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Exploration for volcanogenic mineralisation in Devonian rocks north of Wadebridge, Cornwall

R C Leake, K Smith, K E Rollin and D G Cameron

BRITISH GEOLOGICAL SURVEY

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Correction
Throughout this report for **Bouger** read **Bouguer**.

CONTENTS

FIGURES

TABLES

DATA PACKAGE

This report contains details of some of the geochemical surveys carried out and other results of general scientific interest but much has been omitted. A comprehensive data package is available at a current (1989) cost of 1000 pounds sterling. This includes:

A Consultation with available staff of the British Geological Survey who carried out the work.
B Examination of borehole core.
C A data package containing the items listed below.

1. Listing of chemical analyses of overburden samples.
2. Maps showing the distribution of single elements in follow-up overburden samples.
3. Results and interpretation of ground geophysical surveys.
4. Listing of chemical analyses of borehole core samples.
5. Location and graphic logs of eight boreholes collared to investigate the source of five overburden anomalies.

SUMMARY

The exploration for mineralisation associated with Middle Devonian volcanic rocks of the area north of Wadebridge in north Cornwall is described. There are no significant aeromagnetic anomalies associated with the volcanic rocks though some shallow density variations can be inferred from the Bouger gravity anomaly map. Reconnaissance overburden sampling was carried out along a series of traverses roughly at right angles to the mapped main outcrops of the volcanic rocks. The position of contacts between volcanic and sedimentary rocks was clearly discernable from the overburden geochemical data either as sharp increases in the concentration of elements like titanium or in the value of principal component 1 derived from a principal component analysis of the raw geochemical data.

Follow-up overburden sampling with further traverse and grid surveys in two localities were carried out. This work delineated a number of varieties of overburden anomaly, some of which were investigated further with ground geophysical surveys. Finally a series of eight diamond drill holes were collared to test the source of five overburden anomalies. A total of 40 horizons of basic igneous rock were intersected in the drill holes, some clearly volcanic and others clearly intrusive, which varied in inclined thickness from a few centimetres to over 50 metres. Four compositional groups of basic igneous rock were recognised on the basis of relative concentrations of the "immobile elements" Ti, Y, Zr and Nb.

Two varieties of quartz vein were found as loose blocks during the overburden sampling, containing boulangerite + galena and arsenopyrite + pyrite respectively. A significant amount of gold (up to 1.0 ppm) was subsequently found by analysis to be associated with the arsenopyrite-bearing veins. No veins corresponding exactly to these two varieties were intersected in the drill holes though quartz veins and veinlets with either manganoan siderite or ankerite are common. Associated with some of these veins and with chloritic veins are pyrite, arsenopyrite, chalcopyrite, sphalerite and galena in varying proportions and minor amounts of tetrahedrite, some of which is richly argentiferous. A second variety of mineralisation consisting of minor amounts of bournonite, jamesonite and stibnite is closely associated with intrusive greenstone bodies and their immediate aureoles. Stibnite and secondary products of its alteration in association with siderite is a third type of mineralisation.

INTRODUCTION

Exploration for mineralisation associated with the Devonian volcanic rocks of North Cornwall was carried out in parallel with a detailed overburden geochemical survey of the belt of Devonian volcanic rocks to the south of the Dartmoor granite (Leake et al 1985). Drilling as a follow-up of the reconnaissance overburden sampling in the latter area proved the existence of significant exhalative and other mineralisation and hydrothermal alteration associated with the volcanic rocks independant of the intrusion of the later Dartmoor granite. The volcanic rocks of the area to the north of Wadebridge appeared broadly similar in both age and chemical composition and were therefore also investigated with a series of reconnaissance soil traverses.

The area north of Wadebridge has had a history of significant though small scale mining activity (Dines 1956). Relatively thin veins consisting of quartz and siderite commonly with the lead-antimony sulphosalt mineral jamesonite were worked, though details of the material obtained is often not available. Galena and chalcopyrite are commonly associated with the jamesonite and more locally found are arsenopyrite and bournonite. In addition there are also veins where the ore minerals are predominantly galena and sphalerite. The Treore mine is of particular interest having provided, in the past, fine specimens of vein quartz containing native gold. Little is known about the controls of this mineralisation but it has been suggested (Edwards 1976) that the mineralisation is genetically linked to the volcanic rocks.

GENERAL GEOLOGY

A general geological map of the area surveyed is shown in figure 1. It is taken largely from the 1:50,000 BGS geological sheets 335 and 336. The map shows boundaries of volcanic rocks and greenstones but is without structural information. More recently the eastern part of the area has been remapped at the 1:10,000 scale (Warr 1988) as part of the remapping of geological sheets 335/336. This work includes detailed structural studies of the coastal exposures. The major features of S.W. England geology have been interpreted in terms of thrust and nappe tectonics (Isaac et al 1982) and thin-skinned thrust belt tectonics (Shackelton et al 1982). Evaluation of the relative importance of thrusting and major folding in the control of outcrop patterns is disputed with thrust-dominated models (Selwood and Thomas 1988) and nappe-dominated models (Seago and Chapman 1988) both being put forward. Much of the uncertainty originates from the contrast between excellent coastal exposures and an almost complete lack of inland exposure. The area lies to the north of the Polzeath facing confrontation (Gauss 1967), about which there has been a great deal of debate in the literature, and within the zone of anomalous south-facing folds.

The area surveyed consists essentially of the Middle Devonian Trevose slates. These are designated by Warr (1988) as a grey slate sequence within which there are significant amounts of basic igneous rocks, including the 60m thick pillow lavas of Pentire Head. Slaty cleavage is well developed and dips generally gently to the S or SW. Bedding can be seen in the boreholes and this appears generally to dip at a moderate to steep angle to the north or NE.

REGIONAL GEOPHYSICS

Gravity anomalies

Bouger gravity anomalies across north Cornwall show a general decrease towards the SE, reflecting the low density of the St Austell and Bodmin Moor granites. However the curvature of the contours just north of the Camel estuary (Figure 2) is most likely related to density variations within the Devonian rocks.

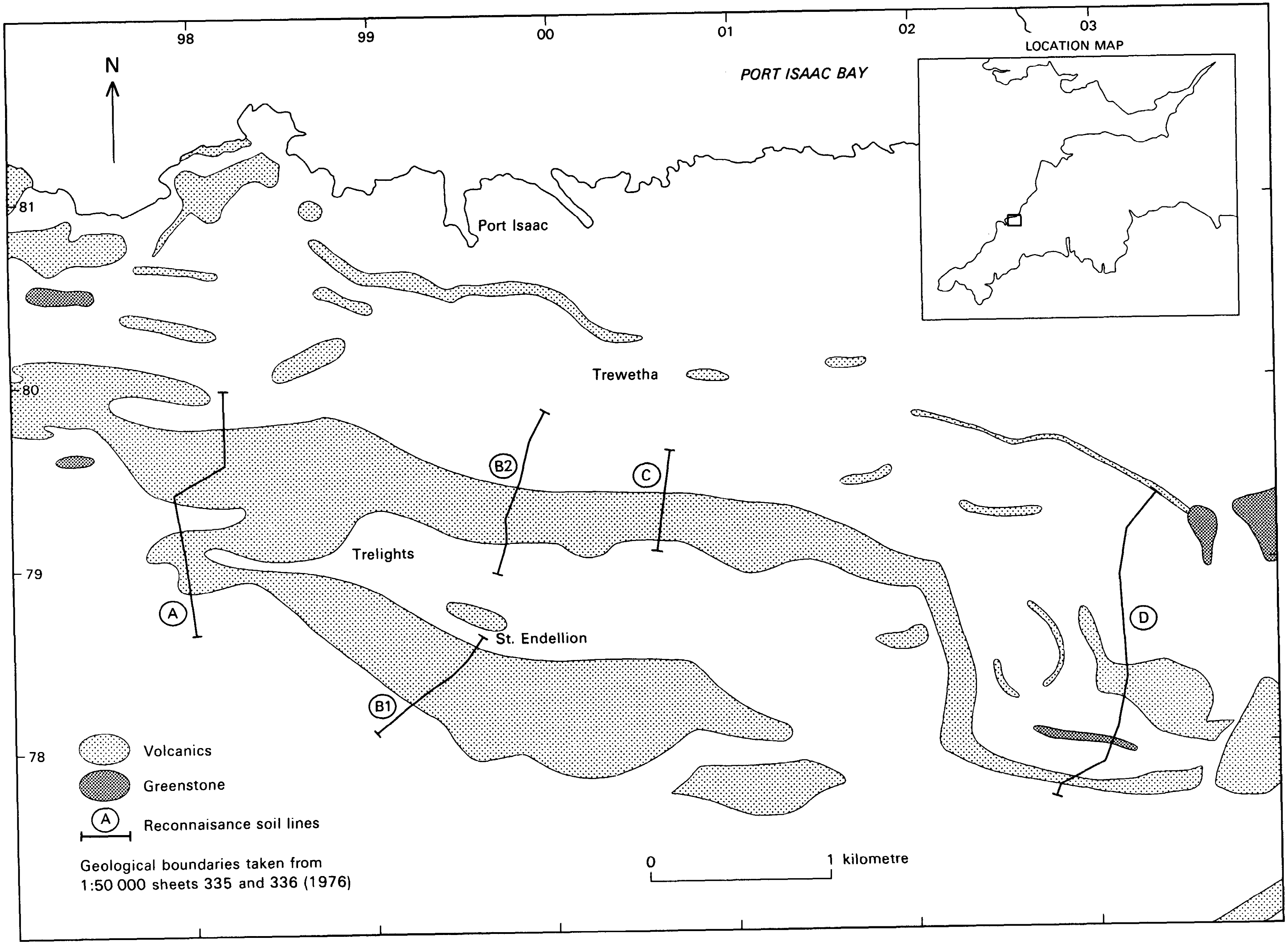


Figure 1 Location of reconnaissance overburden sampling lines.

