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A MINERALOGICAL, GEOCHEMICAL AND PETROGRAPHIC STUDY OF THE ROCKS OF DRILLHOLE BCD1 FROM THE BEASLEY CREEK GOLD MINE - LAVERTON, WESTERN AUSTRALIA

I.D.M. Robertson and S.F. Gall

CRC LEME OPEN FILE REPORT 7

November 1998

(CSIRO Division of Minerals and Geochemistry Report MG67R, 1988.
Second impression 1998)

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

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

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

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

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

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

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

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

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

This report (CRC LEME Open File Report 7) is a Second impression (second printing) of CSIRO, Division of Minerals and Geochemistry Restricted Report MG67R, first issued in 1988, which formed part of the CSIRO/AMIRA Project P241.

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PREFACE

The CSIRO - AMIRA project "Exploration for Concealed Gold Deposits, Yilgarn Block, Western Australia" has as its overall aim the development of improved geological, geochemical and geophysical methods for mineral exploration that will facilitate the location of blind, concealed or deeply weathered gold deposits.

This report presents results of research conducted as part of Module 2 of this project (AMIRA Project 241): "Gold and Associated Elements in the Regolith - Dispersion Processes and Implications for Exploration". The objectives of this Module are:

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

II. To determine characteristics useful for exploration, especially in areas of transported overburden, for:
   a. Further lateritic and supergene deposits, and
   b. Primary mineralisation - including that with no expression as appreciable secondary mineralisation.

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

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

This report describes a mineralogical, geochemical and petrographic study of the weathered rocks of the Beasley Creek orebody and of its footwall sequence. Its aim is to provide some background information on the overall stratigraphy, degree of metamorphism, alteration and subsequent weathering of the ore and its wall rocks and to provide criteria (petrographic, mineralogical and geochemical) by which they may be distinguished and matched with their unweathered counterparts. In addition preliminary information has been gathered on the distribution of ore-related elements and their dispersion around the orebody and on the processes involved in weathering. Continuing research includes a multi-element dispersion study of a section through the Beasley Creek Mine and, in collaboration with Module 1, an investigation of the near surface expression of the mineralisation.

C.R.M. Butt
Project Leader
February 1989.

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A MINERALOGICAL, GEOCHEMICAL AND PETROGRAPHIC STUDY OF THE ROCKS OF DRILLHOLE BCD1 FROM THE BEASLEY CREEK GOLD MINE - LAVERTON, WA.

I. D. M. Robertson and S.F. Gall

ABSTRACT

The mineralogy, petrology and geochemistry of selected samples from DDH BCD1 were examined in detail to gain a preliminary understanding of the lithology, weathering characteristics and geochemistry of the Beasley Creek gold deposit (Laverton). Vertical drillhole BCD1 intersects the ore zone and footwall rocks to a depth of 100 m. The footwall consists of foliated basaltic amphibolites metamorphosed to the upper greenschist facies, consisting of a tremolite-albite-quartz assemblage. They contain at least one felsic unit and have been locally carbonated. Near the bottom of the hole kaolinite occurs with fresh pyrite but above this, pyrite is oxidised to goethite. Feldspars have weathered progressively to kaolinite and amphiboles to smectite. The rocks become upwardly friable and their foliation is cemented with clay, iron oxide and calcite.

The ore zone lies mainly within phyllitic rocks which are variably kaolinised and ferruginised. Garnet pseudomorphs indicate metamorphism more precisely to the quartz-albite- epidote-almandine subfacies. Progressive ferruginisation has replaced both minerals and fabrics, leaving only relict muscovite and shard-like quartz. Vesicles are lined with goethite, which becomes progressively poorer in Al, hematite and several Mn minerals including cryptomelane and lithiophorite. The upper part of the weathered profile has been subjected to calcrete formation where the rocks have been brecciated and set in a complex carbonate cement. Some of this has subsequently been dissolved leaving carbonate-lined vesicles.

The Ti/Zr ratio, together with Al and Cr are useful lithological indicators. Weathering has progressively depleted Mg, Ca and Sr and this is complete above 65 m except where calcrete formation has occurred. Mineralisation is marked by anomalous Pb, W, As and to a lesser extent by Be, Fe, Zn, Sb and Co.

INTRODUCTION

An intensive study of the Beasley Creek Gold Deposit, owned by Western Mining Corporation Ltd., is being carried out as part of this Project. This gold deposit lies about 12 km west north-west of Laverton at 122° 18'E, 28° 34'S. It lies in a small window, surrounded by presumed Permian sediments. Deeply weathered and lateritised Archaean rocks very occasionally outcrop but generally subcrop in this window. Proved and probable ore reserves of 2.1 million tonnes at 2 g/t have so far been outlined (as at June 1988) and mining began at the end of 1987. Beasley Creek presents a unique opportunity to study a weathered gold deposit from the surface to near fresh rock.

Intense weathering at Beasley Creek has made field recognition of what little outcrop there is, very difficult. The study was commenced during the final stages of project evaluation when it had been explored largely by percussion drilling in the weathered zone with only a minimum of diamond drilling. As little was known of the stratigraphy of the deposit, it was seen as essential to gain an understanding of the lithology, weathering characteristics and overall geochemistry.

Geomorphology and Weathering

The subcrop of the ore lies on a very low hill about 5 m above the plain. The country overlying the deposit is covered by evenly distributed mulga vegetation. The soils are generally thin and carbonate-rich and are underlain by various saprolites, hardpan and calcrete and overlain by a thin veneer of lag, consisting largely of iron-rich nodules with some vein quartz. The vegetation on the plains to the east and west is a grove - intergrove mulga community on red clay loams, with hardpan at 30-40 cms depth.

The orebody lies within amphibolites and dips at about 45 degrees to the east. It is completely oxidised and consists of kaolinite, quartz and hydrated iron oxides. Some of the ferruginous material outcrops patchily as an ironstone capping. The depth of weathering is very variable, being deepest (>100 m) and most intense around the mineralisation but to the east and west relatively fresh amphibolites may in places be encountered at depths of less than ten metres. Potable water is encountered at a relatively shallow depth of 16m in DDH BCD 1, within the deposit, and at 17 m depth in PDH BCP 222, to the south of the deposit. A bore which is part of the town water supply lies about a kilometre to the north of Beasley Creek.

There are no old workings or prospect pits though a pisolitic part of the south end of the hanging wall of the deposit has been used for road gravel.

Study Methods

Samples from DDH BCD1 were selected for petrographic study and geochemical analysis. This vertical drillhole was collared at 38862N 33980E at the hangingwall contact, near the centre of the proposed open pit mine. It passes obliquely through the mineralised zone, which is affected by weathering and ferruginisation. The drillhole was completed in relatively fresh amphibolite footwall rocks at a vertical depth

SUMMARY LOG - DDH BCD1

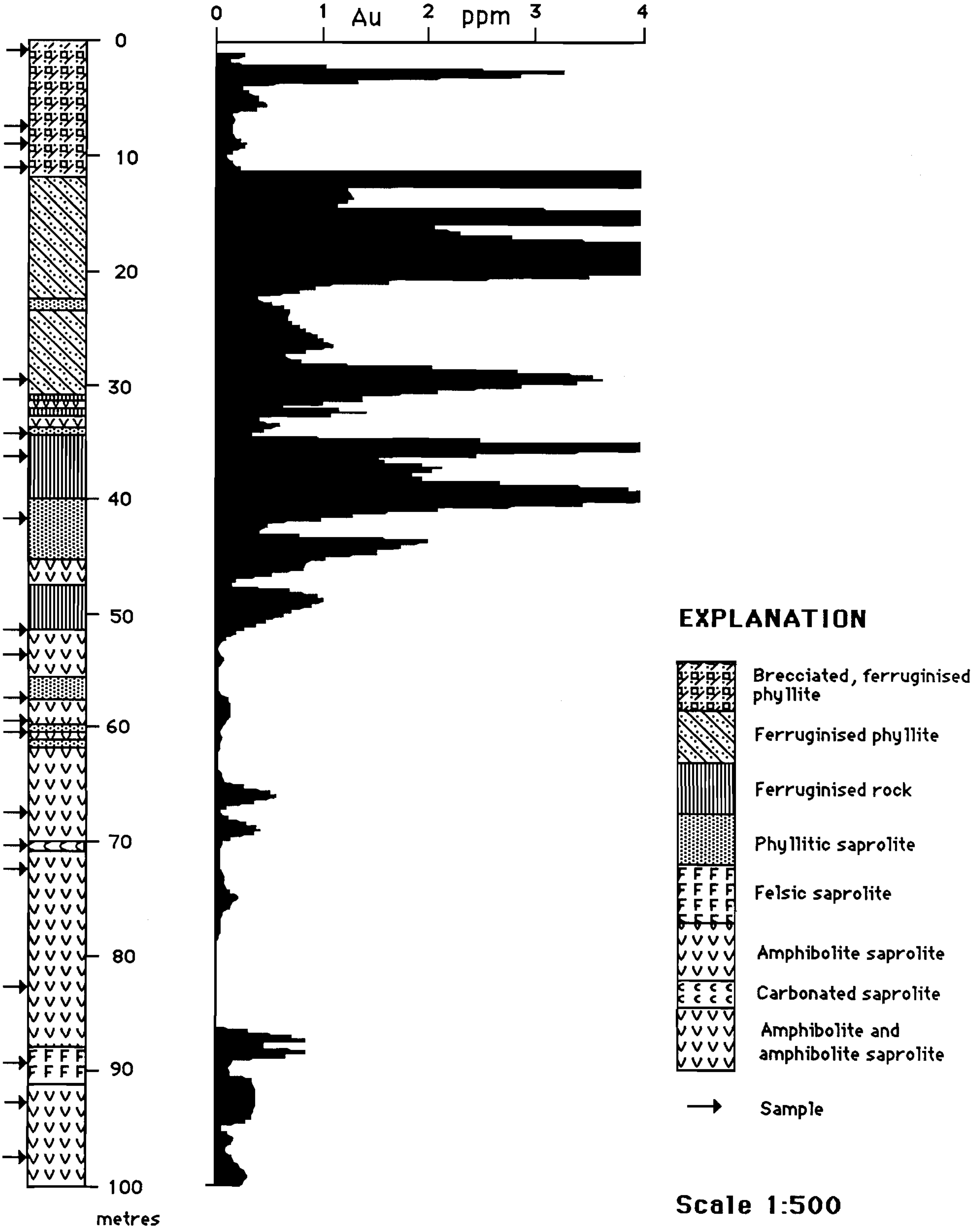


Figure 1

of 100.30 m. A summary log of this drillhole, using the results of this lithological study, is given in Figure 1. The top 45 m of this drillhole intersect variously mineralised and ferruginised phyllites, the remainder intersects mostly weathered mafic rocks.

The major rock types were investigated by collecting 20 clean spot samples of single lithologies. From each, a polished thin-section was cut, a pulp prepared and a small reference sample retained for description. The pulps were prepared by jaw crushing in Mn steel and grinding in a Ketos swingmill (trace Cr-Mn steel). Major elements were determined by the Hilger E-100 ICP at Floreat Park after Li-metaborate fusion. Minor and trace element analysis was largely performed on pressed discs by the method of Norrish and Chappell on the Philips PW1220C XRF, with some by ICP. Gold analyses were not performed as very close-spaced gold analyses had already been carried out by Western Mining Co. Ltd. These are shown in Figure 1 to illustrate the position of the ore. The analytical results are presented in tabular form in Appendix 4 and graphed in Appendix 3.

The mineralogy of each pulp was examined semi-quantitatively by X-ray powder diffractometry using graphite crystal monochromated CuKå radiation at the North Ryde laboratory. The results are tabulated in Appendix 2 and graphed in Appendix 3. The principal minerals were used to aid the petrographic study. Microprobe analyses were performed on the MAC microprobe at Floreat Park in energy dispersive mode. Word processing, data manipulation, data compilation, graphics and drafting were carried out using an Apple Macintosh SE microcomputer.

PETROGRAPHY

Several factors influence the mineralogy and fabrics of the rocks in DDH BCD1.

(1) Pre-metamorphic lithology varies considerably across strike. The principal rocks were basalts and argillaceous sediments.

(2) Metamorphism to upper greenschist facies lead to the development of tremolite and albite in the basalts and white mica and garnet in the argillites.

(3) Alteration, associated with mineralisation, has undoubtedly been imprinted on these various metamorphic rocks though this has largely been masked by weathering. Carbonation on a limited scale and alteration of mafic minerals to clays prior to degradation of sulphides by weathering may be the products of this alteration.

(4) Weathering of the metamorphosed and altered rocks included migration of iron, with deposition near the surface and as ferruginisation of rocks associated with ore at greater depth. Where weathering and particularly iron deposition is intense,the nature

Figure 2 Photomicrographs of BCD1 thin sections.

A and B. Fresh amphibolite at 97.45 m depth, showing decussate-textured tremolite (Tr) overprinting a groundmass of quartz, albite and biotite (Bi) which depicts a cleavage. Plane polarised light and crossed polarisers respectively.

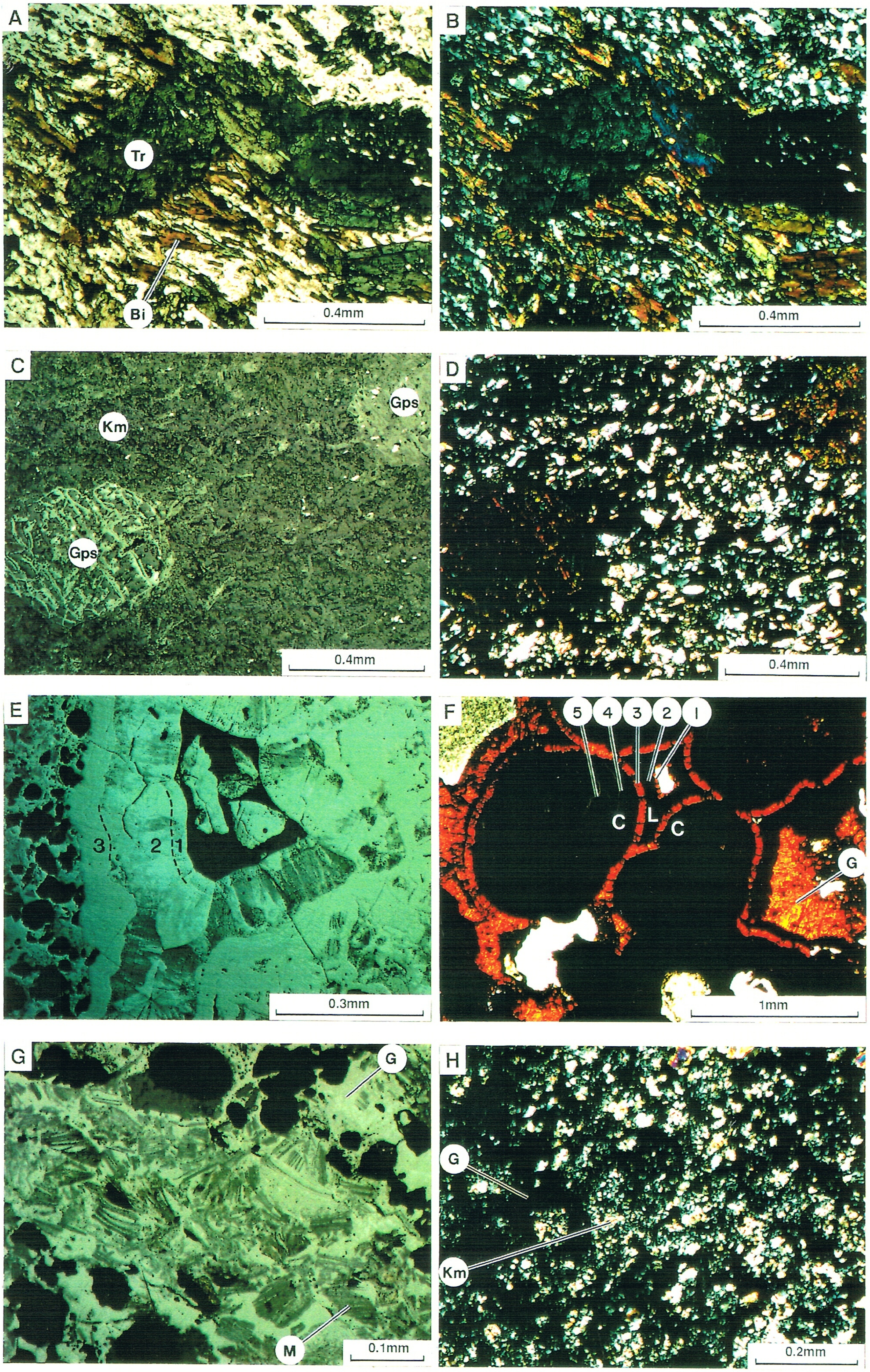
C and D. Weathered phyllite from 29.6 m depth, showing garnet pseudomorphs (Gps) overprinting a fine-grained kaolinite and muscovite fabric (Km). The fractures in the garnet are filled with goethite and the garnet has subsequently been dissolved away. Reflected light and transmitted light with crossed polarisers respectively.

E. Ferruginised phyllite from 11.0 m depth. A vesicle lined with goethite and fibrous goethite with a variable Al content (numbers denote layers analysed by microprobe - see mineralogy section). Reflected light.

F. Colloform goethite-manganese oxide rock from 36.1 m depth. The translucent red-brown fibrous mineral is goethite (G) and the black minerals are manganese oxides, cryptomelane (C) and possibly lithiophorite (L). Numbers denote layers analysed by microprobe - see mineralogy section. Plane polarised light.

G. Ferruginised phyllite from 11.0 m depth. Sheets of muscovite (M) lie enclosed in goethite (G) which has split some of the muscovite sheets apart. Reflected light.

H. Weathered amphibolite from 59.4 m depth. Rounded patches of fine-grained, intimately mixed kaolinite and muscovite (Km), surrounded by powdery goethite (G). Note the variability of the birefringence of the kaolinite-muscovite mixture. Crossed polarisers.


A
Tr
Bi
0.4mm
B
0.4mm
C
Km
Gps
Gps
0.4mm
D
0.4mm
E
3
2
1
0.3mm
F
5
4
3
2
1
C
L
C
G
1mm
G
G
M
0.1mm
H
G
Km
0.2mm

of the original rock type is largely obscured, though there are a number of fabrics and mineral relics which leave hints as to the original material.

Descriptions of the principal litho-units in DDH BCD1 are given below. Full details for each sample are presented in Appendix 1.

Fresh Amphibolites

The base of the drillhole (samples 97.45 and 92.8) are fine-grained amphibolites which consist mainly of tremolite, untwinned albite and quartz. They are finely cleaved and the cleavage contains decussate tremolite blades indicating metamorphism during and after the main deformation (Figure 2A, B). These rocks were probably basalts. The lowermost sample is dark green, contains stable pyrite and appears to be unweathered, though fracture planes are stained brown by iron oxides. The upper sample is paler green, the amphiboles are largely degraded to chlorite and smectite. Pyrite occurs as a 'paint' on some cleavage planes. The co-existence of clays and fresh pyrite suggest that some hydrothermal alteration rather than weathering may have altered the amphiboles.

Weathered Amphibolites and Mafic Rocks

Weathered mafic rocks occur at 82.7, 72.2, 70.2, 67.7, 59.4 and 57.6m. They are variably schistose, slightly fibrous and friable. The friability becomes more marked and the schistosity weaker and is cemented by secondary minerals higher in the profile. The rocks consisted originally of quartz, albite and tremolite. Higher in the profile, quartz becomes shard-like, albite becomes altered to kaolinite and tremolite becomes recognisable only as clay relics in the cleavage. Clay patches are common higher in the profile. Exposed cleavage and fracture surfaces are generally extensively etched and are coated by clays and carbonate minerals. Traces of pyrite occur lower down but it is absent in all the upper mafic saprolites.

The clay patches are an intimate sub-micron mixture of kaolinite and muscovite, which has the fabric of a kaolinite but an anomalously high (grey-white) birefringence (Figure 2H). This is similar to kaolinite-muscovite mixtures found in weathered profiles in east Queensland and New South Wales (Robertson and Eggleton, in prep) and it is necessary to resort to the transmission electron microscope to resolve these phases.

The sample at 70.2 m is very rich in carbonate minerals. It has no textural similarities to the other mafic rocks but geochemical evidence suggests it is part of this suite. Some of the mafic rocks are cut by veinlets of quartz ± chlorite and later carbonate veinlets.

The gradation of textures in these rocks clearly indicate that they formed by progressive weathering of the basaltic amphibolites encountered further down hole.

Felsic Schist

Felsic schist occurs between 88.2 and 90.95 m. They have a strong sericitic cleavage and contain a higher proportion of quartz and feldspar than the amphibolites. They consist of felsic layers (quartz-albite>clay-goethite) and mafic layers (chlorite-muscovite>quartz- albite-goethite±calcite). The feldspars show the first signs of degrading to kaolin. Goethite stains the cleavage and mafic layers.

Weathered Phyllites

These are quite variable in composition as they constitute much of the ore zone and have been extensively altered by mineralisation, weathering and associated iron deposition. Phyllite occurs intercalated in mafic saprolite between 59.9 and 60.5 m, the rest occur above 51.5 m.

These rocks are pale yellowish green to yellowish brown, fibrous, slightly mottled and friable, with a weak foliation that has been largely re-cemented by clay minerals and iron oxides. Where quartz is seen, it is shard-like or occurs as lenses marking a silicified cleavage. Apart from quartz, the rock consists of kaolinite, muscovite (sericite) and an intimately mixed kaolinite-muscovite phase. These phyllosilicates are stained and penetrated to a varying extent by fine-grained goethite. Garnet pseudomorphs occur in the phyllosilicate groundmass, veined with goethite. All of the garnet has been subsequently dissolved away, leaving an open boxwork of goethite veinlets with the form of a garnet (Figure 2C, D).

Where iron deposition is more prevalent, the phyllites are dark brown, dense and their foliation is extensively cemented by iron oxides. Although they still contain kaolinite, muscovite and the common kaolinite-muscovite mixture in parts, where goethite is concentrated, only relict books of sericite are preserved in some of the goethite patches (Figure 2G).

Iron-rich Rocks

These rocks are dominant near the top of the drillhole. Where goethite is abundant, it forms spongy masses and the foliation of the rock is progressively destroyed. Sericite relics are common in the massive goethite. Some of these goethite-rich rocks are vesicular and colloform textures have developed in the goethite, close to the surface, which show rims of fibrous goethite and an outer layer of Al-poor goethite (Figure 2E) or hematite with dehydration fractures.

Calcite cementation has occurred in some near surface samples (7.4 and 1.0 m), where they have formed iron- and carbonate-rich breccias in which cellular goethite and phyllosilicate rock fragments are set in a carbonate matrix. Later leaching has removed much of this carbonate cement, leaving a carbonate coating on the breccia fragments. The carbonate has in places formed ellipsoidal granules. Examination of these by SEM shows worm-like carbonate excrescences attached to their surfaces. The quartz is generally angular though some grains show re-entrant boundaries, indicating corrosion.

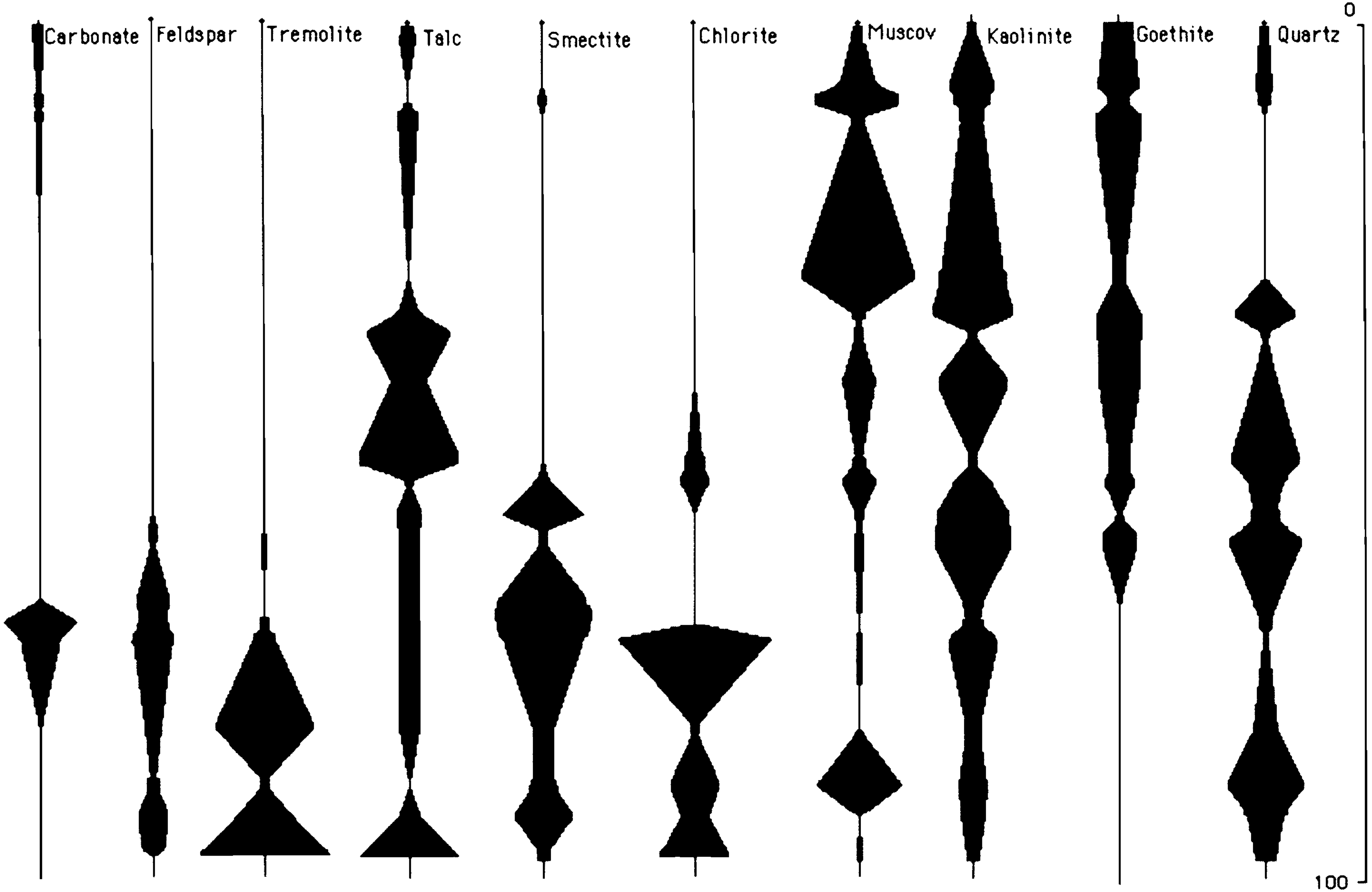

Carbonate
Feldspar
Tremolite
Talc
Smectite
Chlorite
Muscov
Kaolinite
Goethite
Quartz
0
100

Figure 3

Metamorphism

The fresh amphibolites give the most direct indication of the grade of metamorphism. The presence of whispy tremolite, rather than well-crystallised hornblende, coexisting with untwinned albite, are typical of the upper greenschist facies, although the paragenesis of these minerals is relatively broad. Argillaceous rocks are the most sensitive to metamorphism but, in DDH BCD1, all these have had their mineralogy drastically altered by weathering. Some garnet pseudomorphs still remain in the phyllites to place the metamorphic grade more precisely in the quartz-albite-epidote-almandine subfacies of the greenschist facies (Turner and Verhoogen,1960; Winkler, 1967).

MINERALOGY

X-ray Diffraction Analysis

The fine-grained mineralogy of the weathered rocks is almost impossible to determine optically, so that semi-quantitative X-ray diffraction analysis was carried out to aid the petrographic study. The results are tabulated in Appendix 2 and graphed in Appendix 3. It must be emphasised that the quantitative estimates are only approximate. The values refer to the heights (in mm) above background of selected peaks on the trace. They reflect a comparison of the relative abundances of *single* minerals *between* samples; they do not indicate the abundances of different minerals in each sample.

A graphical summary of the mineralogy (Figure 3) shows the appearance and disappearance of minerals in the weathered profile. Quartz and kaolinite occur almost throughout the profile. Feldspar, chlorite and tremolite occur only below 68 m and their places are taken by kaolinite and smectite. Smectite is almost completely confined to the mafic rocks and muscovite to the phyllites. Goethite becomes important above 70 m. Carbonates occur near the surface (above 30 m and particularly above 10 m) where they reflect carbonate precipitation (calcrete) and occur at depth (67-83 m) only where there has been intense hydrothermal carbonation.

Three samples (29.6, 36.1 and 51.25) contain Mn as a major component (8%). Secondary manganese oxides tend to be poorly crystalline and are difficult to determine by XRD. Careful examination of the traces suggested that cryptomelane was present in 36.1 and 51.25 but no Mn minerals could be detected in 29.6 by XRD. The [-101] reflection of cryptomelane at 6.98 Å is easily camouflaged by the diffuse [001] reflection of kaolinite at 7.17 Å. The presence of cryptomelane in sample 36.1 was confirmed by the presence of K, determined by microprobe analysis.

Electron Microprobe Analysis

The colloform structure of Samples 36.1 and 11.0 were investigated by microprobe (Appendix 5) to gain some insight into the mineralogy and the distribution of minor elements in the iron oxide layers. A hematite standard was used for calibration.

Sample 36.1

The layers are described from the outside (Figure 2F). Each layer, except the innermost, shows a very constant composition, though there are marked differences in composition between the layers.

Layer 1 (outermost) is Fe-rich, with small amounts of Al, Si and Mn and it corresponds to goethite. The water content, determined by difference, is unusually high ($3H_2O$) but some of this could be due to porosity on the sub-micron scale.

