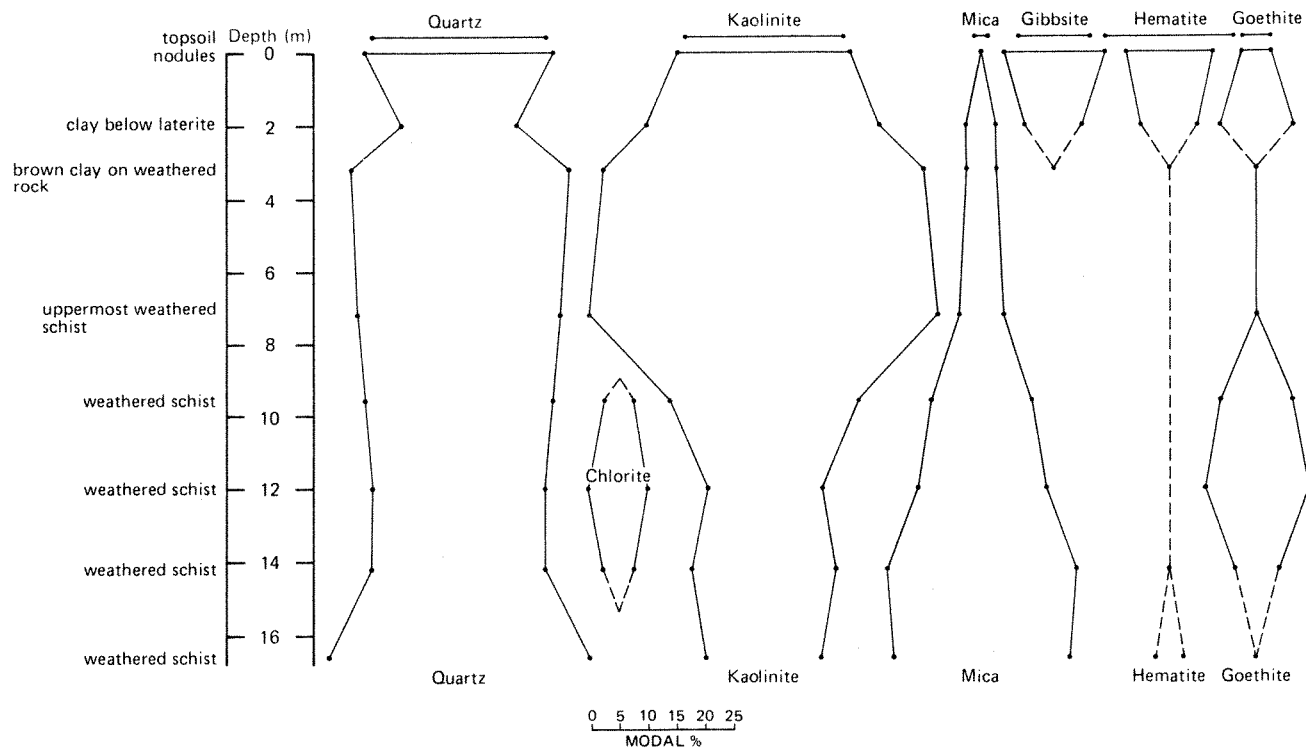


FIGURE 4j: MICA SCHIST, PROFILE J, SITE 5  
42377-84

G.S.W.A. 16950

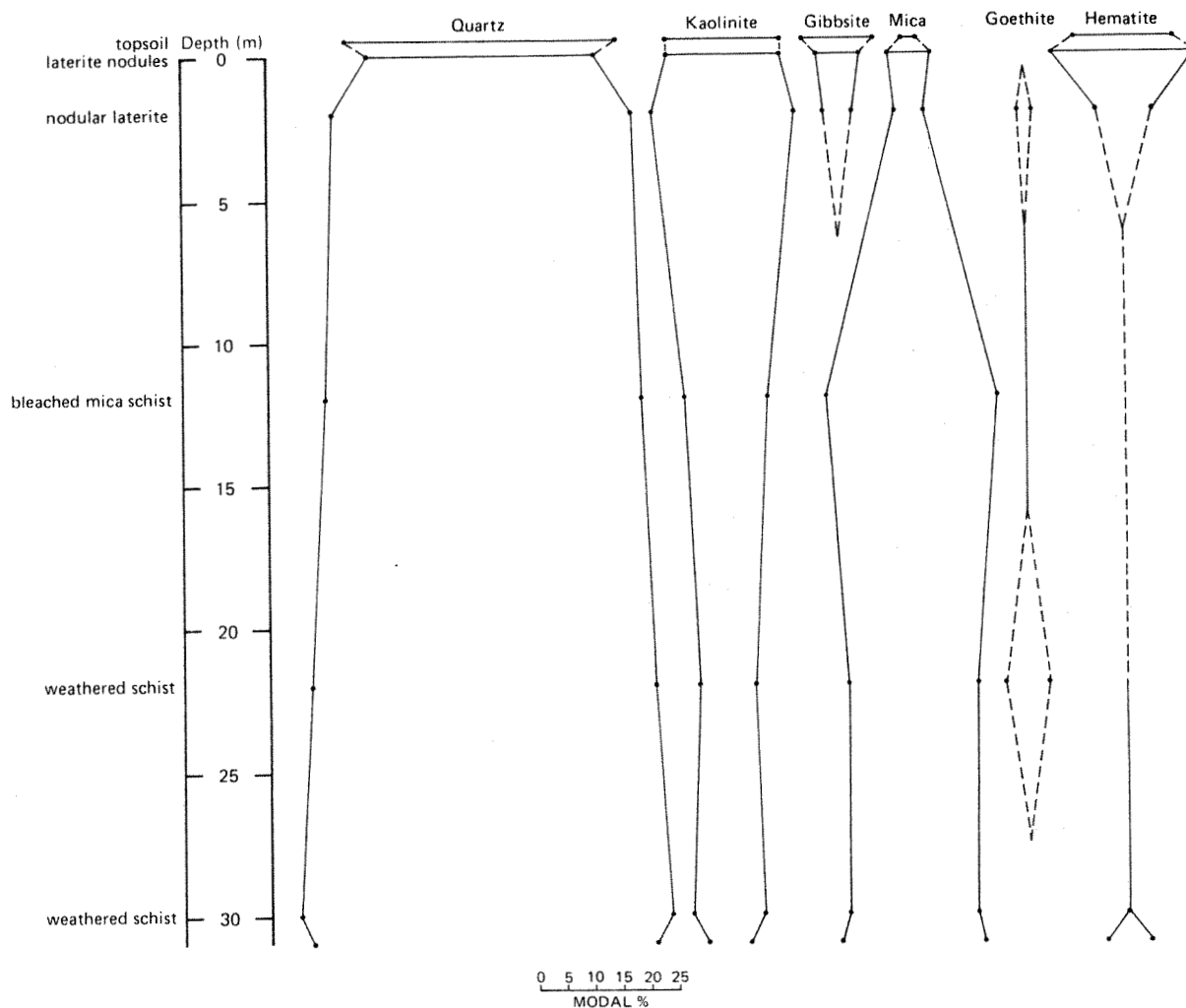


FIGURE 4k: MICA SCHIST, PROFILE K, SITE 6  
42385-91