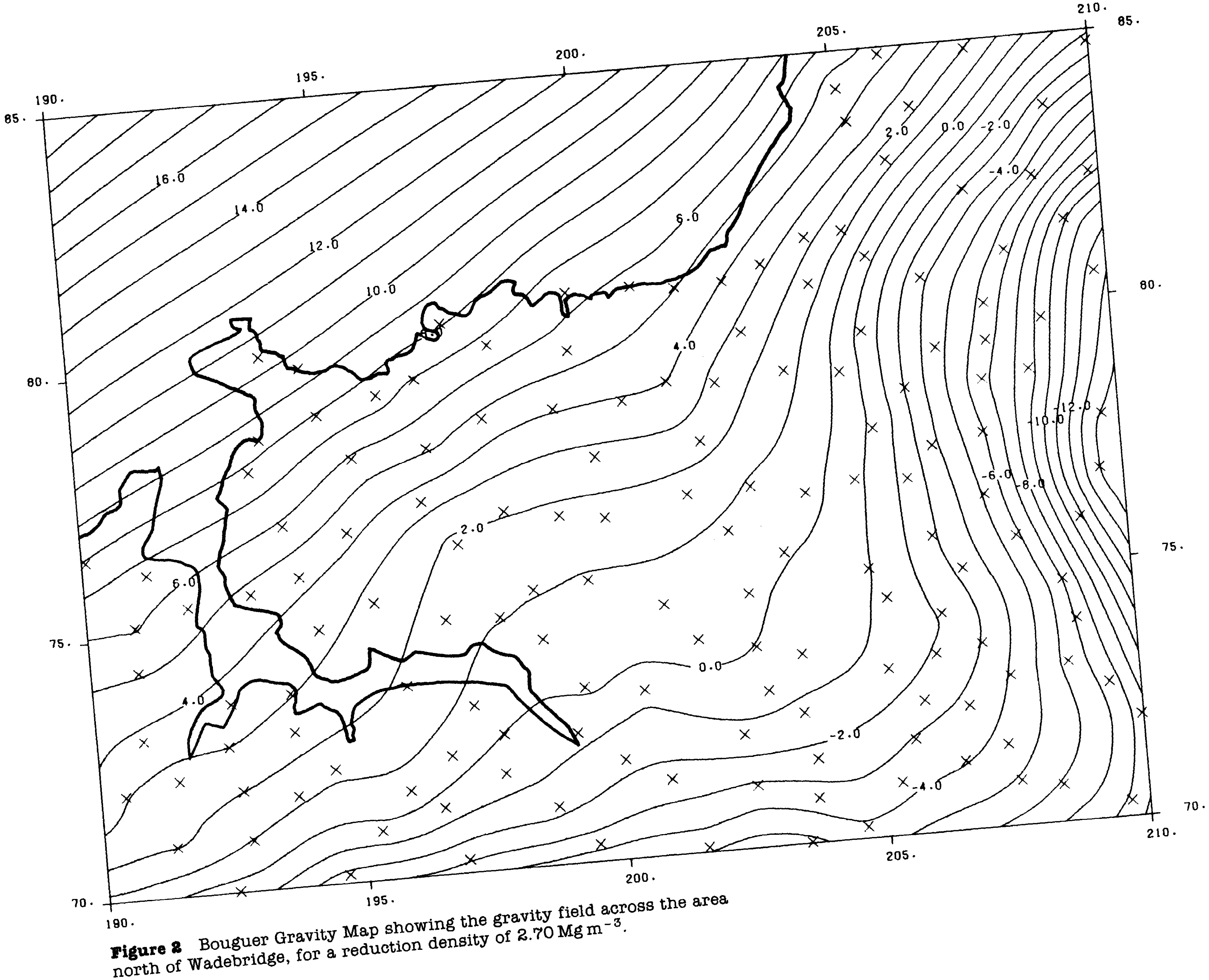


Figure 2 Bouguer Gravity Map showing the gravity field across the area north of Wadebridge, for a reduction density of 2.70 Mg m^{-3}.

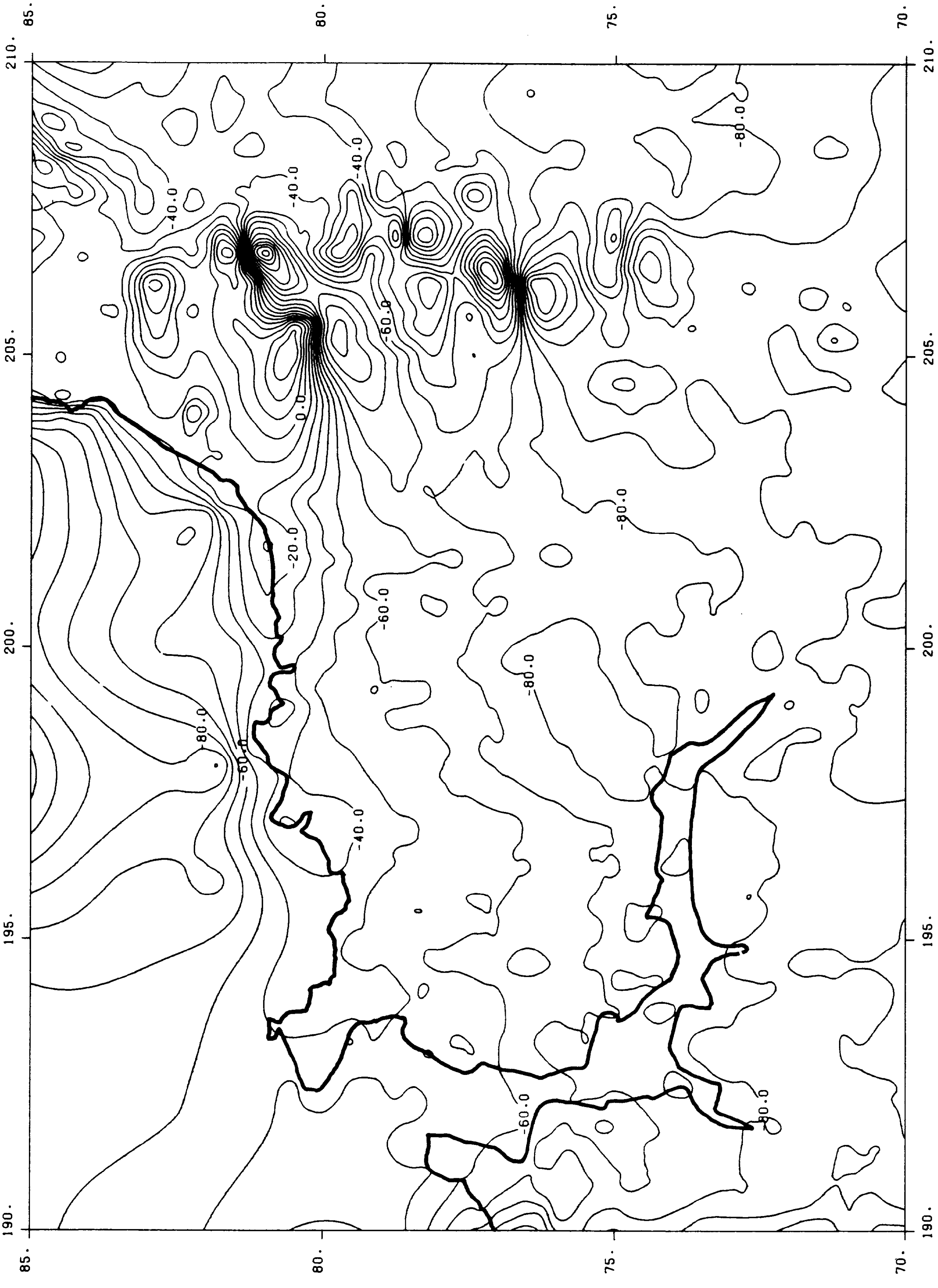


Figure 3 Aeromagnetic anomaly map of the area north of Wadebridge at a mean terrain clearance of 152 m.

Aeromagnetic anomalies

Aeromagnetic data were collected in 1957 along N-S flight lines spaced approximately 400 m apart, with a mean terrain clearance of 152 m. These data have subsequently been digitised at BGS. A series of discontinuous anomalies, exhibiting a south directed polarisation vector, occur around the north and west margins of the Bodmin Moor granite. These are much simplified on the published 1:250 000 BGS aeromagnetic anomaly map of 1977, but a detailed contour map for the data around Wadebridge (Figure 3) indicates similar anomalies in grid square SX 07. In contrast in the area covered by the reconnaissance survey (Figure 1) there are no significant aeromagnetic anomalies.

Airborne electro-magnetic data

Airborne EM measurements were made in conjunction with the aeromagnetic survey. Phase differences between primary and resultant EM fields were measured for two frequencies, 400 Hz and 2300 Hz. These data are available as compiled worksheets at 1: 25 000 scale but have not been digitised.

SCOPE OF MRP INVESTIGATION

A series of 5 reconnaissance soil traverses were sampled across the main oucrops of volcanic rocks as shown in figure 1. The siting of these was based to some extent on the areas thought on the basis of the previous MRP drainage geochemical survey of Cornwall (Jones 1981) to have some potential for undiscovered mineralisation. They were also sited to avoid the areas known to be mineralised and affected by old mining activity. Subsequently further soil sampling and ground geophysical surveys were carried out. Finally eight boreholes were drilled at seven sites to test the source of various types of overburden anomaly.

RECONNAISSANCE OVERBURDEN SAMPLING SURVEY

Sampling and analytical methods

Overburden sampling was carried out at 20 m intervals along the 5 reconnaissance lines using a soil auger. Sampling depths were highly variable from 30 cm to 1.4 m depending on the stoneyness of the soil but averaged about 55 cm. Samples weighing around 100 gm were placed in Kraft paper bags and subsequently dried and disaggregated before sieving to obtain a minus 85 BSS fraction (180 micrometres). Each sample was further ground and analysed for Cu, Pb, Zn, Co, Ni and Ag by atomic absorption spectrophotometry (AAS) after a nitric-perchloric acid attack and for Ca,Ti, Mn,Fe,Ni,Sn,Sb,Ba and Ce by X-Ray Fluorescence Spectrometry (XRF) at the BGS laboratories in Gray's Inn Road, London. Since Ni was determined by both analytical methods a comparison can be made between the two; good agreement between the two data sets exists with XRF values slightly higher than AAS values at the highest concentrations (fig.4) At lower concentrations there are a few samples with significantly higher Ni by XRF than Ni by AAS perhaps due to the incomplete dissolution of Ni during the acid attack.