Layer 2 is rich in both Al and Mn but has no other major component. There are few minerals containing both Mn and Al (galaxite, mengxianminite, shigaite and lithiophorite) but the best approximation is lithiophorite $(Al,Li)MnO_2.(OH)_2$. Lithium is too light to be detected by energy dispersive X-ray analysis. If Fe, Ni and Mg substitute for Mn, the number of Al ions is low (0.654) so 0.346 Li ions, equivalent to 3.37 wt% Li_2O, would be required to balance the lithiophorite molecule. The water content (4.67 molecules or 27.43 wt%), is high. It is expected that some of this is due to porosity.

Lithiophorite Structural Formula

Si	0.007	
Al	0.654 **	
Li	0.346 **	
Fe	0.002 *	
Mn	0.972 *	* Sum to 1.000
Ni	0.017 *	** Sum to 1.000
Mg	0.009 *	
Na	0.049	
OH	4.667	

Layer 3 is similar to Layer 1, with high Fe and minor Al, Si and Mn. It is slightly richer in Si and Al and poorer in Ti and Fe than the outermost layer, but has a similarly high water content.

Layer 4 is very rich in Mn and has significant K and minor Al. Very little Ca is present so the most likely minerals are cryptomelane $[K.Mn_8O_{16}]$ or manjiroite $[(Na,K)Mn_8O_{16}.nH_2O]$. If the alkali ions are summed to one then the formula is quite close to cryptomelane $KMn_8O_{16}.6H_2O$.

Layer 5 Analysis of the innermost zone was unsatisfactory; it revealed a highly heterogeneous material on the micron scale with five analyses showing varying proportions of Fe, Mn, K and Al. These are probably mixtures of the various hydrous oxides of iron and manganese described above.

Cryptomelane Structural Formula

Si	0.029	
Ti	0.021	
Al	0.318	
Cr	0.003	
Mn	8.607	
Mg	0.066	
Ca	0.021	
Na	0.276 *	*Sum to 1
K	0.831 *	

Sample 11.0

The layers are described from the outside (Figure 2E). They are all goethite with a slightly excessive water content (computed by difference) and are very consistent in composition. There are a few minor differences, the outer layers (towards the centre of the vesicle) become progressively enriched in Si and, possibly, Mn, and depleted in Al, Cr and possibly Mg.

GEOCHEMISTRY

The geochemical data is shown graphically in Appendix 3 and tabulated in Appendix 4. Detection limits (XRF) together with typical levels (Turekian and Wedepohl, 1961) for ultramafic, mafic, granitic and argillaceous rocks are shown in Appendix 4 and on the graph ordinate axes for each trace element for comparison.

There are several factors influencing the litho geochemistry, which are described separately. These are:-

- Primary lithology
- Alteration and dispersion of ore related elements
- Weathering which includes leaching, ferruginisation, silicification and calcrete formation.

The interaction of the weathered profile and the local stratigraphy makes it impossible to study each rock type in all weathering environments from this drillhole alone, though some general conclusions can be drawn.

Lithology

Each rock type has fairly distinct geochemical characteristics, the most easily defined are those of the mafic rocks below 51.5 m. These have a high Ti/Zr ratio (Figure 4), despite their state of weathering, of about 100 (range 95-117) and a fairly close and relatively low range of Cr (19-74 ppm centred (log mean) on 42 ppm). Hallberg (1984) used the Ti/Zr ratios and the Cr contents of weathered rocks to deduce the parent igneous rocks. The Ti/Zr ratio decreases from basalt (>60), through andesite (<60 >12) to dacite and rhyolite. Both elements tend to be resistant in the weathering environment. This method may also be

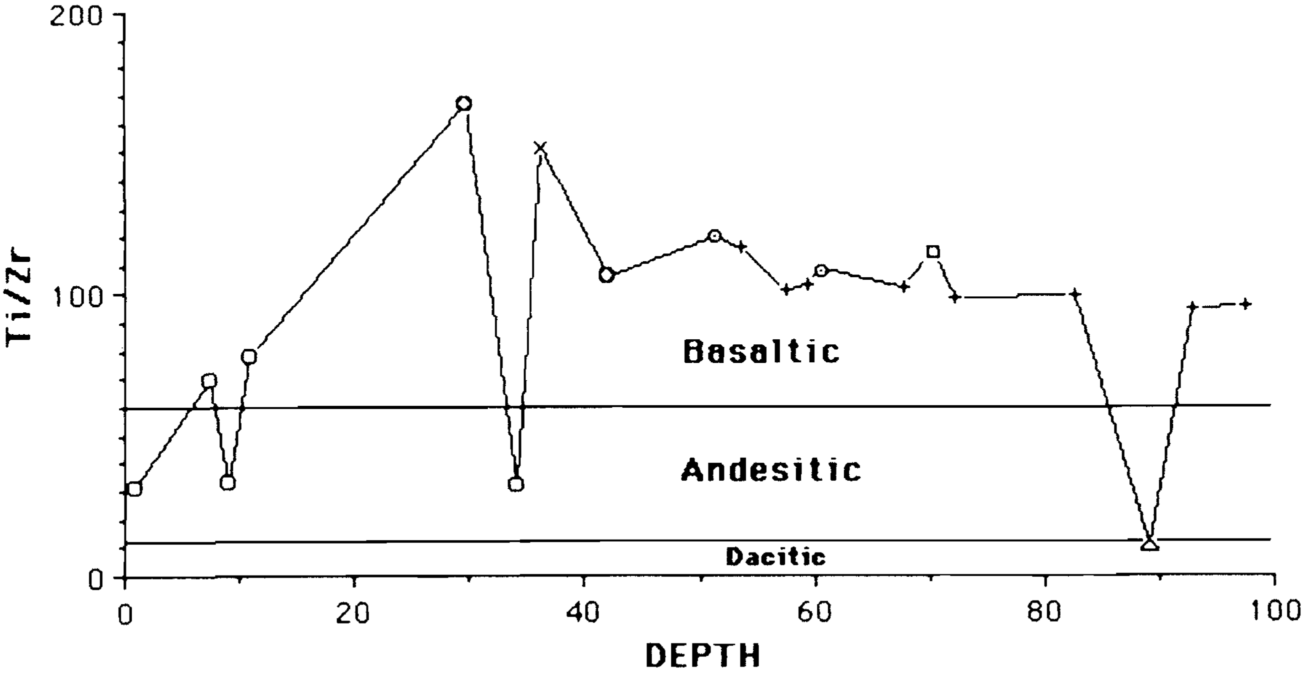

200
100
0
Ti/Zr
Basaltic
Andesitic
Dacitic
0
20
40
60
80
100
DEPTH

FIGURE 4

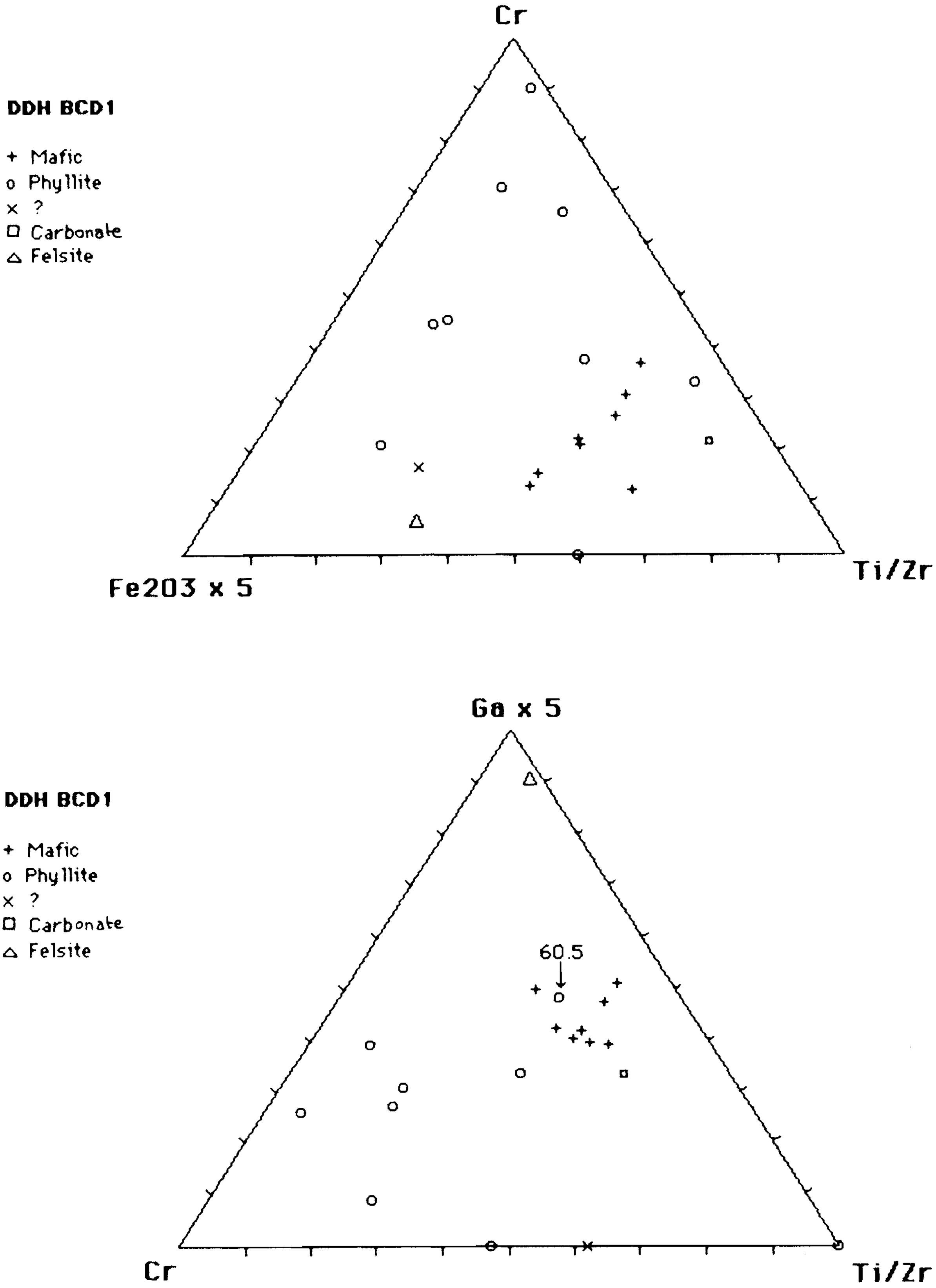
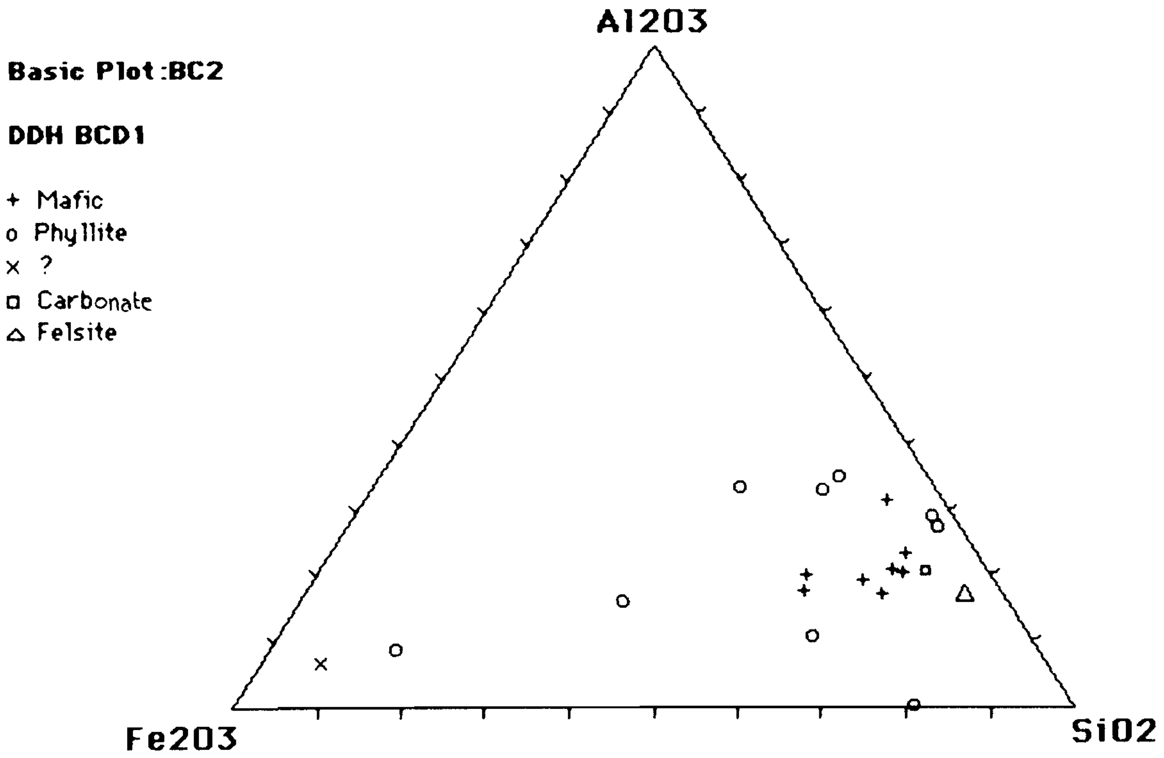

Cr
DDH BCD1
+ Mafic
o Phyllite
× ?
□ Carbonate
△ Felsite
Fe2O3 x 5
Ti/Zr
Ga x 5
DDH BCD1
+ Mafic
o Phyllite
× ?
□ Carbonate
△ Felsite
60.5
Cr
Ti/Zr

FIGURE 5



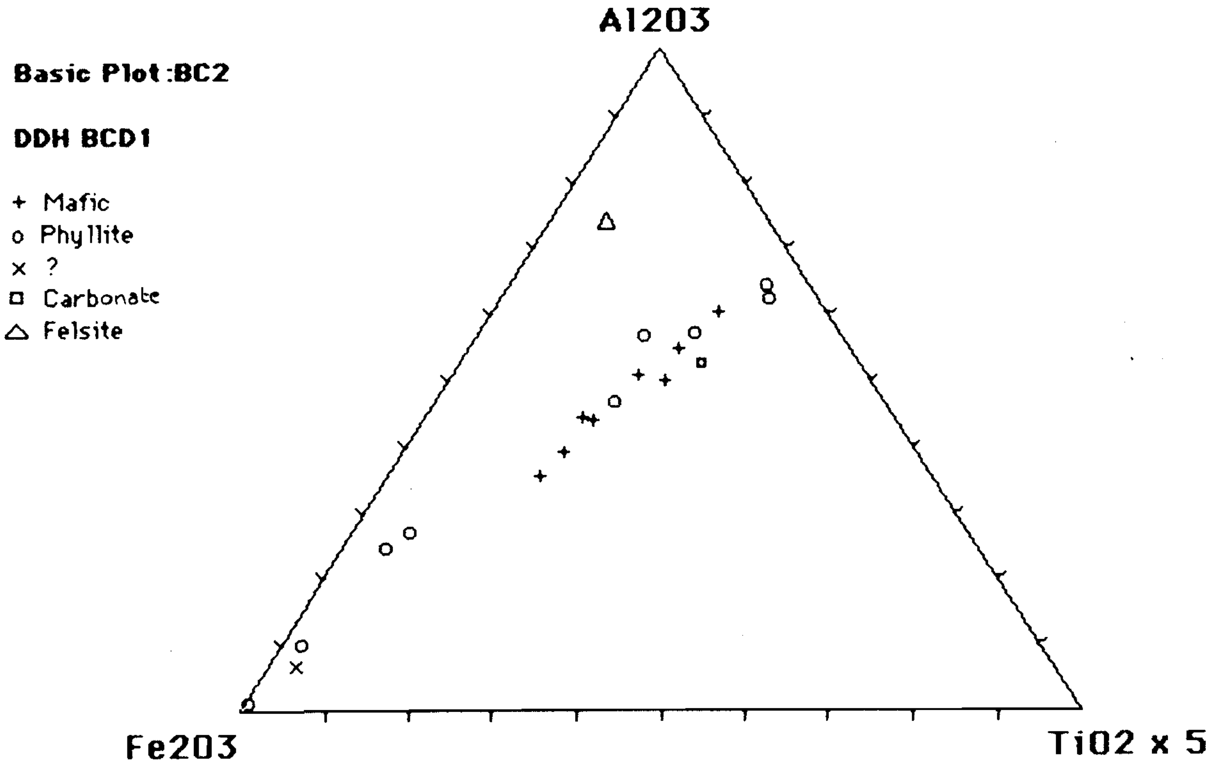


FIGURE 5 (contd)

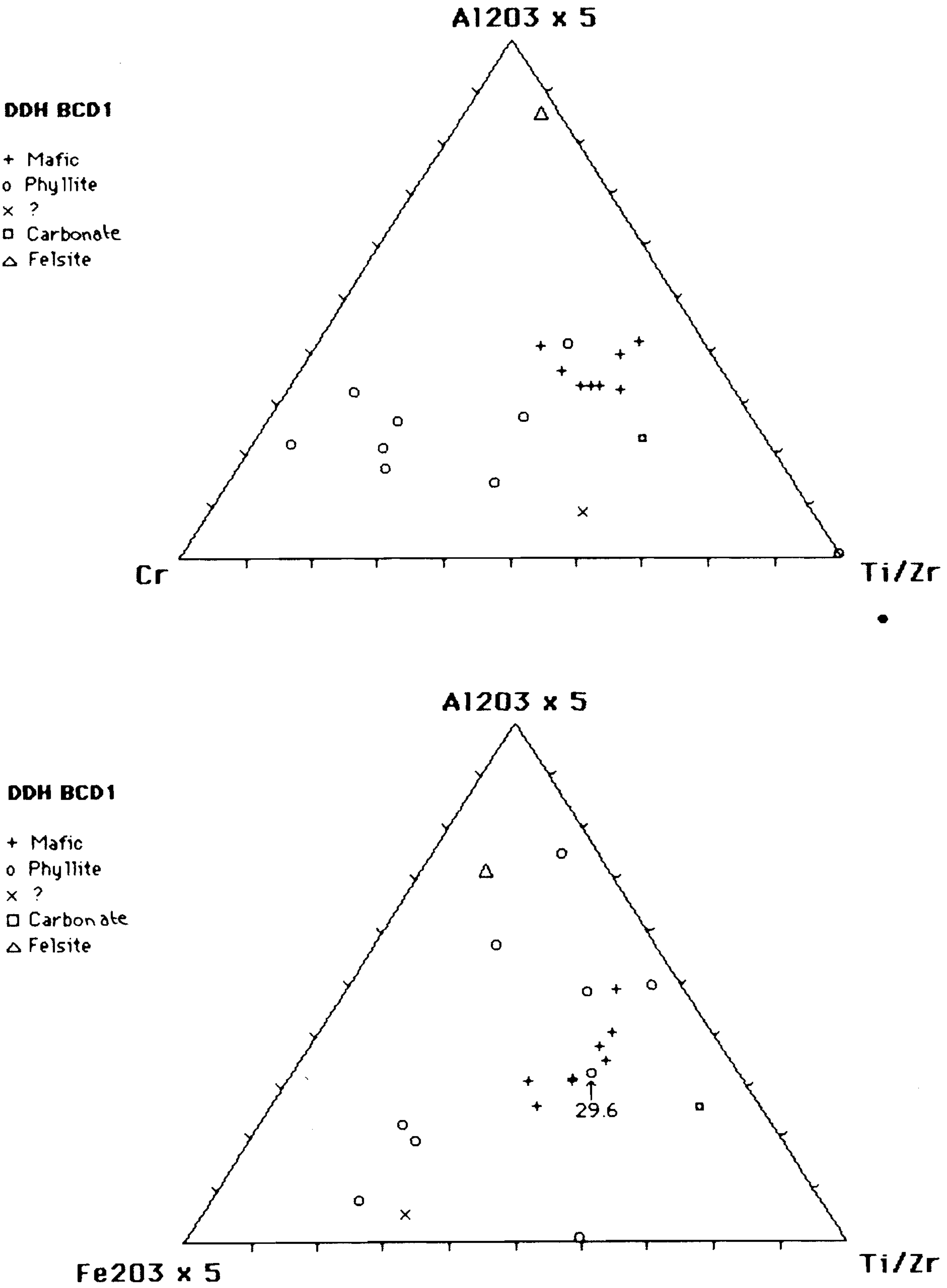


FIGURE 5 (contd)

effective, possibly to a lesser extent, to indicate the provenance of sediments derived from igneous detritus.

Gallium and Al tend to be closely correlated both in magmatic processes and during weathering, though there can be a slight decrease in the Ga/Al ratio when weathering takes place under strongly oxidising conditions. Changes in the Ga/Al ratio was investigated and, though there is a slight decrease towards the surface, the scatter is high and the validity of the trend may be questioned on statistical grounds. As it is a trace element, the Ga content of weathered rocks is less influenced than Al by the abundances of major elements.

Weathered phyllitic rocks, which make up the balance of DDH BCD1, have very variable Al and Ga contents but they can usually be distinguished on the basis of higher Cr than the mafic rocks. The two phyllites which have the lowest Cr contents are found either in or immediately adjoining the mafic rocks and were probably derived from a mafic source. The tight grouping of the mafic rocks may be clearly distinguished from the larger scatter of the phyllites on the ternary plots in Figure 5. The Al-Cr-Ti/Zr, Ga-Cr-Ti/Zr and to a lesser extent the Al-Fe-Ti/Zr plots are probably among the most effective in differentiating between the two major rocktypes despite the degree of ferruginisation.

The one carbonate-rich rock (70.2) has a greater affinity to the basaltic rocks than to the phyllites on all the ternary plots and this is confirmed by its overall geochemical composition.

The single felsic rock is characterised by a very low Ti/Zr ratio and relatively high granite-related element content Si, Zr, Rb, Pb, Ce, La and Ba.

Weathering

There is a marked depletion in the alkaline earth elements Ca, Mg and Sr from the fresh to the first altered amphibolite. Unusually the depletion is evident even before pyrite is destroyed and may reflect some hydrothermal alteration which may only be visible in relatively unweathered rocks. Depletion in Ca, Mg and Sr continues into the weathered zone and is complete for Ca above 65m depth, though some Mg is retained between 50-60m. Calcium, with only minor Mg, re-appears strongly above 12 m, related to the formation of calcrete. There appears to be no significant silicification in the samples analysed.

Mineralisation

The mineralised zone is marked by anomalous Pb, W and As with erratic increases in Be, Fe, Zn, Sb and Co and a depletion in Si. The Si depletion is probably more apparent than real because zones of quartz veining were deliberately omitted.

Arsenic is probably one of the most widely dispersed elements around the ore zone. It has a mean value of 3.5 ppm below 65 m (range 0-16 ppm) and 42 ppm above (range 2-226 ppm). The envelope for As slightly exceeds that of Au. Tungsten is restricted to the ore zone. Below 34m the W level averages 3 ppm (range 0-11) but above it averages 14 (range 1-57). This W anomaly lies within the gold envelope, though there is one anomalous value at 53.5 m. Lead is even more restricted, there being only three anomalous samples.

It is difficult to assess the distribution and and geochemical use of Bi, In, Ag, Cd, Be, Se, Ge and Sn because of the low levels encountered (3-7 ppm) and the analytical precision at these levels. They must not be excluded until they have been investigated using an improved analytical technique.

CONCLUSIONS

The following conclusions were reached from this study:-

- The footwall rocks at Beasley Creek are in mafic amphibolites which probably represent metabasaltic rocks. Interspersed in this is at least one small unit of dacitic composition.
- Most of the ore zone lies within a phyllitic unit.
- The rocks have been metamorphosed to the quartz-albite-epidote-almandine subfacies of the greenschist facies.
- There is a suggestion of hydrothermal alteration imprinted on fresh rock near the base of the hole which has subsequently been masked by weathering elsewhere.
- Weathering has progressed first with alteration of the amphiboles to smectites and chlorite and destruction of pyrite, followed closely by breakdown of feldspars to kaolinite. The rocks show a greater friability towards the surface, accompanied by increased cementation of the cleavage by clays, carbonates and iron oxides.
- Kaolinisation of the phyllites (originally mostly white mica) is incomplete, resulting in an intimately mixed (sub-micron scale) kaolinite-muscovite phase. Garnets have had their fractures filled by goethite and the garnet itself has been completely dissolved, leaving a pseudomorph that can only be recognised by its characteristic overall morphology.
- Deposition of alternating layers of hydrated iron and manganese oxides have occurred at depth within the ore zone to form a colloform texture in highly ferruginous rocks.

- Progressive ferruginisation (goethite) has penetrated the cleavage of the rocks, finally replacing all in its path except relics of white mica. Here even quartz is re-textured and becomes shard-like. The outer layers of some ferruginous fragments consist of fractured hematite, indicating late dehydration of iron minerals.

- Lastly carbonates have invaded, brecciated and re-cemented the rocks in the top few metres (formation of calcrete). Subsequently this carbonate cement has been extensively dissolved.

- The Ti/Zr ratio combined with the Cr, Al and Ga contents have proved useful in distinguishing the original rock types in spite of intense weathering. The phyllites are more Cr-rich than the mafic rocks suggesting an ultramafic provenance while phyllites intermixed with the mafic rocks have a more 'mafic' Cr content.

- Weathering has progressively depleted the rocks in Mg, Ca and Sr and this is complete above 65 m depth.

- The mineralised zone is marked by anomalous Pb, W and As with erratic increases in Be, Fe, Zn, Sb and Co.

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REFERENCES

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

Hallberg, J. A., and Glickson, A. Y. (1981) Archaean granite-greenstone terranes of Western Australia. *in* D.R. Hunter (ed). *Precambrian of the Southern Hemisphere.* Developments in Precambrian Geology, 2. Elsevier, Amsterdam.

Hallberg, J. A., and Williams, D. A. C. (1972). Archaean mafic and ultramafic rock associations in the Eastern Goldfields Region, Western Australia. *Earth and Planitary Science Letters*, 15. 191-200.

Huebner, J. S. (1976). The Manganese Oxides - a bibliographic commentary. *in* D. Rumble (ed) *Oxide Minerals.* Min. Soc. Amer. Short Course Notes. pp SH1-17.

Naldrett, A. J., and Turner, A. R. (1977). The geology and petrogenesis of a greenstone belt and related nickel sulfide mineralization at Yakabindie, Western Australia. *Precambrian Research*, 5, 43-103.

Robertson, I. D. M. and Eggleton, R. A. (in prep). Observations on the weathering of muscovite to kaolinite and kaolinite to halloysite. *Clays and Clay Minerals.*

Turekian, K. K., and Wedepohl, K. H. (1961). Distribution of the elements in some major units of the Earth's crust. *Geol. Soc. Amer. Bull*, 72. pp 175-191.

Turner, F. J., and Verhoogen, J. (1960). *Igneous and metamorphic petrology.* McGraw-Hill Book Co, Inc. New York 694p.

Winkler, H. G. F. (1967). *Petrogenesis of metamorphic rocks.* Springer-Verlag, Berlin. 237p.

APPENDIX 1

Systematic Petrography

APPENDIX 1
SYSTEMATIC PETROGRAPHY

The petrographic study was made difficult by intense alteration, weathering and ferruginisation. The study is best followed from the base of DDH BCD1 upwards, from the least to the most altered rocks. Photomicrographs in Figure 2 are referred to throughout the text. The sample numbers correspond to the down-hole depths. Comments on the geochemistry are also included and these should be read in conjunction with the graphs in Appendix 3 and the tabulated geochemistry in Appendix 4.

97.45: Fresh amphibolite schist

The hand specimen is dark greenish grey, fresh and well-foliated. It consists of bladed dark green amphibole crystals lying with a decussate texture in the plane of the foliation, surrounded by a sugary felsic groundmass. There is also a small amount of pyrite. Where weathering has penetrated joints and a fracture cleavage marked by very felsic layers, pyrite has altered to brown iron oxides that locally stain the rock.

Mineralogy:

Microscope: quartz, tremolite, albite, chlorite, biotite, calcite, goethite, sphene, pyrite

Diffractometer: quartz, tremolite, albite, chlorite, talc (tr), smectite (tr), muscovite (tr)

This rock is an amphibolite with a well-developed fabric. It consists of blades of tremolite [0.2-1.5mm] set in a much finer-grained groundmass of quartz and untwinned albite [0.05mm]. The fine grained groundmass has a sutured texture (Figure 2 a, b). Accessory minerals are sphene, iron oxides, chlorite and biotite. Pyrite occurs scattered throughout, mainly associated with biotite and tremolite. Sphene occurs as inclusions in the tremolite. Biotite is unevenly distributed and occurs where the foliation is most intense. The whole fabric is cut by carbonate veins.

The major element geochemistry is illustrated in Appendix 4. Though it is an amphibolite, it is not unlike the tholeiitic basalts common in greenstone terrain (Hallberg and Williams, 1972; Naldrett and Turner, 1976; Hallberg and Glickson, 1981). This is confirmed by its characteristic Ti/Zr ratio (Hallberg, 1984), although it is slightly siliceous. Though this basaltic rock is both unaltered by hydrothermal processes and unweathered, greenschist metamorphism and tectonism have retextured it.

92.8: Altered amphibolite schist

Though the foliated appearance, grain-size and micro-texture of this rock are very similar to sample 97.45, it is much paler in colour (yellowish-green) with pale grey foliae and is friable. A patina of pyrite occurs on some joint surfaces.

Mineralogy:

Microscope: quartz, tremolite, albite, chlorite, kaolinite, hematite, magnetite, pyrite

Diffractometer: quartz, tremolite, albite, chlorite, smectite, kaolinite

The rock shows blades of tremolite, partly altered to smectite, lying in a patchy matrix of granular quartz [0.05mm] and untwinned albite. Some of the relict tremolite [0.2-0.4mm], is associated with chlorite and granular pyrite. The tremolite, in particular, is masked by a cloudy grey clay mineral, while the felsic groundmass is only slightly clouded, the feldspar being preferentially attacked.

The metamorphic grade of this rock is upper greenschist facies. It is likely that the rock was a basalt or dolorite. The former is preferred as no ophitic texture is preserved. The alteration of this rock is reflected in a decrease in its content of alkali and alkaline-earth elements (Rb, Mg, Ca, Sr, Ba). Iron, Cr and Mn are also depleted. The presence of fresh pyrite together with altered amphiboles suggest hydrothermal alteration of this rock rather than weathering.