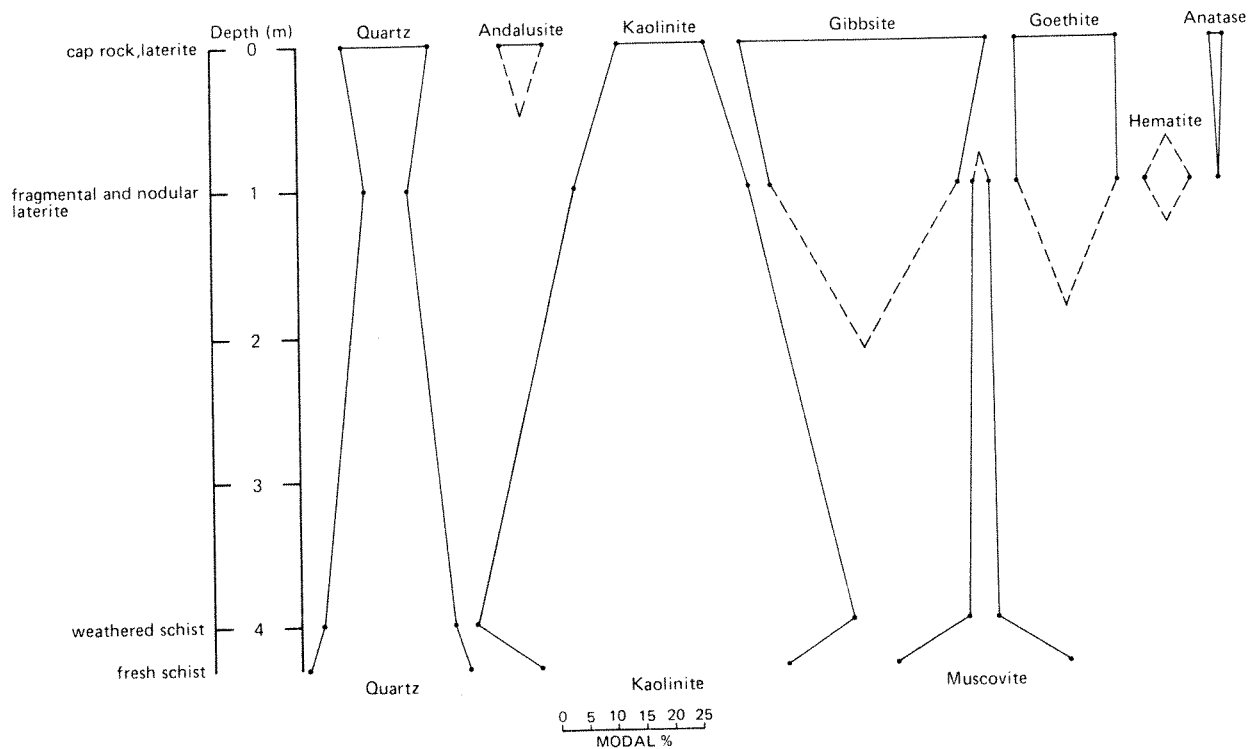


FIGURE 4i: ANDALUSITE MICA SCHIST, PROFILE L, SITE 7  
42351-54

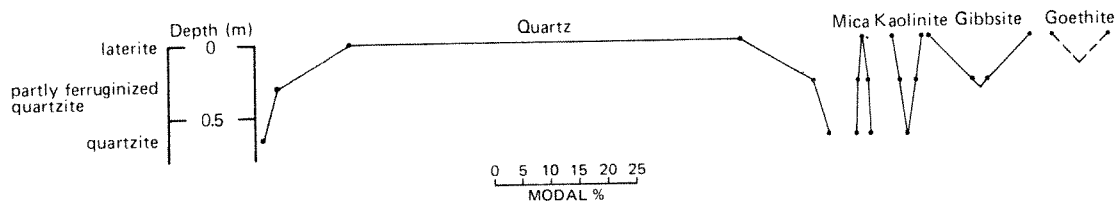


FIGURE 4m: QUARTZITE, PROFILE M, SITE 8  
42360-62