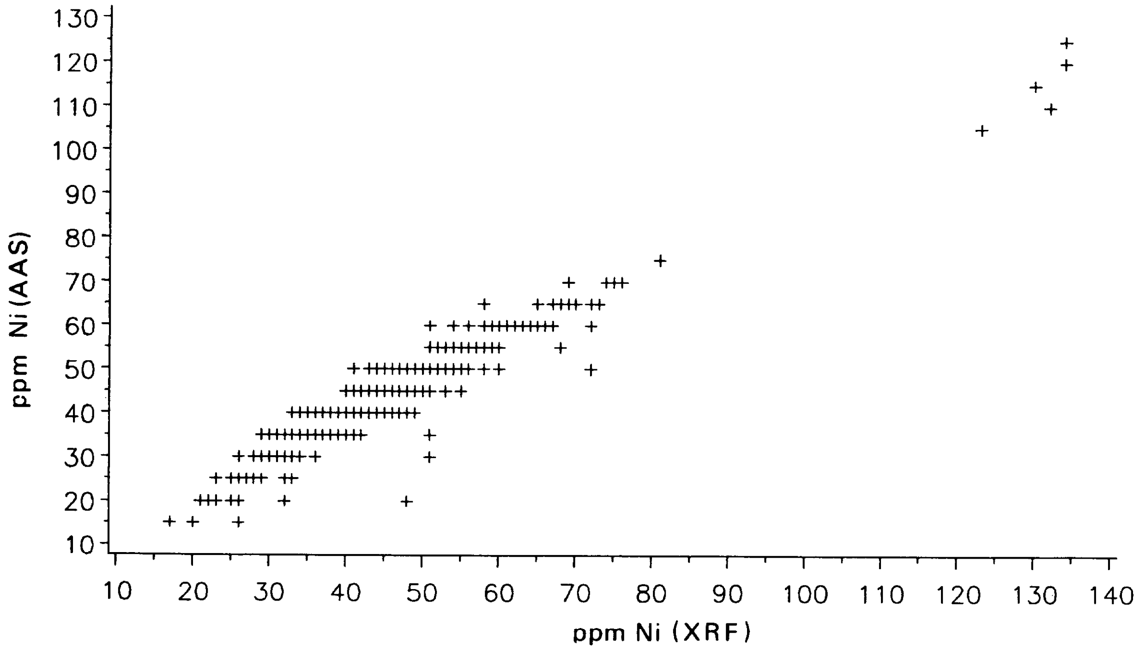


Figure 4 Comparison of nickel determinations by XRF (NIX) and AAS (NAI). Axes in ppm.

Results

Summary statistics of the reconnaisaance soil data are shown in table 1 below.

Table 1 Summary statistics of reconnaissance soil data

Element	Mean	Stan. Dev.	Min.	Max.
Ca %	0.26	0.15	0.05	2.45
Ti %	1.12	0.35	0.59	2.04
Mn ppm	2600	1100	230	6970
Fe %	8.70	1.47	5.08	15.15
Co ppm	33	9	5	70
Ni ppm (XRF)	44	14	17	134
Ni ppm (AAS)	43	13	15	125
Cu ppm	33	9	10	95
Zn ppm	142	46	50	440
As ppm	77	69	18	1046
Ag ppm	1	<1	<1	3
Sn ppm	9	6	<1	82
Sb ppm	18	26	<1	368
Ba ppm	349	58	204	610
Ce ppm	63	12	21	97
Pb ppm	66	46	20	480

Total of 459 samples

Cumulative frequency plots for each element in the reconnaissance soil samples are shown in figures 5 and 6. The distribution of titanium shows clear evidence of the existence of two populations about equally abundant. For the elements Ca,Ni,Cu,Zn,Sn,Sb and perhaps Ba there is

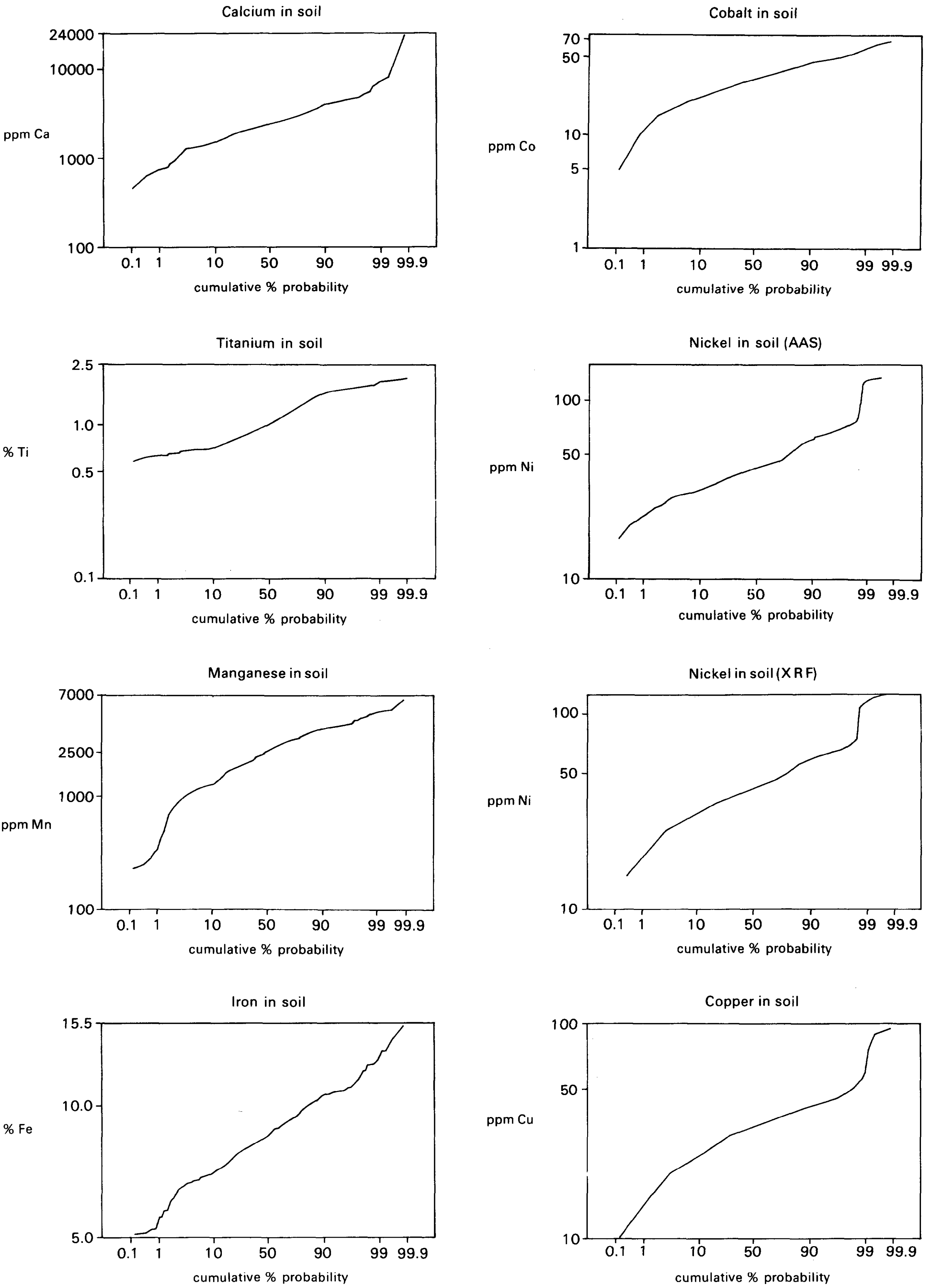


Figure 5 Cumulative frequency plots of Ca, Ti, Mn, Fe, Co, Ni (AAS), Ni (XRF) and Cu in reconnaissance soil samples.

