British Geological Survey

Mineral Reconnaissance Programme

Mineralisation in the Middle Devonian volcanic belt and associated rocks of South Devon

Department of Trade and Industry

MRP Report 129
Technical Report WF/93/6

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R C Leake and G E Norton

BRITISH GEOLOGICAL SURVEY

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This report was prepared for the Department of Trade and Industry

Maps and diagrams in this report use topography based on Ordnance Survey mapping

Bibliographical reference

Leake, R C, and Norton, G E. 1993. Mineralisation in the Middle Devonian volcanic belt and associated rocks of South Devon. *British Geological Survey Technical Report* WF/93/6 (*BGS Mineral Reconnaissance Programme Report* 129).

Keyworth, Nottingham 1993

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Printed in England for the British Geological Survey by Saxon Graphics Limited, Derby

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SUMMARY

This report describes the results of further exploration within the belt of Middle Devonian volcanic rocks between Plymouth and Totnes in south Devon. Soil sampling was carried out to augment the coverage of the volcanic belt described in Mineral Reconnaissance Programme Report No. 79 (Leake et al., 1985) and to extend it into adjacent sedimentary rocks. The 4815 overburden samples indicate that the area as a whole is highly enriched in antimony and, to a lesser extent, arsenic.

No evidence was found of further stratiform exhalative mineralisation in addition to the massive pyrite and ferruginous carbonate at Higher Ludbrook and the baryte at Lower Burraton described in MRP Report No. 79. However, four main areas showing evidence of metal-enriched sedimentary rocks have been outlined. In three of the areas, enrichment in Mn in the soils derived from the sedimentary rocks is accompanied by low amplitude enrichment in Zn and Pb, reaching around 200 ppm Zn and 170 ppm Pb. The fourth area, adjacent to the separate belt of volcanic rocks northwest of Totnes, is more extensive and of higher amplitude (reaching over 700 ppm Zn and 600 ppm Pb). The soil and drillhole data indicate that extensive hydrothermal systems were associated with the alkali basaltic volcanism in the area and that submarine hydrothermal activity took place. The close similarity in geology between the area and the Rhenish basin in Germany, which hosts the Meggen SEDEX deposit, indicates that south Devon and east Cornwall remain prospective for submarine exhalative mineralisation.

Overburden samples indicate that polymetallic mineralisation occurs within a zone about 3 km long in the west of the area. The zone is enriched in As, Pb, Zn, Mn and Cu and is similar to polymetallic mineralisation carrying gold which occurs further south in Devon, described in Mineral Reconnaissance Programme Report No 121 (Leake et al., 1992). Evidence for further polymetallic mineralisation is present in the northeast of the area but this differs geochemically from the other areas in having a higher proportion of Zn to Pb and in the presence of anomalous concentrations of Sn. Proximity to the Dartmoor granite suggests that this anomalous zone could be related to the contact aureole of the granite.

Two further boreholes were drilled to investigate the source of the zone of anomalous antimony in soil at Ladywell, as the earlier hole described in MRP report No. 79 did not intersect sufficient mineralisation to account for the surface anomaly. One hole intersected a zone of oxidised rock containing 120 ppm Sb over 6.4 m within a wider zone showing lower amplitude enrichment in antimony (75 ppm over 21m) and containing minor amounts of bournonite, tetrahedrite and stibnite. This enrichment in antimony may be primary, in association with one episode of volcanicity. No evidence of an association of precious metals with this mineralisation was found, though there was some enrichment in mercury (up to 11 ppm). The second hole showed no enrichment in antimony but contained minor amounts of base metal sulphides in association with carbonate veinlets and sections of dark slate enriched in Zn (up to 1600 ppm Zn over 1 m).

INTRODUCTION

The Devonian and Lower Carboniferous rocks of Devon and north Cornwall have potential for exhalative base-metal and baryte mineralisation. This is particularly a consequence of their close similarity with rocks of equivalent age in the Rhenish and Harz basins of Germany which host the major Meggen and Rammelsberg deposits. Mineral Reconnaissance Programme Report no 79 (Leake et al., 1985) described exploration work within the Middle Devonian volcanic belt between Plymouth and Totnes aimed at detecting evidence for the existence of volcanogenic exhalative mineralisation. After the report's publication, further soil samples were collected to augment the coverage of the volcanic belt and to extend it into adjacent sedimentary rocks, especially to the south. The boundary of the area covered is shown in Figure 1. By analogy with the Meggen deposit, which is of the SEDEX type with a minor volcanic imput, the sedimentary rocks more remote from the volcanic outcrop may have greater potential for significant mineralisation than the proximal volcanic environment. The additional sampling was aimed particularly at detecting evidence for enrichment in base metals which could be of exhalative origin within sedimentary rocks. This could then provide justification for further exploration in the belt in rocks more remote from the volcanic outcrops.

The further sampling was also carried out to provide information on other styles of mineralisation that were thought to be present. Two additional boreholes were drilled at Ladywell farm, as the borehole drilled previously (Leake et al., 1985) failed to locate the source of the high amplitude antimony anomalies in soil. This report presents the new borehole data and an interpretive analysis of the combined soil dataset and all the borehole material.

The volcanic belt is very poorly exposed and therefore not amenable to orthodox geological and geochemical study. However, the region escaped glacial action and residual soils are present over most of the area. The locations of all the soil lines and their assigned numbers are given in Figures 2 and 3. The wide systematic residual overburden sample coverage of the belt allows study of any zonation that may be related to hydrothermal alteration associated with exhalative mineralisation or with subsequent epigenetic mineralising systems.

TECTONIC ENVIRONMENT OF DEVON AND NORTH CORNWALL

In recent years there have been several attempts to provide a coherent plate tectonic model for the geological evolution of Cornubia based on structural and sedimentological studies and on the geochemistry of the volcanic rocks (eg Floyd, 1982a, b). A recent model (Merriman pers. comm.) suggests that the rocks in south Devon and north Cornwall originated in an intracontinental rift to the north of an oceanic basin of probable limited extent. Lower Devonian volcanic rocks are highly variable, consisting of both magmatic arc and within plate alkaline basalts (Merriman pers. comm.) together with slightly peralkaline dacite and rhyolite. In contrast, volcanics erupted during the Middle Devonian to the Lower Carboniferous are mostly within plate alkali basalts. Some of the Lower Devonian basalts show evidence of crustal contamination and may have been derived from subduction-modified subcontinental lithospheric mantle (Merriman pers. comm.). Considerable uncertainty still exists as to the nature and history of the oceanic basin to the south of Cornubia and the location and timing of any subduction that may have occurred. Evidence from the Rhenish basin in Germany (Werner, 1989) suggests that any subduction would have been south-directed and located to the south of the basin.