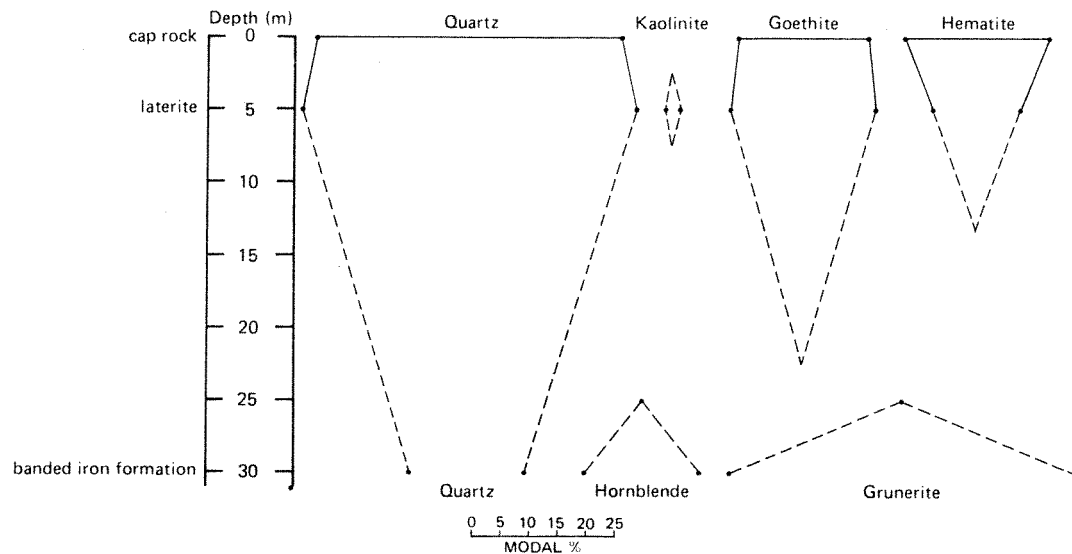


FIGURE 4n: IRON FORMATION, PROFILE N, SITE 9  
42363-65

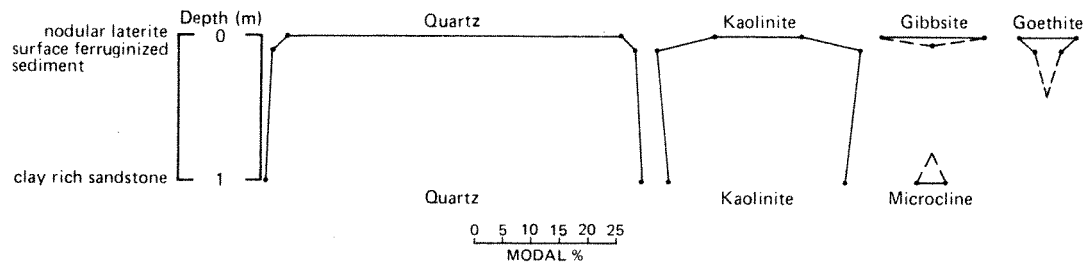


FIGURE 4o: SILTY SANDSTONE, PROFILE O, SITE 10  
42368-70

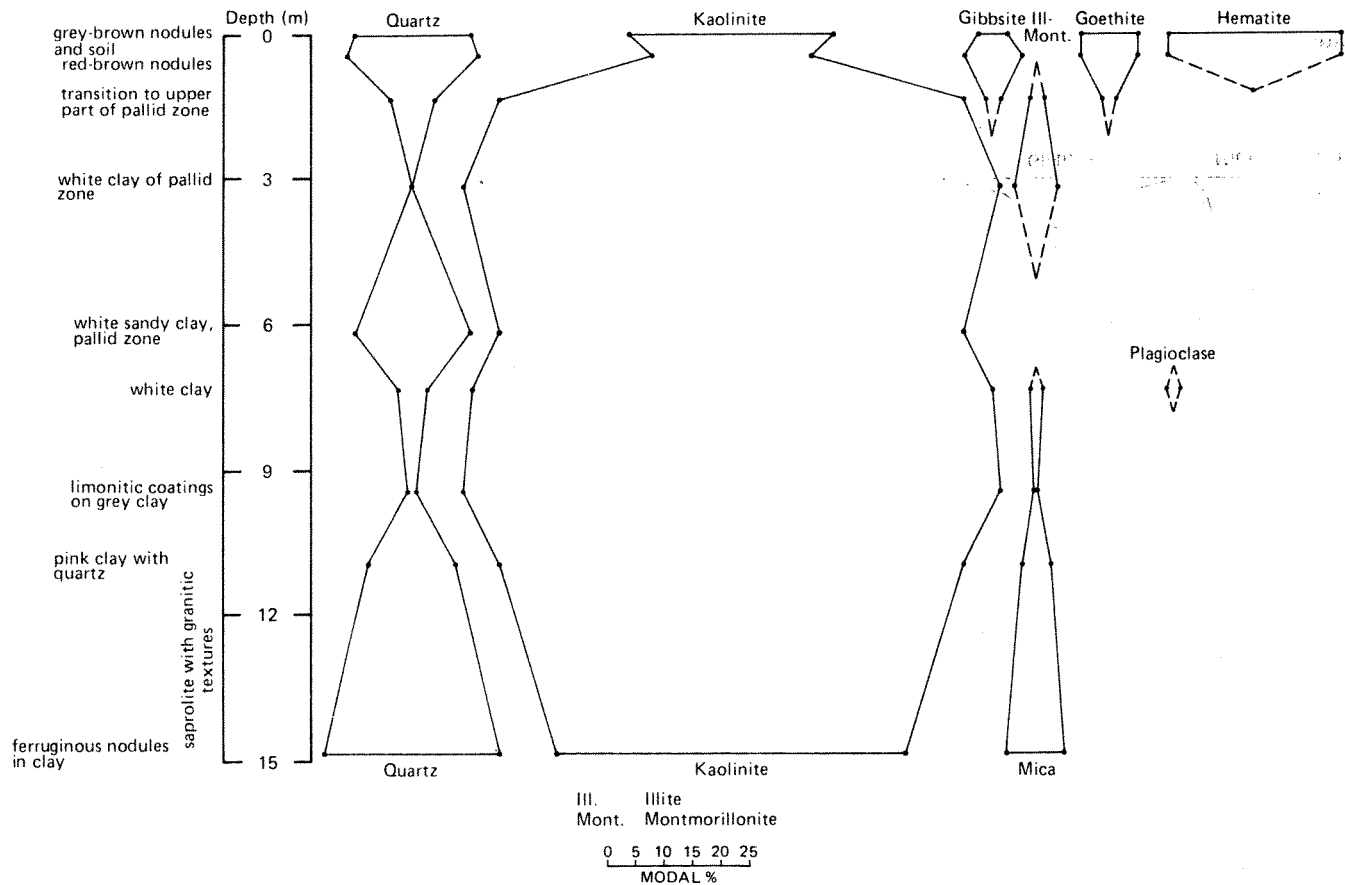