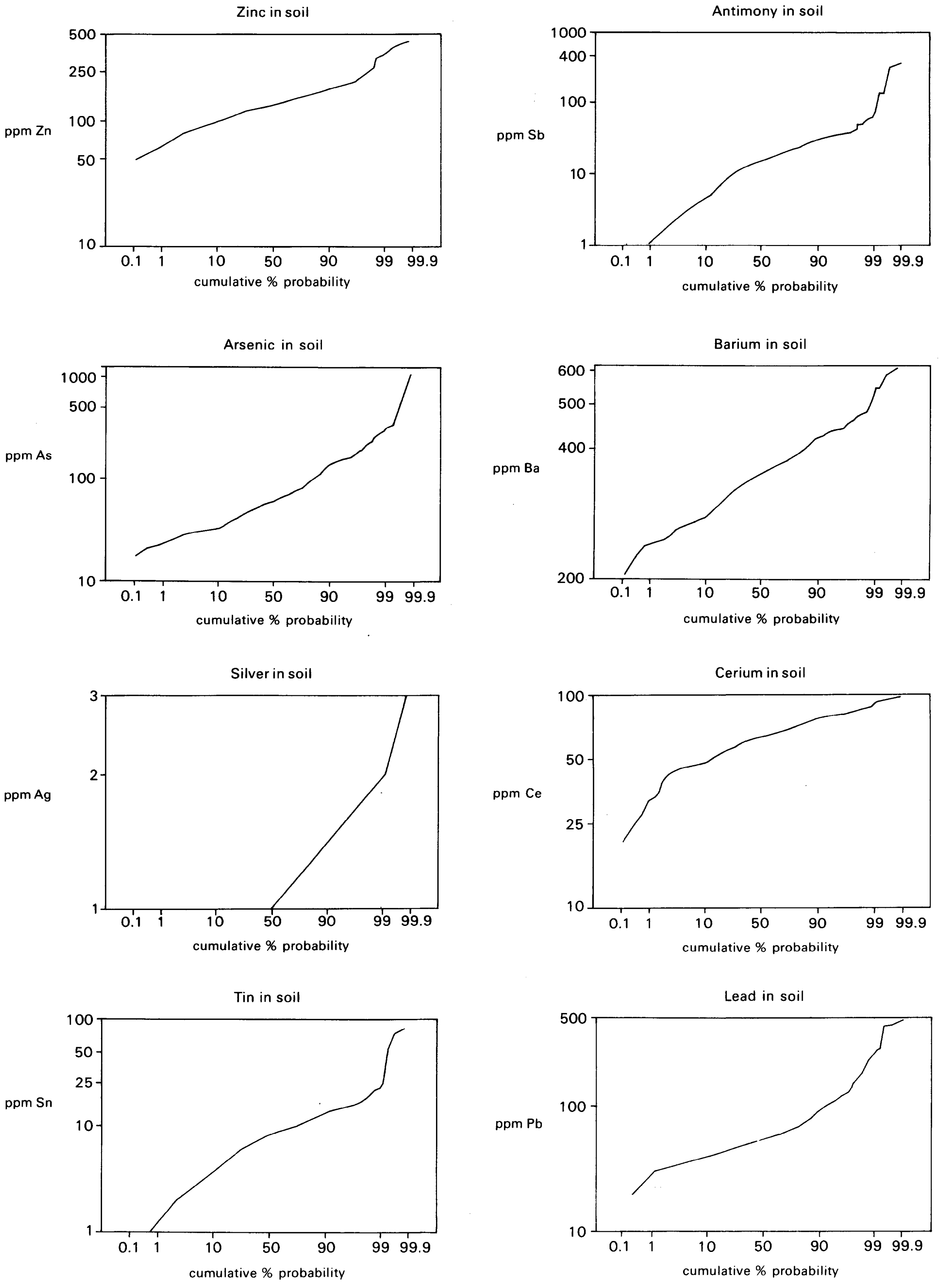


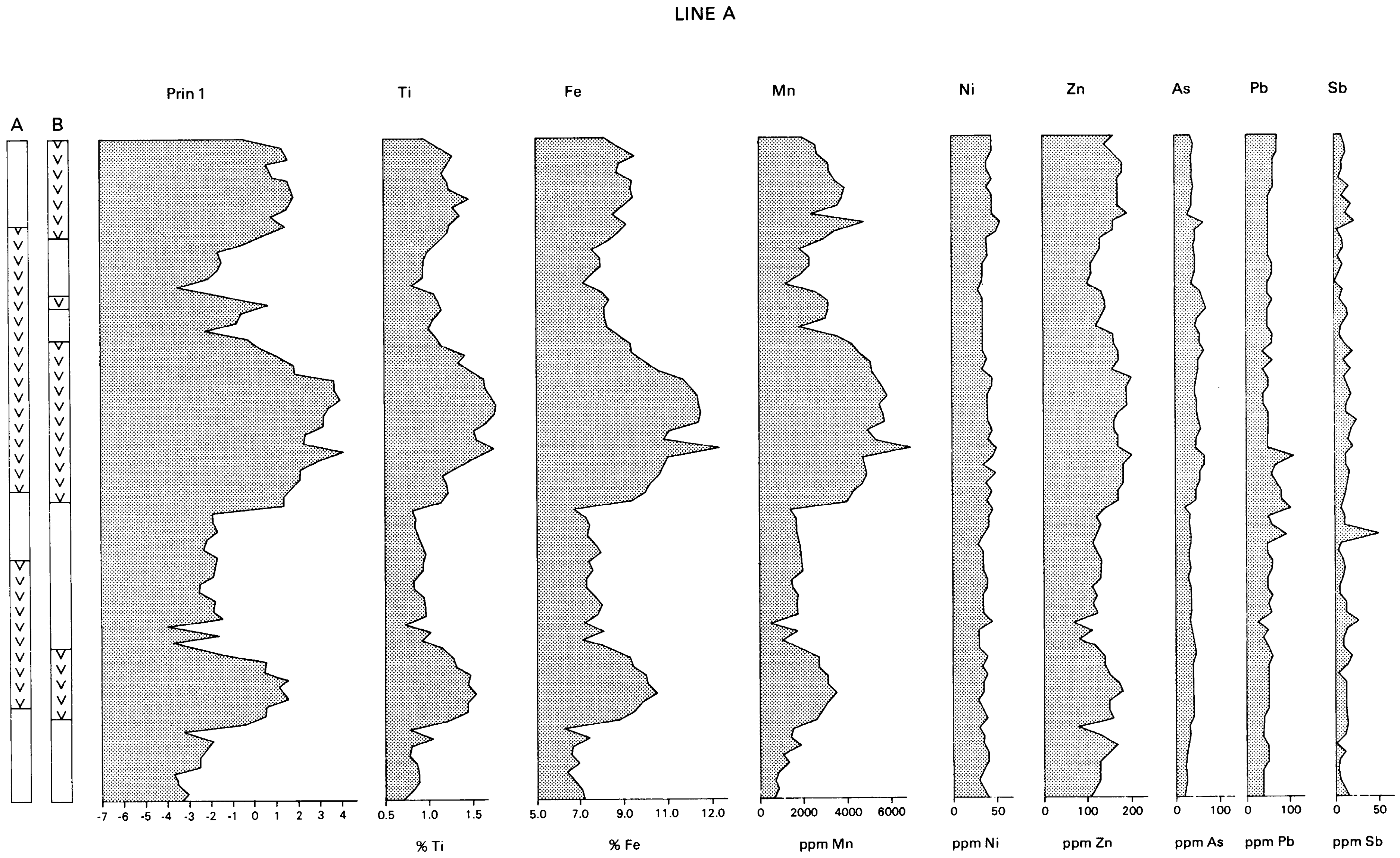
Figure 6 Cumulative frequency plots of Zn, As, Ag, Sn, Sb, Ba, Ce and Pb in reconnaissance soil samples.

evidence for a small anomalous population above the 95 to 99 percentile. For As and Pb the anomalous populations are larger, above the 90 percentile.

A principal component analysis of the reconnaissance soil data provided five principal components with eigenvalues in excess of 1. The first principal component grouped Ti,Mn,Fe,Co and Zn as the main positive contributants and Ba as the main negative component. Values of this principal component have been plotted along with some single elements in the profile of each soil line in figures 7,8,9,10 and 11. This principal component reflects the difference in chemistry of soils derived from igneous rocks and those derived from sedimentary rocks. The second principal component has Ti,Mn and Sb as the main positive components and Ni as the main negative component and probably reflects an association of Sb and Mn enrichment with some of the volcanic rocks. The third principal component has Pb,Sb,Cu and Zn as the main positive components and reflects mineralisation. The significance of the fourth principal component which has Ce,Ni and Ba as the main positive contributants and Ca,Sn and Ag as the main negative components is unclear but it may reflect geochemical differences in the sedimentary rock from which the soil samples are derived. The fifth principal component is dominated by Sn and Ce as the main positive components and As as the main negative component and probably reflects the influence of the Bodmin Moor granite to the east of the area surveyed.

Experience in several parts of S.W. England (Smith and Leake 1984, Leake et al 1985, Shepherd et al 1987) has shown that soil geochemistry can be a powerfull technique in geological mapping of unexposed ground. In all areas predictions of geology based on soil geochemistry have been confirmed by drilling. Three influences can be recognised which disturb the relationship between soil and underlying geology. Firstly this results from the presence of any overburden of exotic origin, for example water-transported periglacial gravel or alluvium or wind-blown loess. Secondly, and a much more serious problem, because it is difficult to detect, is the transportation of soil as a result of farming activity, for example removal of hedgerows and smoothing of slopes . This sort of operation is generally of limited extent but must be considered a possibility if drainage has been diverted and field boundaries changed. Thirdly where steep slopes exist it is likely that soil creep will have caused boundaries reflected in the soils to have moved downslope.

The plot of single elements Ti,Fe,Mn,Ni,Zn,As,Pb and Sb together with principal component 1 for line A is shown in figure 7. Also plotted are the boundaries of the volcanic rocks taken from the published BGS geological map, based on mapping carried out at the beginning of the century, and the boundaries of the volcanic rock deduced from the sharp increase in levels of Ti,Fe,Mn and especially principal component 1. The strong correlation between principal component 1 and the above three elements is very evident as is the accentuation of the differences shown by principal component 1. This principal component is thus a better discriminant between the volcanic-derived soils and those originating from sedimentary rocks than the single elements.Comparison of the two sets of boundaries (Fig. 7) shows both similarities and differences. The southernmost outcrop of volcanic



A Boundaries of volcanic rock from published original 1:50 000 geological map

B Boundaries of volcanic rock deduced from soil geochemistry

V Mafic igneous rocks (mostly volcanic)

Figure 7 Profile plot of concentrations of Ti, Fe, Mn, Ni, Zn, As, Pb, Sb and value of principal component 1 in soil samples from line A.