89.2: Felsic schist saprock

This pale yellowish-brown schist consists of alternating pinkish and grey layers depicting at least two cleavages. Fine mica in the schistosity gives it a sheen and a few dark lenses probably represent altered mafic minerals. Yellow staining, apparently goethite from oxidised pyrite, preferentially follows some layers.

Mineralogy:

Microscope: quartz, muscovite, kaolinite, albite, chlorite, goethite, calcite(?)

Diffractometer: quartz, muscovite, kaolinite, albite, chlorite, smectite, calcite (tr)

This rock is strongly laminated and it consists of alternating mafic and felsic layers. The felsic layers consist of quartz and untwinned albite with a small amount of white to pale yellow clay and iron oxide minerals (oblique light). The clay, presumably kaolinite, is an alteration product of the feldspar. The thin section is difficult to study because the clay minerals have reacted with the impregnating epoxy resin to produce a wide variety of colours (green, blue, mauve and red-brown). The mafic layers consist of small proportions of quartz and untwinned albite in dominant chlorite and muscovite and possibly some calcite, thought to be pseudomorphs after tremolitic amphibolite. The iron minerals are mainly goethite, associated with and staining the mafic layers. Though the rock is foliated, the cleavage is not intense. The rock type is either of intermediate to felsic igneous association and was given a laminated texture by tectonism or the interlamination of mafic and felsic layers may suggest a locally-derived sediment or waterlain tuff.

The geochemistry of this rock differs from those immediately adjacent in being very poor in Ti, resulting in a very low Ti/Zr ratio more typical of a dacite than a basalt. It is also significantly depleted in Fe, Mn, the alkaline-earths (Mg, Ca and Sr) and the base metals (V, Co, Cr, Ni, Cu and Ag). It is enriched in granite-related elements Si, Zr, Rb, Pb, Ce, La and Ba. If this rock was tuffaceous or sedimentary, there was a high proportion of felsic detritus.

82.7: Foliated amphibolite saprock

The rock is pale greenish-grey and, though quite foliated, it is not very schistose. It has a pepper-and-salt texture of dark green mafic minerals set in a sugary grey felsic phase. There is very little iron-staining except along discrete foliae. Minor pyrite occurs as lensoid patches.

Mineralogy:
Microscope: quartz, tremolite, kaolinite, albite, goethite, hematite, pyrite
Diffractometer: quartz, tremolite, kaolinite, albite, smectite, siderite

The rock consists of intensely altered, matted blades of tremolite [0.3-0.8mm] which are clouded by smectite and kaolinite. These are set in a patchy matrix of finer grained quartz [0.05mm] and untwinned albite with some cloudy kaolinite. The iron minerals consist of pyrite, which is largely granular [0.05-0.4mm] and fractured, coexisting with a separate lozenge-shaped goethite phase.

Chemically this rock is basaltic in terms of both its major and trace element chemistry though, compared to average basalts, it is slightly enriched in Cd, W, V and Cu and slightly depleted in Cr, Nb, Mn and Ni. The rock is like 92.8, a weathered upper greenschist facies metabasalt.

72.2: Altered and weathered amphibolite saprolite

The rock is pale green, has a granular to weakly fibrous micro-texture, is weakly schistose and friable and is cut by a discrete fracture cleavage filled with chlorite. Many of the exposed surfaces are etched and coated with greenish clays and carbonate. Iron staining is not apparent, neither is there any pyrite on the exposed surfaces.

Mineralogy:
Microscope: quartz, tremolite, chlorite, albite, goethite, carbonate, pyrite (tr)
Diffractometer: quartz, tremolite, chlorite, albite, smectite, dolomite

This rock consists of lensoid mafic laminae of bladed tremolite, partly altered to chlorite, set in a granular matrix of quartz and untwinned albite. It is a little more felsic than the ones further down hole. Veins of dolomite and comb-textured quartz crosscut the fabric. Some veins indicate an earlier quartz-chlorite phase and a later carbonate phase. The only iron minerals are goethite and a trace of pyrite, which is granular and is associated with both the mafic and felsic phases. Some of the quartz, carbonate and chlorite veins have been re-opened by weathering and very small amounts of clay minerals have been deposited. This rock is fairly even-grained and there is no strong foliation.

This rock is basaltic in terms of both its major and trace element geochemistry though, compared to average basalts, it is slightly enriched in Cd, W, V and Cu and slightly depleted in Cr, Nb, Mn and Ni.

70.2: Carbonated amphibolite saprolite

This is a pale green rock with a mottled appearance with a slightly foliated, fine-grained, sugary texture that is similar to that of the underlying amphibolites. Exposed fracture surfaces are strongly etched and coated with secondary minerals.

Mineralogy:
Microscope: quartz, kaolinite, albite, carbonate, goethite
Diffractometer: quartz, kaolinite, albite, dolomite

The rock consists largely of granular carbonate [0.05-0.3mm] with some quartz [0.1-0.3mm], albite and some kaolinite, stained with iron oxides. It is in places cut with quartz veins and some chlorite is associated with a fracture cleavage. There are a few grains of quartz in the matrix as well. It was not possible to determine the origin of the rock from the thin section.

The very low Si content, together with high Ca and Mg in a dolomitic ratio are not inconsistent with an impure carbonate facies or marl. In spite of a significant increase in calcium there has not, however, been a corresponding increase in strontium. Its Ti/Zr ratio is basaltic and it shows no anomalous behaviour in any trace element from the norm of basaltic rocks in this drillhole. It is suspected that it was a basaltic rock that has undergone intense early carbonation, possibly along a fracture.

67.7: Amphibolite saprolite

Two strongly foliated to schistose phases are apparent. (1) is pale greenish-yellow, with a sugary texture. Fibrous clay pseudomorphs after decussate textured tremolite lie in the foliation planes from which they have been etched. (2) is dark green and chloritic, with iron oxides which penetrate and stain a fracture cleavage.

Mineralogy:
Microscope: quartz, mica, kaolinite, biotite, talc, goethite, hematite
Diffractometer: quartz, kaolinite, albite, smectite, muscovite (tr), talc (tr)

The rock consists of alternating mafic and felsic layers. The felsic layers consists of granular to shard-like quartz [0.05-0.2mm] and untwinned albite which forms lenses and patches. The mafic layers consist of bladed tremolite relics, now completely altered to biotite, smectite and other phyllosilicates. The mafic layers are picked out by dusty kaolinite (oblique light). The strongly laminated nature of this rock suggests a mafic tuff. Some of the quartz grains are slightly coarser [0.2mm] and rounded. The rock is quite foliated and cut through with foliae of extensive alteration, consisting largely of clay minerals (kaolinite) and secondary iron oxides (goethite and hematite). Biotite seems to be associated with this. The clay alteration seems to represent weathering penetrating a cleavage.

The Ti/Zr ratio is basaltic and so are the Si, Al, Mn, Zr, Ce, Cu, Pb, Cr, Ni, V, La and Fe contents. Significant depletion of Co, Mg and Ca has occurred but not in Ba. Strontium, Cr and Rb seem to be slightly enriched.

60.5: Argillaceous saprolite

Pale yellowish-green clays make up most of this rock which still retains a fracture cleavage but no remnant of a sugary texture. Pale yellow fibrous minerals are concentrated on the cleavage planes where etching is evident. Very minor pale yellow iron oxide staining has occurred along some cleavage planes.

Mineralogy:
Microscope: quartz, kaolinite, muscovite, talc, goethite, hematite, chlorite
Diffractometer: quartz, kaolinite, muscovite (tr), amphibole (tr), talc (tr), goethite (tr)

The rock consists of two lensoid phases. (1) Lenses of shard-like quartz, which are quite porous, contain abundant voids. These are cut by small veinlets of chlorite. The quartz is in places stained, largely by powdery goethite. (2) A very fine grained, matted intimate mixture of kaolinite and muscovite, which results in a mixed mineral with a yellowish birefringence, intermediate between the two end members. This has been stained to a varying extent by secondary iron oxides, mainly goethite. The quartz and clay mineral layers are generally quite distinct but in places are mixed, suggesting a mixed argillaceous and psammitic sediment.

This rock has a Ti/Zr ratio and contents of Cr, V, Cu, Zn, Ce, Y, W, Nb and Rb typical of the associated basaltic rocks. It is enriched in Si, Al, Ga, Ti, Zr, Se, Pb, As and Sn and depleted in Fe, Ca, Mg, Sr, Mn, P, Co, Ni and La. It seems probable that it was an argillite derived locally from basaltic detritus.

59.4: Mafic saprolite

This fine- and even-grained yellow rock is slightly schistose with fibrous amphibole pseudomorphs lying in the schistosity. Exposed surfaces have been etched. Patches of white clay cut across the schistosity and clearly do not pseudomorph any minerals related to the metamorphic history of this rock but rather relate to a later weathering and retexturing event.

Mineralogy:
Microscope: quartz, muscovite, kaolinite, goethite
Diffractometer: quartz, goethite, kaolinite, muscovite (tr), talc (tr), goethite (tr),amphibole (tr)

This rock has two principal components, granular to shard-like quartz, mixed with kaolinite and stained with secondary iron oxides and mixed mica-kaolinite. The kaolinite is largely fragmented into rounded patches (Figure 2 h), surrounded by very fine grained kaolinite. The iron oxide is largely powdery goethite, which occurs with the quartz. The goethite seems to occur in patches not related to either of the two major components. It could have formed around now completely degraded primary iron oxides and sulphides.

The chemistry is largely basaltic and this is typified by the Ti/Zr ratio and the contents of Si, Al, Ga, Ti, Mn, P, Zr, Rb, Cr, Ni, V, Co, La, Ce, Y and Nb. There has been significant depletion of Ca, Sr, Mg and Mn and enrichment of Fe, Cu, Pb and As.

57.6: Mafic saprolite

This very pale yellowish-grey rock is weakly foliated and highly friable. Though it still retains a pepper-and-salt texture, all its component minerals are secondary. It is cut by clay-filled fractures, some of which are intensely stained with iron oxides. Exposed surfaces are etched.

Mineralogy:
Microscope: quartz, kaolinite, muscovite, goethite
Diffractometer: quartz, kaolinite, smectite, talc (tr), goethite (tr), muscovite (tr)

The rock consists largely of an intimately mixed kaolinite and muscovite phase now extensively stained by the slide-making epoxy resin (colours blue, red, green and mauve). Kaolinite is very fine grained and in places is dusted with secondary kaolinite emating from cracks and veins. The rock is flecked with very small granules of goethite. The quartz forms patches which are internally granulated and in places even shard-like. They appear to be related to a fracture cleavage. The whole rock is cut by numerous cracks, now filled with epoxy resin.

The composition is basaltic for most elements however Ca, Mg, Sr, Mn and P are depleted and Al, Ga, Ti, Zn, Y and Rb are enriched.

53.5: Ferruginous mafic saprolite

This is a schistose, yellow-brown, very fine-grained rock with a slight micaceous sheen. A few sugary quartz layers, presumably representing quartz veins, lie in the foliation and are penetrated by intense ferruginisation. It appears that these porous zones have acted as routes for weathering fluid access and iron cementation.

Mineralogy:
Microscope: quartz, muscovite, biotite, chlorite, kaolinite, goethite, hematite
Diffractometer: quartz, muscovite, kaolinite, goethite, chlorite(tr), feldspar(tr), smectite(tr)

The rock consists of finely alternating layers of quartz and phyllosilicates. These phases are in places quite mixed and only the proportions of the key minerals change. The quartz is granular [0.05-0.1] but in places, where it is surrounded by goethite, it becomes shard-like. The phyllosilicate phase consists of flakes of yellowish-brown, iron-stained, mixed biotite, muscovite and kaolinite [from finely crystalline to 0.2mm]. Some of the phyllosilicate layers form a cleavage. The iron staining is very pervasive and powdery.

The composition is basaltic in terms of most elements. Ca, Mg, Sr and Y have been depleted and in turn Fe, W, Rb and As have been enriched.

51.25: Ferruginised sediment saprolite

This is a dark brown, ferruginous rock which contains patches of fine-grained muscovite and sugary quartz, set in patches of cinder-like hematite and earthy brown goethite. The quartz is generally coated thinly with iron oxides. There are no iron oxide pseudomorphs after sulphide.

Mineralogy:
Microscope: quartz, muscovite, goethite, hematite
Diffractometer: quartz, goethite, muscovite , cryptomelane, (tr), chlorite (tr), kaolinite (tr), talc (tr)

The rock consists largely of closely packed, globular quartz grains which have a varied grain size [0.05-0.2mm]. Part of the matrix, which is largely void, has been invaded by secondary iron and manganese oxides, mainly goethite and cryptomelane. Where this has occurred, the quartz grains are shard-like. Where iron is absent, muscovite occupies a few cracks and veins. Where Fe and Mn is present, these oxides fill the spaces between the quartz and contain relict phyllosilicates. The rounded quartz grains suggest a sedimentary origin.

Though the Zr and Ti contents of this rock are low, the Ti/Zr ratio is basaltic. As would be expected Si is high as well as Mn which is very high and is a major constituent. It also contains anomalous Sr, As and Zn. It is poor in W, Cu , Ce, Co, Cr, Nb, Ga, Al, Y, Rb, Ca and Mg.

41.9: Phyllitic saprolite

This is a slightly mottled, pale, yellowish-brown, friable rock with very few small [1-2 mm] nodules of iron oxides and a weak foliation. Widely dispersed mica gives it a very slight sheen. The mottling is caused by patches of white kaolinite and pale yellow sericite.

Mineralogy:
Microscope: quartz, muscovite, kaolinite, goethite
Diffractometer: quartz, muscovite, kaolinite, talc (tr)

The rock consists of a mat of very fine-grained, low birefringent kaolinite and muscovite. There are also some intimately mixed kaolinite-muscovite phases showing white birefringence as well as slightly coarser flakes of a separate muscovite phase. This mat is in places broken into patches which are separated by powdery goethite with possibly some secondary kaolinite. The kaolinite-muscovite mat is set with brown intensively veined goethite pseudomorphs after garnet [1-3mm]. In detail the garnet structure is picked out by very narrow goethite veins following fractures in the garnet but the garnet itself has been completely dissolved. There are a few quartz remnants as inclusions within the garnet. This rock appears to have been a phyllite.

The argillaceous nature of this rock is reflected in its high Al and Ga contents. Thought Ti and Zr are also high, the Ti/Zr ratio is basaltic, suggesting derivation from basaltic detritus. The W, Ce, La, Fe, Si, V and Ni contents are also basaltic. The Cu and Cr levels are high, suggesting that there may have been some ultramafic detrital input which would not be detected by the Ti/Zr ratio (Hallberg, 1984). Enriched elements are Pb, As, Rb and Nb, the first two associated with mineralisation. Depleted elements are Zn, Co, Mn, Y, Ca, Mg, Sr and P.

36.1: Colloform goethite-hematite rock

This is a dark, vesicular rock, composed of cinderlike, dark grey hematite and patches of earthy goethite. The interiors of the vesicles are lined with botryoidal iron oxides with a finely crystalline surface.

Mineralogy:

Microscope: goethite, hematite, cryptomelane

Diffractometer: goethite, chlorite, cryptomelane, hematite (tr), quartz (tr), muscovite (tr), talc (tr)

This rock consists predominantly of vesicular to spongy Fe and Mn oxides. Goethite is the earliest phase and there are at least two opaque manganese phases (cryptomelane and possibly lithiophorite) interleaved with two further translucent deep brown goethite phases, the earlier with shrinkage cracks and the later phase with a fibrous comb texture. These all form an overall colloform structure (Figure 2 f). The voids are lined with poorly crystalline hematite as well as with goethite. Iron replacement in this rock has been very intense and the original rock texture is now obscured. The colloform structures were investigated by microprobe (see mineralogy section).

Ferruginisation of the rock is reflected in a high Fe, Mn and Co content. The rock is also enriched in Cu, Zn, Ce, Ba, La, As and Ni. The Si content is low as is W, Sr, Ga, Al, Rb, Nb, Ca and Mg. The Ti/Zr ratio, though basaltic, is slightly high.

34.2: Phyllitic saprolite

This is a very pale yellowish-brown friable rock which retains a weak foliation. Patches of white kaolinite form a mottled texture with yellowish sericite. Very small tabular specks of a fresh black vitreous mineral, apparently tourmaline, are scattered in the foliation.

Mineralogy:

Microscope: quartz, muscovite, kaolinite, goethite

Diffractometer: quartz, kaolinite, muscovite (tr), talc (tr)

This rock consists mainly of very fine-grained kaolinite, which occurs mainly as flakes, and a mixed kaolinite-muscovite phase. This groundmass is patchily stained with iron oxides. Within the kaolinite-muscovite areas are larger flakes of muscovite [0.4mm] as well as isolated quartz grains and lensoid quartz aggregates [1mm], marking a silicified cleavage.

The argillaceous nature of this rock is reflected it its high Al and Ga contents. Though it also contains high

Ti and Zr, the Ti/Zr ratio is low, more typical of an andesite than a basalt. The rock is rich in W, Cr, Nb and As and depleted in Zn, V, Co, Mn, Rb, Fe, P, Ca, Mg and Sr. The rock was a phyllite.

29.6: Phyllitic saprolite

This is a compact, dark-brown rock consisting of an intimate mixture of iron oxides and phyllosilicates. Some parts are rich in kaolinite and sericite. There is a weak foliation which has been largely cemented by iron oxides.

Mineralogy:
Microscope: muscovite, kaolinite, goethite , Mn oxides
Diffractometer: muscovite, kaolinite, goethite, cryptomelane

The rock consists of fine flakes of kaolinite, set with flakes of a mixed, interleaved kaolinite-muscovite phase. The groundmass is set with garnet pseudomorphs [0.5mm]. No garnet remains. The fractures in the garnet pseudomorphs have been filled with goethite and the garnet between the fractures has been leached away (Figure 2 c, d). Patches of the groundmass has been stained and invaded by goethite. In many instances, where this is intense, the goethite has pseudomorphed the phyllosilicates. Where it is less intense, it has divided the kaolinitic groundmass into small domains and has intensively stained the edges of these phyllosilicate domains. The rock also shows large areas with manganese oxide, possibly cryptomelane or manganite. The rock appears to have been a phyllite that has undergone low-grade metamorphism.

The argillaceous nature of this rock is reflected in its high Al and Ga content. It is also rich in Cu, W, V, La, Co, Ti, Mn (major component), Y, Rb, As, Cr and Ni and very rich in Ce and Ba. It is mildly depleted in Si, Pb, Ca and Mg. The Ti/Zr ratio is high.

11.0: Sediment saprolite

The rock is a pale yellow-brown mass of kaolinite and sericite, with a few patches of yellowish cellular goethite and quartz. Late ferruginisation has destroyed almost all the foliation.

Mineralogy:
Microscope: quartz, goethite, carbonate, kaolinite, muscovite
Diffractometer: quartz, goethite, calcite, kaolinite, talc (tr), muscovite (tr)

Goethite is dominant in this rock, in which it forms a spongy mass. Included in the goethite and largely leached from it are remnants of quartz, opaline silica and kaolinite. The texture of some of the kaolinite is similar to those previously described. In places the goethite is massive and, where vesicles occur, their walls show mixed, fibrous, colloform goethite structures [thickness 0.1mm](Figure 2 e). Where the goethite is relatively massive, very fine scale remnants of phyllosilicates are present (Figure 2 g). Here the phyllosilicates form vermiculite-like expanded books and stacks. An SEM EDAX examination of this material showed dominant Si and Al, with minor K and Fe and traces of Ti and V. If the Fe and Ti are from the adjoining goethite, which seems likely in view of the small width of the phyllosilicate target (3μm), then the phyllosilicate is muscovite, rather than biotite. It is possible that some of the voids may have contained quartz, which would indicate a sandy layer within the argillite. Very little if any clastic materials remain. The rock seems to be formed of more and less banded layers of crystallized schist, containing sand and clay. Other layers of foliated schist consist mostly of clay minerals.

Ferruginisation is reflected in a very high Fe content together with complementary loss in Al, Ga and Si. There is also high Cu, Zn, P, V, Y, W, Pb and As, the last three probably reflect mineralisation. Though the Ti/Zr ratio is basaltic, it is slightly low; depleted elements are Ce, Co, Ti, Nb, Zr, Mn, Sr, Ga, Al, Si, Ca and Mg.

9.0: Ferruginised phyllitic saprolite

The rock is yellow to pinkish brown, consists of patches of sericite and kaolinite and has preserved some of its foliation as bands of stained phyllosilicates. It is cut by numerous veinlets filled with crystalline calcite and by patches of cellular yellow goethite.

Mineralogy:
Microscope: quartz, muscovite, calcite, kaolinite, goethite, hematite
Diffractometer: quartz, muscovite, calcite, kaolinite, smectite, goethite

The rock is very strongly foliated and consists largely of kaolinite with powdery goethite and some carbonate, sericite and a lesser amount of quartz and specks of hematite. The original rock fabric appears to have been phyllitic. Weathering has penetrated the foliation and deposited goethite, which now stains the kaolinite and forms a powdery mass. The whole fabric is cut both parallel to the foliation and to a lesser extent across the foliation by carbonate veinlets. A few shard-like quartz grains occur, and these seem closely associated with the vein material. Where it is visible, the original kaolinitic mat appears to contain some muscovite.

The argillaceous nature of the rock is reflected in slightly elevated Al and Ga. Iron is not as high as would be expected from the extent of ferruginisation. The rock has elevated contents of V, Cr, Ni, Ba, Ca, Nb, W and Zr. The Ti/Zr ratio is low with an andesitic affinity. Depleted elements are Si, Mn, P, Cu, Zn, Co, Ce and La.

7.4: Ferruginised, carbonate cemented, sedimentary saprolite breccia

This consists of fragments of dark brown cellular goethite and pale yellowish-brown phyllosilicate rock (sericite and kaolinite) set in a matrix of porous carbonate. Some carbonate-rich parts have a nodular appearance.

Mineralogy:

Microscope: quartz, muscovite, carbonate, goethite, hematite

Diffractometer: quartz, muscovite, calcite, dolomite, kaolinite, goethite

The rock is a polymictic breccia of iron oxides, lithofragments and some quartz fragments set in carbonate. The quartz fragments are generally small and angular. The lithofragments consist of a mass of goethite, with some muscovite, extensively stained by powdery goethite. Some of these contain angular quartz fragments and a few show evidence of corrosion. It is possible that some of these fragments may be primary and may indicate a tuffaceous component. Other clastic fragments are very ferruginious and consist of goethite enclosing phyllosilicate relics which appear to be biotite (SEM) and powdery goethite set with shard-like quartz fragments. Some hematite shows dehydration cracks, suggesting alteration of goethite to hematite. Some of the hematite shows pseudomorphs after magnetite (martite). The surrounding carbonate material is generally fine-grained and contains numerous irregular vesicles. The carbonate is slightly stained but the walls of the voids and the interiors of a few carbonate veins are lined with a clearer, slightly coarser grained carbonate.

The rock is ferruginous and carbonate-bearing, accounting for high Fe and Ca. The Ti/Zr ratio is basaltic but slightly low. Depleted elements are Al, Ga, Mn, Si, Ti, P, Zr, and Ce. Mineralisation in this rock is clearly shown by anomalously high Pb, As and W.

1.0: Ferruginous calcrete breccia

It consist of rounded to angular fragments of black to brown partly cellular and partly massive goethite and khaki brown iron-stained phyllosilicate rock, with no remnant foliation, set in and supported by a nodular calcite cement. A close examination of the elipsoidal nodules of the cement (SEM), show worm-like growths partly fused with their surfaces, which is also calcite.

Mineralogy:

Microscope: quartz, carbonate, clays, goethite, hematite, muscovite

Diffractometer: quartz, calcite, goethite, kaolinite, muscovite, feldspar (tr), talc (tr)

The clasts [3-10mm] are very heterogeneous. They vary from fragments consisting of fine-grained goethite with minor quartz to fragments of shard-like quartz and lithorelics, set in a goethite-carbonate matrix, to spongy goethite with included carbonate fragments. Parts of the matrix contains oval structures of carbonate and clay. Some are almost oolitic and have formed as concretions around quartz grains, patches of goethite or carbonate. The matrix in which they are set is a slightly coarser-grained carbonate which has largely been leached out. The goethite in the clasts contains relics (SEM) of sericitic material. Less well-crystallized goethite has been dehydrated to hematite.

The high carbonate content of the rock is reflected in a high Ca content without elevated Mg and Sr contents, indicating calcite. The Ti/Zr ratio is andesitic. Depleted elements are Al, Ga, Mn, Si, Ti, Mg, P, V, Zr, Cu, W, Ce and Co. Mineralisation is indicated by elevated Pb and to a lesser extent As and possibly Ba.

APPENDIX 2

Tabulated XRD Mineralogy

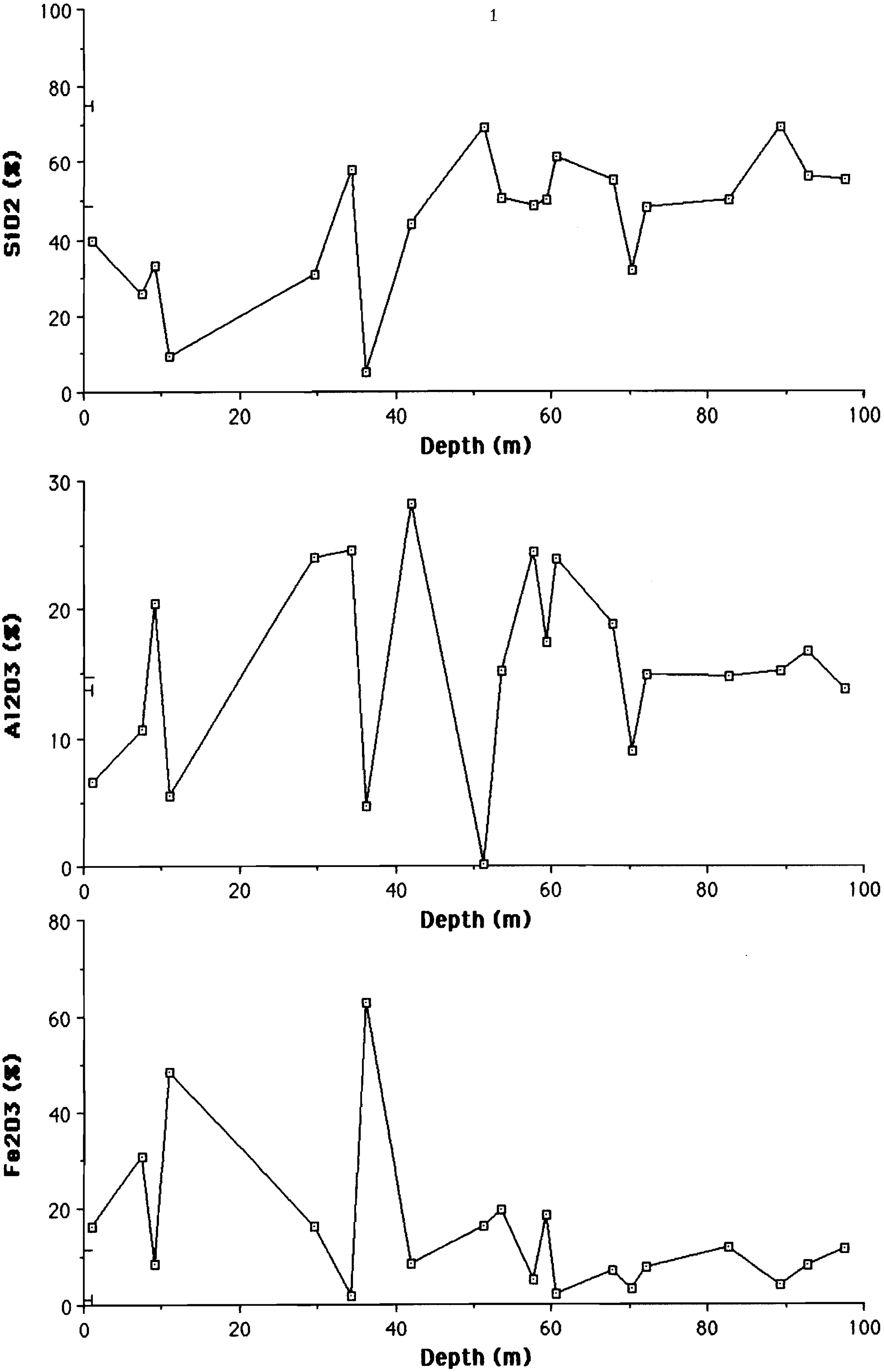
MINERALOGY OF DDH BCD1

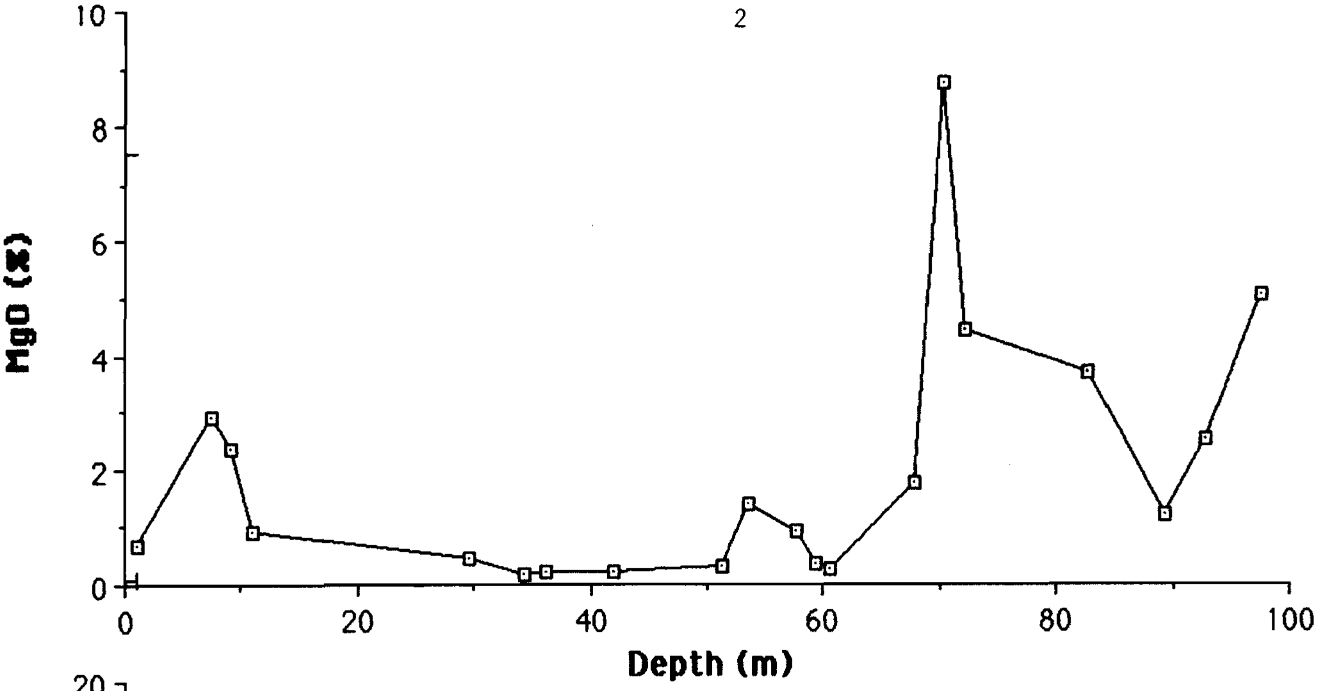
			1.818 Å	4.18 Å	7.15 Å	10.0 Å	14.0 Å	15.0 Å	9.4 Å	8.4 Å	4.04 Å	3.85 Å
DEPTH	MAJOR MINERAL	TRACE MINERALS	Quartz	Goeth	Kaolin	Muscov	Chlor	Smect	Talc	Tremol	Felds	Calcite
1	cc, goe, q, kao, mus	talc, fspar	16	113	35	23	0	0	5	0	0	58
7.4	kao, mus, cc, goe, q, dol		33	177	220	82	0	0	0	0	0	13
9	mus, cc, kao, goe, q, sm		16	62	150	250	0	18	0	0	0	42
11	cc, goe, kao, q	mus, talc	0	200	88	22	0	0	5	0	0	18
29.6	kao, mus, goe		0	28	300	270	0	0	0	0	0	0
34.2	kao,. q,	mus, talc	158	212	400	7	0	0	5	0	0	0
36.1	goe, chlor	talc, mus, hem, q	0	160	0	12	0	0	21	0	0	0
41.9	kao, q, mica	talc	55	177	350	78	0	0	8	0	0	0
51.25	q, goe,	talc, mus, chlor, kao	168	70	6	7	10	0	25	0	0	0
53.5	kao, mus, goe, q	feld, chlor, sm	83	125	175	80	20	20	0	2	2	0
57.6	sm, kao, q, micro	goe, mus, talc	47	2	350	10	0	150	7	0	2	0
59.4	kao, goe, q, mic	mus, talc	110	150	320	7	0	0	5	0	35	0
60.5	kao, q,	mus, talc, amph, goe	182	150	400	16	0	0	5	5	0	0
67.7	sm, alb, kao, q,	mus, talc	53	0	85	7	0	170	5	2	130	0
70.2	dol, alb, q, kao		20	0	58	0	0	190	5	0	127	300
72.2	alb, sm, chlor, dol, trem, q		10	0	250	5	110	150	5	50	175	167
82.7	trem, alb, q, sm, kao, sid		58	0	65	0	0	40	5	230	65	0
89.2	q, kao, mus, alb, chlor, sm	cc	185	0	140	195	37	38	0	0	10	0
92.8	alb, smec, kaol, trem, q, chlor		80	0	113	0	20	110	5	120	133	0
97.45	trem, alb, q, chlor	talc, mus, sm	44	0	55	8	50	10	23	300	85	0