FIGURE 4p: GRANITOID, PROFILE P, SITE 11  
42601-09

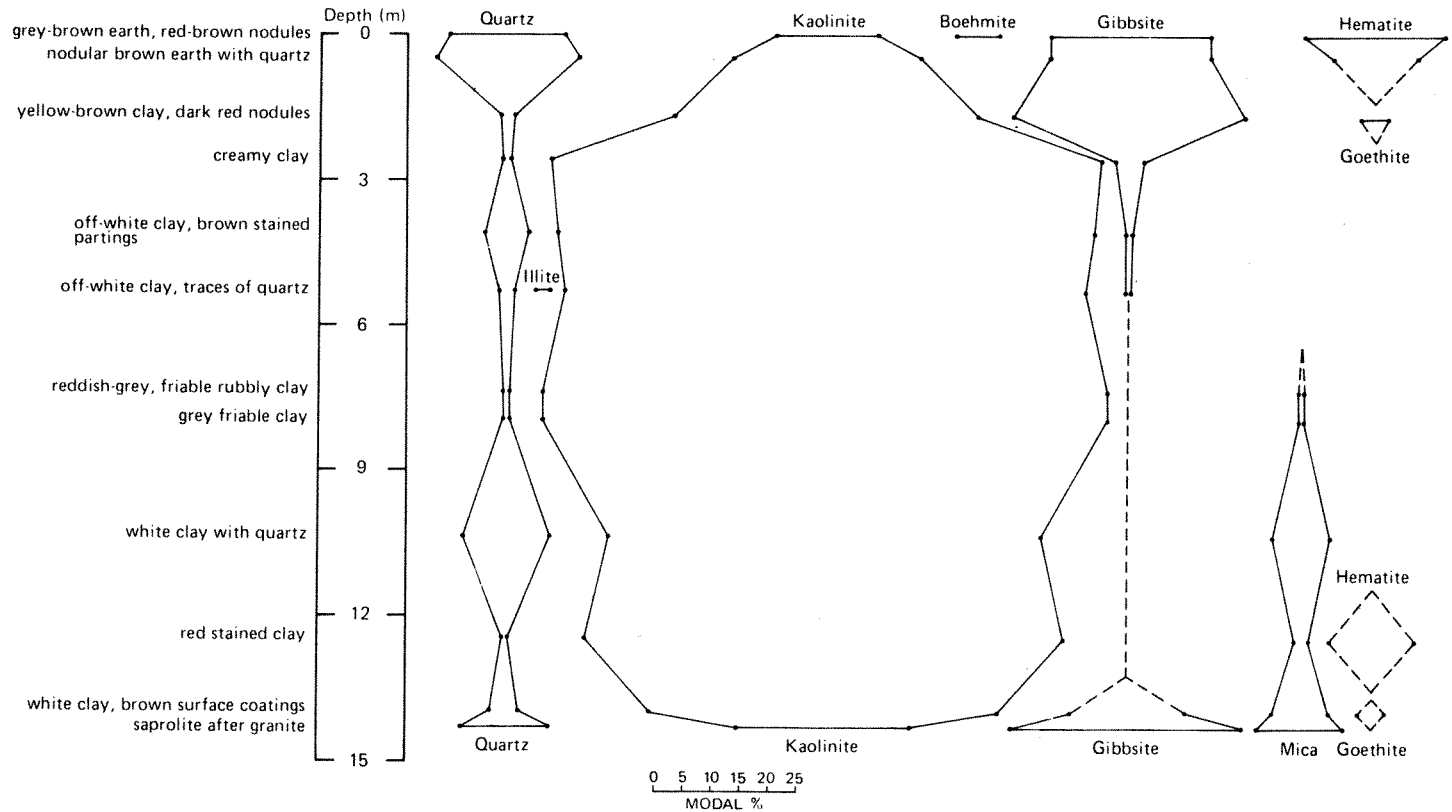


FIGURE 4q: GRANITOID, PROFILE Q, SITE 11  
42610-21

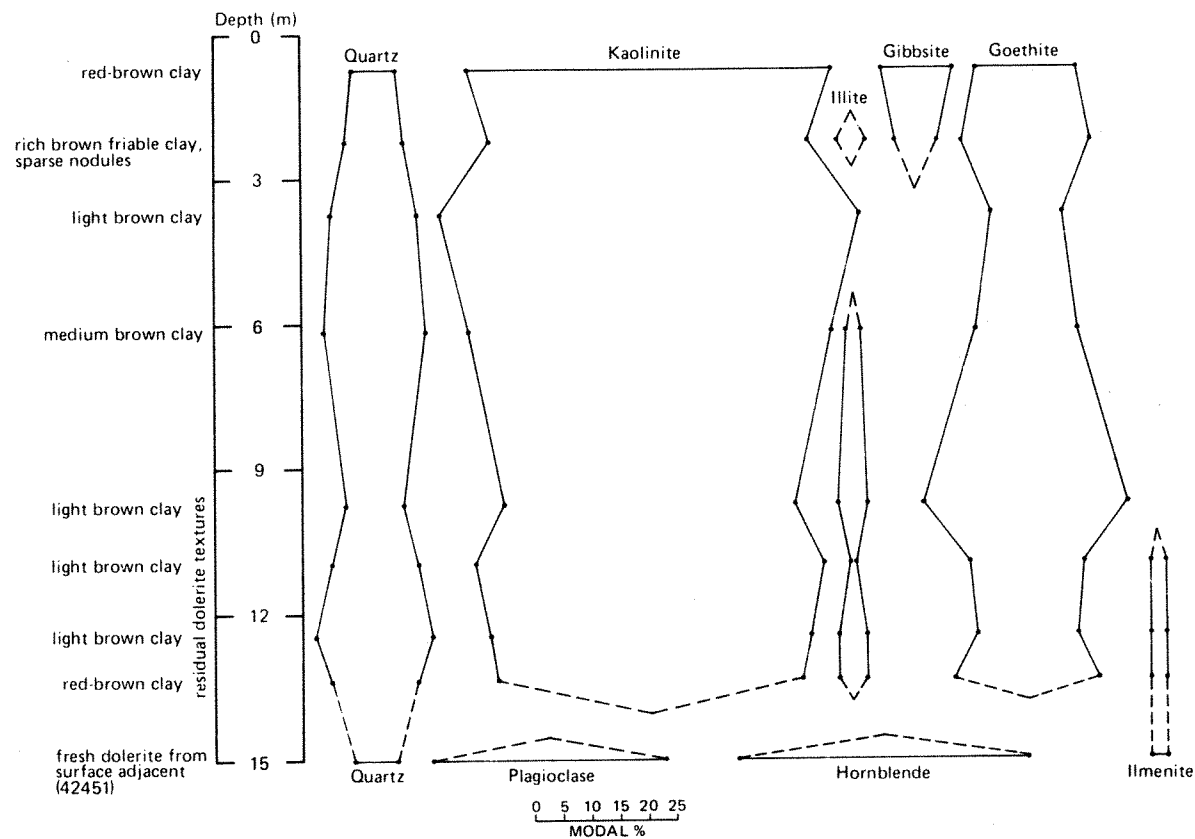