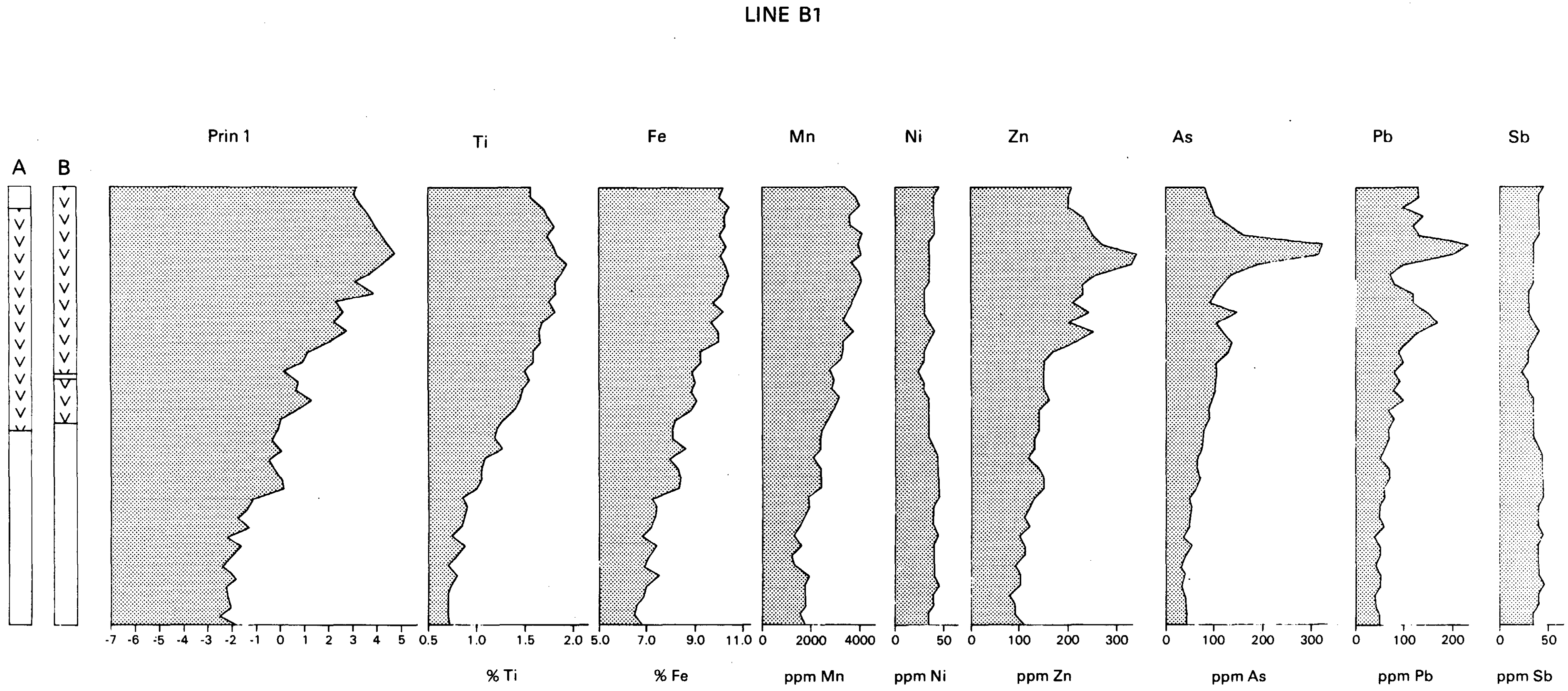


Figure 8 Profile plot of concentrations of Ti, Fe, Mn, Ni, Zn, As, Pb, Sb and value of principal component 1 in soil samples from line B1.

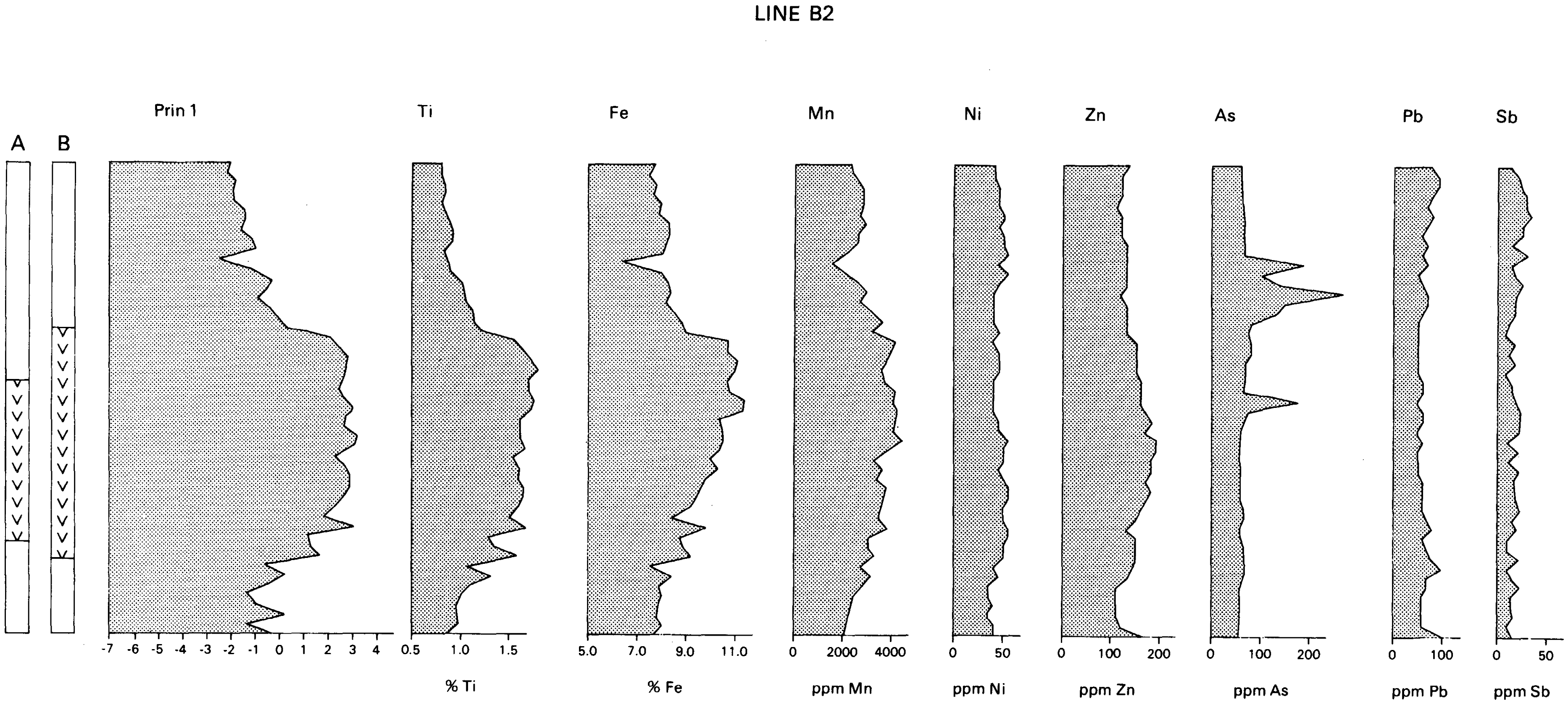


Figure 9 Profile plot of concentrations of Ti, Fe, Mn, Ni, Zn, As, Pb, Sb and value of principal component 1 in soil samples from line B2.

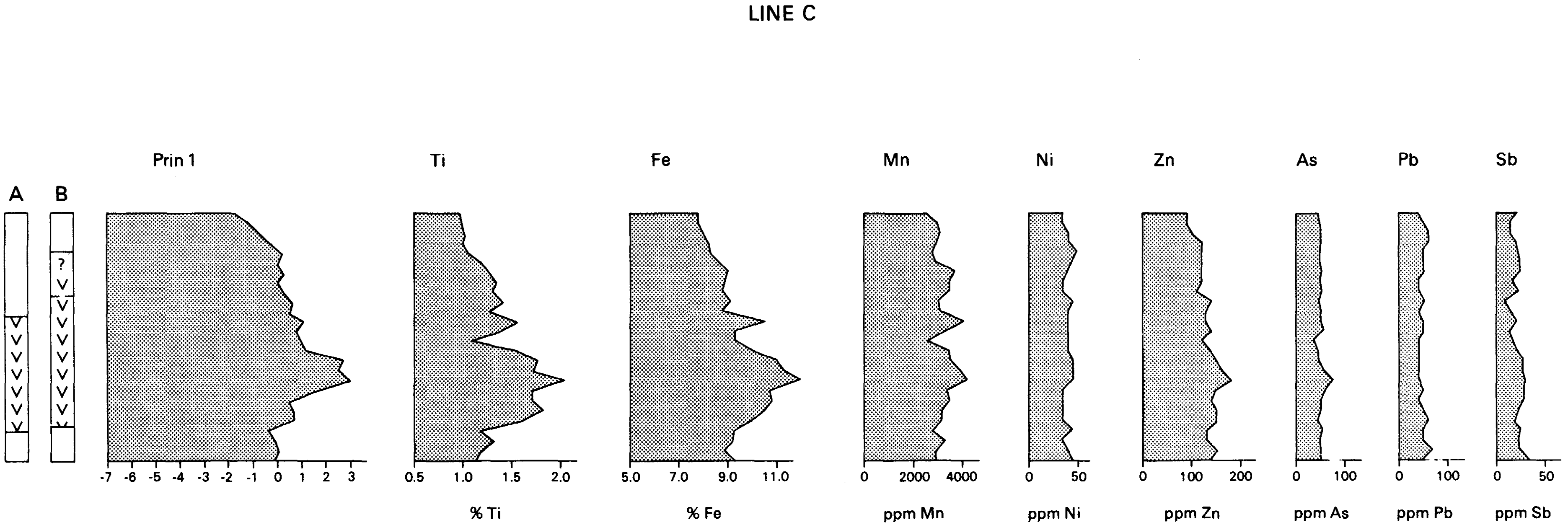


Figure 10 Profile plot of concentrations of Ti, Fe, Mn, Ni, Zn, As, Pb, Sb and value of principal component 1 in soil samples from line C.