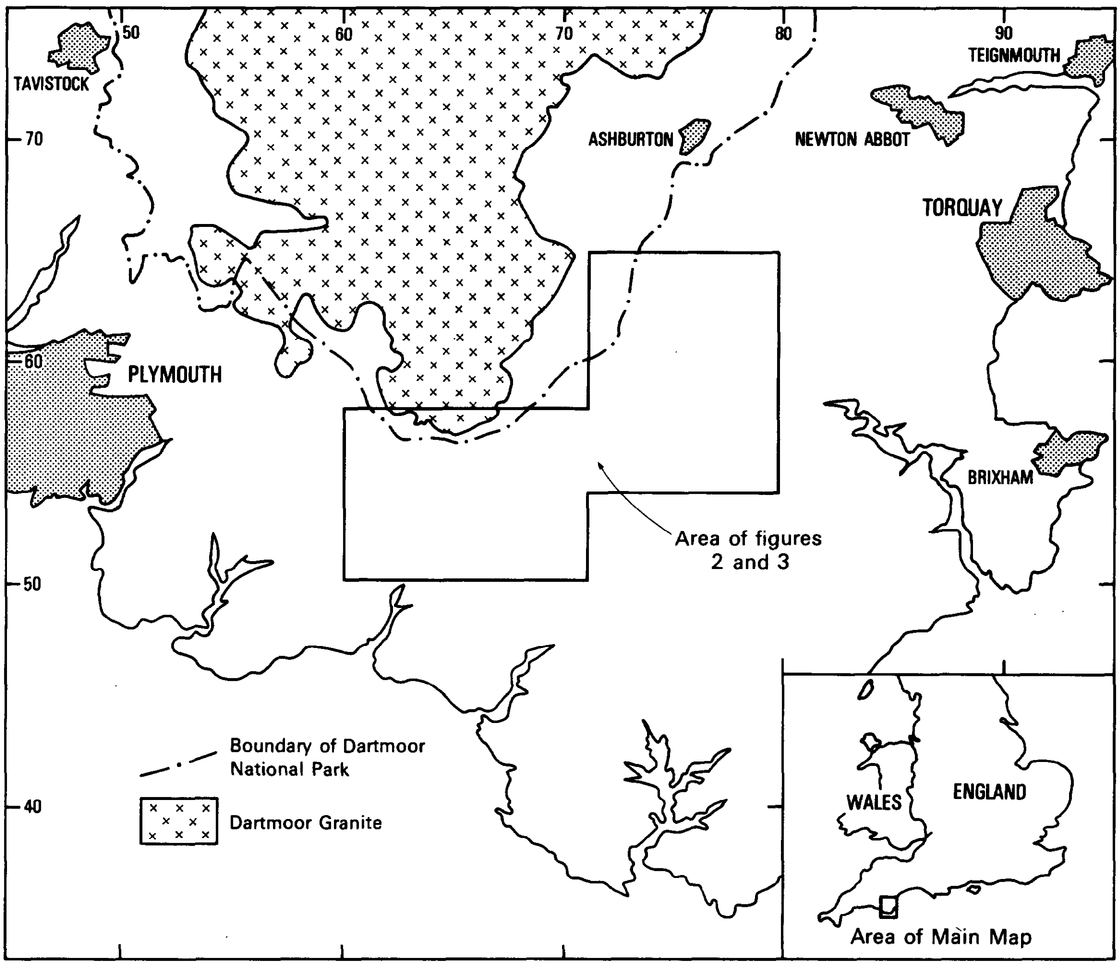

Figure 1 Location of survey area

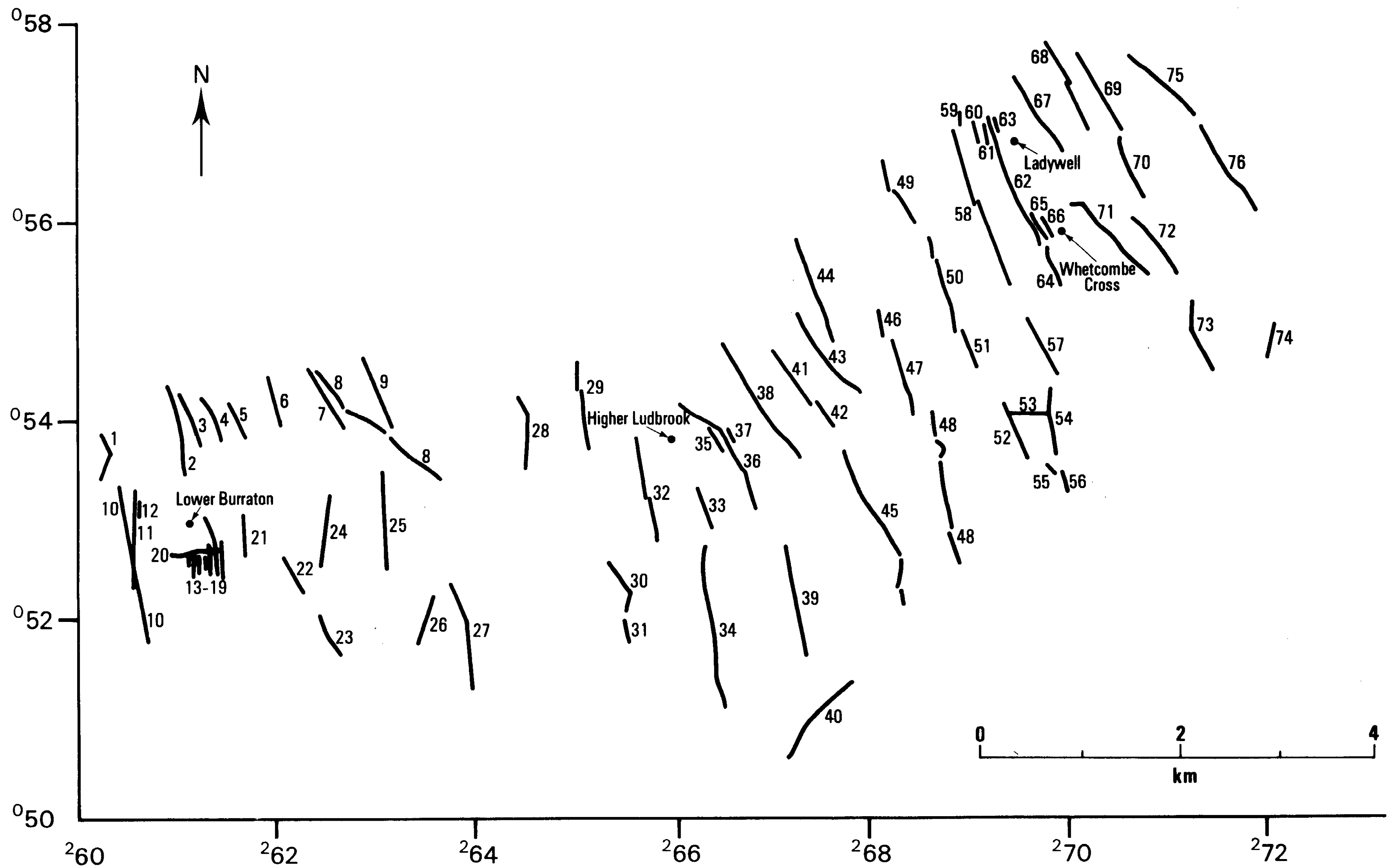

Figure 2 Location of soil traverse lines in south and west part of area

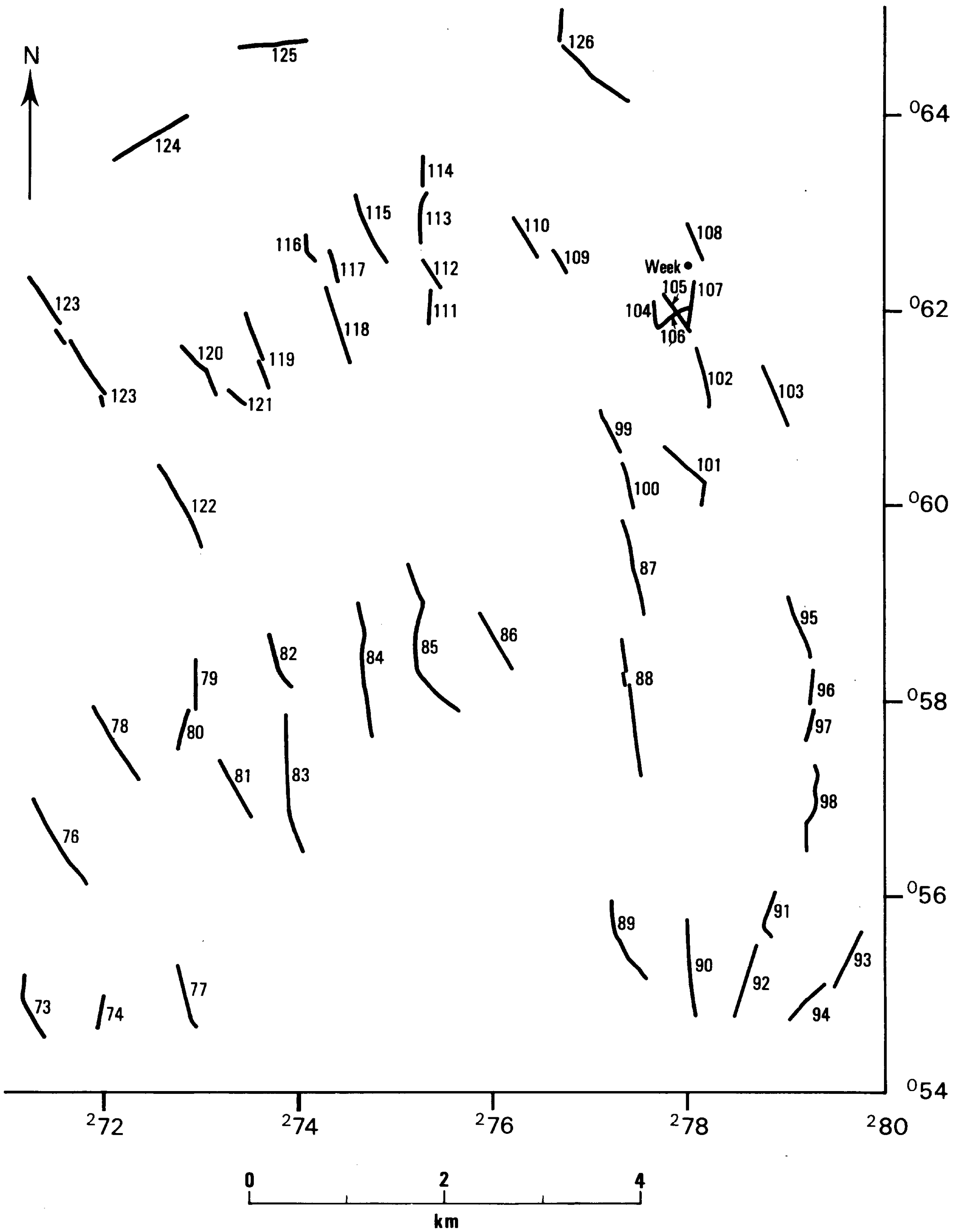

Figure 3 Location of soil traverse lines in north and east part of area

CHEMICAL ANALYSIS

Soil samples

Collection and preparation of the additional soil samples were carried out as described in MRP Report No. 79 (Leake et al., 1985). They were analysed by XRF at Birmingham University. However, differences between these analyses and some check determinations made at the BGS analytical laboratories in Keyworth prompted redetermination of several elements in about 25% of the samples and the production of comprehensive regressions between the two datasets, available for inspection at BGS Keyworth. The Birmingham University data have been adjusted using these regressions to make them compatible with the original BGS data. All samples containing clearly anomalous concentrations of elements of economic interest were reanalysed at BGS and in all cases the presence of anomalous concentrations was confirmed.