FIGURE 4r: DOLORITE, PROFILE R, SITE 11  
42451, 42622-29

G.S.W.A. 16950

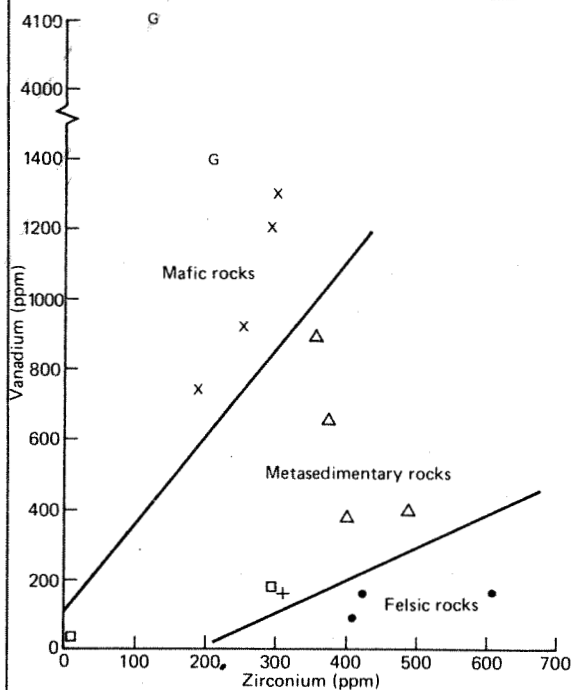


FIGURE 5a: SCATTER DIAGRAM FOR V  
PLOTTED AGAINST Zr

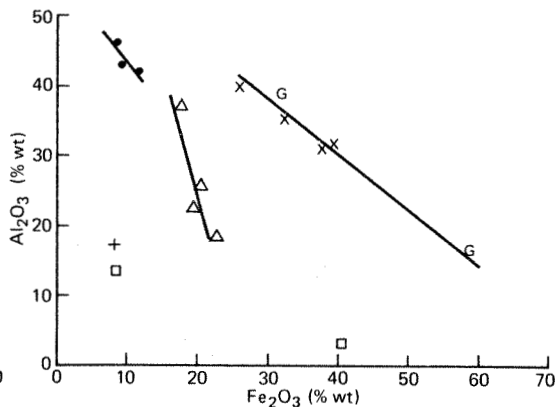