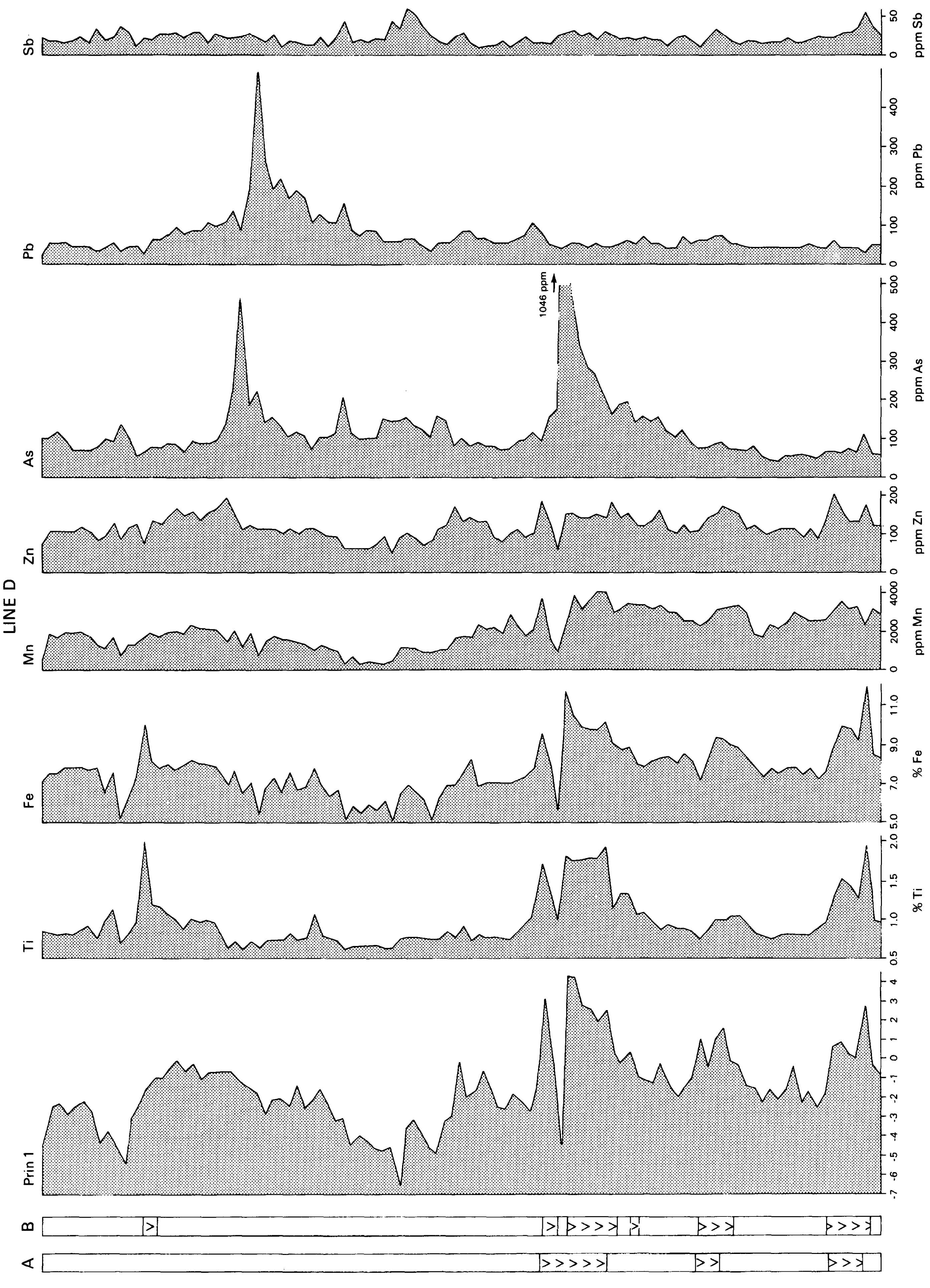


Figure 11 Profile plot of concentrations of Ti, Fe, Mn, Zn, As, Pb and Sb and value of principal component 1 in soil samples from line D.

rocks is, on the basis of soil geochemistry, significantly less than on the original geological mapping though there is relatively close agreement for the position of the southernmost contact. This suggests that the "nose" joining the two main masses of volcanic rock shown on the geological map does not exist and that they may therefore represent separate thrust sheets. There is again relatively close agreement between the southern boundary of the next body of basic igneous rock but again it is significantly narrower on the basis of soil geochemistry compared with the original geological mapping. Furthermore there appears to be a separate thinner horizon of volcanic rock to the north of the main body on the basis of the soil geochemistry. In addition the soil geochemistry clearly indicates that the tongue of volcanic rock shown on the geological map to terminate just west of the line actually extends further to the east.

The agreement between the boundaries of the volcanic rock by the two methods on line B1 (Fig. 8) is very close though there is a suggestion from the soil geochemistry that a sediment layer occurs within the volcanic. For line B2 (Fig. 9) the soil geochemistry indicates a wider outcrop of volcanic rock than the original geological mapping, especially to the north. On line C (Fig. 10) there is again close agreement as to the position of the southern contact of the volcanic unit. The soil geochemistry suggests that the northern extent of the volcanic is greater than shown on the geological map though it seems less titanium-rich than material to the south. This could reflect a difference in composition or perhaps a composite sequence of volcanics and sediments. The agreement between the two sets of boundaries for line D (Fig. 11) is close with a few differences in detail. In the north high Ti and Fe levels in soil suggest the presence of a thin volcanic horizon though this is not apparrent in the principal component 1 values. For the main outcrop of volcanic rocks soil geochemistry suggests some interlayering of sedimentary rocks with the volcanics and a wider total outcrop. The greenstone shown to be crossed by the line is detected with the soil samples, characterised by lower levels of Ti, Fe and principal component 1 than the volcanic rocks. The reconnaissance soil lines also demonstrate that some metallic element anomalies are clearly associated with the outcrop of volcanic rocks while others are not.

FOLLOW-UP OVERBURDEN SAMPLING

Follow-up overburden sampling was carried out in several stages and comprised pig digging at some anomalous sites and additional lines and grids in areas of interest. The results of this work forms part of the data package. Summary statistics of the follow-up overburden data are however shown in Table 2.

Table 2 Summary statistics of follow-up soil data

Element	Mean	Stan. Dev.	Min.	Max.
Ca %	0.18	0.11	0.03	1.37
Ti %	1.08	0.47	0.60	3.17
Mn ppm	2231	1219	200	7930
Fe %	8.47	2.03	4.36	24.64
Co ppm (1)	23	10	5	40
Ni ppm	42	14	16	107
Cu ppm (3)	33	12	10	135
Zn ppm (3)	180	126	30	811
As ppm (3)	149	200	25	1767
Sn ppm	8	4	<1	24
Sb ppm	116	257	4	2755
Ba ppm	418	80	134	626
Pb ppm (3)	88	122	8	1233
W ppm (2)	4	2	<1	12

Number of analyses (1) 56, (2) 153, (3) 342, rest 320.

DETAILED GEOPHYSICAL SURVEYS

Ground reconnaissance geophysical traverses using Very Low Frequency (VLF), self potential (SP) and magnetic methods were surveyed at three localities. Subsequent work included induced polarisation (IP) and shallow electromagnetic profiling at two of these sites. Details of these surveys form part of the data package which accompanies this report.

DRILLING

A total of eight diamond drill holes were collared to test the source of five overburden anomalies of different varieties. Details of their location, lithological logs and chemical analyses are included in the data package. Some general conclusions are, however, presented below. Chemical analyses of 603 samples of core have been obtained for Ca, Ti, Mn, Fe, Ni, Cu, Zn, As, Rb, Sr, Y, Zr, Nb, Sb, Ba and Pb. In addition the elements Mo, Sn, La, Ce, W, Au, Bi, Th and U have been determined in smaller numbers of samples.

Forty separate bodies of basic igneous rock were intersected in the boreholes varying in inclined thickness from a few centimetres to over 50 metres. All the igneous rocks are readily distinguishable chemically from the sedimentary rocks particularly on the basis of higher contents of TiO_2. Thus in figure 12 the field occupied by the sedimentary rocks is clearly different from the fields of the various igneous rocks. This is entirely consistent with the recognition of the boundaries of igneous rocks on the basis of the chemistry of residual soil samples described above.

The vast majority of sedimentary rock intersected in the boreholes is argillaceous and geochemically all this material shows similar