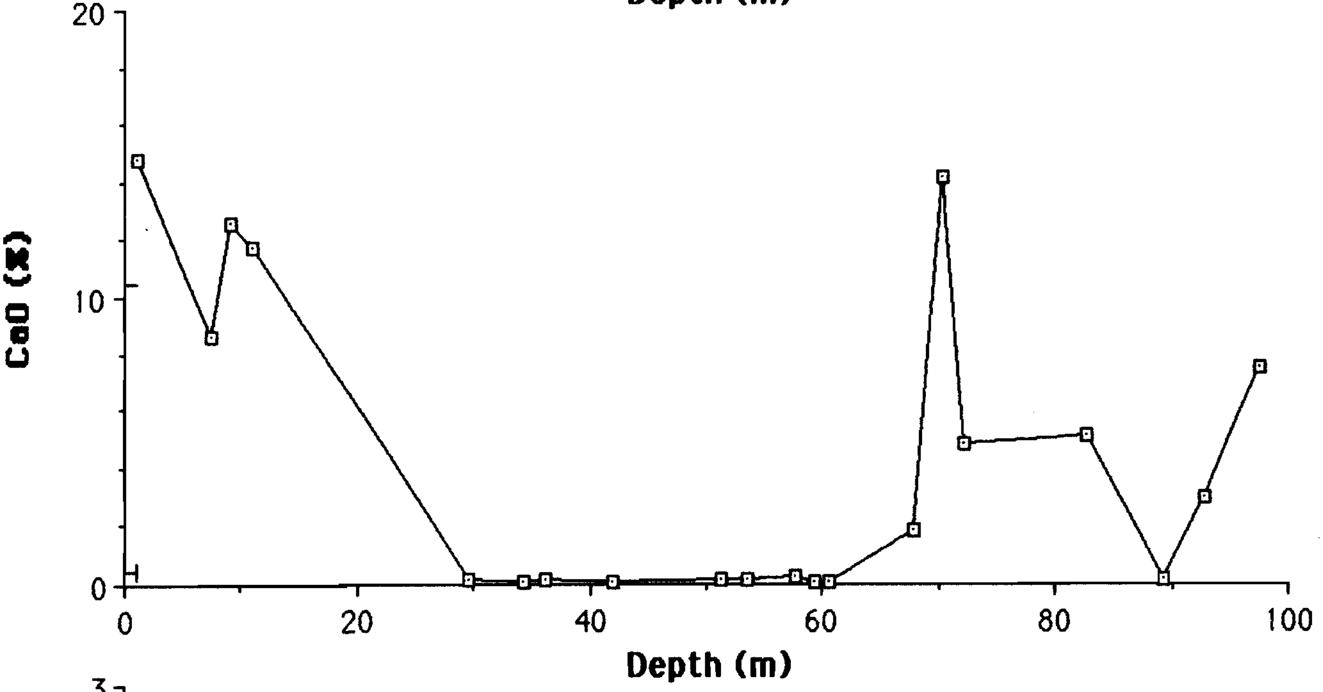
APPENDIX 3

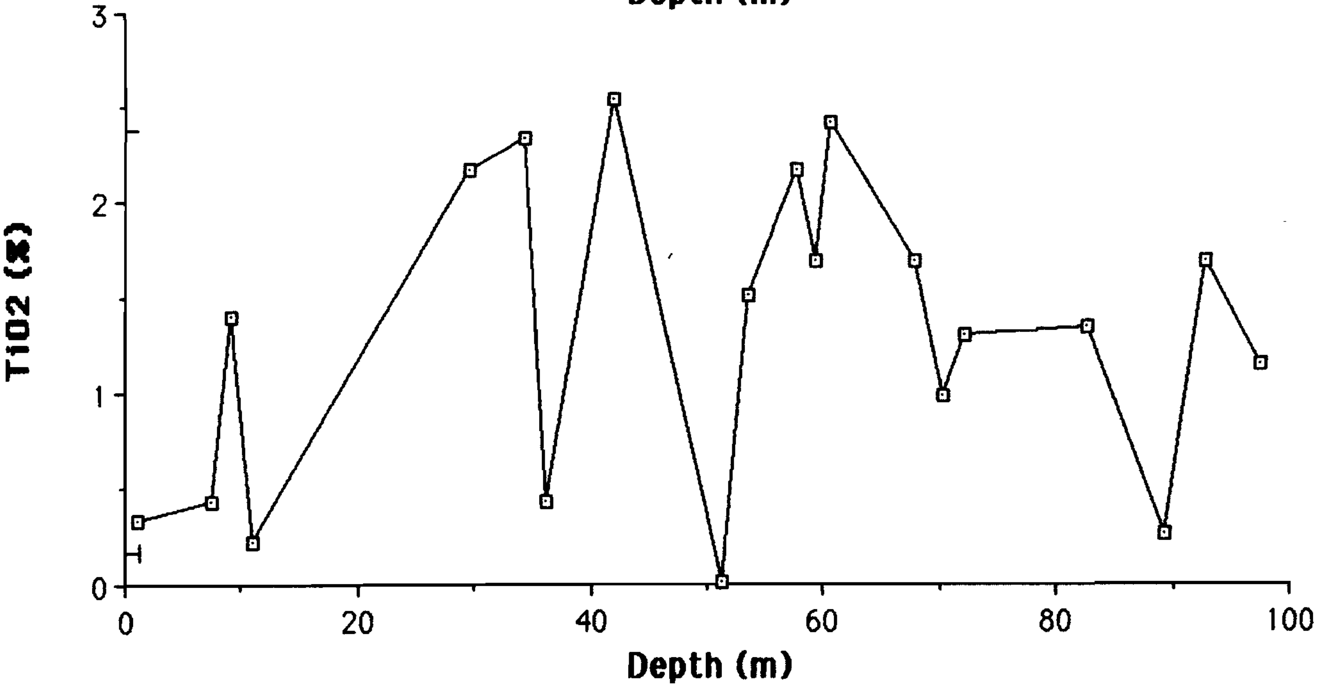
Graphed Geochemistry and Mineralogy

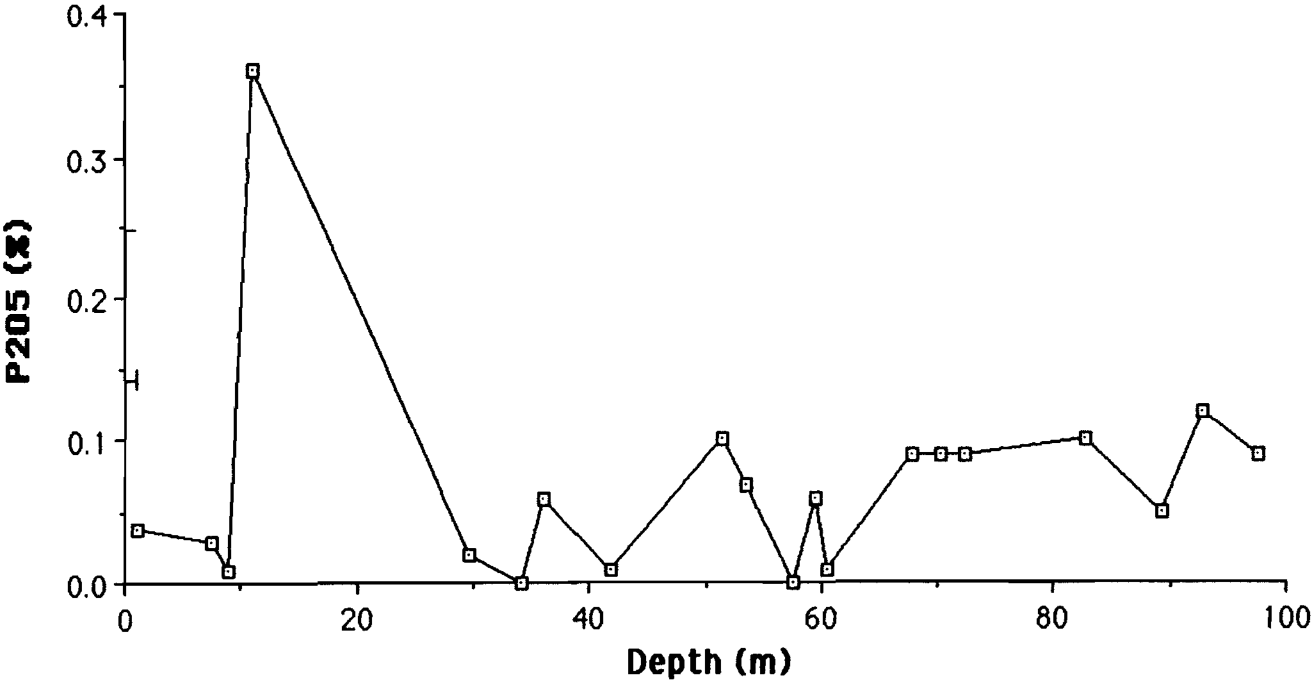
- Average basalt
⊣ Average granite

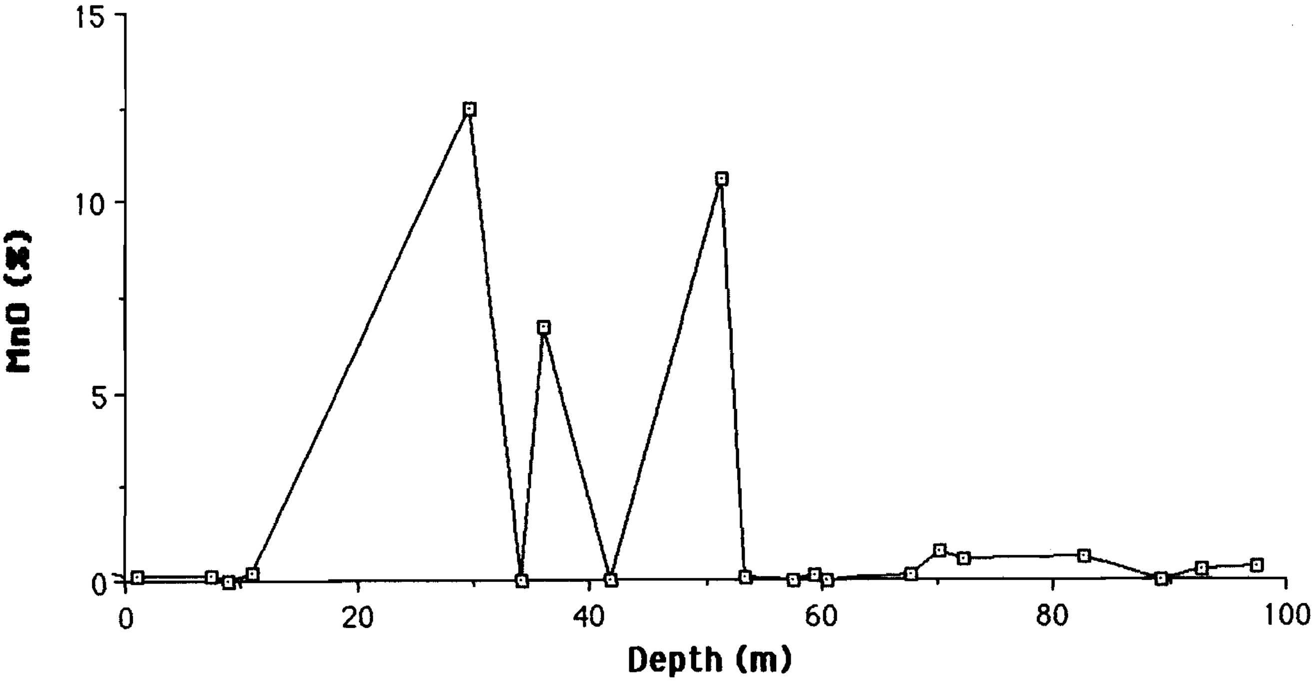

100
80
60
40
20
0
SiO2 (%)
0
20
40
60
80
100
Depth (m)
30
20
10
0
Al2O3 (%)
0
20
40
60
80
100
Depth (m)
80
60
40
20
0
Fe2O3 (%)
0
20
40
60
80
100
Depth (m)

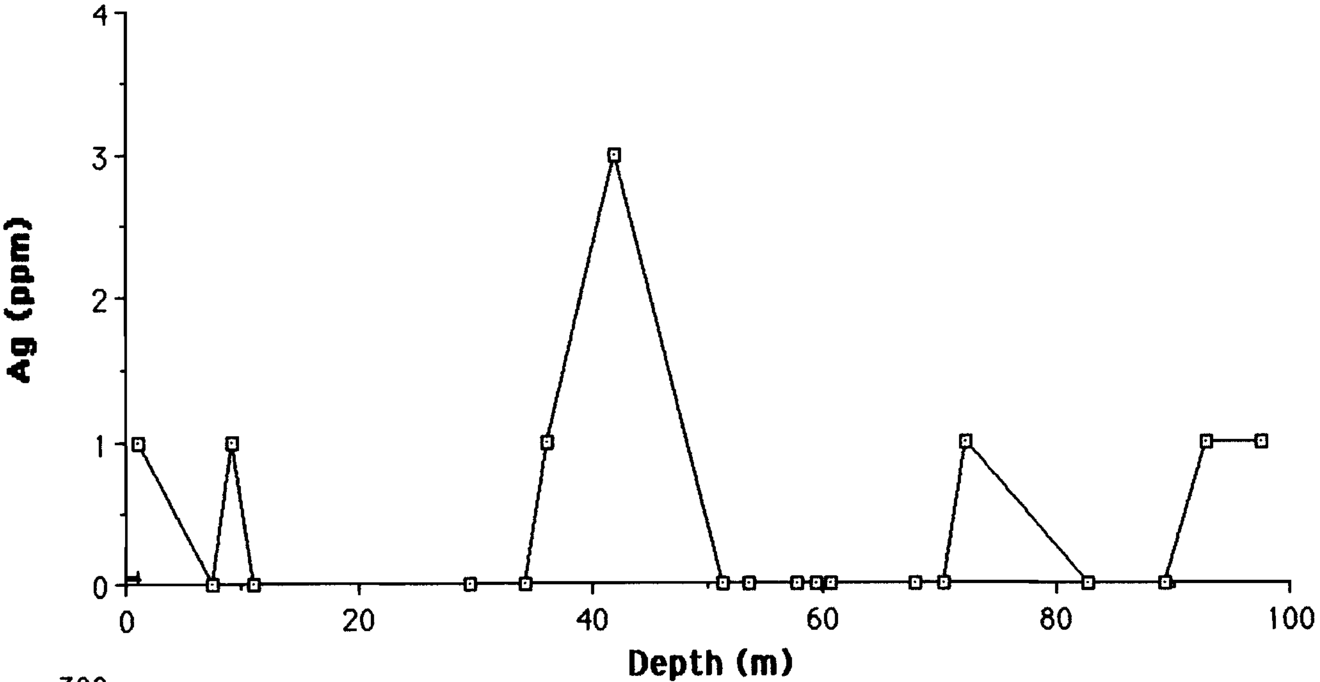

10
8
6
4
2
0
MgO (%)
0
20
40
60
80
100
Depth (m)


20
10
0
CaO (%)
0
20
40
60
80
100
Depth (m)


3
2
1
0
TiO2 (%)
0
20
40
60
80
100
Depth (m)


0.4
0.3
0.2
0.1
0.0
P205 (%)
0
20
40
60
80
100
Depth (m)


15
10
5
0
MnO (%)
0
20
40
60
80
100
Depth (m)


Ag (ppm)
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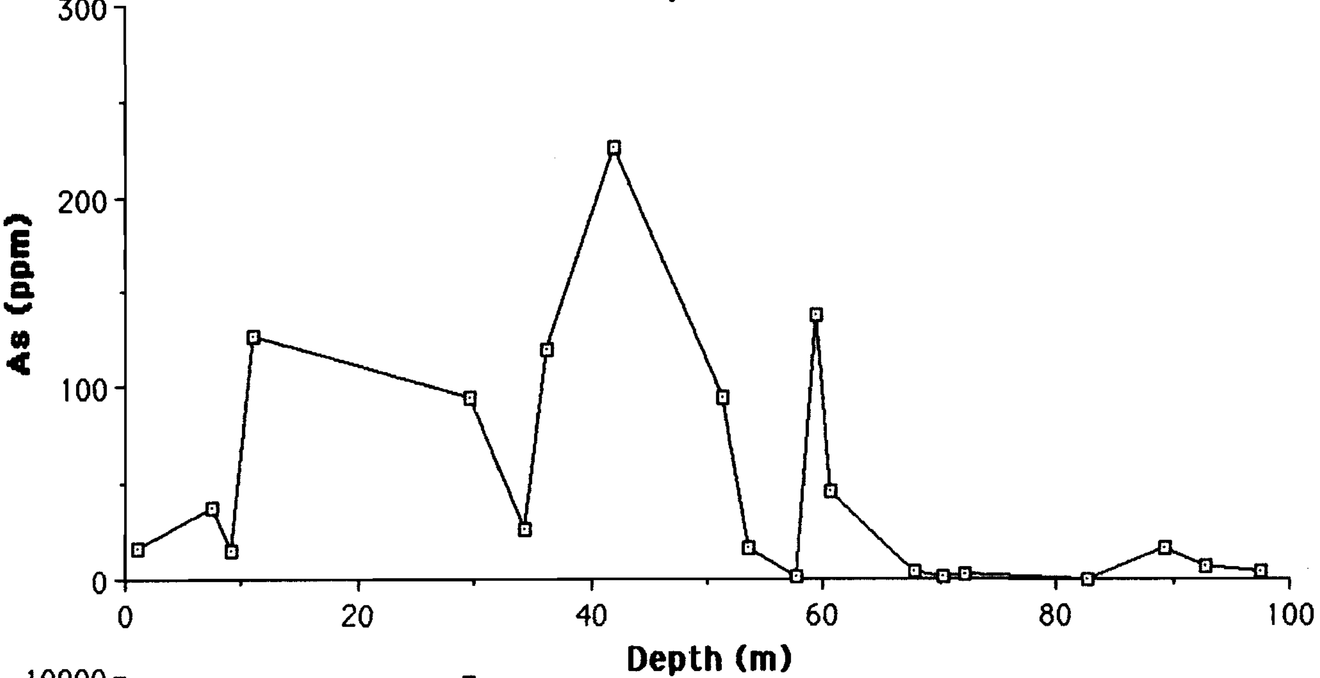
1
2
3
4
0
20
40
60
80
100
Depth (m)


As (ppm)
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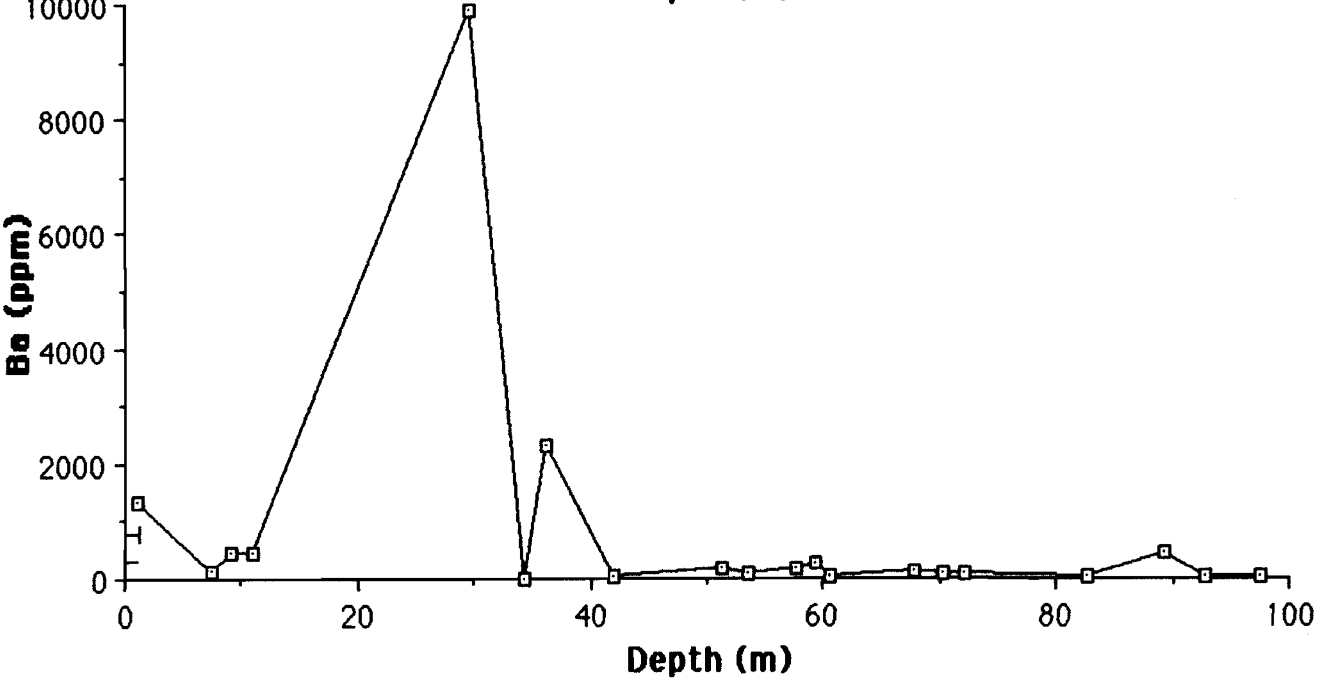
100
200
300
0
20
40
60
80
100
Depth (m)


Ba (ppm)
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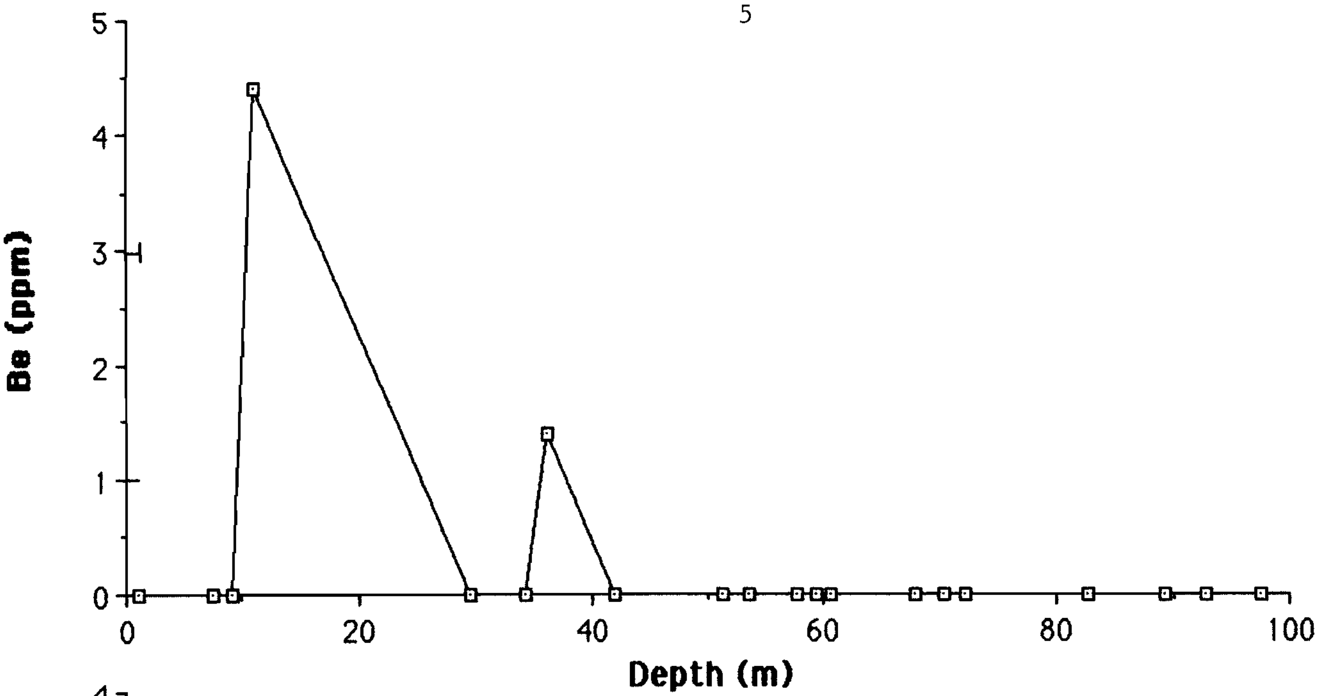
2000
4000
6000
8000
10000
0
20
40
60
80
100
Depth (m)


Be (ppm)
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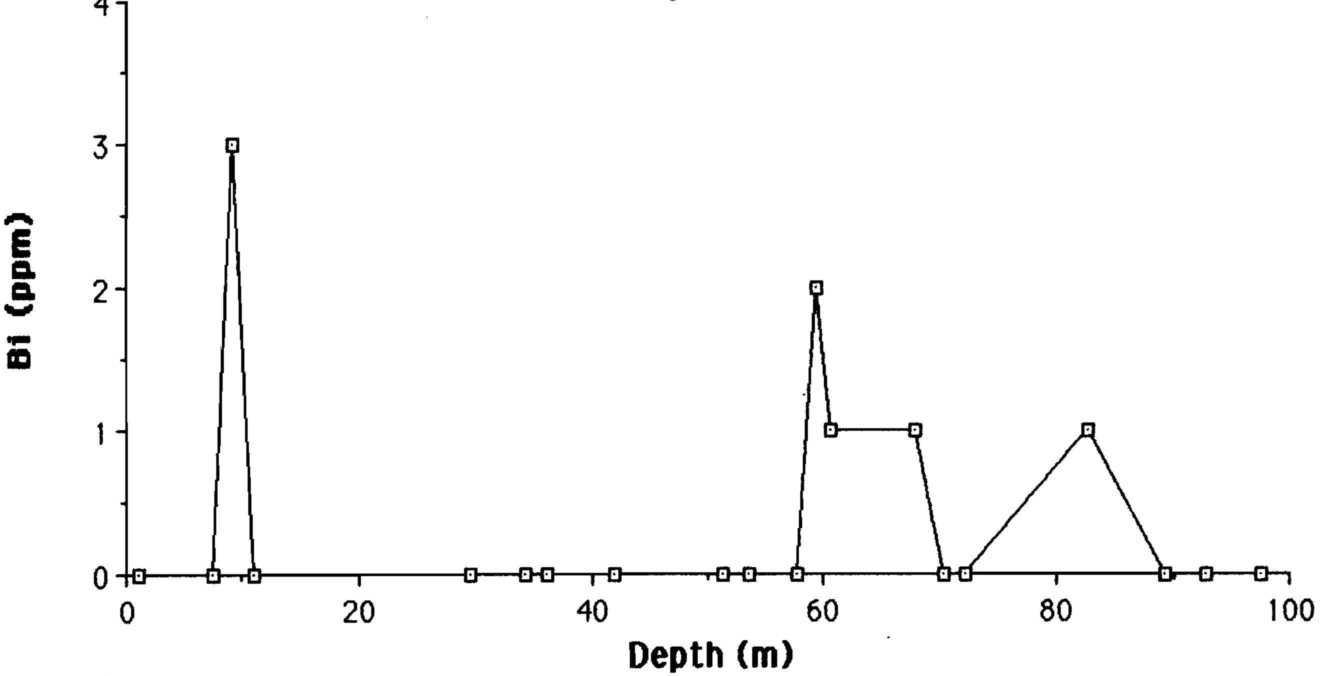
2
3
4
5
0
20
40
60
80
100
Depth (m)