FIGURE 5b: SCATTER DIAGRAM FOR  $Al_2O_3$   
PLOTTED AGAINST  $Fe_2O_3$

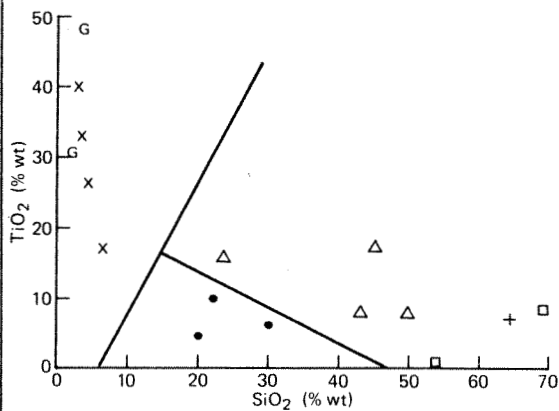


FIGURE 5d: SCATTER DIAGRAM FOR  $TiO_2$   
PLOTTED AGAINST  $SiO_2$

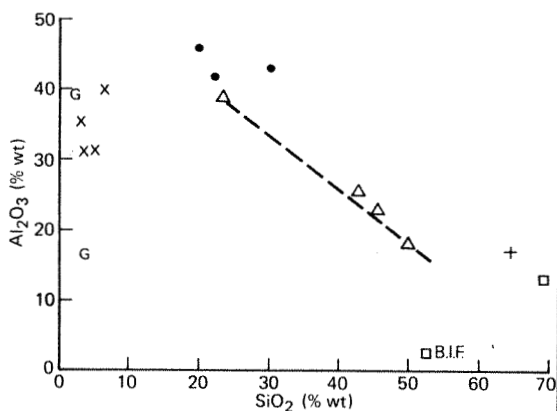


FIGURE 5c: SCATTER DIAGRAM FOR  $Al_2O_3$   
PLOTTED AGAINST  $SiO_2$

- x Dolerite
- G Gabbro
- Felsic igneous rocks
- Δ Schist
- Other Archaean metasedimentary rocks
- + Cretaceous sandstone