The concentrations of Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Sn, Sb, Ba and Pb were determined by XRF or by XRF and AAS (Co, Ni, Cu, Zn, and Pb by AAS in earlier data) as described in the previous MRP report (Leake et al., 1985). Correlation between earlier AAS data and XRF analyses for Ni, Cu, Zn and Pb is good and justifies the combination of the AAS and XRF datasets. Silver was determined in the earlier samples but has been removed from the dataset as concentrations in the samples are below or close to the detection limit of the analytical method.

Borehole core

The concentrations of Ca, Ti, Mn, Fe, Co, Ni, Cu, Zn, As, Rb, Y, Zr, Nb, Sb, Ba and Pb were determined in powdered samples of core from boreholes 2 and 3 by XRF at the BGS analytical laboratories and are summarised in Tables 1 and 2. In addition, the major elements were determined in 11 samples from borehole 2 by XRF on fused beads at the BGS laboratories, summarised in Table 3. There is only partial overlap between elements determined in borehole 1 and in samples from boreholes 2 and 3, i.e. Ca, Ti, Mn, Fe, Co, Ni, Cu, Zn, As, Sb, Ba and Pb.

REGIONAL GEOCHEMISTRY

Summary statistics of the complete overburden dataset are given in Table 4. Cumulative frequency plots of the elements most closely related to mineralisation (Mn, Fe, Cu, Zn, As, Sb, Ba and Pb) are shown in Figure 4. Corresponding cumulative frequency plots for the other elements are omitted as they are very similar in shape to the plots of the partial dataset illustrated in the previous MRP report (Leake et al., 1985).

A broad assessment of the mineralisation potential of the area as a whole can be made on the basis of the general concentration of elements of potential economic interest and those closely associated with mineralisation. This is best achieved by analysis of the cumulative frequency plots of individual elements in the entire dataset (Figure 4). The shape of a cumulative frequency plot and also the gradient of individual sectors can give significant information. This is particularly the case for soils of residual origin where secondary environmental factors influencing elemental concentration are not of importance. A relatively high gradient sector or complete plot is indicative of a large range in concentration resulting from mineralisation superimposed on the background variation in the element as a consequence of varied geology.

Table 1. Summary statistics, Ladywell borehole 2 (Ca, Ti, Mn, Fe in wt%; other elements in ppm)

	Ca	Ti	Mn	Fe	Co	Ni	Cu	Zn	Rb	Y	Zr	Nb	Sb	Ba	Pb	As
Mean																
Volcanics	5.932	1.520	0.129	7.828	29.7	20.8	21.5	85.3	47.0	22.8	198.2	27.9	29.5	230.4	5.6	13.4
Breccias	4.586	0.664	0.182	7.148	17.9	21.4	17.0	66.1	29.1	14.0	93.0	12.9	14.5	132.1	4.8	13.9
Sediments	4.086	1.060	0.104	6.306	24.6	23.6	23.9	85.3	67.9	21.8	189.2	22.9	0.6	371.2	5.6	13.1
Median																
Volcanics	6.190	1.477	0.127	7.800	30.0	20.0	21.0	76.0	49.0	22.0	188.0	27.0	13.0	194.0	4.0	12.0
Breccias	4.465	0.675	0.187	6.445	19.0	15.5	5.0	60.0	25.0	15.0	95.0	12.5	7.5	114.0	3.0	8.0
Sediments	4.130	1.053	0.105	5.930	25.0	25.0	23.0	70.0	74.0	24.0	201.0	24.0	0.0	371.0	5.0	13.0
Minimum																
Volcanics	0.080	0.645	0.013	4.120	9	7	0	42	0	12	79	12	0	52	0	1
Breccias	0.380	0.235	0.112	5.090	5	12	1	42	3	8	27	5	0	32	0	4
Sediments	2.990	0.307	0.067	4.890	6	10	6	47	6	9	71	6	0	51	0	7
Maximum																
Volcanics	9.920	2.515	0.265	13.200	47	61	80	212	99	74	342	48	186	887	37	49
Breccias	9.260	1.370	0.261	13.000	31	42	79	96	63	22	182	24	38	223	17	59
Sediments	4.920	1.578	0.191	8.510	33	29	46	247	82	27	229	31	3	504	12	17
Average*																
alkali basalt	7.220	1.440	0.120	8.420	42	101	108	105	51	30	138	19	0.2	244	6	2

*Ca, Ti, Mn, Fe, Co, Ni, Cu, Rb, Y, Zr, Ba from Floyd, 1976; As, Nb, Zn, Pb, Sb from Turekian and Wedepohl, 1961

Table 2. Summary statistics, Ladywell borehole 3 (Ca, Ti, Mn, Fe in wt%; other elements in ppm)