Bi (ppm)
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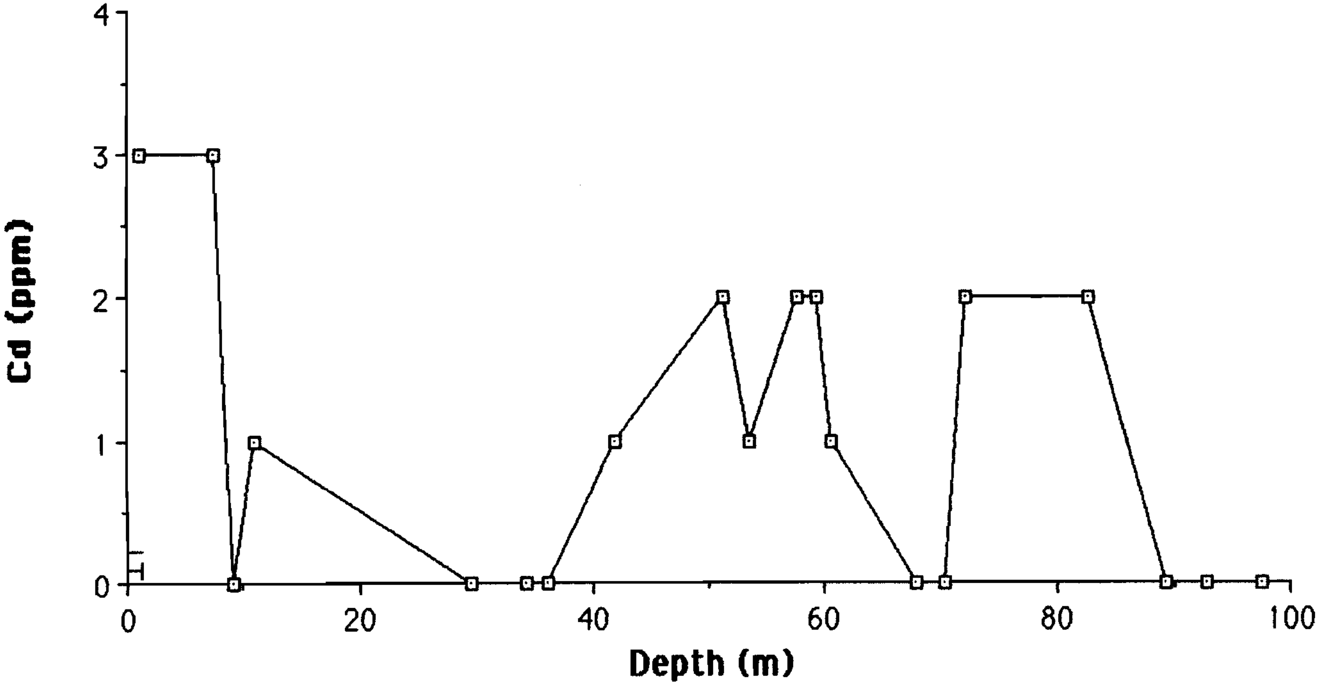
1
2
3
4
0
20
40
60
80
100
Depth (m)


Cd (ppm)
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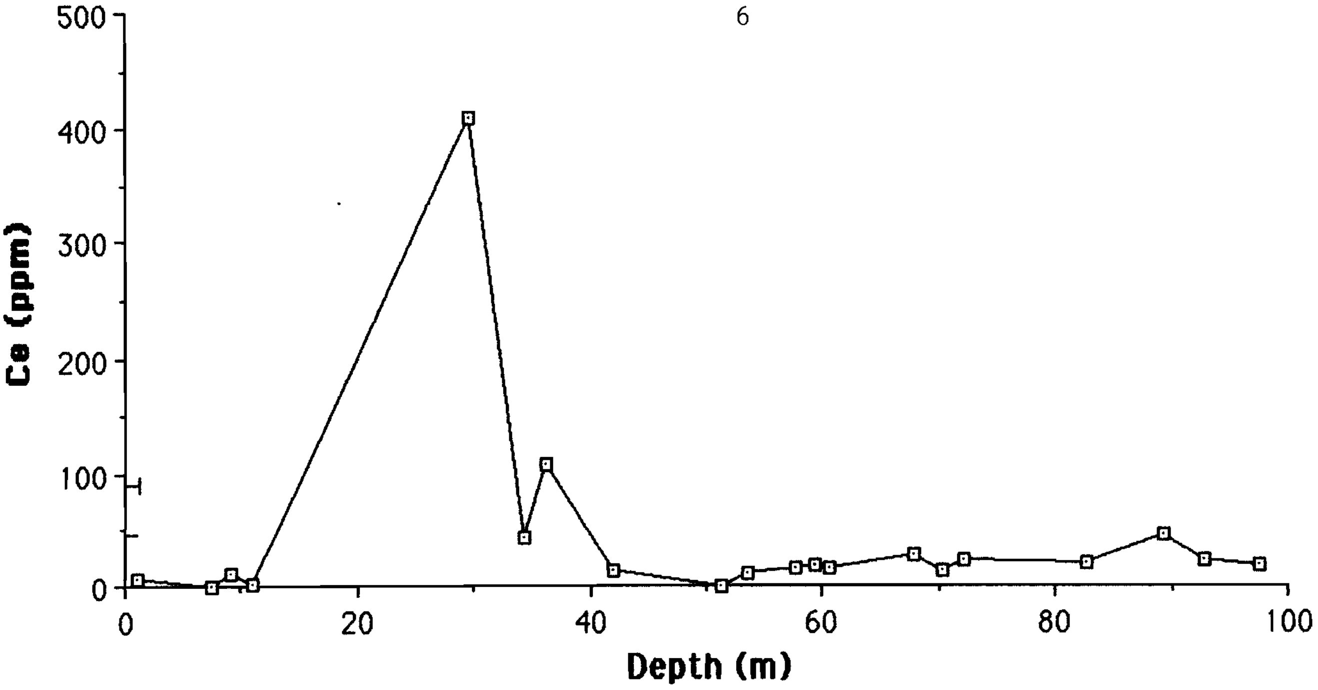
1
2
3
4
0
20
40
60
80
100
Depth (m)


Ce (ppm)
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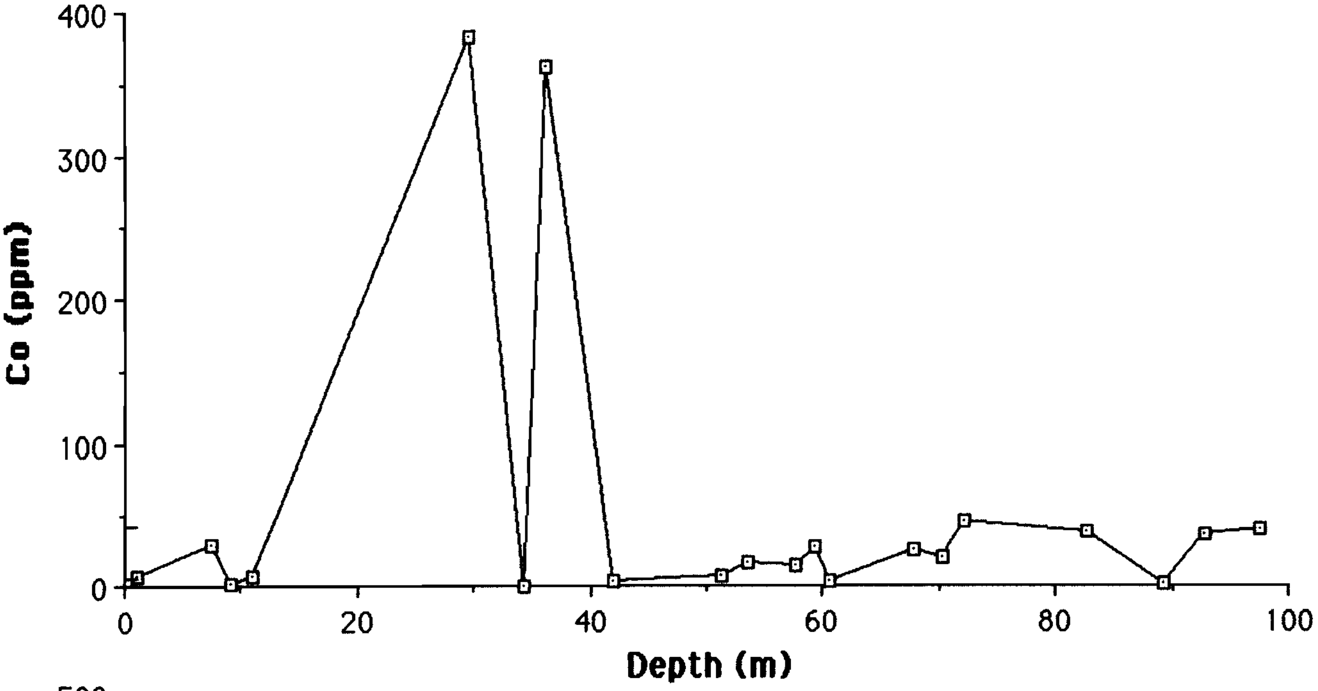
400
300
200
100
0
0
20
40
60
80
100
Depth (m)


Co (ppm)
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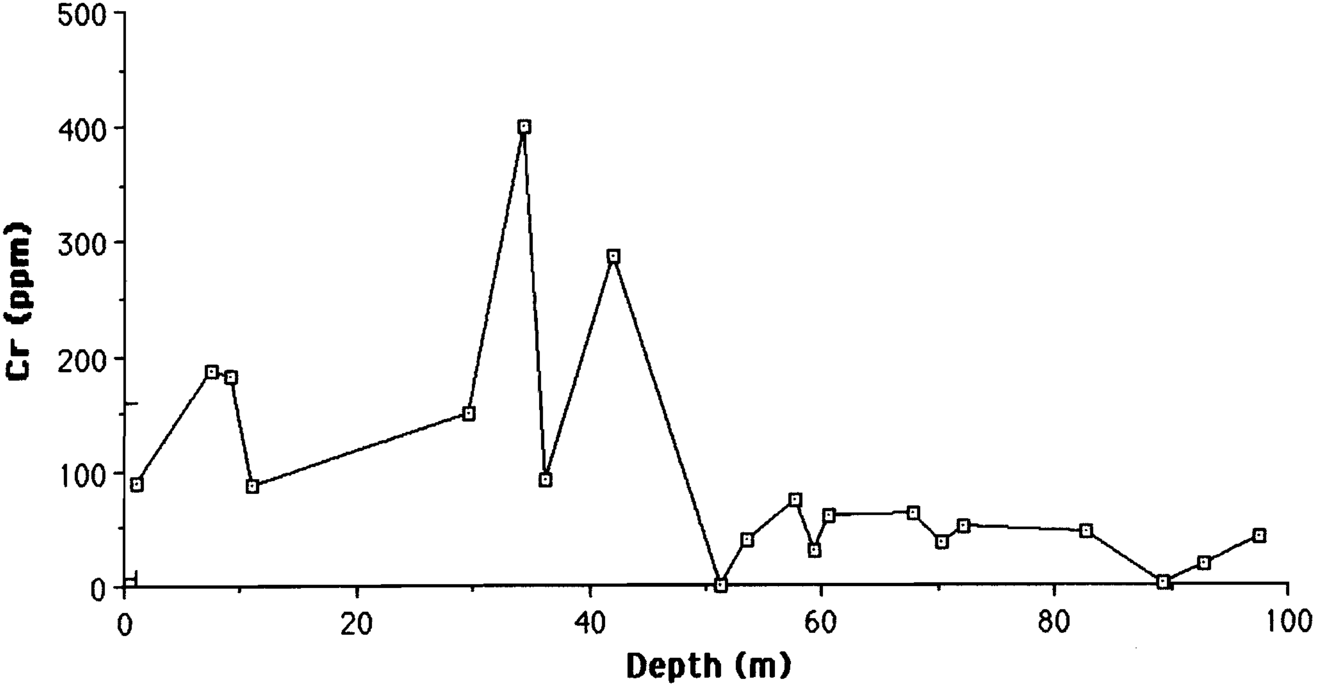
300
200
100
0
0
20
40
60
80
100
Depth (m)


Cr (ppm)
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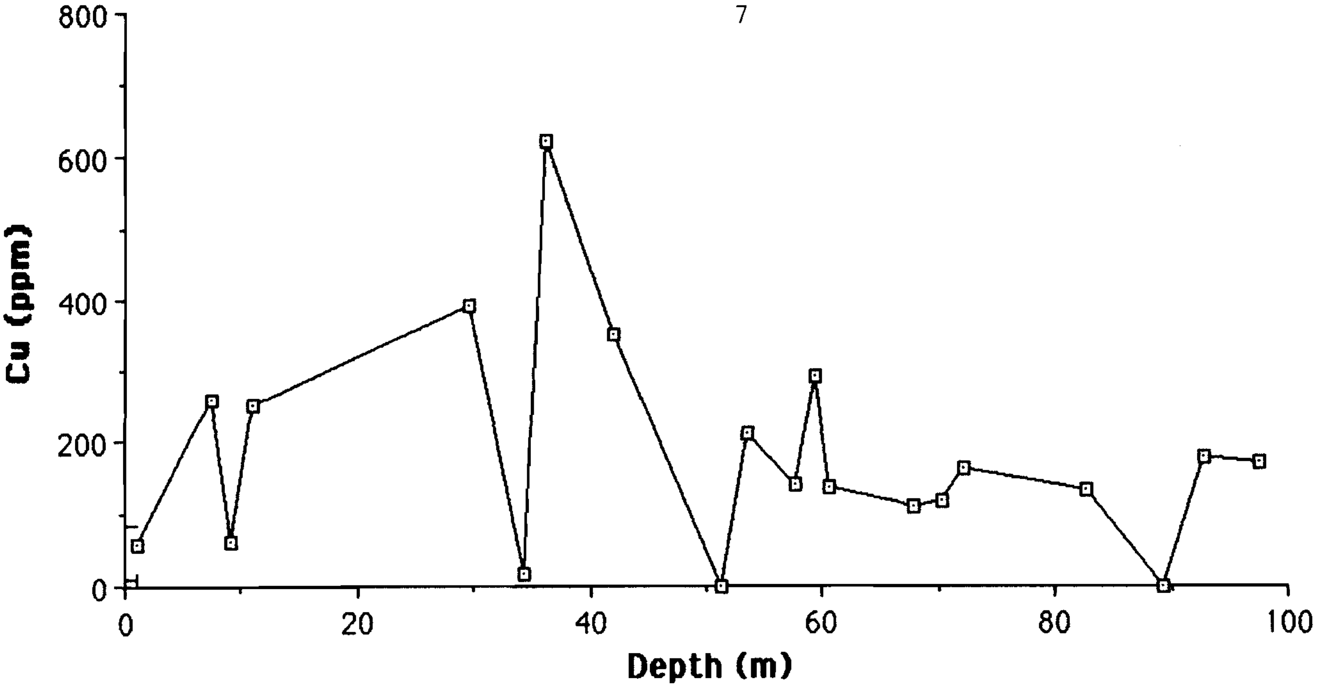
400
300
200
100
0
0
20
40
60
80
100
Depth (m)


Cu (ppm)
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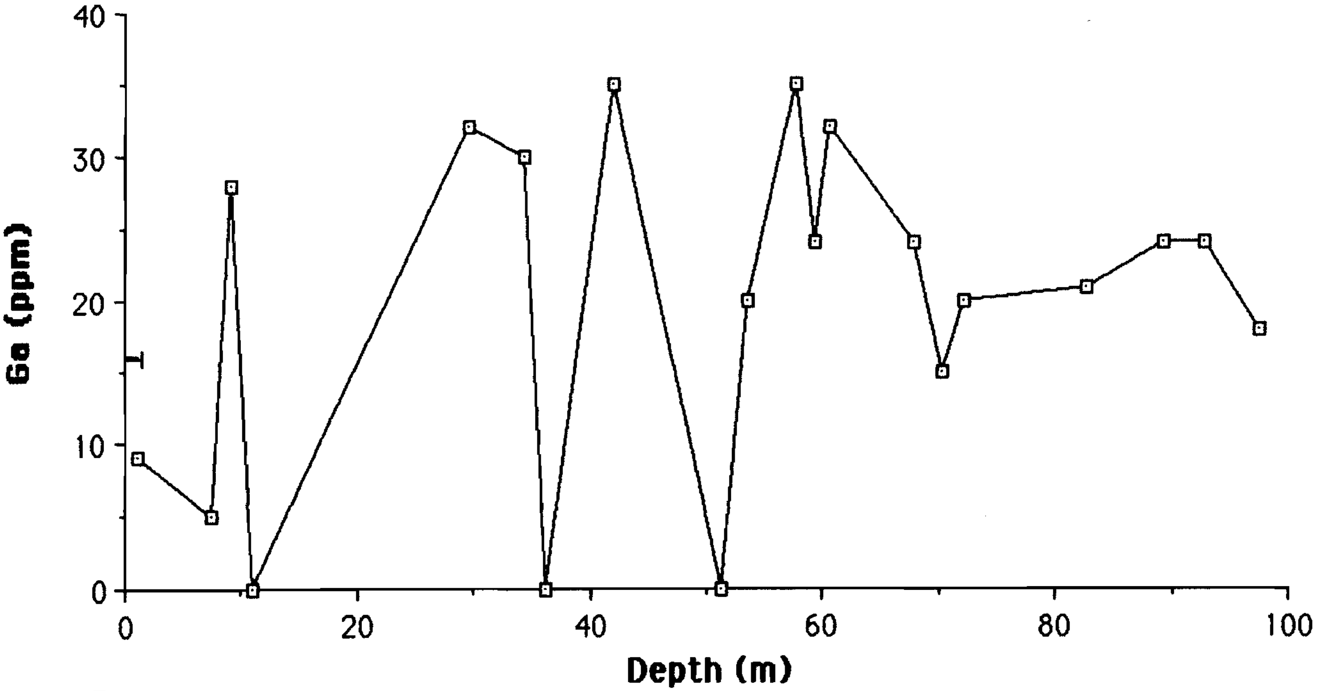
0
0
20
40
60
80
100
Depth (m)


Ga (ppm)
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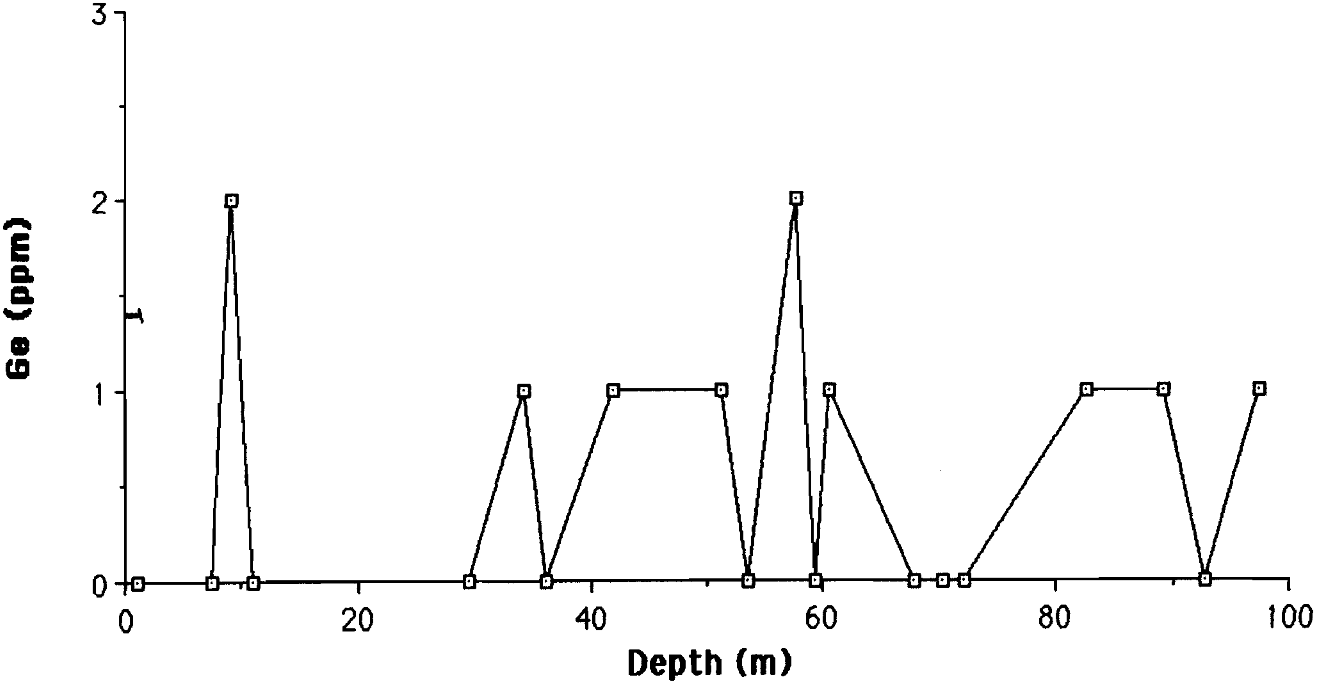
30
20
10
0
0
20
40
60
80
100
Depth (m)


Ge (ppm)
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2
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60
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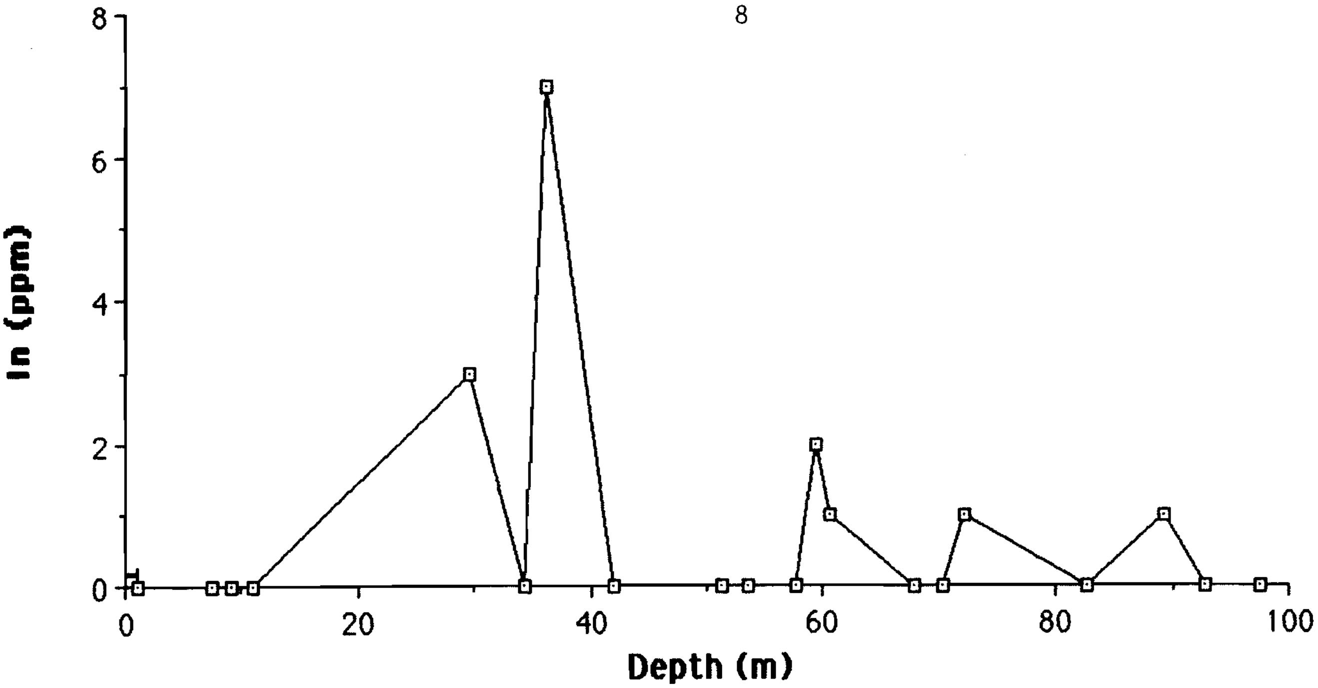
100
Depth (m)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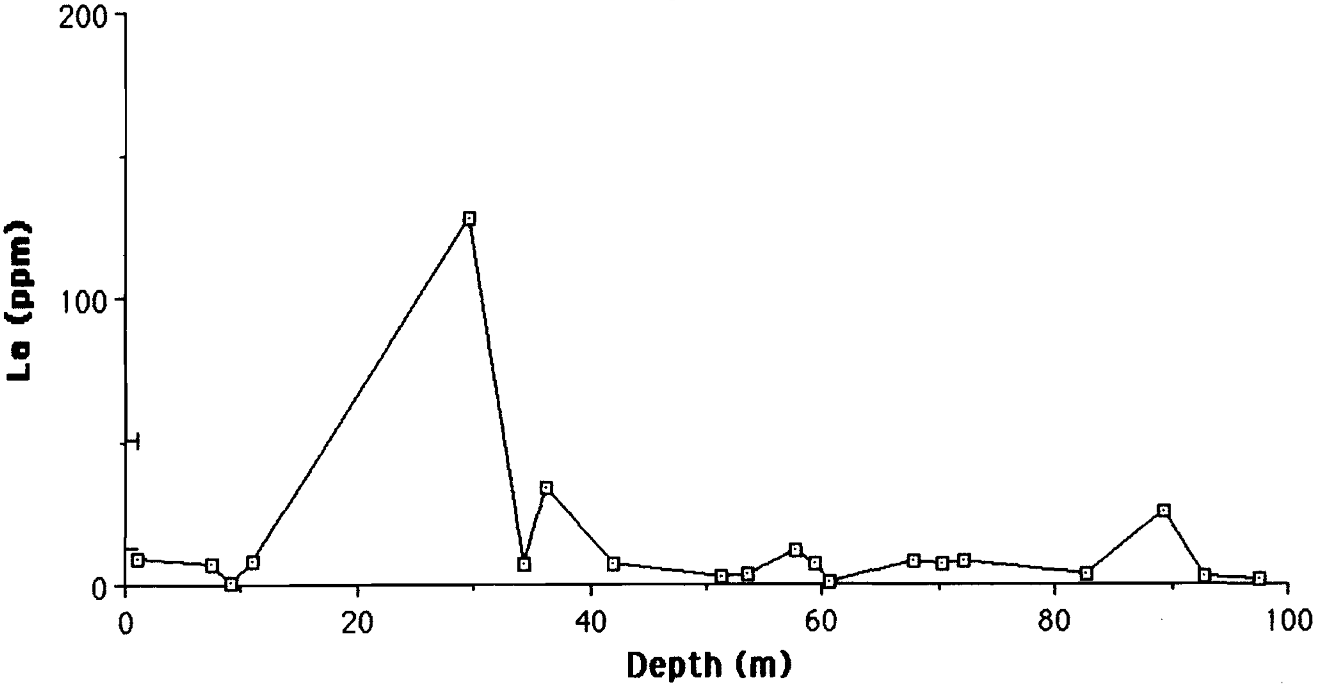
6
4
2
0
0
20
40
60
80
100
Depth (m)


La (ppm)
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100
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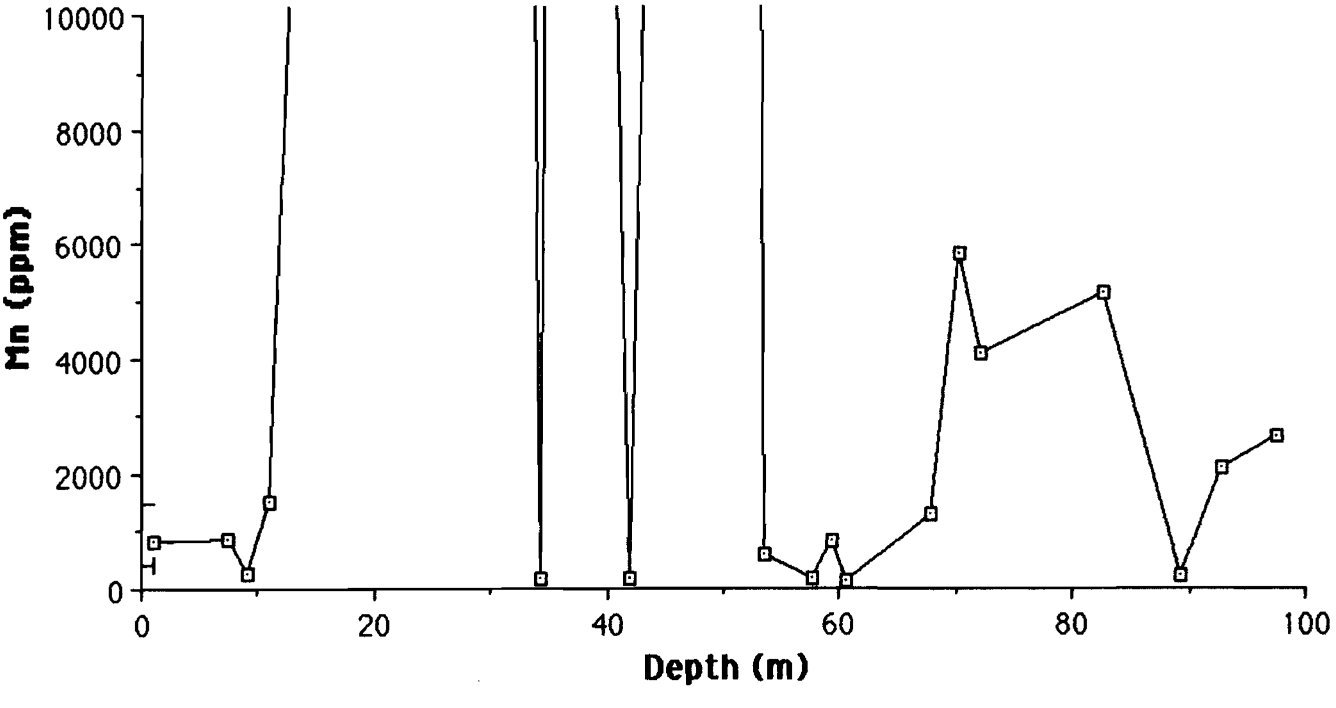
0
20
40
60
80
100
Depth (m)