# REFERENCES

- Baxter, J.L., in prep., Molybdenum, tungsten, vanadium and chromium in Western Australia: West. Australia Geol. Survey Min. Resour. Bull. 11.
- Bestow, T.T., 1976, The effects of bauxite mining at Del Park on groundwater hydrology: West. Australia Geol. Survey Ann. Rept 1975, p. 13–31.
- Carroll, D., 1932, Mineralogy of the fine sand fractions of some Australian soils: Jour. Roy. Soc. West. Australia, v. 18, p. 125–144.
- , 1942, Mineralogy of the Donnybrook sandstones, Western Australia: Jour. Roy. Soc. West. Australia, v. 27, p. 211–218.
- , 1944 (a), Mineralogical examination of some soils from southwestern Australia: West. Australia Dept. Agric. Jour., v. 21, p. 83–93.
- , 1944 (b), Mineralogy of some soils from the Margaret River district: West. Australia Dept. Agric. Jour., v. 21, p. 313–319.
- Carroll, D. and Jones, N.K., 1947, Laterite developed on acid rocks in southwestern Australia: Soil Sci., v. 64, p. 1–16.
- Davy, R., 1976, The mineral content of Del Park groundwaters: West. Australia Geol. Survey Record 1976/13 (unpublished).
- , 1978, A comparative study of the geochemistry of Archaean bedrock in part of the northeast Yilgarn Block: West. Australia Geol. Survey Rept 4.
- Gilkes, R.J., Scholz, G. and Dimmock, G.M., 1973, Lateritic deep weathering of granite: Jour. Soil Sci., v. 24, no. 4, p. 523–536.
- Glassford, D.K. and Killigrew, L.P., 1976, Evidence of Quaternary westward extension of the Australian desert into southwestern Australia: Search, v. 7, no. 9, p. 394–396.
- Grubb, P.L.C., 1966, Some aspects of lateritization in Western Australia: Roy. Soc. West. Australia, v. 49, no. 4, p. 117–124.
- , 1971, Mineralogical anomalies in the Darling Ranges bauxites at Jarrahdale, Western Australia: Econ. Geol., v. 66, no. 7, p. 1005–1016.
- Hallberg, J.A., 1972, Geochemistry of Archaean volcanic belts in the Eastern Goldfields region of Western Australia: Jour. Petrol., v. 13, no. 1, p. 45–56.
- Hallberg, J.A. and Williams, D.A.C., 1972, Archaean mafic and ultramafic rock associations in the Eastern Goldfields region, Western Australia: Earth and Planetary Sci. Letters, v. 15, no. 2, p. 191–200.
- Harrison, J.B., (1933) in Hardy, F., (ed), The katamorphism of igneous rocks under humid tropical conditions: Imp. Bur. Soil Sci., 79pp.
- Hudson, D.R., 1967, The vanadium bearing magnetite gabbro at Coates, Western Australia: Jour. Roy. Soc. West. Australia, v. 50, no. 2, p. 60–64.
- Jones, W.R., 1965, Vanadium deposits of Western Australia, in McAndrew J., (ed) 'Geology of Australian Ore Deposits': Eighth Commonwealth Mining and Metallurgical Congress Australia and New Zealand 1965 Publications, v. 1, p. 154–155.
- Maignien R., 1966, Review of research on laterites: Unesco, Paris, 148 pp.
- Marcos G., 1974, Weathering profile of granitic rocks in the borrow area of the proposed lower Wungong Dam: West. Australia Geol. Survey Ann. Rept, 1973, p. 26–29.
- Mazzuccelli, R.H., and James, C.H., 1966, Arsenic as a guide to gold mineralization in laterite covered areas of Western Australia: Trans. I.M.M. Lond., v. 75, no. 720, p. B286–B294.
- Millot, G. and Bonifas, M., 1955, Transformations isovolumétriques dans les phénomènes de latéritisation et de bauxitisation: Serv. Carte Geol. Alsace Lorraine Bull., v. 8, no. 1, p. 3–19.
- Norton, S.A., 1973, Laterite and bauxite formation: Econ. Geol., v. 68, no. 3, p. 353–361.
- Russell, E.W., 1973, Soil conditions and plant growth: Longman, London, 10th edition, 849pp.
- Sadler, S.B. and Gilkes, R.J., 1977, Development of bauxite in relation to parent material near Jarrahdale, Western Australia: Geol. Soc. Aust. Jour., v. 24, pt 4, p. 333–344.
- Schellmann, W., 1975, Formation of, and prospecting for, tropical bauxite above silicate rocks: Mining Magazine, July 1975, p. 33–35, 37, 39.
- Sivarajasingham, S., Alexander, L.D., Cady, J.G., and Cline, M.G., 1962, Laterite: Advances in Agronomy, Academic Press, New York, v. 14, p. 1–60.
- Terrill, S.E., 1950, Notes on laterite in the Darling Ranges near Perth, Western Australia: Roy. Soc. West. Australia, Jour., v. 34, p. 105–113.
- Trendall, A.F., 1962, The formation of 'Apparent Peneplains' by a process of combined lateritization and surface wash: Annals of Geomorphology, v. 6, no. 2, p. 183–197.
- Turton, A.G., Marsh, N.L., McKenzie, R.M. and Mulcahy, M.J., 1962, The chemistry and mineralogy of lateritic soils in the southwest of Western Australia: Australia C.S.I.R.O. Soil Publication no. 20.
- Valeton, I., 1972, Bauxites: Developments in Soil Sci. I Elsevier, Amsterdam, 226 pp.
- Wilde S.A., 1974, Explanatory notes on the Archaean Rocks of the Perth 1:250 000 geological sheet, Western Australia: West Australia Geol. Survey, Record 1974/15 (unpublished).
- , 1976, Explanatory notes on the Precambrian of the Pinjarra 1:250 000 geological sheet: West Australia Geol. Survey, Record 1976/15 (unpublished).