	Ca	Ti	Mn	Fe	Co	Ni	Cu	Zn	Rb	Y	Zr	Nb	Sb	Ba	Pb	As
Mean																
Buff volcanics	7.640	1.379	0.152	8.838	35.5	28.3	17.8	82.0	28.8	21.8	161.8	22.0	0.3	656.8	9.3	11.0
Pink volcanics	6.858	1.349	0.176	8.591	34.2	23.9	18.6	86.0	23.5	20.9	161.8	21.2	2.3	412.9	42.6	19.2
Green volcanics	5.786	1.453	0.133	8.934	38.4	27.1	22.8	103.7	23.2	21.1	170.9	22.6	2.5	434.2	10.7	14.3
All volcanics	6.522	1.383	0.154	8.806	36.3	25.7	20.6	94.2	23.4	20.7	164.1	21.7	2.3	436.4	25.2	16.5
Sediments	1.324	0.462	0.101	6.424	20.0	50.7	23.7	193.2	160.8	23.6	126.3	13.5	2.0	485.4	23.3	18.0
Breccias	5.334	0.767	0.202	8.239	30.2	20.8	19.2	83.1	20.3	14.8	96.0	13.1	3.2	286.9	16.2	12.4
Median																
Buff volcanics	7.880	1.341	0.145	9.030	33.0	26.0	18.5	88.0	27.5	20.5	155.0	22.0	0.0	708.5	9.0	11.5
Pink volcanics	7.660	1.371	0.177	8.770	36.0	23.0	17.0	79.0	23.0	22.0	166.0	22.0	2.0	340.0	17.0	18.0
Green volcanics	6.185	1.477	0.129	8.910	35.5	27.0	19.0	106.0	26.0	21.5	175.5	24.0	2.0	467.0	8.5	13.0
All volcanics	6.780	1.433	0.146	8.800	35.0	25.0	18.0	97.0	25.0	22.0	168.0	22.0	1.0	382.0	10.0	16.0
Sediments	1.110	0.493	0.094	5.870	21.0	51.0	23.0	92.0	177.0	24.0	135.0	14.0	0.0	469.0	20.0	15.0
Breccias	5.930	0.684	0.186	8.160	26.0	21.0	19.0	71.0	14.0	15.0	88.0	12.0	2.0	225.0	10.0	14.0
Minimum																
Buff volcanics	6.680	1.098	0.129	7.400	25	23	12	42	18	18	134	18	0	213	5	4
Pink volcanics	0.320	0.803	0.081	5.300	13	14	9	38	9	13	97	14	0	84	0	6
Green volcanics	0.230	0.580	0.054	7.160	25	17	10	62	5	13	71	11	0	94	0	5
All volcanics	0.230	0.580	0.054	5.300	13	14	9	38	5	13	71	11	0	84	0	4
Sediments	0.270	0.195	0.061	4.250	10	31	11	56	62	13	51	7	0	209	1	6
Breccias	0.300	0.024	0.134	5.670	4	4	3	41	1	7	3	3	0	122	0	2
Maximum																
Buff volcanics	8.120	1.735	0.188	9.890	51	38	25	110	42	28	203	26	1	997	14	17
Pink volcanics	9.760	1.919	0.269	10.610	56	34	40	196	37	27	226	29	9	906	526	39
Green volcanics	9.490	2.317	0.290	11.040	80	43	57	151	35	30	259	34	9	642	43	30
All volcanics	9.760	2.317	0.290	11.040	80	43	57	196	42	30	259	34	9	997	526	39
Sediments	4.320	0.552	0.194	12.870	27	64	50	1577	200	28	157	17	13	743	111	55
Breccias	9.510	1.820	0.371	10.360	67	49	34	172	128	29	213	27	9	668	44	26
Average* alkali basalt	7.220	1.440	0.120	8.420	42	101	108	105	51	30	138	19	0.2	244	6	2

*Ca, Ti, Mn, Fe, Co, Ni, Cu, Rb, Y, Zr, Ba from Floyd, 1976; As, Nb, Zn, Pb, Sb from Turekian and Wedepohl, 1961

Table 3. Ladywell borehole 2, major element geochemistry (in wt%)

SAMPLE	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	K_2O	Na_2O	P_2O_5	LOI	Total
DCD4007	36.23	3.08	14.28	14.14	0.16	5.18	6.28	2.08	0.64	0.49	17.02	99.58
DCD4028	34.38	2.33	11.67	11.53	0.17	6.48	9.81	2.16	0.38	0.32	20.63	99.86
DCD4035	38.35	2.96	13.69	11.81	0.13	4.87	7.65	2.00	0.35	0.40	17.58	99.79
DCD4042	37.26	2.86	14.66	12.14	0.16	4.68	7.63	1.59	0.27	0.34	18.25	99.84
DCD4049	38.80	3.14	14.61	10.64	0.16	4.35	7.96	1.80	0.24	0.39	17.59	99.69
DCD4055	37.85	2.33	12.73	11.40	0.15	5.01	9.04	2.07	0.34	0.27	18.73	99.92
DCD4079	9.79	1.19	5.55	13.25	0.39	9.72	24.15	0.32	0.14	0.20	35.53	100.23
DCD4088	40.33	3.56	19.12	10.11	0.14	2.92	5.69	2.44	1.01	0.54	14.12	99.98
DCD4105	36.86	3.75	15.61	15.28	0.17	3.34	5.32	1.34	1.20	0.68	15.91	99.46
DCD4110	41.52	3.57	14.91	13.02	0.12	4.35	6.10	0.36	4.62	0.64	10.34	99.55
DCD4111	39.29	4.21	17.23	18.03	0.06	5.54	3.83	0.03	4.03	0.75	7.40	100.41

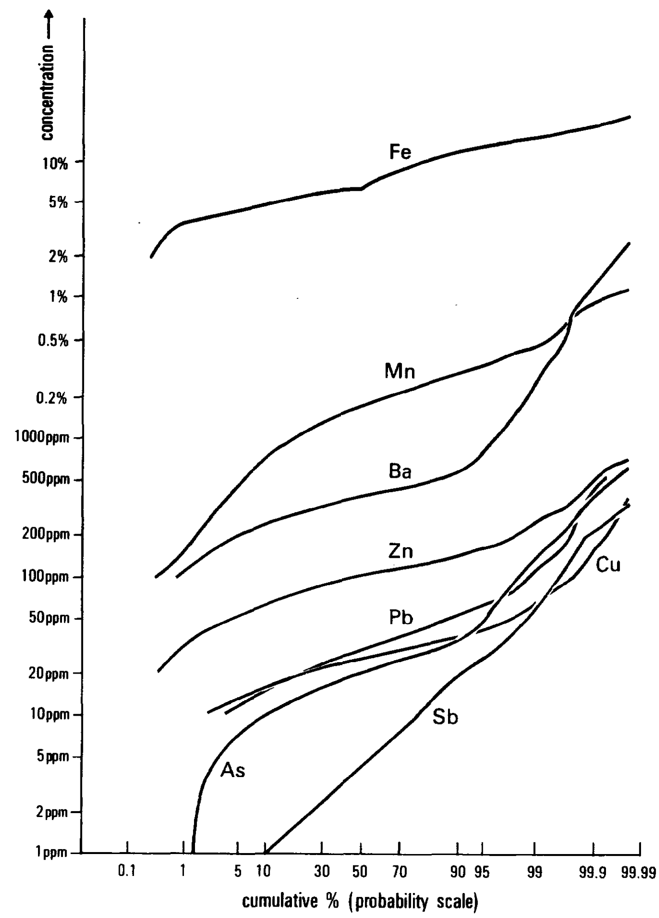

Figure 4 Cumulative frequency plots of Mn, Fe, Cu, Zn, As, Sb, Ba and Pb in overburden samples