Mn (ppm)
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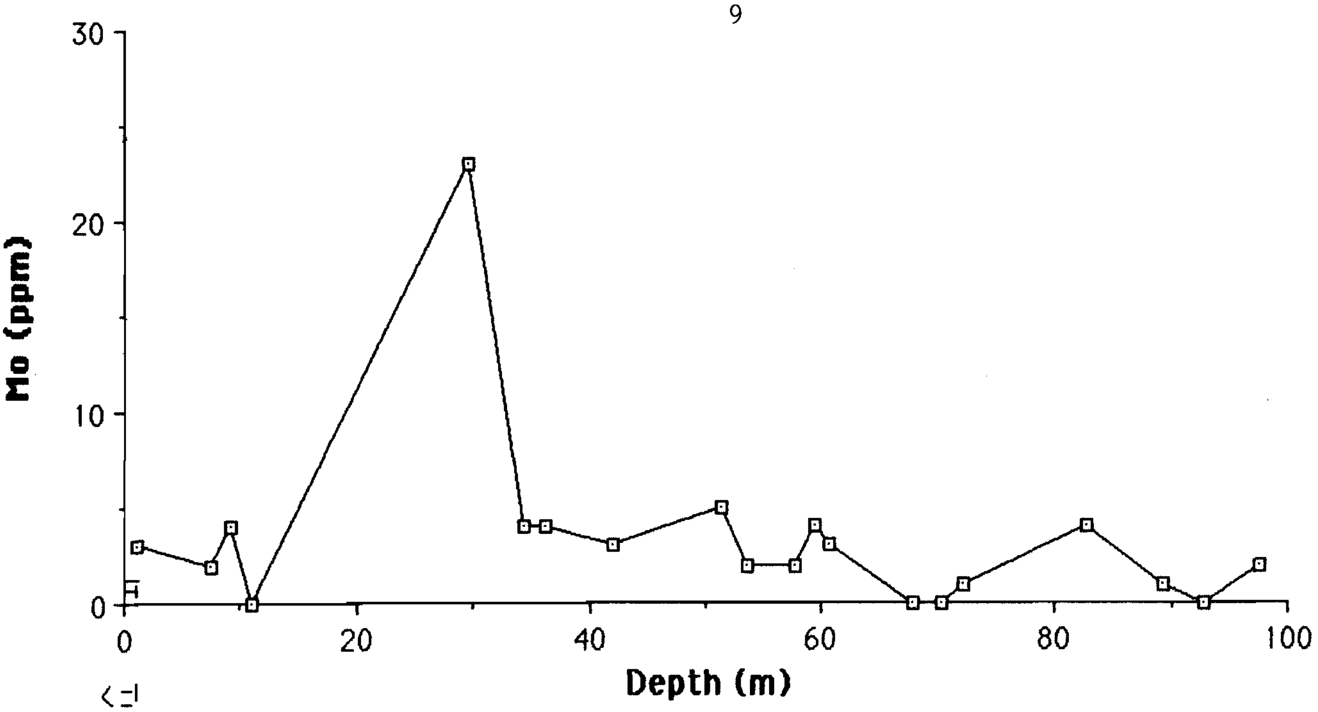
6000
4000
2000
0
0
20
40
60
80
100
Depth (m)


Mo (ppm)
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20
10
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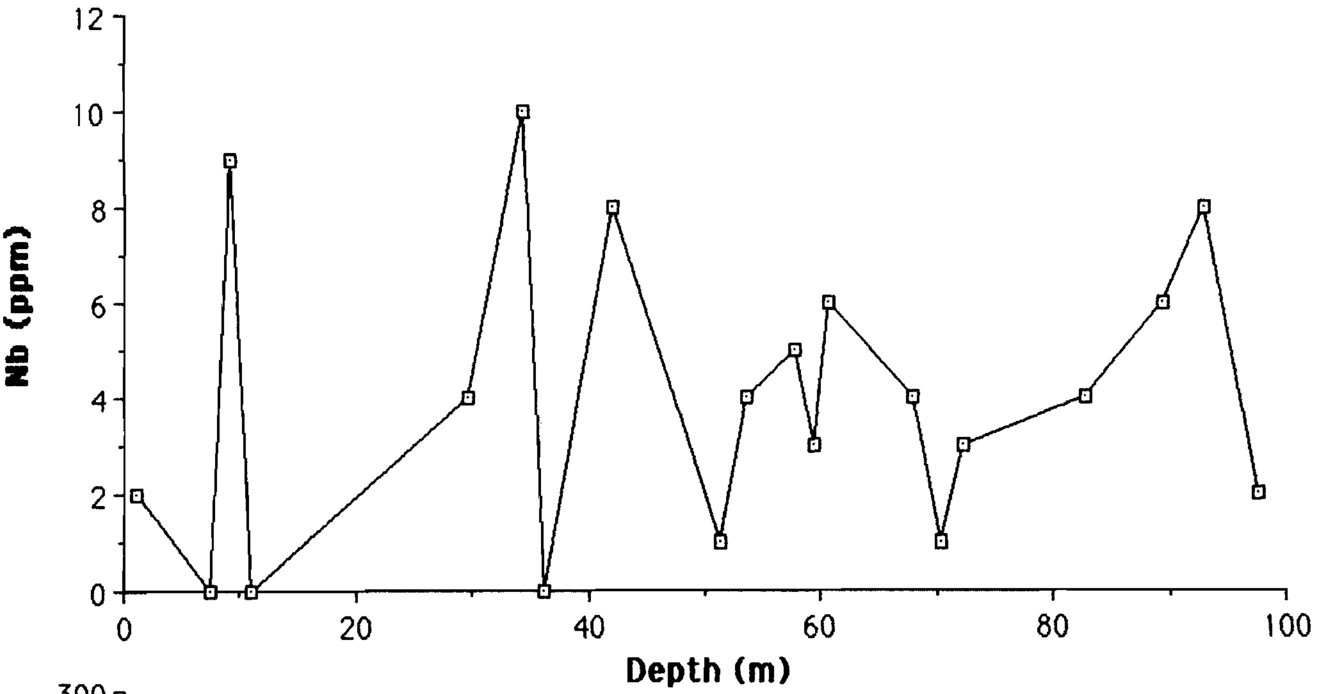
0
20
40
60
80
100
Depth (m)


Nb (ppm)
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8
6
4
2
0
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20
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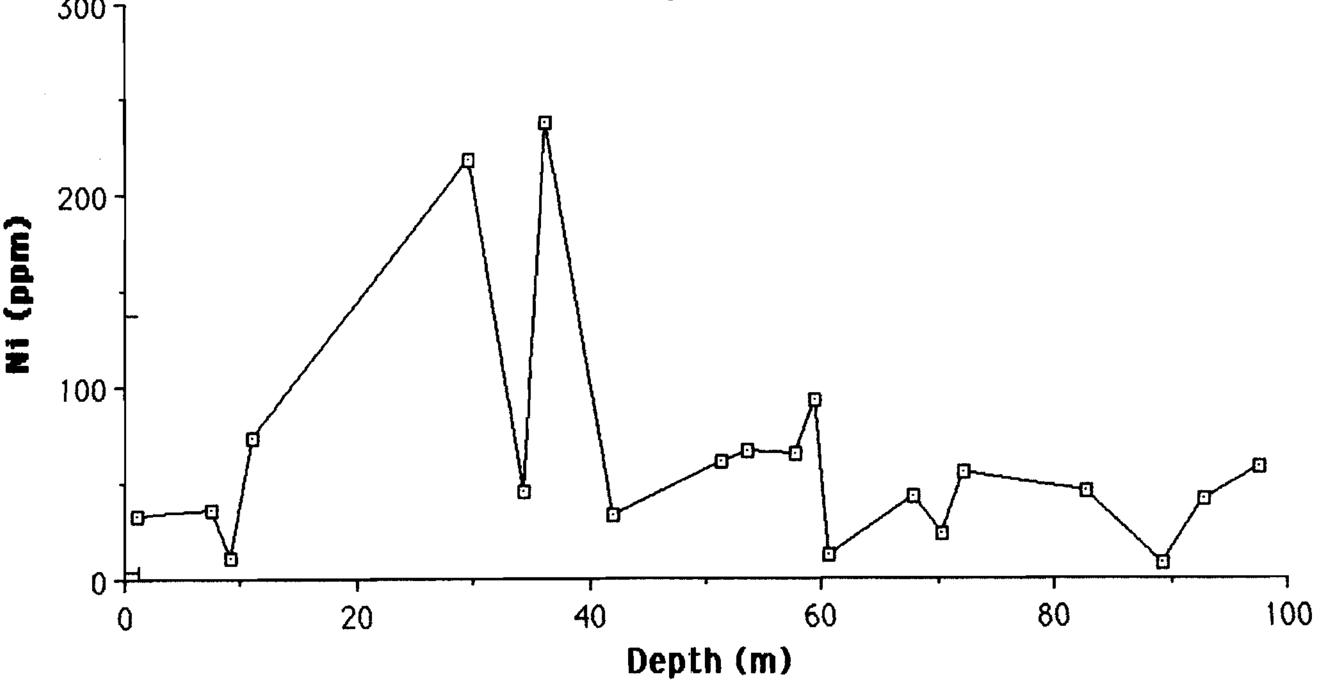
80
100
Depth (m)


Ni (ppm)
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200
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0
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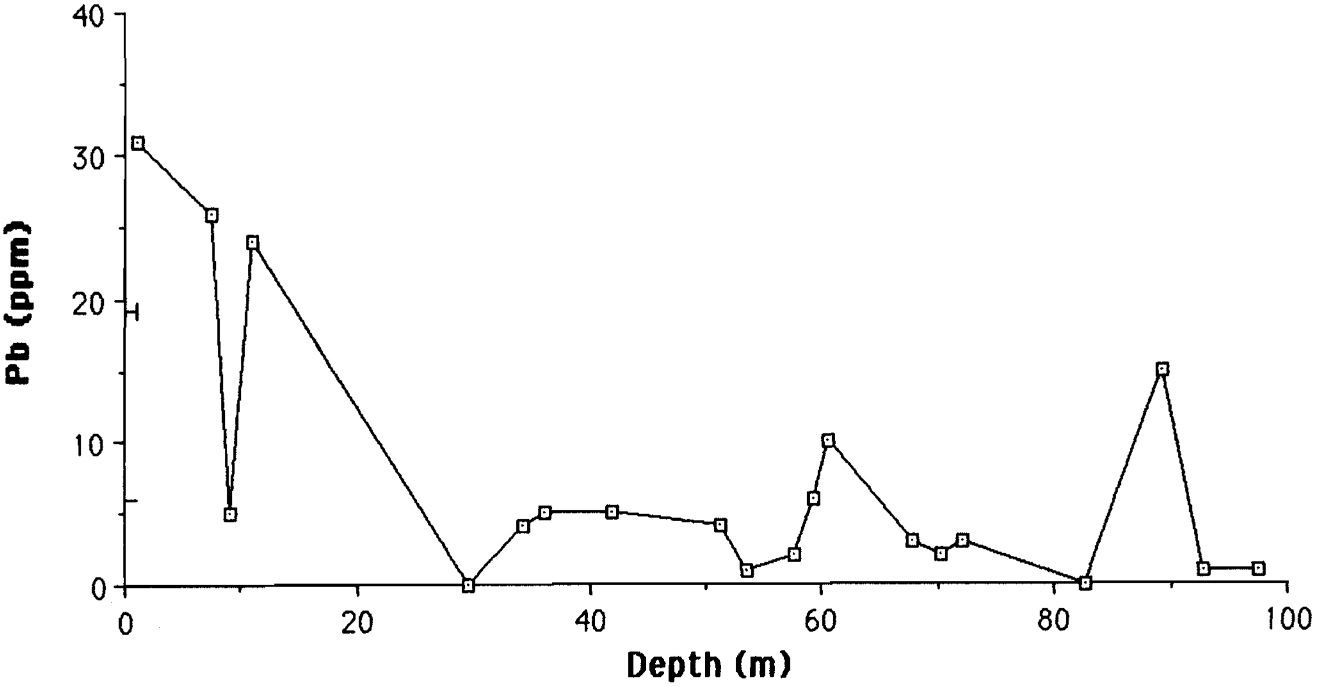
60
80
100
Depth (m)


Pb (ppm)
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10
20
30
40
Depth (m)
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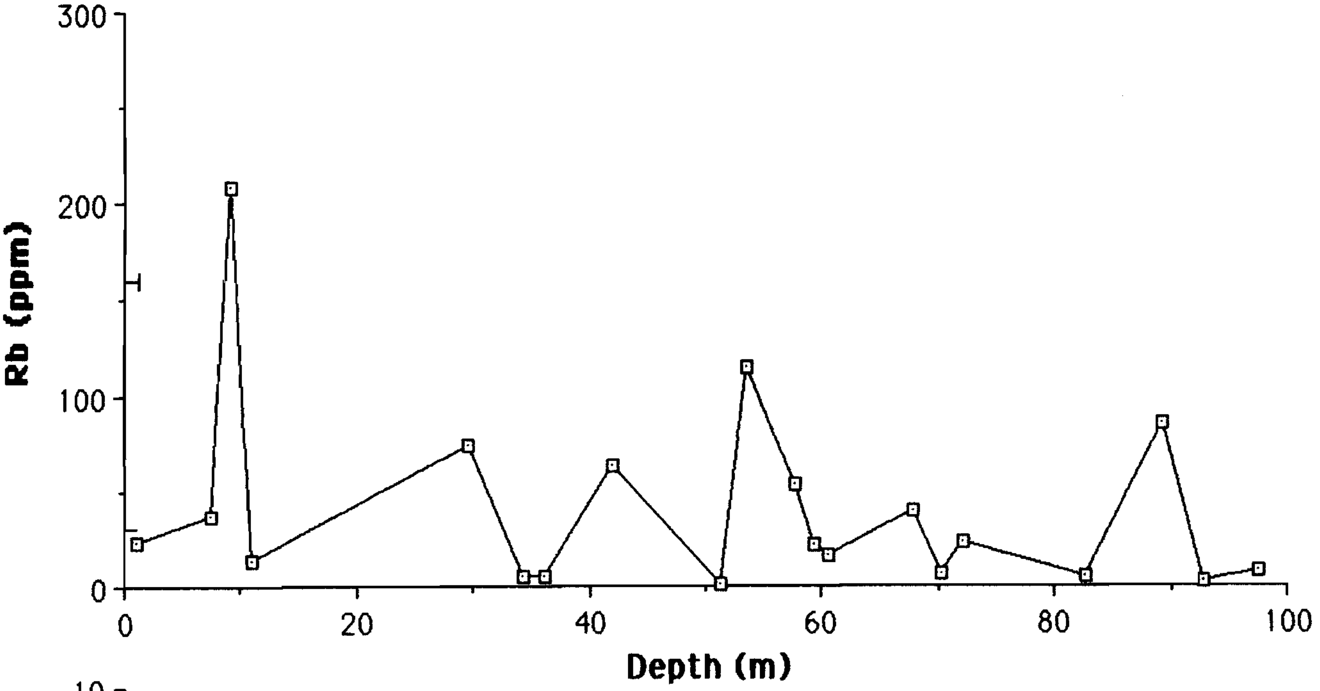
20
40
60
80
100


Rb (ppm)
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100
200
300
Depth (m)
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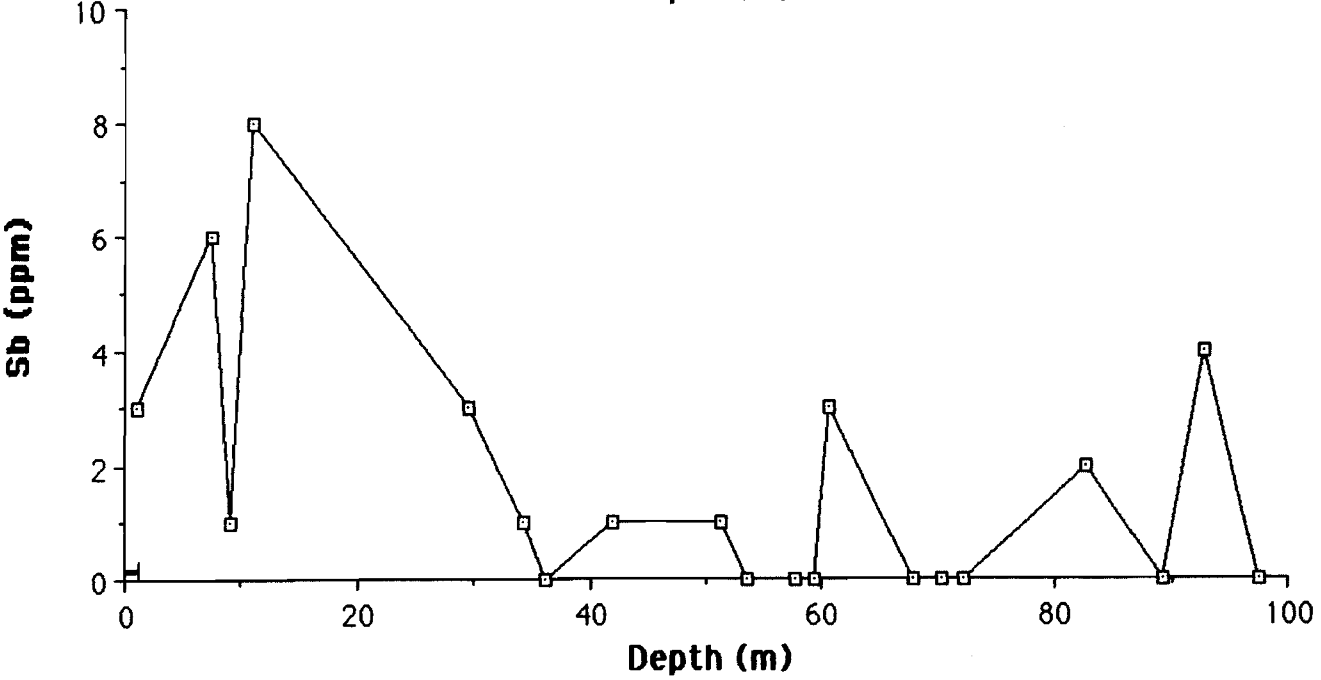
20
40
60
80
100


Sb (ppm)
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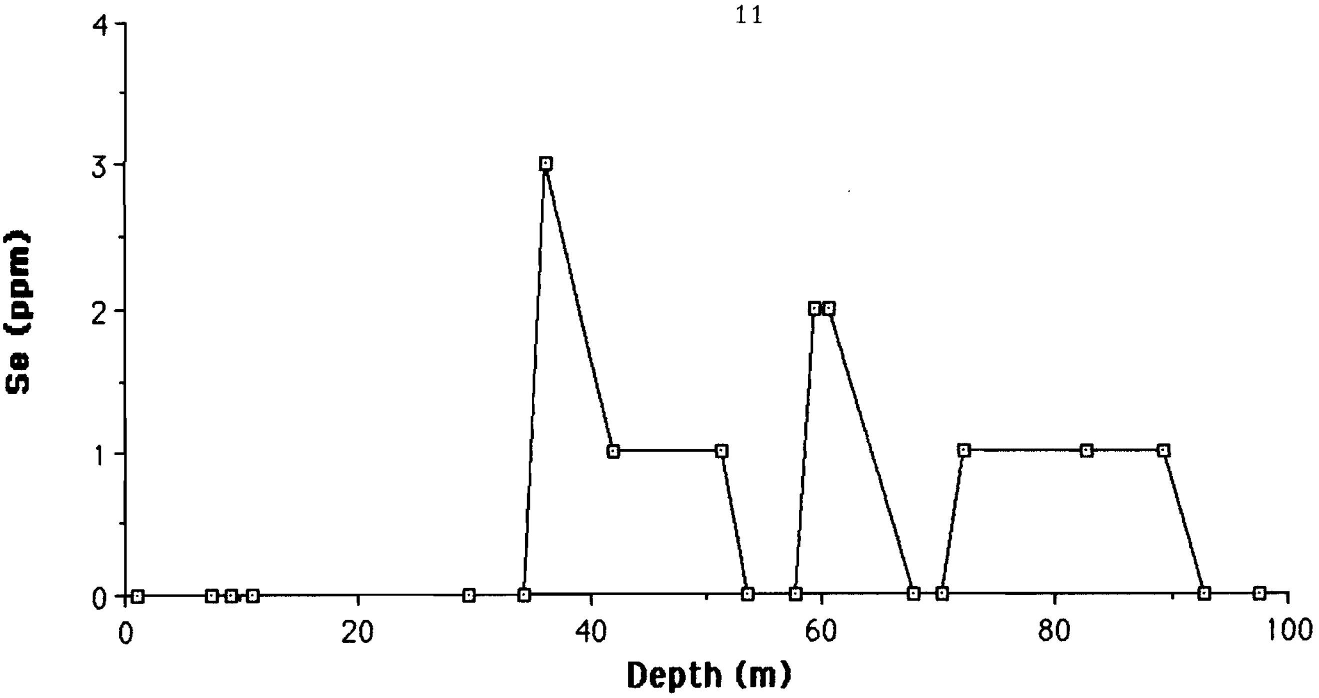
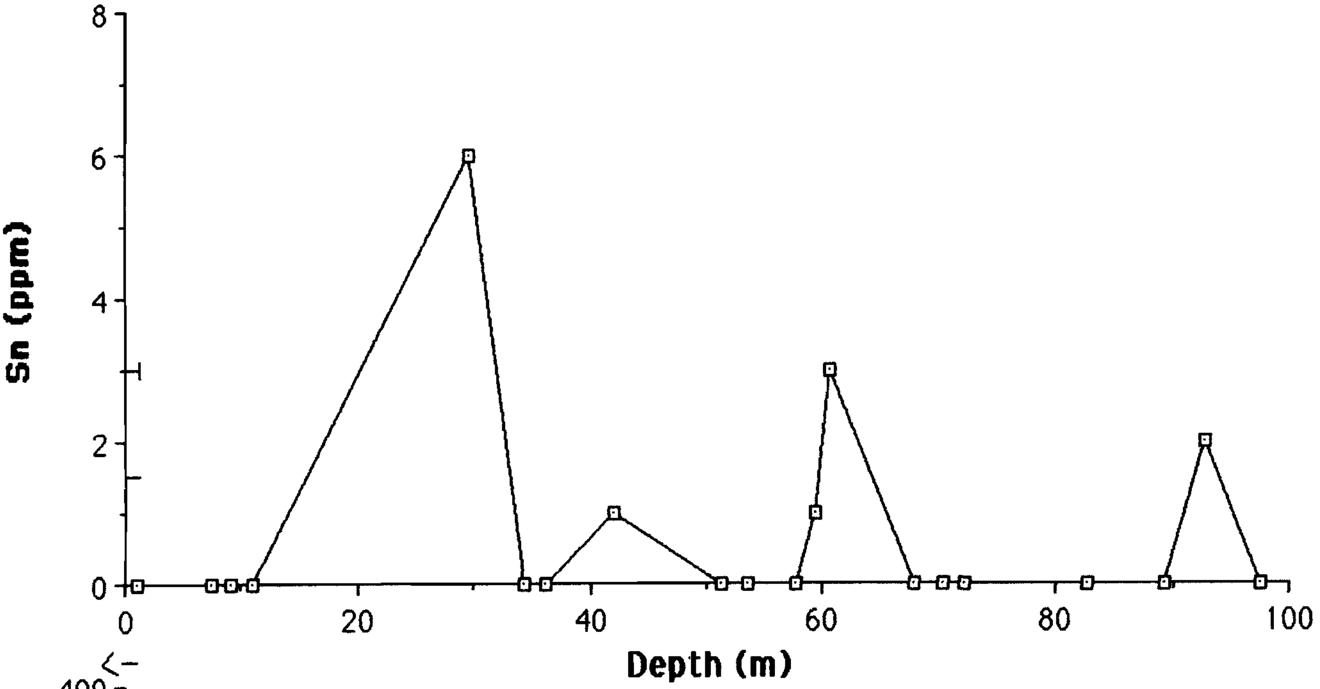
2
4
6
8
10
Depth (m)
0
20
40
60
80
100