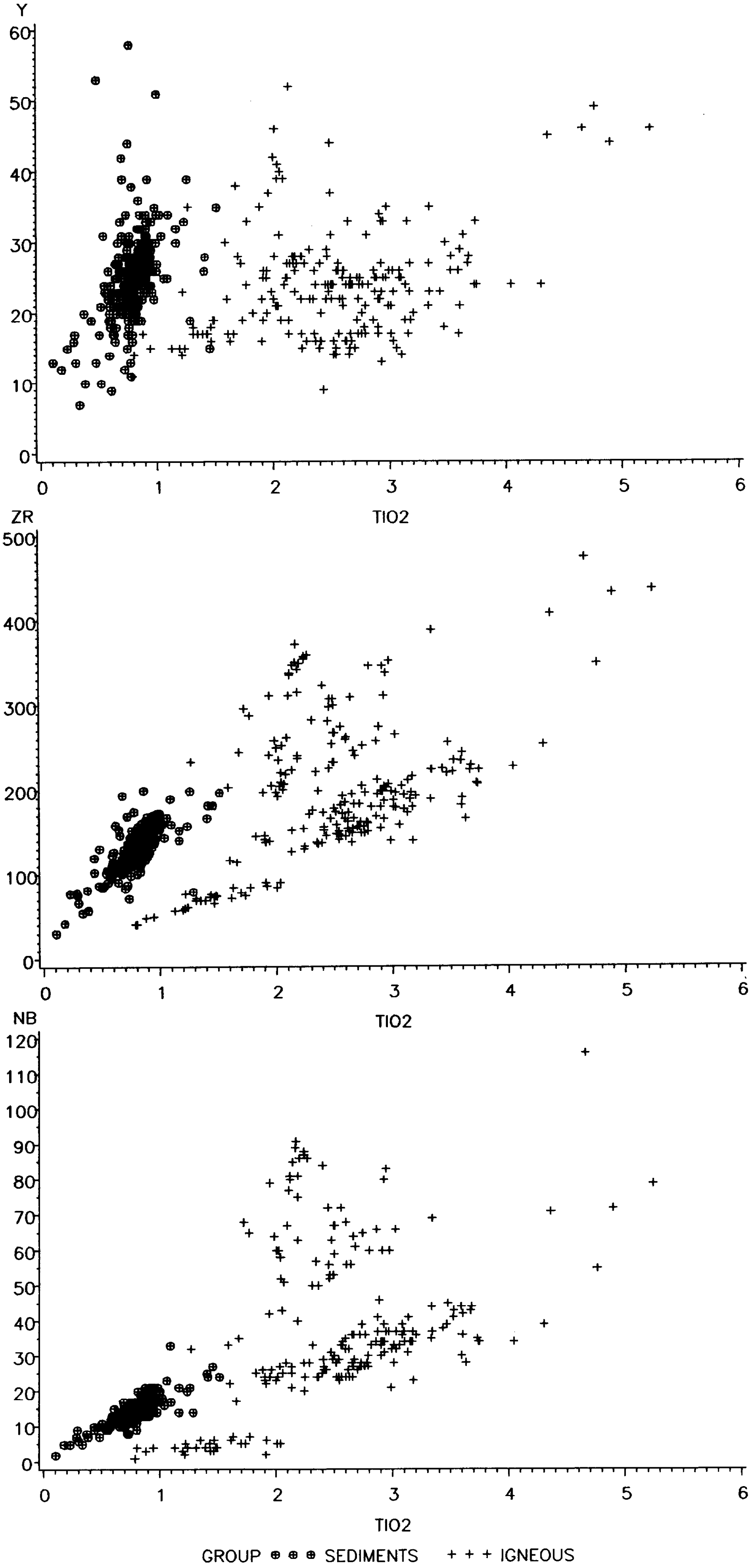


Figure 12 Plot of element pairs Y-TiO_2, Zr-TiO_2 and Nb-TiO_2 in borehole core samples with igneous rocks distinguished from sedimentary rocks and veins. Y, Zr and Nb axes in ppm, TiO_2 axes in %.

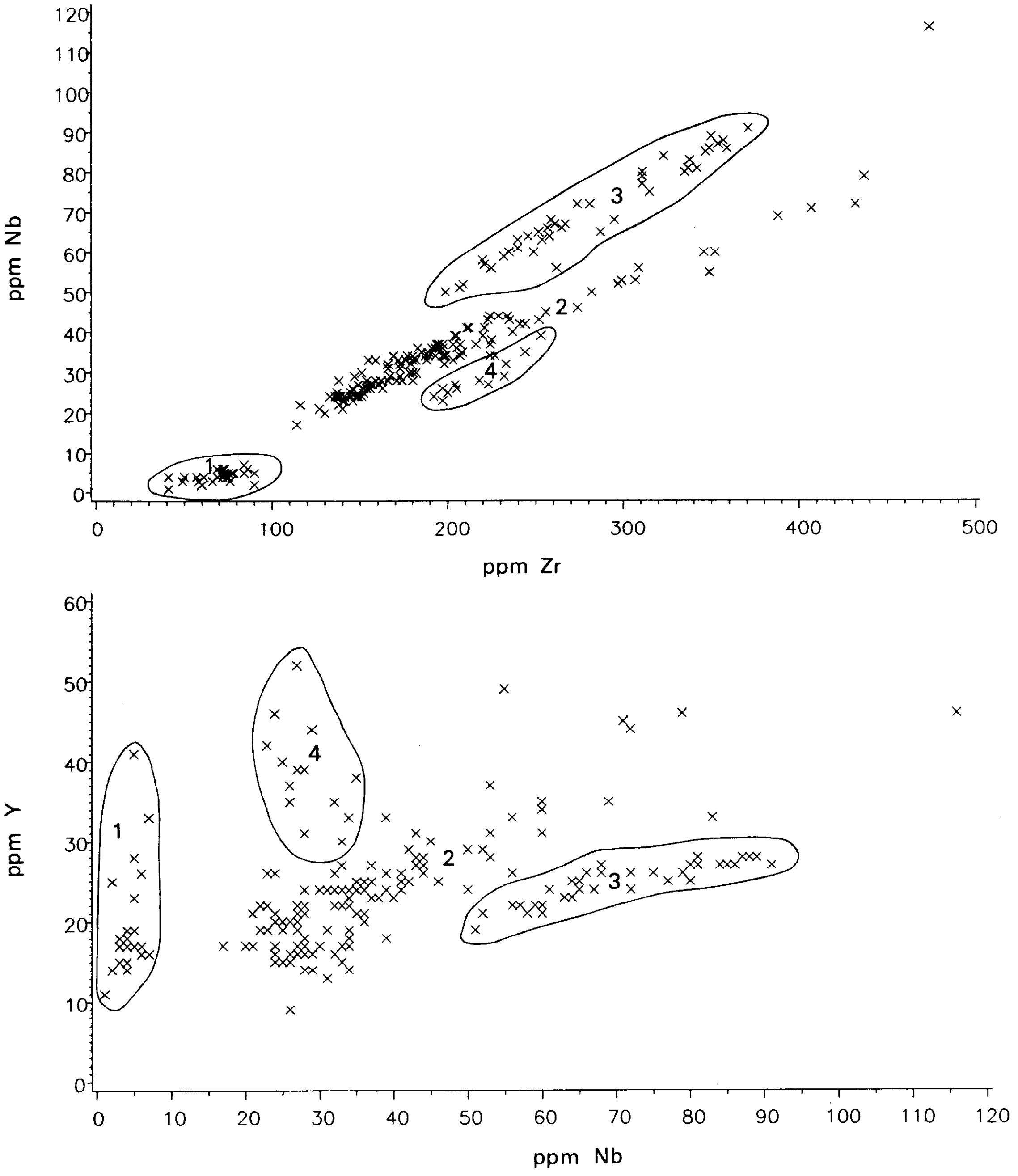


Figure 13 Plot of element pairs Nb-Zr and Y-Nb in borehole core igneous rock samples. All axes in ppm. Igneous rock groups 1, 2, 3, and 4 are distinguished.

characteristics. Two other varieties of sedimentary rock occur but in much smaller amounts and both are characterised by lower concentrations of Ti, Y, Zr and Nb than the dominant argillaceous rock that can be seen as distinct tails in figure 12. There are rare cherty sediments up to 80 cms thick containing a significant amount of chemically precipitated silica associated with the contacts between horizons in a relatively thick volcanic unit. In addition there are calcareous horizons interlayered with argillaceous rocks in one hole, the thickest being about 50 cms in inclined width. There appears to be a gradual decrease in both interlayered slate and the detrital component of the calcareous rocks downwards in the hole, the lowest horizon intersected being a relatively pure calcite rock with a relatively small detrital component. This is shown by the point with the lowest concentration of the elements Ti and Zr (figure 12). To a limited extent there is a gradation in composition between the sedimentary and the igneous rocks due to the presence of volcanic inclusions in some horizons of argillaceous rock.

Figure 12 also demonstrates the wide compositional variation of the igneous rocks. At least four major compositional groupings can be recognised in figure 12 and in the plots of Nb against Zr and Y against Nb shown in figure 13. Group 1 is relatively depleted in Ti, Zr and Nb and represents a series of four intrusive doleritic bodies or greenstones intersected in two boreholes. The majority of samples can be assigned to a second group which on the basis of Nb and Zr concentrations are chemically similar to analysed samples of the Pentire volcanic group exposed on the coast (Floyd, 1983; Rice-Birchall and Floyd, 1988) but with several samples significantly richer in Nb and Zr than the analysed coastal material. Group 3 samples are clearly enriched in Nb relative to Zr, Y and Ti and in Zr relative to Ti. They comprise five bodies, three of which appear to be intrusive doleritic and two, in a separate borehole, appear to be thin volcanic horizons. The fourth group is made up of seven relatively thin volcanic units which is depleted in Nb relative to Zr and relatively enriched in Y relative to Ti and Nb.

The compositions of the igneous rocks have also been plotted in figure 14 on a $TiO_2 x 60$-Zr-Yx3 triangular diagram used as a tectonic discrimination diagram by Pearce and Cann (1973). The majority of samples plot in the field of "intraplate basalts" on this diagram but the composition of group 1 samples is relatively more Y-rich and they partly plot in the fields of "predominantly arc tholeites" and "predominantly mid-ocean ridge basalts". The composition of group 4 samples is also relatively enriched in Y and these tend to plot in the field of "calc-alkali basalts". The Y enrichment may be an original chemical feature, however, it is unlikely that the indicated wide variation in tectonic environment is real. It is more probable that a secondary process has modified the rock chemistry, perhaps hyrothermal activity involving CO_2 as suggested by Rice-Birchall and Floyd (1988). Most of the igneous rocks have undergone intense alteration and carbonation though it may be significant that the majority of the rocks showing the relative enrichment in Y are probably shallow intrusive rocks rather than lavas.