Table 4 Summary statistics of overburden data

	Number	Median	Mean	st.dev.	max.	min.
Ca%	4669	0.27	0.33	0.24	5.93	0.02
Ti%	4669	0.97	1.29	0.66	3.84	0.12
V ppm	3489	174	195	60	1709	96
Cr ppm	3489	99	97	40	600	<10
Mn%	4818	0.176	0.185	0.104	2.568	0.003
Fe%	4818	6.55	7.68	2.82	34.95	1.20
Co ppm	2338	20	25	12	90	3
Ni ppm	4742	35	39	20	723	5
Cu ppm	4815	27	30	15	435	<1
Zn ppm	4815	108	112	46	1004	15
As ppm	4815	21	27	33	786	<1
Sn ppm	3742	4.4	5.4	5.0	114	<1
Sb ppm	4669	4.4	9.2	17.3	464	<1
Ba ppm	4816	395	518	1109	48900	60
Pb ppm	4815	32	36	31	1113	1

Antimony is the element which shows the longest high gradient sector and is therefore the element showing regionally the most anomalous behaviour. A background low gradient sector is not discernable as the concentrations of Sb which would characterise this are below the detection limit (1-2 ppm) of the analytical method utilised. The antimony content of common igneous rocks and argillaceous sedimentary rocks is usually less than 3 ppm (Onishi, 1978). This is less than the median of the present soil results (4.4 ppm). Thus there are a large number of samples containing highly anomalous concentrations of antimony, to a maximum of 464 ppm. Anomalous concentrations of antimony are associated with all the different anomaly types within both volcanic and sedimentary rocks, though with the former predominant. There is no clear indication of a general enrichment in antimony in volcanic rocks throughout the area; rather there are distinct but broad anomalous sectors within the volcanic subcrop.

On the basis of the total soil dataset, arsenic can be considered to be the next most anomalous element. The median concentration of 21 ppm is high compared with concentrations of less than 15 ppm associated with all common igneous and argillaceous rocks and soils derived from them (Onishi, 1969). Superimposed on the low gradient sector of the curve is a high gradient sector roughly at the 90% level. This represents a separate mineralised population with concentrations reaching a maximum of 786 ppm.

Barium exhibits similar behaviour to As in terms of the total dataset. A well defined high gradient sector is present above the 94% level with concentrations reaching a maximum of 4.9% Ba. The median Ba concentration of 395 ppm is well within the range of concentrations in common sedimentary rock types and also alkali basalt (Table 1).

The cumulative frequency plot of tin also exhibits a sharp increase in gradient at about the 96% level and a maximum concentration of 114 ppm. It is probable that the tin concentrations in soil at many anomalous sites may have been underestimated as any grains of cassiterite in excess of 0.18 mm would not be retained.

The upper high gradient sectors of the distributions of Cu, Zn and Pb are much smaller proportionally than those associated with the elements above. Furthermore, the median concentrations of these elements are relatively low compared with concentrations found in common igneous rocks.

Distribution of overburden anomalies

The distribution of anomalies in overburden samples of elements most likely to be associated with mineralisation (Mn, Cu, Zn, As, Sb, Ba and Pb) are shown in Figures 5-18. Anomalies are presented as an area enclosing the anomalous samples or as individual sample points. The positions of alluvium and the outcrop of the volcanic rocks, taken from the published 1:50,000 geological maps, are shown as background to the anomaly maps. The detailed position of contacts shown on these geological maps, which date from the early part of the century, are sometimes at variance with those deduced from the overburden geochemical data.

Barium

Most of the barium anomalies occur in a zone about 5 km long, roughly following the strike of the volcanic rocks (Figure 5). Within this zone anomalous Ba is found in association with both volcanic