Se (ppm)
0
1
2
3
4
Depth (m)
0
20
40
60
80
100


Sn (ppm)
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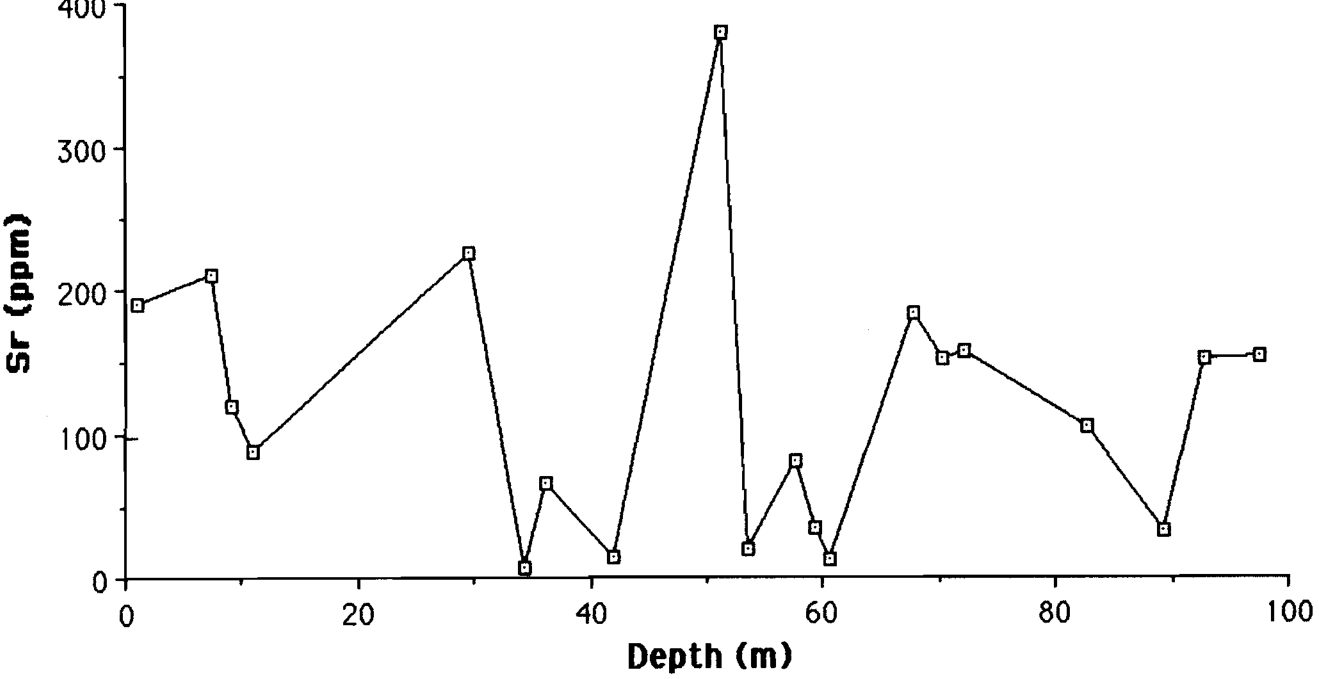
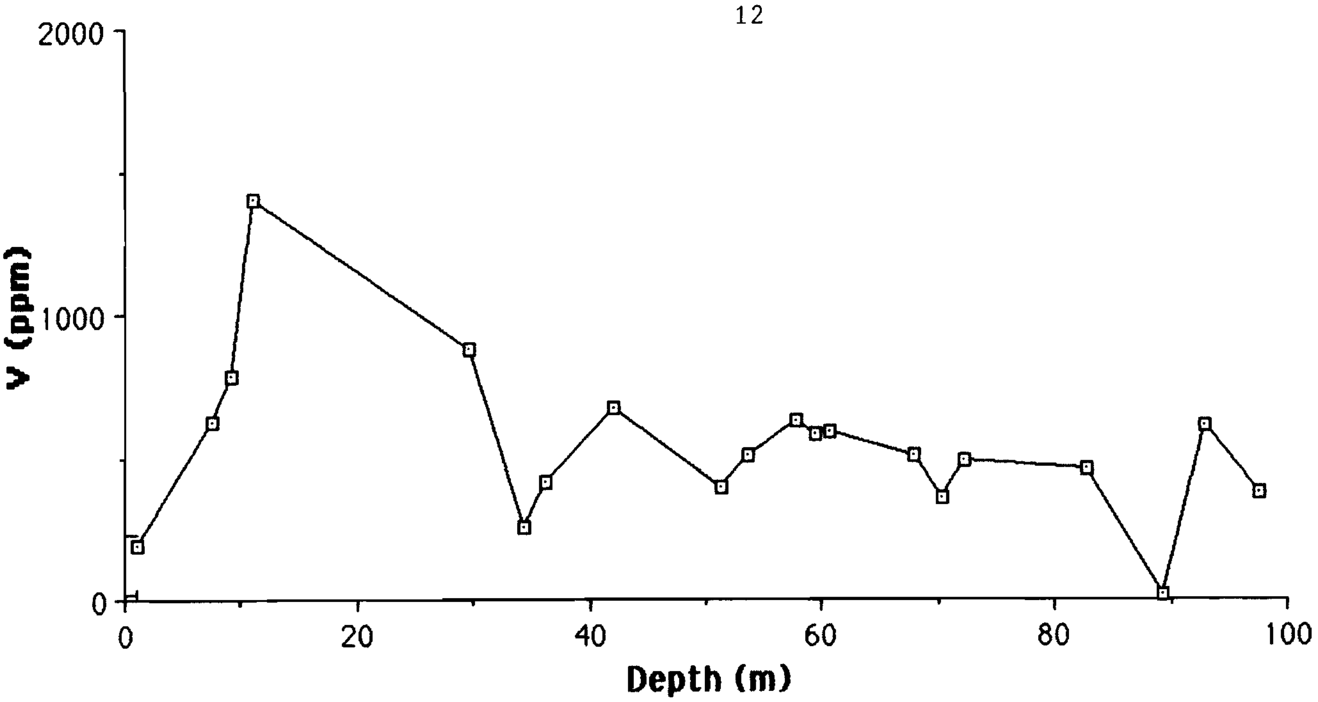
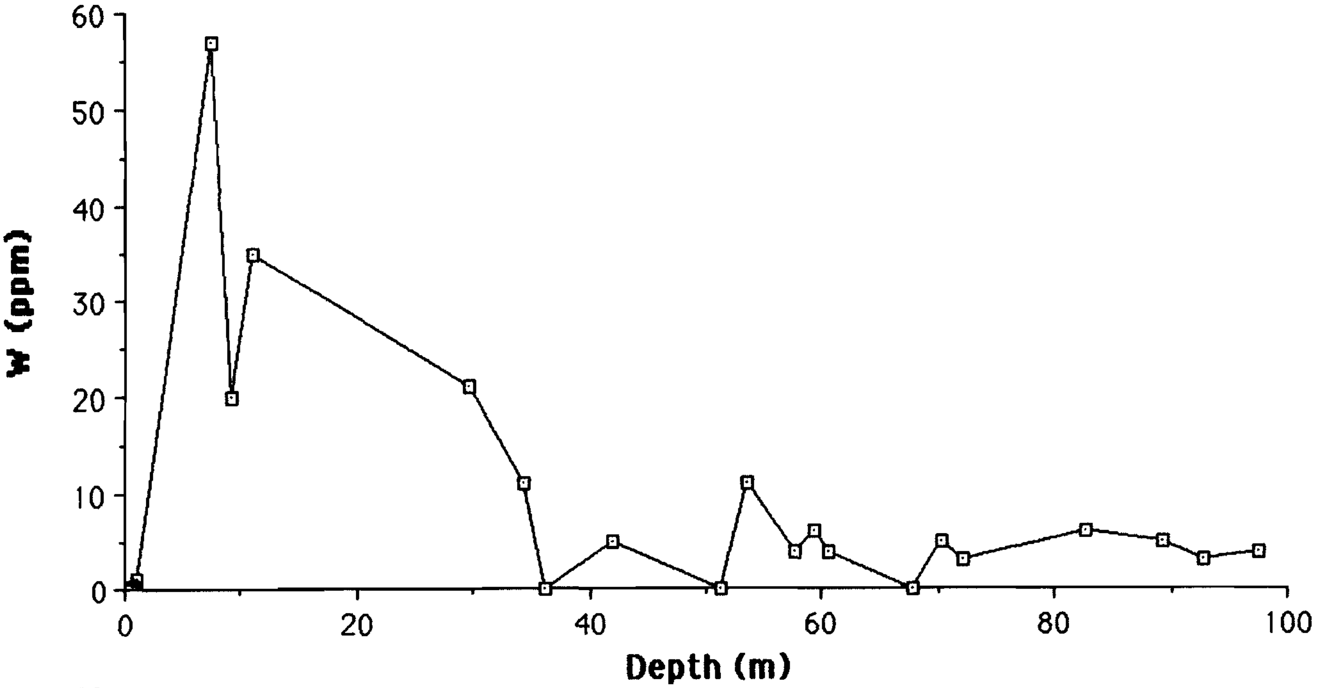
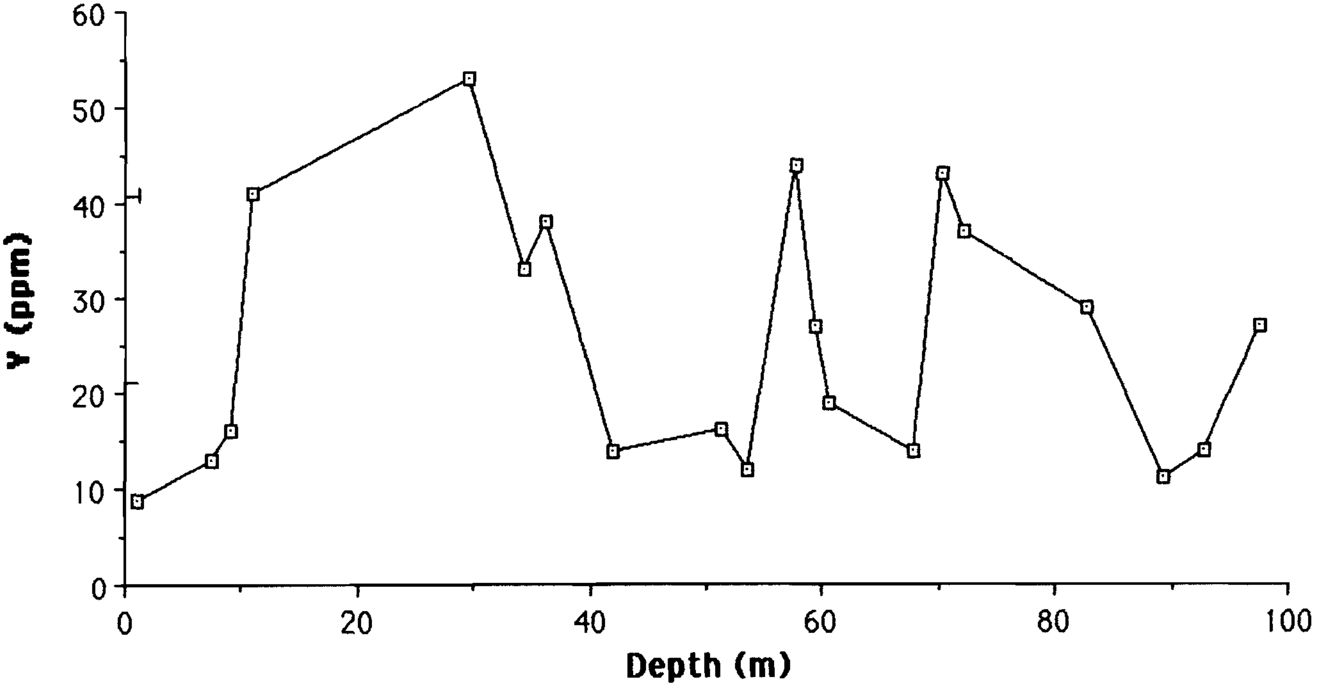
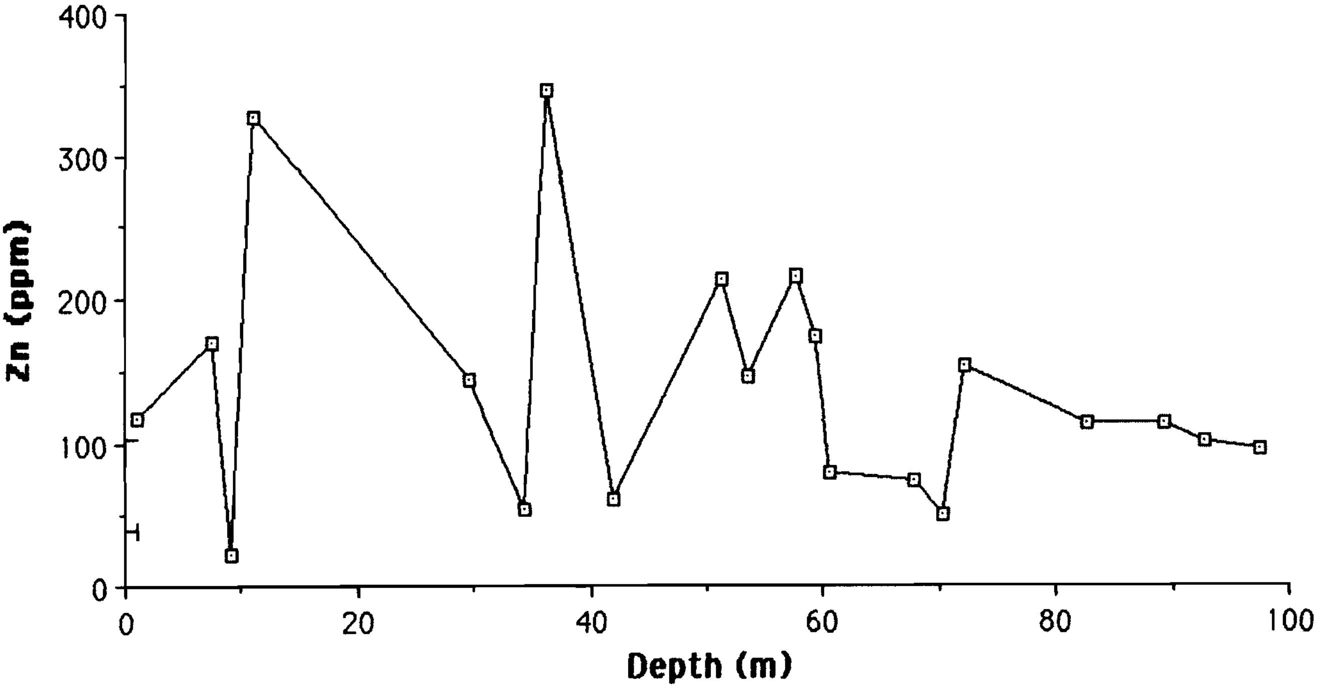
2
4
6
8
Depth (m)
0
20
40
60
80
100

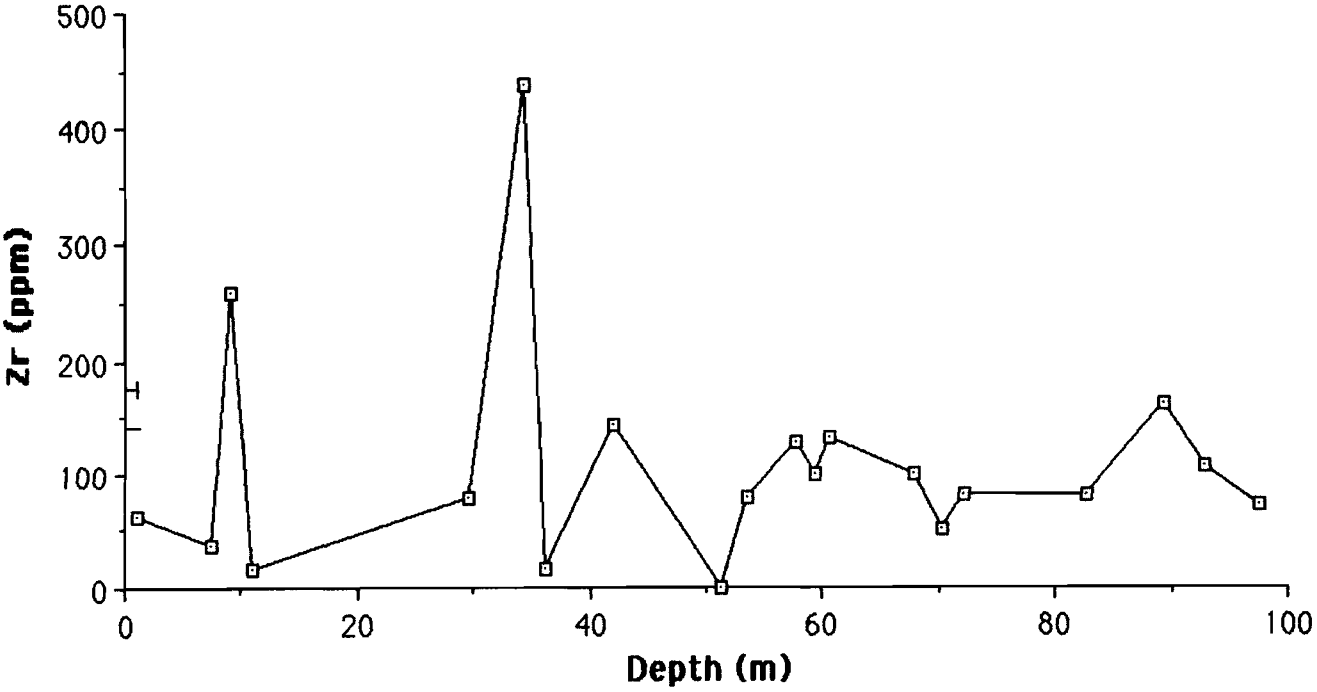

Sr (ppm)
0
100
200
300
400
Depth (m)
0
20
40
60
80
100

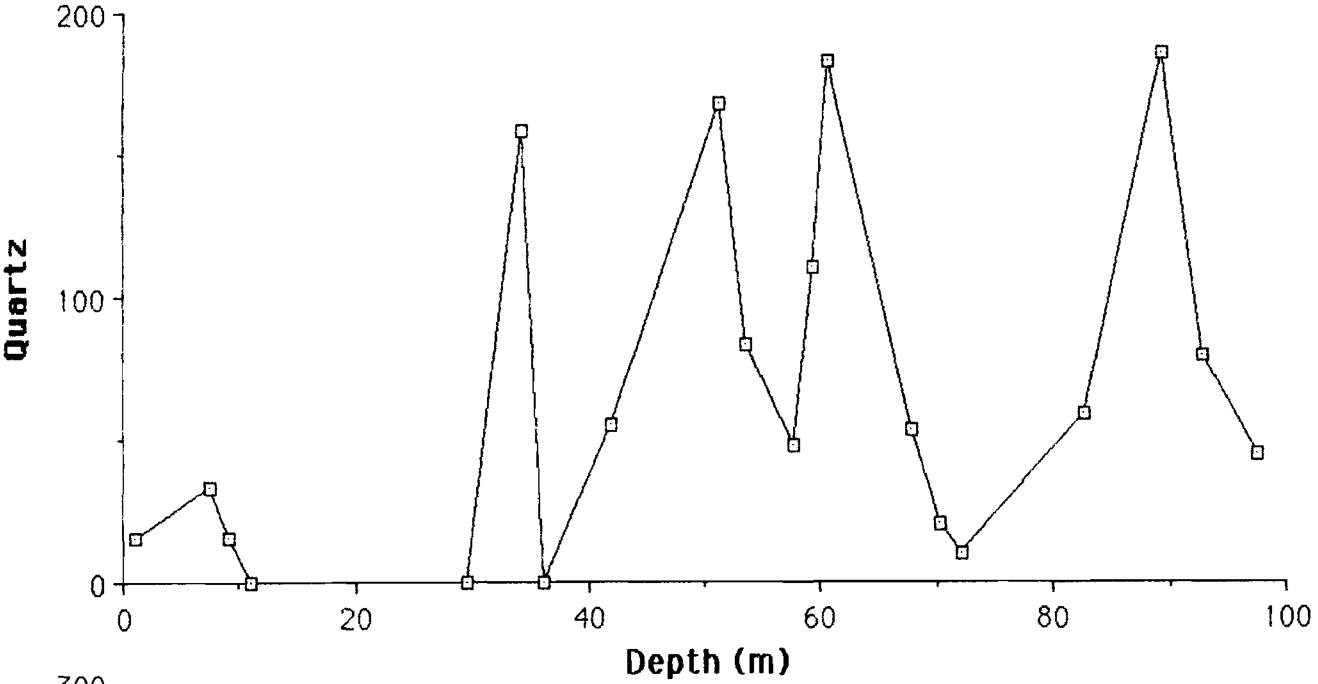

V (ppm)
2000
1000
0
Depth (m)
0
20
40
60
80
100

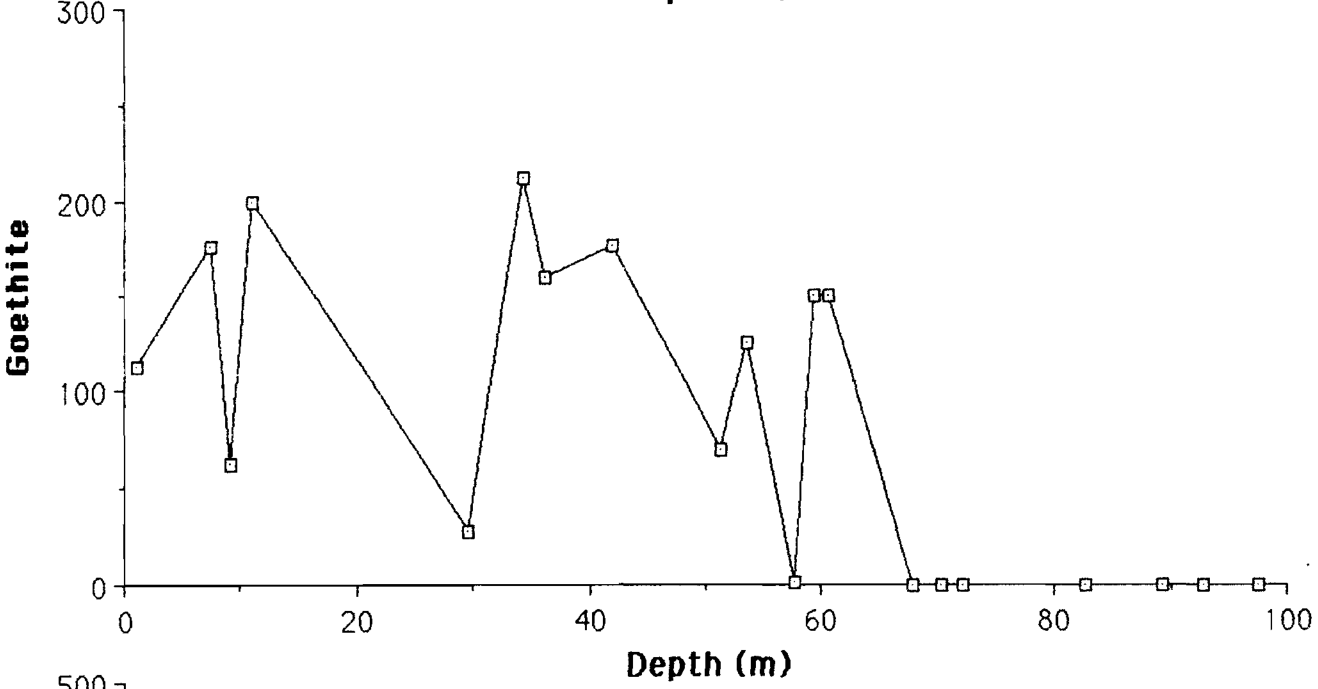

W (ppm)
60
50
40
30
20
10
0
Depth (m)
0
20
40
60
80
100

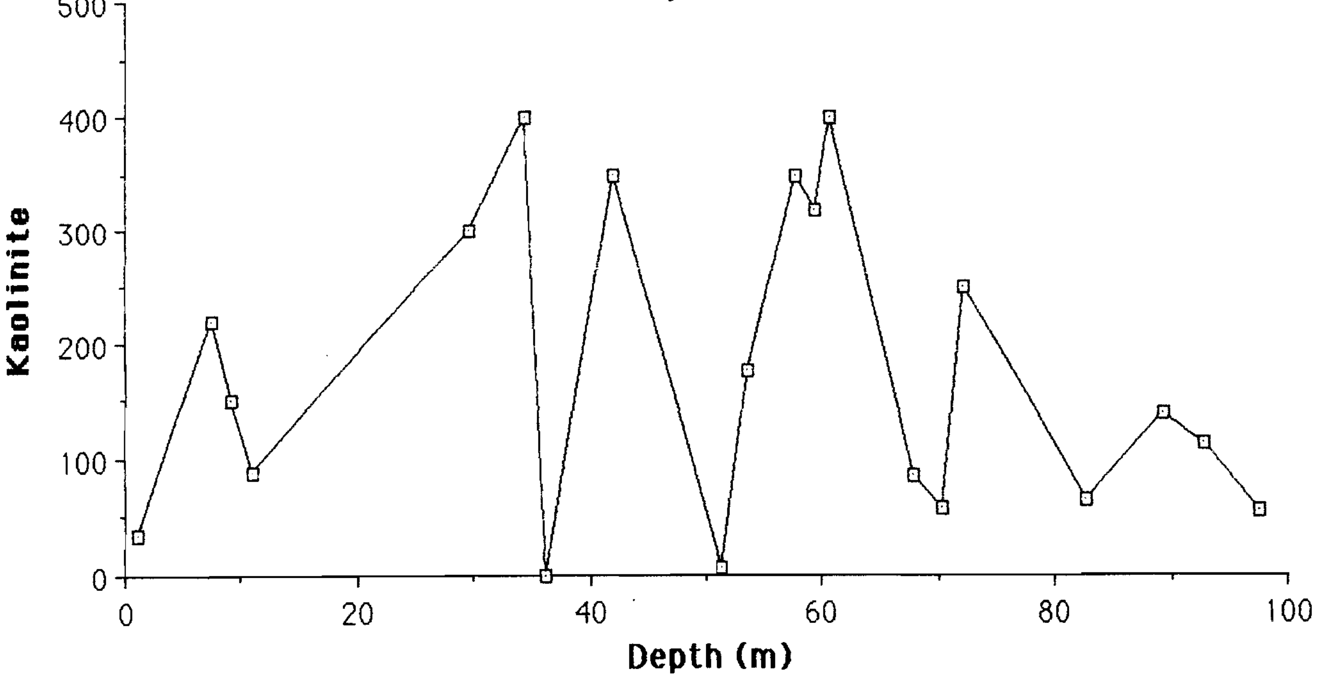

Y (ppm)
60
50
40
30
20
10
0
Depth (m)
0
20
40
60
80
100

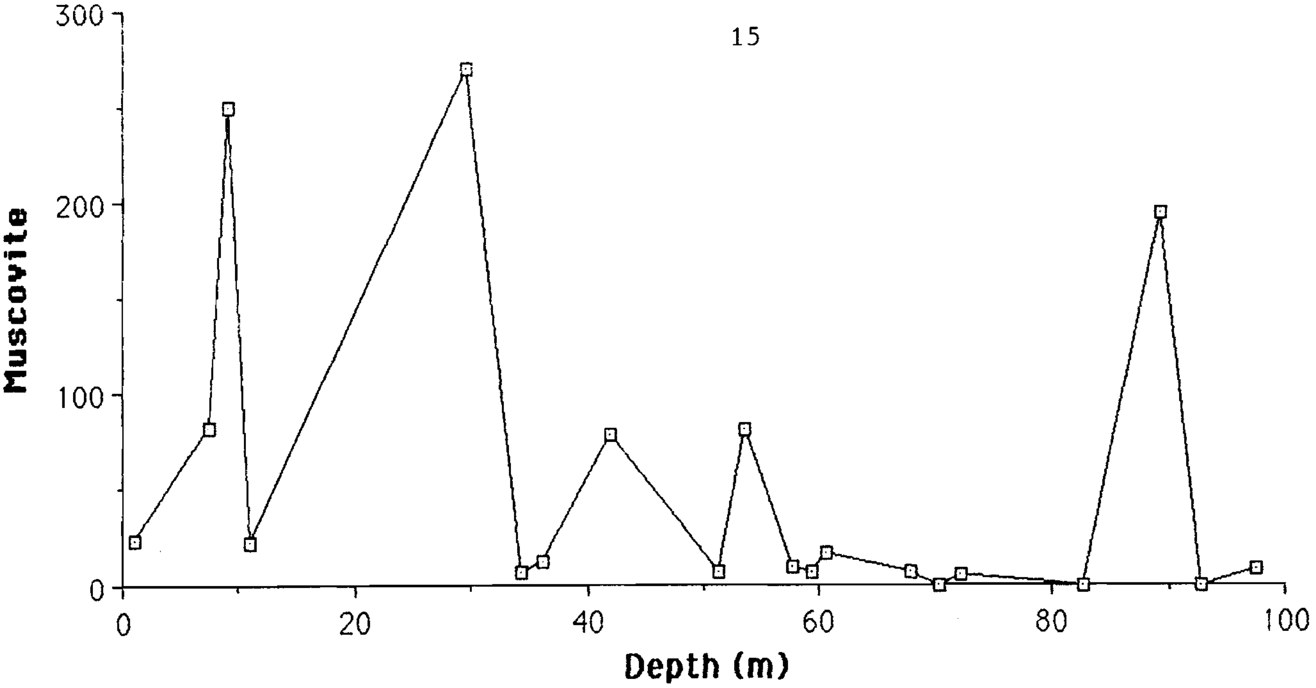

Zn (ppm)
400
300
200
100
0
0
20
40
60
80
100
Depth (m)

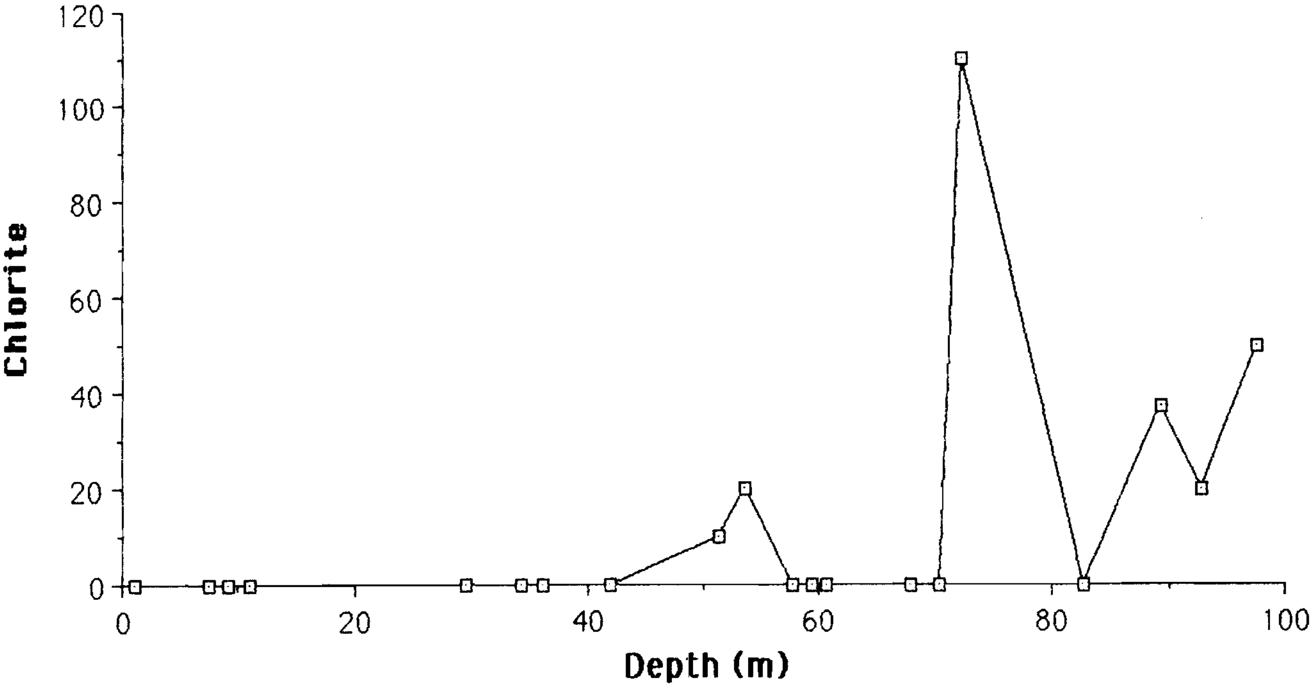

Zr (ppm)
500
400
300
200
100
0
0
20
40
60
80
100
Depth (m)

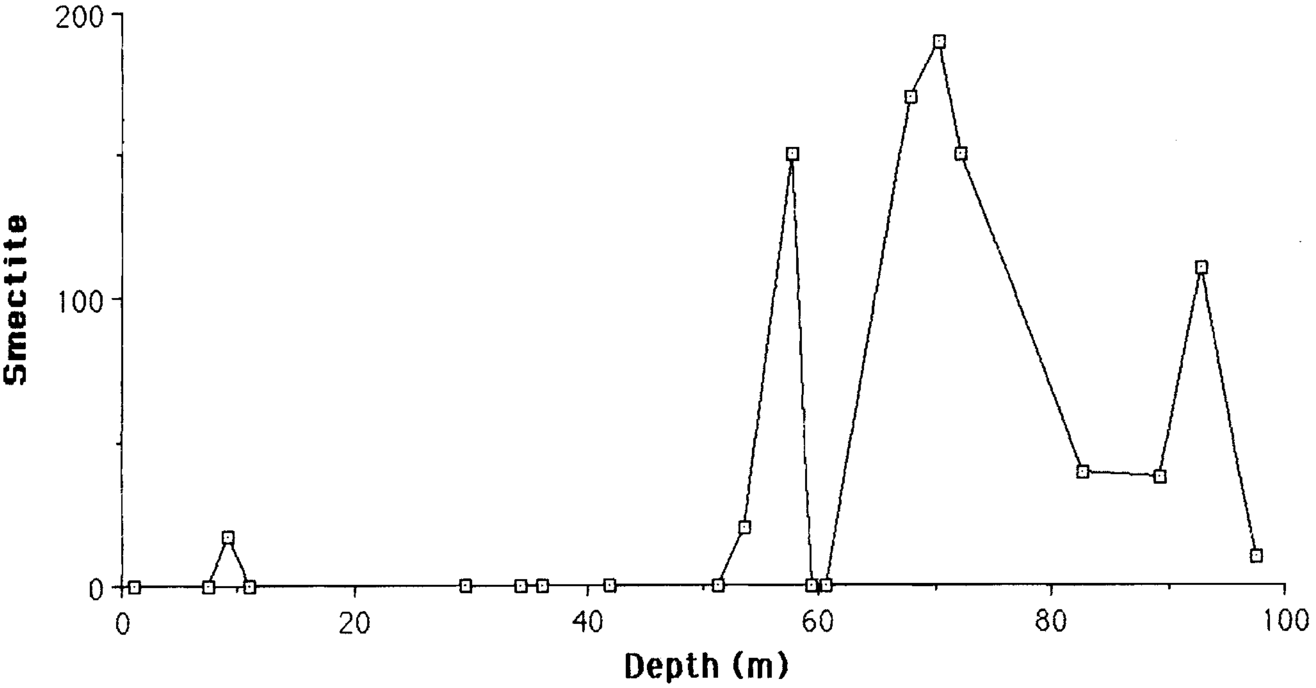

Quartz
200
100
0
0
20
40
60
80
100
Depth (m)