The different compositional groups of igneous rock commonly occur within the same borehole. Thus in one borehole there are successive

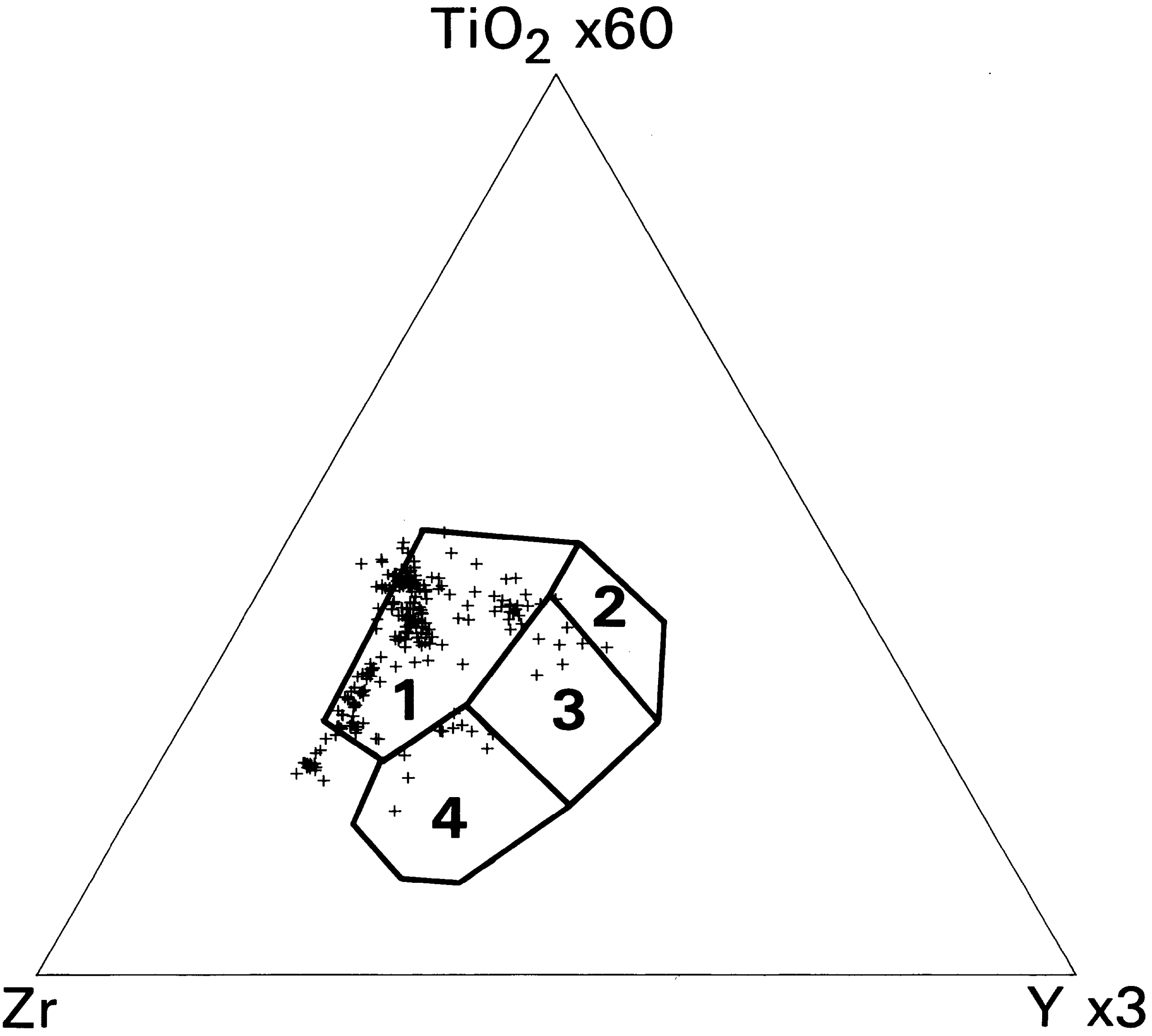


Figure 14 Triangular plot of TiO_2% x 60-Zr-Y x 3 plot of borehole core igneous rock samples with Pearce and Cann (1973) tectonic discrimination diagram fields. Fields are 1. intraplate basalts; 2. predominantly arc tholeiites; 3. predominantly mid-ocean ridge basalts; 4. predominantly arc calc-alkali basalts.

thin volcanic horizons of groups 2, 3, 2 and 3 within a 20 metre section of core and in another hole there are successive thin volcanic horizons of groups 4 and 3 separated by 3.5 metres of sedimentary rock. Such a relationship between volcanic rocks suggests a rapidly evolving tectonic environment. The age difference between the various units of volcanic rock and the intrusive rocks forming group 1 is not known. No volcanic rocks of similar composition have been intersected and in view of the very large compositional difference between group 1 and the others there is probably a relatively large time gap between the volcanic rocks and the intrusive rocks. According to data presented by Floyd (1982) there are intrusive rocks in west Cornwall which are similar in composition to the group 1. Group 1 is also similar in composition to some volcanic rocks in the Lower Devonian of South Devon (unpublished BGS data). There are volcanic rocks of apparently similar Middle Devonian age to the south of the Dartmoor granite (Leake et al 1985). However there are insufficient analyses of the more immobile elements like Zr and Nb for a direct chemical comparison to be made with the volcanic rocks of the present area. The Ti contents of the South Hams volcanics are broadly similar to those of group 2.

MINERALISATION

During the reconnaissance soil sampling a number of loose blocks of mineralised vein material of two varieties were found. Chemical analyses of samples of this material are shown in Table 3.

Table 3 Chemical analyses of loose blocks of vein material

Sample	Cu	Zn	As	Ag	Sb	Pb	Au
DCR 1	165	350	7	3	5600	8400	<13
DCR 2	9	42	10700	<1	92	114	1030
DCR 3	2	3	6590	<1	38	23	271
DCR 4	5	10	6460	<1	35	18	499

All results in ppm except for Au which is in ppb

Sample DCR 1 is of a quartz vein containing a small amount of muscovite and aggregates of small radiating acicular crystals of boulangerite. Galena is also present intergrown with the boulangerite. The yellow secondary antimony mineral bindheimite occurs along grain boundaries and coats the outer surface of the sample. Samples DCR 2 to 4 are of a second variety of vein quartz with interstitial muscovite and chlorite, with which arsenopyrite is associated, together with pyrite and rare small grains of sphalerite. A secondary arsenic mineral, probably scorodite, rims and in some cases entirely replaces the arsenopyrite.

No veins exactly corresponding to the above types were intersected in the boreholes but several other varieties of veinlet occur. Carbonate-bearing veinlets are particularly common and in some sections abundant. The carbonate in these veins is either sideritic with an appreciable manganese content and showing a strong positive correlation between Fe and Mn (Fig.15) or ankeritic with a higher Mn to Fe ratio and an appreciable Ca content (separate field in Fig. 15). Though both carbonate types occur in one borehole, in all the others either one or the other is dominant, a feature which could be of regional significance. The carbonate veining is not confined to the igneous rocks but it is much more frequent (75%) within these than the sediments.

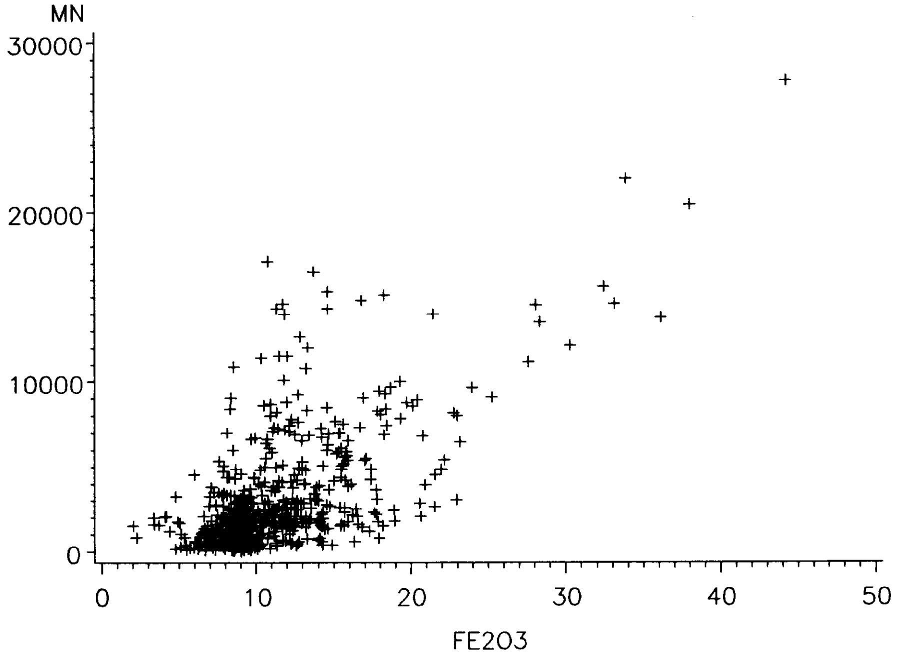


Figure 15 Plot of Mn against total iron as Fe_2O_3 in borehole core.

Summary statistics of the analyses of borehole material are given in table 4.

Table 4 Summary statistics of borehole chemical data

Element	Mean	Stan. Dev.	Min.	Max.
Mn	3058	3418	<10	2.77%
Cu	34	127	<1	3072
Zn	187	376	25	5482
As	97	421	1	7673
Ag	1.5	1.8	<1	24
Sb	30	93	<1	2134
Pb	47	221	<1	4245
Au (ppb)	3	6	<1	57

603 samples analysed (174 for Au)
All results in ppm except Au

Three main sulphide assemblages occur within the boreholes. Associated with quartz, quartz + siderite and chloritic veins or lenses are varying proportions of the minerals pyrite, arsenopyrite, chalcopyrite, sphalerite and galena. Minor amounts of tetrahedrite are also frequently present usually intimately associated with chalcopyrite. The silver content of the tetrahedite is highly variable, some grains being richly argentiferous (freibergite). In addition minute inclusions of native silver have been observed in chalcopyrite associated with argentiferous tetrahedrite. The silver-rich tetrahedrite appears to be associated with chalcopyrite and galena and only minor sphalerite and no arsenopyrite. Less silver is present in tetrahedrite where arsenopryite and sphalerite are dominant and chalcopyrite absent. Minor amounts of bournonite also occur frequently in association with pyrite. The richest mineralisation of this type is associated with a network of chloritic veinlets in brecciated sedimentary rocks.

The second type of mineralisation consists of minor amounts of the antimony-bearing minerals bournonite, jamesonite and stibnite in association with pyrite in disseminations and carbonate-rich veinlets within type 1 intrusive greenstone bodies and their immediate aureoles. Minor amounts of sphalerite, arsenopyrite, chalcopyrite and galena can also occur.

The third main variety of mineralisation was only intersected in oxidised near surface form and is dominated by antimony. Most of the antimony was in the form of secondary minerals like stibiconite ($H2Sb2O5$) and an Sb-Fe oxide, though some probable stibnite is also present. Secondary zinc minerals, chalcopyrite and a lead-bearing tetrahedrite are other minerals found in small amounts. Siderite appears to be the main gangue mineral with which the mineralisation is associated.

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