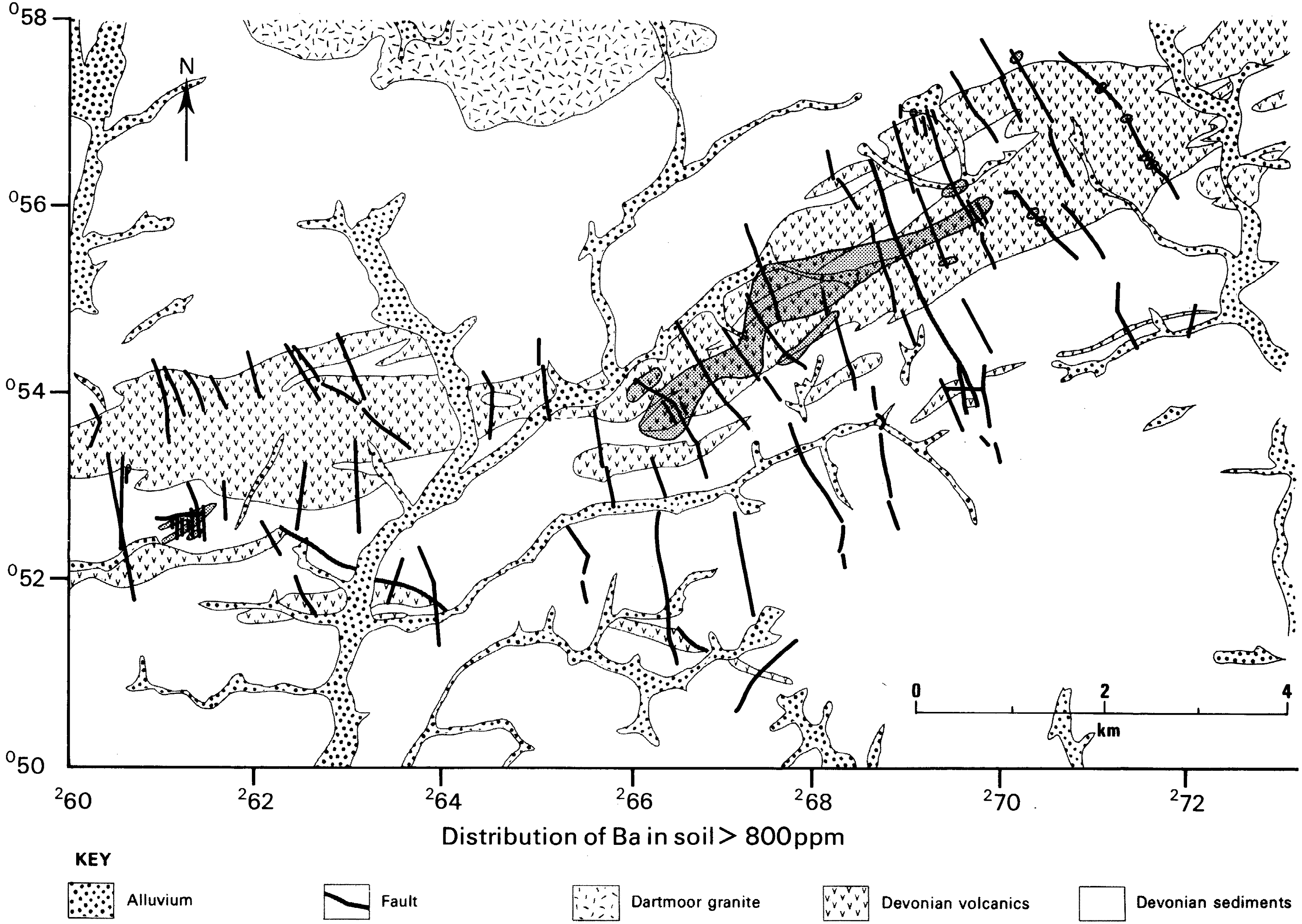

Figure 5 Distribution of soil samples containing anomalous concentrations of barium (> 800 ppm Ba) in south and west of area

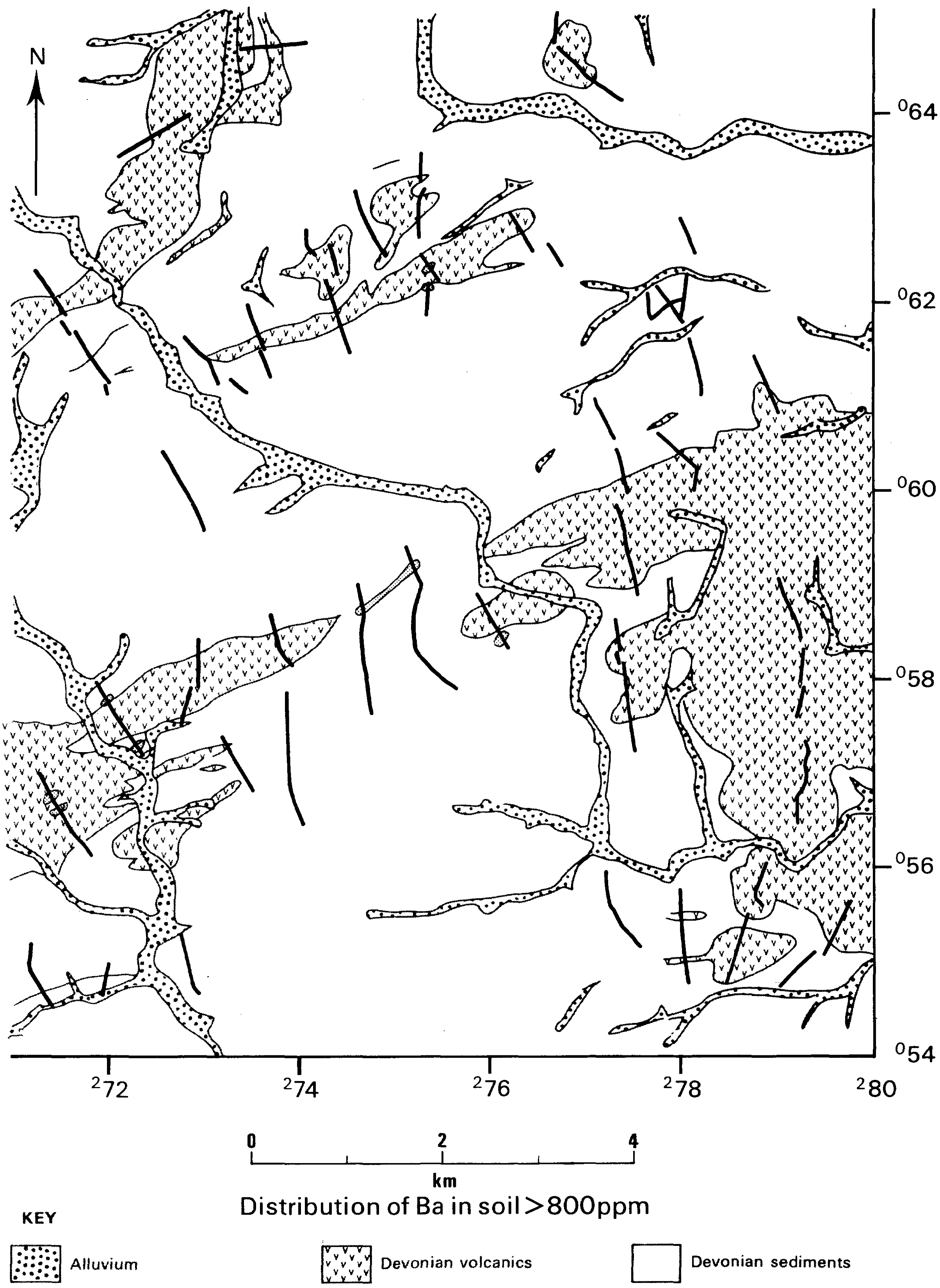

Figure 6 Distribution of soil samples containing anomalous concentrations of barium (> 800 ppm Ba) in north and east of area

and sedimentary rocks, though the former are predominant. The drilling near Higher Ludbrook at the southwestern end of the zone, reported in MRP Report No. 79 (Leake et al., 1985), demonstrated that Ba was enriched in sedimentary rocks, both chemical and detrital, overlying the mafic volcanic sequence (max. 1.32% Ba), in inclusions of volcanic rock within these rocks (max. 5.32% Ba) and within some parts of the underlying mafic volcanic rocks (max. 0.33% Ba). It is probable that most of the barium is accommodated in Ba-rich muscovite within most samples in view of their low sulphur content, though one lens of baryte occurs within the massive ferroan dolomite immediately overlying the volcanics (Leake et al., 1985).

A separate grouping of Ba anomalies occurs near Lower Burraton, some 5 km to the west of Higher Ludbrook (Figure 5). Both the previous drilling (Leake et al., 1985) and the soil data indicate that sedimentary rocks are predominant at Lower Burraton with only relatively thin (10 m) horizons of mafic tuffs. Massive baryte occurs as float in the region and Ba is accommodated in both baryte and probable Ba-rich muscovite in the boreholes.