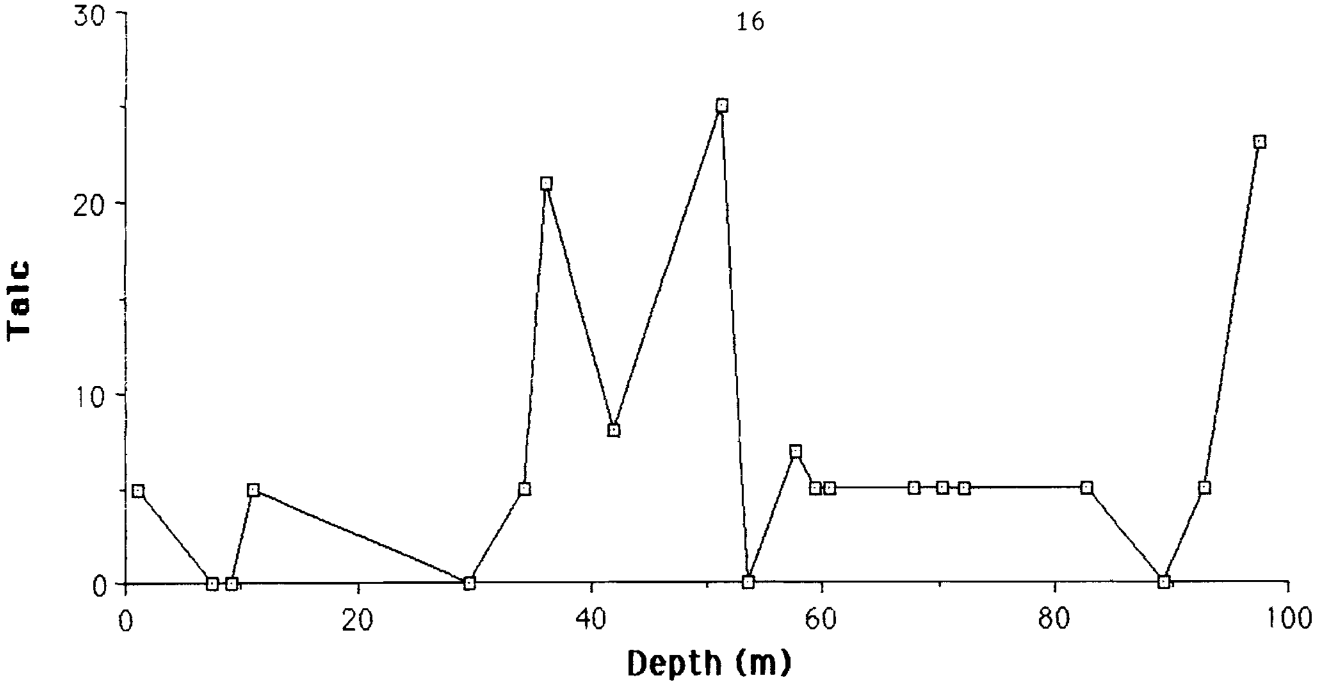

Goethite
300
200
100
0
0
20
40
60
80
100
Depth (m)

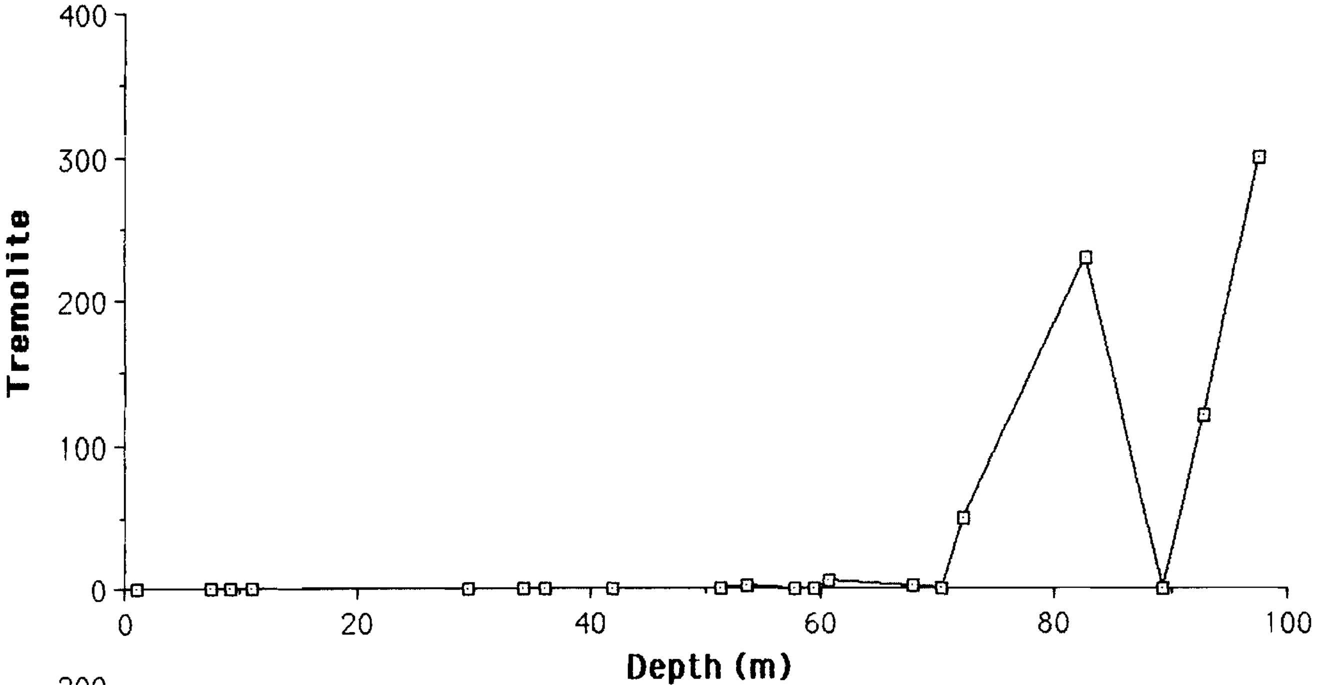

Kaolinite
500
400
300
200
100
0
0
20
40
60
80
100
Depth (m)

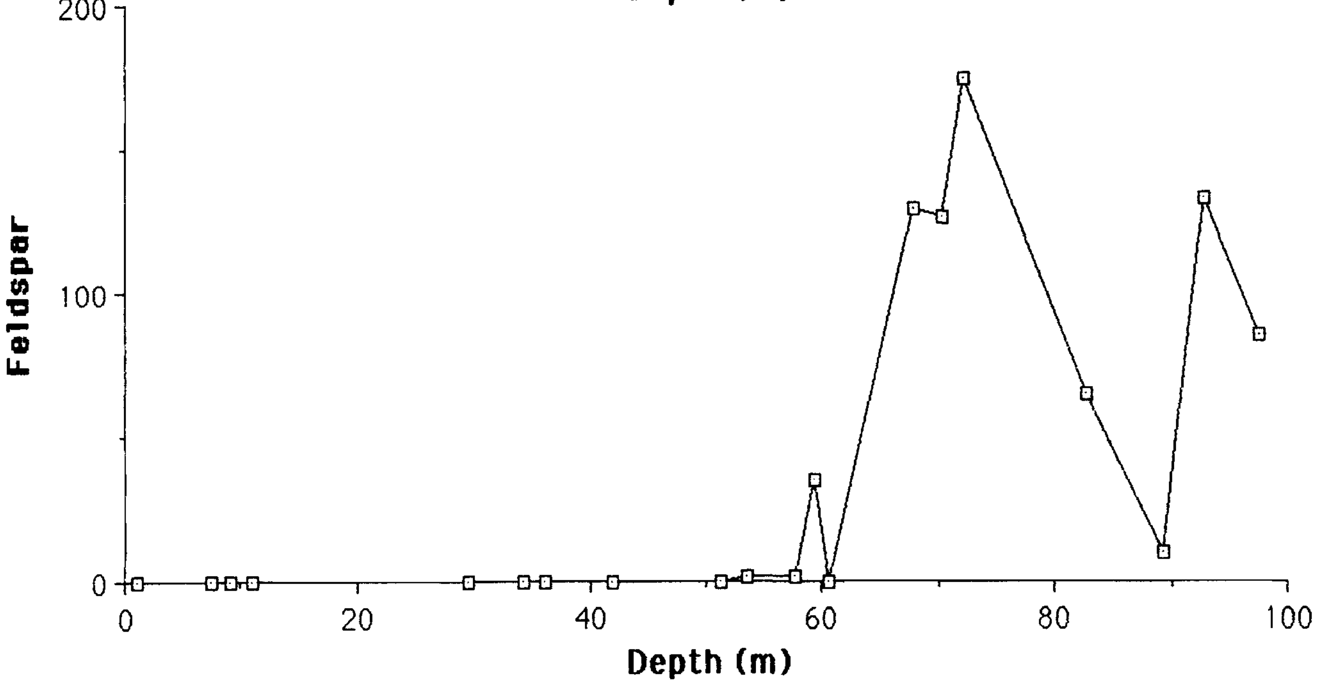

Muscovite
300
200
100
0
0
20
40
60
80
100
Depth (m)

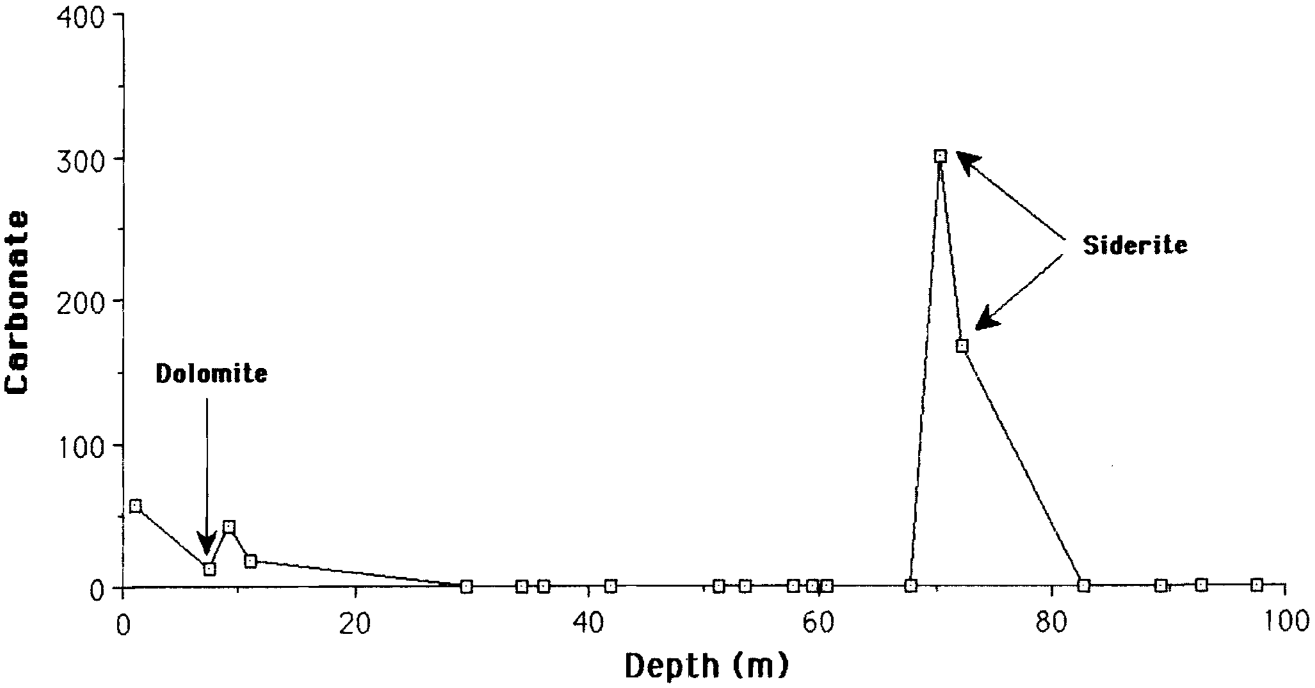

Chlorite
120
100
80
60
40
20
0
0
20
40
60
80
100
Depth (m)


Smectite
200
100
0
0
20
40
60
80
100
Depth (m)


Talc
30
20
10
0
0
20
40
60
80
100
Depth (m)


Tremolite
400
300
200
100
0
0
20
40
60
80
100
Depth (m)


Feldspar
200
100
0
0
20
40
60
80
100
Depth (m)


Carbonate
400
300
200
100
0
Dolomite
Siderite
0
20
40
60
80
100
Depth (m)

APPENDIX 4

Tabulated Geochemistry

DETECTION LIMITS AND AVERAGE ROCK COMPOSITIONS FOR MINOR AND TRACE ELEMENTS

Element	Det. Limit	Ultramafic	Basalt	Granite	Shale
Ag	5	0.06	0.11	0.037	0.07
As	5	1	2	1.5	13
Ba	15	0.4	330	840	580
Bi	5	-	0.007	0.01	-
Cd	5	0.1	0.22	0.13	0.3
Ce	10	0.1	48	92	59
Co	12	150	48	1	19
Cr	5	1600	170	4.1	90
Cu	10	10	87	10	45
Ga	5	1.5	17	17	19
Ge	3	1.5	1.3	1.3	1.6
In	5	0.01	0.22	0.26	0.1
La	10	0.1	15	55	92
Mn	20	1620	1500	390	850
Mo	5	0.3	1.5	1.3	2.6
Nb	5	16	19	21	11
Ni	10	2000	130	4.5	68
Pb	5	1	6	19	20
Rb	5	0.2	30	170	140
Sb	5	0.1	0.2	0.2	1.5
Se	5	0.05	0.05	0.05	0.6
Sn	5	0.5	1.5	3	6
Sr	3	1	465	100	300
V	10	40	250	44	130
W	10	0.77	0.7	2.2	1.8
Y	3	0.1	21	40	26
Zn	5	50	105	39	95
Zr	4	45	140	175	160

MAJOR ELEMENTS DDH BCD1

				ICP	ICP	XRF	ICP	ICP	ICP	XRF	ICP	ICP	XRF	ICP
Field No	**DEPTH**	**LAB SEQ**	**LIB NO**	**SIO2**	**Al2O3**	**Fe2O3**	**Fe2O3**	**MgO**	**CaO**	**TIO2**	**TIO2**	**P2O5**	**MnO**	**MnO**
BC 1	01.00	188	08 - 167	39.70	6.61	16.16	16.30	0.71	14.80	0.33	0.31	0.04	0.11	0.11
BC 7.4	07.40	181	08 - 168	25.70	10.70	30.60	30.70	2.90	8.62	0.43	0.35	0.03	0.11	0.12
BC 9	09.00	183	08 - 169	33.20	20.40	9.29	8.36	2.35	12.60	1.40	1.22	0.01	0.03	0.03
BC 11	11.00	186	08 - 170	9.49	5.56	46.89	48.40	0.92	11.80	0.22	0.17	0.36	0.20	0.21
BC 29.6	29.60	167	08 - 171	31.00	24.00	19.30	16.40	0.46	0.20	2.16	1.42	0.02	12.48	8.46
BC 34.2	34.20	171	08 - 172	57.90	24.60	2.14	1.83	0.20	0.07	2.33	1.87	0.00	0.02	0.02
BC 36.1	36.10	170	08 - 173	5.08	4.78	65.48	63.00	0.22	0.15	0.43	0.29	0.06	6.72	8.46
BC 41.9	41.90	175	08 - 174	44.10	28.20	9.01	8.42	0.25	0.09	2.54	2.02	0.01	0.02	0.02
BC 51.25	51.25	184	08 - 175	69.20	0.18	19.73	16.20	0.34	0.20	0.01	0.03	0.10	10.59	8.46
BC 53.5	53.50	178	08 - 176	50.40	15.10	20.44	19.70	1.38	0.18	1.52	1.26	0.07	0.08	0.08
BC 57.6	57.60	173	08 - 177	48.50	24.50	5.58	5.03	0.93	0.30	2.16	1.92	0.00	0.02	0.03
BC 59.4	59.40	179	08 - 178	50.00	17.40	19.44	18.50	0.35	0.11	1.70	1.37	0.06	0.11	0.13
BC 60.5	60.50	182	08 - 179	60.90	23.90	2.43	2.13	0.26	0.09	2.42	1.91	0.01	0.02	0.02
BC 67.7	67.70	168	08 - 180	55.30	18.70	7.72	6.97	1.78	1.81	1.70	1.48	0.09	0.17	0.21
BC 70.2	70.20	172	08 - 181	31.80	9.06	4.29	3.19	8.74	14.20	0.99	0.69	0.09	0.75	0.63
BC 72.2	72.20	174	08 - 182	48.00	14.90	9.15	7.95	4.43	4.82	1.31	1.17	0.09	0.53	0.47
BC 82.7	82.70	185	08 - 183	49.90	14.70	12.15	12.00	3.72	5.08	1.35	1.18	0.10	0.66	0.71
BC 89.2	89.20	180	08 - 184	69.20	15.20	4.43	3.89	1.20	0.16	0.27	0.23	0.05	0.03	0.03
BC 92.8	92.80	169	08 - 185	55.80	16.60	8.29	7.97	2.52	2.99	1.70	1.55	0.12	0.27	0.29
BC 97.45	97.45	177	08 - 186	55.20	13.80	12.01	11.50	5.03	7.48	1.15	1.07	0.09	0.34	0.34

MINOR AND TRACE ELEMENTS DDH BCD1

DEPTH	XRF Ag	XRF As	XRF Ba	ICP Ba	ICP Be	XRF Bi	XRF Cd	XRF Ce	XRF Co	XRF Cr	ICP Cr	XRF Cu	ICP Cu	XRF Ga	XRF Ge	XRF In
1.00	1	17	1340	1297	0.0	0	3	8	7	91	93.1	61	55.2	9	0	0
7.40	0	37	129	94.3	0.0	0	3	0	30	187	173	261	317	5	0	0
9.00	1	15	485	414	0.0	3	0	11	2	184	168	64	73	28	2	0
11.00	0	126	456	532	4.4	0	1	2	7	87	98.2	252	291	0	0	0
29.60	0	94	9918	6940	0.0	0	0	410	383	150	184	393	430	32	0	3
34.20	0	27	23	10.8	0.0	0	0	44	0	401	332	20	22.4	30	1	0
36.10	1	120	2299	1572	1.4	0	0	109	363	93	136	624	716	0	0	7
41.90	3	226	63	46.8	0.0	0	1	15	4	288	269	352	368	35	1	0
51.25	0	94	195	129	0.0	0	2	0	8	0	35.6	0	15.6	0	1	0
53.50	0	16	92	76.4	0.0	0	1	11	16	40	51.9	211	223	20	0	0
57.60	0	2	205	171	0.0	0	2	17	14	74	69	141	147	35	2	0
59.40	0	137	266	246	0.0	2	2	18	27	30	40.9	291	291	24	0	2
60.50	0	46	63	50.2	0.0	1	1	17	3	60	54.7	136	340	32	1	1
67.70	0	4	159	161	0.0	1	0	27	25	62	64.1	112	105	24	0	0
70.20	0	2	90	75.4	0.0	0	0	15	20	36	35.1	118	101	15	0	0
72.20	1	3	88	87.5	0.0	0	2	23	47	51	53.8	164	200	20	0	1
82.70	0	0	24	14.2	0.0	1	2	21	39	46	49.1	132	165	21	1	0
89.20	0	16	473	467	0.0	0	0	47	2	2	13.3	0	0	24	1	1
92.80	1	7	32	27.9	0.0	0	0	24	37	19	25.5	179	273	24	0	0
97.45	1	4	63	46.4	0.0	0	0	18	41	41	48.5	171	195	18	1	0

MINOR AND TRACE ELEMENTS DDH BCD1

DEPTH	XRF La	XRF Mn	ICP Mn	XRF Mo	XRF Nb	XRF Ni	ICP Ni	XRF Pb	XRF Rb	XRF Sb	XRF Se	XRF Sn	XRF Sr	XRF V	ICP V	XRF W
1	9	849	868	3	2	34	25.7	31	24	3	0	0	191	193	181	1
7.4	7	886	927	2	0	36	37.3	26	37	6	0	0	211	630	592	57
9	1	267	236	4	9	11	15	5	209	1	0	0	120	789	744	20
11	8	1516	1615	0	0	73	71.4	24	14	8	0	0	88	1403	1342	35
29.6	128	96629	65514	23	4	218	266	0	75	3	0	6	226	877	660	21
34.2	7	170	177	4	10	46	37.6	4	5	1	0	0	8	256	169	11
36.1	34	52023	65505	4	0	238	260	5	5	0	3	0	67	415	298	0
41.9	7	181	172	3	8	34	29.7	5	64	1	1	1	15	679	623	5
51.25	3	82046	65516	5	1	61	63.8	4	1	1	1	0	379	402	330	0
53.5	4	597	658	2	4	67	68.7	1	115	0	0	0	20	513	479	11
57.6	12	190	249	2	5	65	60.4	2	54	0	0	0	81	634	552	4
59.4	7	825	1019	4	3	93	95.1	6	22	0	2	1	36	587	529	6
60.5	1	146	151	3	6	13	3.79	10	16	3	2	3	13	592	515	4
67.7	8	1283	1619	0	4	43	37.8	3	40	0	0	0	183	510	438	0
70.2	7	5827	4910	0	1	23	32.4	2	7	0	0	0	151	365	260	5
72.2	8	4072	3654	1	3	55	71.7	3	23	0	1	0	157	489	415	3
82.7	4	5120	5532	4	4	46	45.4	0	5	2	1	0	105	460	425	6
89.2	26	230	202	1	6	8	7.92	15	86	0	1	0	33	20	0.214	5
92.8	3	2068	2243	0	8	42	42.7	1	3	4	0	2	151	613	522	3
97.45	2	2640	2600	2	2	58	55.4	1	9	0	0	0	154	378	389	4

MINOR AND TRACE ELEMENTS DDH BCD1

DEPTH	XRF Y	XRF Zn	XRF Zr	ICP Zr
1	9	119	63	32
7.4	13	170	37	0
9	16	23	260	201
11	41	327	17	0
29.6	53	145	78	228
34.2	33	54	438	309
36.1	38	346	17	88
41.9	14	61	144	78
51.25	16	213	0	117
53.5	12	147	78	29
57.6	44	214	128	68
59.4	27	174	99	46
60.5	19	79	133	68
67.7	14	75	100	57
70.2	43	50	52	38
72.2	37	153	80	44
82.7	29	114	81	41
89.2	11	115	161	110
92.8	14	101	107	61
97.45	27	97	72	32

APPENDIX 5

Tabulated Microprobe Analyses

MICROPROBE ANALYSES OF COLLOFORM STRUCTURES
Sample 36.1

Analysis No Layer	1 1	15 1	16 1	Mean
SiO_2	3.37	3.29	3.32	3.33
TiO_2	0.14	0.12	0.10	0.12
Al_2O_3	1.89	1.75	1.65	1.76
Cr_2O_3	0.18	0.11	0.00	0.10
Fe_2O_3	73.67	72.93	73.19	73.26
MnO	1.38	3.22	1.68	2.09
NiO	0.00	0.00	0.00	0.00
MgO	0.43	0.50	0.47	0.47
CaO	0.10	0.12	0.10	0.11
Na_2O	0.45	0.36	0.24	0.35
K_2O	0.00	0.00	0.00	0.00
(H_2O)	25.76	24.89	26.57	25.74
Probe Total	74.24	75.11	73.43	74.26

Corresponds to $Fe_2O_3.3H_2O$ Hydrous(?) Goethite

Analysis No Layer	2 2	12 2	14 2	Mean
SiO_2	0.47	0.13	0.25	0.28
TiO_2	0.00	0.00	0.00	0.00
Al_2O_3	21.96	21.95	21.41	21.77
Cr_2O_3	0.00	0.00	0.00	0.00
Fe_2O_3	0.00	0.30	0.00	0.10
MnO	45.55	44.98	44.47	45.00
NiO	0.97	0.58	0.92	0.82
MgO	0.28	0.16	0.27	0.24
CaO	0.00	0.00	0.00	0.00
Na_2O	1.01	0.93	1.03	0.99
K_2O	0.00	0.00	0.00	0.00
(H_2O)	29.76	31.00	31.65	30.80
Probe Total	70.24	69.00	68.35	69.20

Corresponds to $Al_2O_3.Li_2O.3MnO_2.4H_2O$ Lithiophorite(??)

Analysis No	3	10	11	
Layer	3	3	3	Mean
SiO2	4.01	3.98	4.04	4.01
TiO2	0.00	0.11	0.00	0.04
Al2O3	2.43	2.50	2.51	2.48
Cr2O3	0.00	0.13	0.12	0.08
Fe2O3	71.29	71.14	71.84	71.43
MnO	2.50	1.79	1.41	1.90
NiO	0.00	0.00	0.00	0.00
MgO	0.54	0.65	0.59	0.59
CaO	0.10	0.10	0.15	0.12
Na2O	0.39	0.55	0.52	0.49
K2O	0.08	0.00	0.00	0.03
(H2O)	25.79	26.16	26.00	25.98
Probe Total	74.21	73.84	74.00	74.02

Corresponds to Fe2O3.3H2O Hydrous(?) Goethite

Analysis No	4	8	9	
Layer	4	4	4	Mean
SiO2	0.21	0.23	0.16	0.20
TiO2	0.20	0.19	0.20	0.20
Al2O3	1.89	1.96	1.81	1.89
Cr2O3	0.00	0.10	0.00	0.03
Fe2O3	0.00	0.00	0.00	0.00
MnO	71.96	71.40	70.41	71.26
NiO	0.00	0.00	0.00	0.00
MgO	0.30	0.41	0.22	0.31
CaO	0.17	0.15	0.10	0.14
Na2O	0.64	0.70	0.48	0.61
K2O	4.56	4.57	4.57	4.57
(H2O)	20.07	20.29	22.05	20.80
Probe Total	79.93	79.71	77.95	79.20

Corresponds to KMn8O16.6H2O Cryptomelane

Analysis No	**5**	**6**	**7**	**17**	**18**
Layer	**5**	**5**	**5**	**5**	**5**
SiO_2	6.89	0.31	6.56	3.78	2.85
TiO_2	0.00	0.25	0.09	0.00	0.11
Al_2O_3	4.09	1.79	3.94	2.88	2.54
Cr_2O_3	0.19	0.10	0.15	0.14	0.00
Fe_2O_3	69.90	0.00	72.04	53.38	37.63
MnO	1.70	70.27	1.53	17.55	33.52
NiO	0.00	0.00	0.00	0.00	0.00
MgO	0.45	0.28	0.51	0.48	0.47
CaO	0.19	0.16	0.14	0.11	0.09
Na_2O	0.35	0.55	0.40	0.34	0.56
K_2O	0.08	4.03	0.07	0.89	1.94
(H_2O)	23.15	22.26	21.77	25.79	24.05
Probe Total	76.85	77.74	78.23	74.21	75.95

Heterogeneous Material

GOETHITES FROM SAMPLE 11.0

Layer	1	1	1	Mean
SiO2	3.24	3.08	3.17	3.16
TiO2	0.00	0.09	0.00	0.03
Al3O3	0.27	0.30	0.34	0.30
Cr2O3	0.00	0.00	0.10	0.03
Fe2O3	78.97	78.45	77.75	78.39
MnO	0.17	0.20	0.19	0.18
MgO	0.40	0.35	0.43	0.39
CaO	0.00	0.00	0.00	0.00
Na2O	0.58	0.37	0.47	0.47
H2O	16.37	17.17	17.56	17.03
TOTAL	83.63	82.83	82.44	82.97

Layer	2	2	2	Mean
SiO2	3.36	2.84	3.16	3.12
TiO2	0.00	0.00	0.10	0.03
Al3O3	0.55	0.47	0.56	0.53
Cr2O3	0.00	0.10	0.11	0.07
Fe2O3	79.32	78.95	78.84	79.03
MnO	0.19	0.19	0.18	0.18
MgO	0.47	0.41	0.43	0.44
CaO	0.11	0.00	0.00	0.04
Na2O	0.39	0.32	0.50	0.40
H2O	15.62	16.73	16.13	16.16
TOTAL	84.38	83.27	83.87	83.84

Layer	3	3	3	Mean
SiO2	2.28	2.33	1.88	2.16
TiO2	0.08	0.00	0.00	0.03
Al3O3	1.41	0.62	0.43	0.82
Cr2O3	0.16	0.11	0.12	0.13
Fe2O3	77.49	78.78	78.18	78.15
MnO	0.00	0.15	0.13	0.09
MgO	0.47	0.48	0.48	0.48
CaO	0.00	0.00	0.00	0.00
Na2O	0.41	0.42	0.51	0.45
H2O	17.71	17.12	18.28	17.70
TOTAL	82.29	82.88	81.72	82.30