Elsewhere Ba anomalies in overburden are isolated (Figures 5 and 6), though several occur roughly along strike from the main zone of anomalies.

Manganese

There are several zones of relative enrichment in manganese outlined in Figures 7 and 8. These zones do not correlate with the zones of Ba enrichment except in the Higher Ludbrook area. To the northeast of Higher Ludbrook the Mn anomalies occur to the south of the Ba anomalies and there are several other areas where anomalous Mn is not accompanied by anomalous Ba. In the Higher Ludbrook area drilling indicated that anomalous manganese is chiefly asssociated with the massive ferroan dolomite horizon (max. 0.86% Mn) but is also enriched to a lesser extent (max. 0.46% Mn) within the altered volcanic rocks. Mn anomalies in soil are relatively rare in the Lower Burraton area but the mafic tuff horizon intersected in one borehole (Leake et al., 1985) is enriched in manganese (max. 0.68% Mn). Much of the outcrop of the volcanic rocks shows Mn enrichment but there are also areas where the sedimentary rocks are enriched in Mn, sometimes associated with base metals; these are discussed below.

Copper

The main concentration of copper anomalies (>55 ppm) is in association with the layered mafic intrusion near Week (Figures 3, 10 and 30), described previously (Leake et al., 1985). More isolated low amplitude Cu anomalies (Figure 9) are associated with enrichment in Ni and probably originate from intrusive greenstones within the volcanic complex. These bodies are marked by significantly higher concentrations of Ni and Cr than the typical alkali volcanics which make up the volcanic belt. The age of these bodies is unknown but probably appreciably later than the main volcanic rock sequence and the associated hydrothermal alteration and exhalative mineralisation. The baryte-rich vein mineralisation near Whetcombe Cross (lines 65 and 66) is relatively enriched in copper and chemically distinct from the Ba enrichments associated with the exhalative mineralisation, as described below. Some of the samples derived from relatively manganiferous sedimentary rocks are also slightly enriched in Cu. Copper is anomalous in some As-rich samples from the northwestern and northeastern parts of the area. There are also a few relatively high amplitude Cu anomalies, not associated with enrichments in other elements, which are of uncertain and possibly artificial origin.

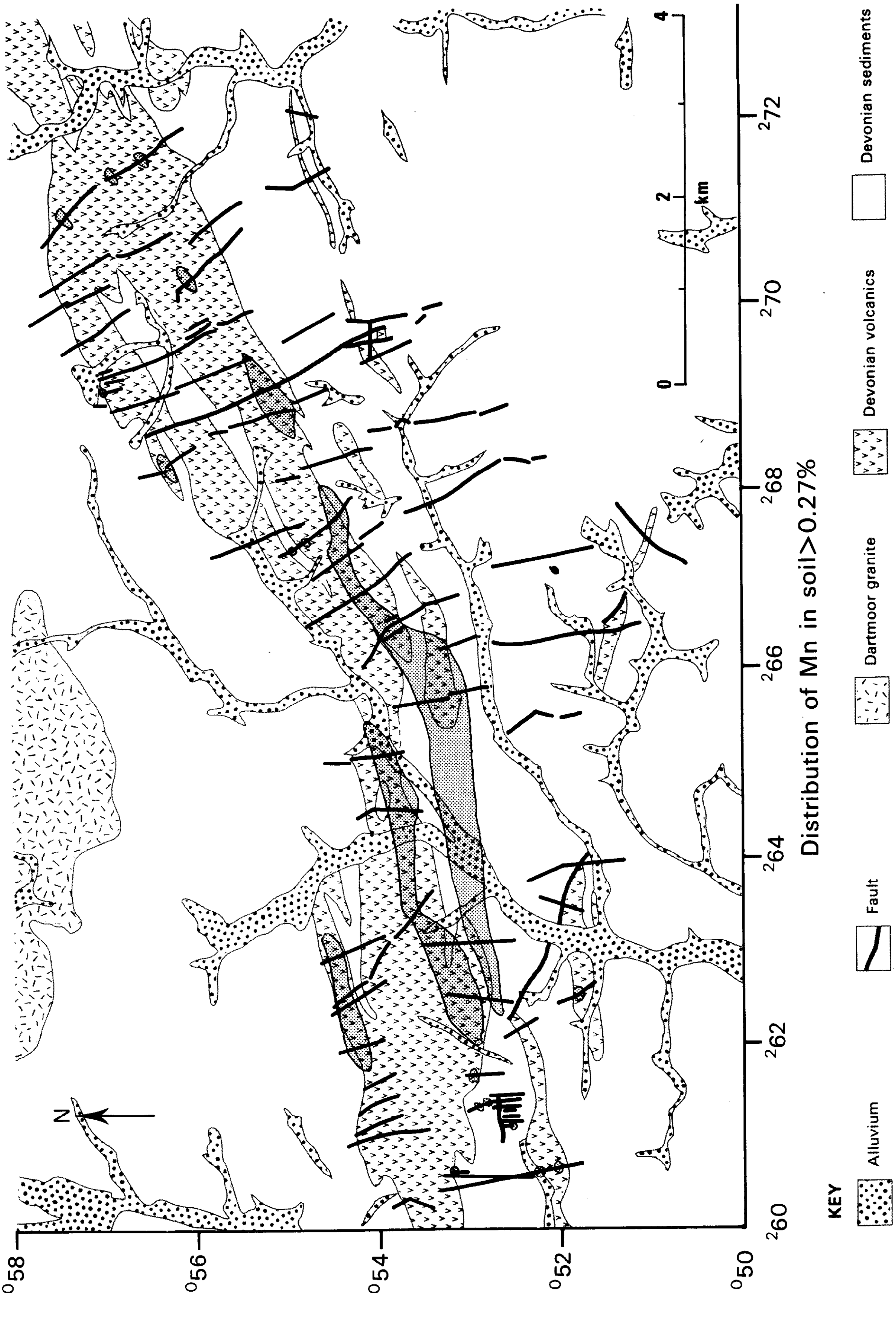

Figure 7 Distribution of soil samples containing anomalous concentrations of manganese (> 0.27% Mn) in south and west of area

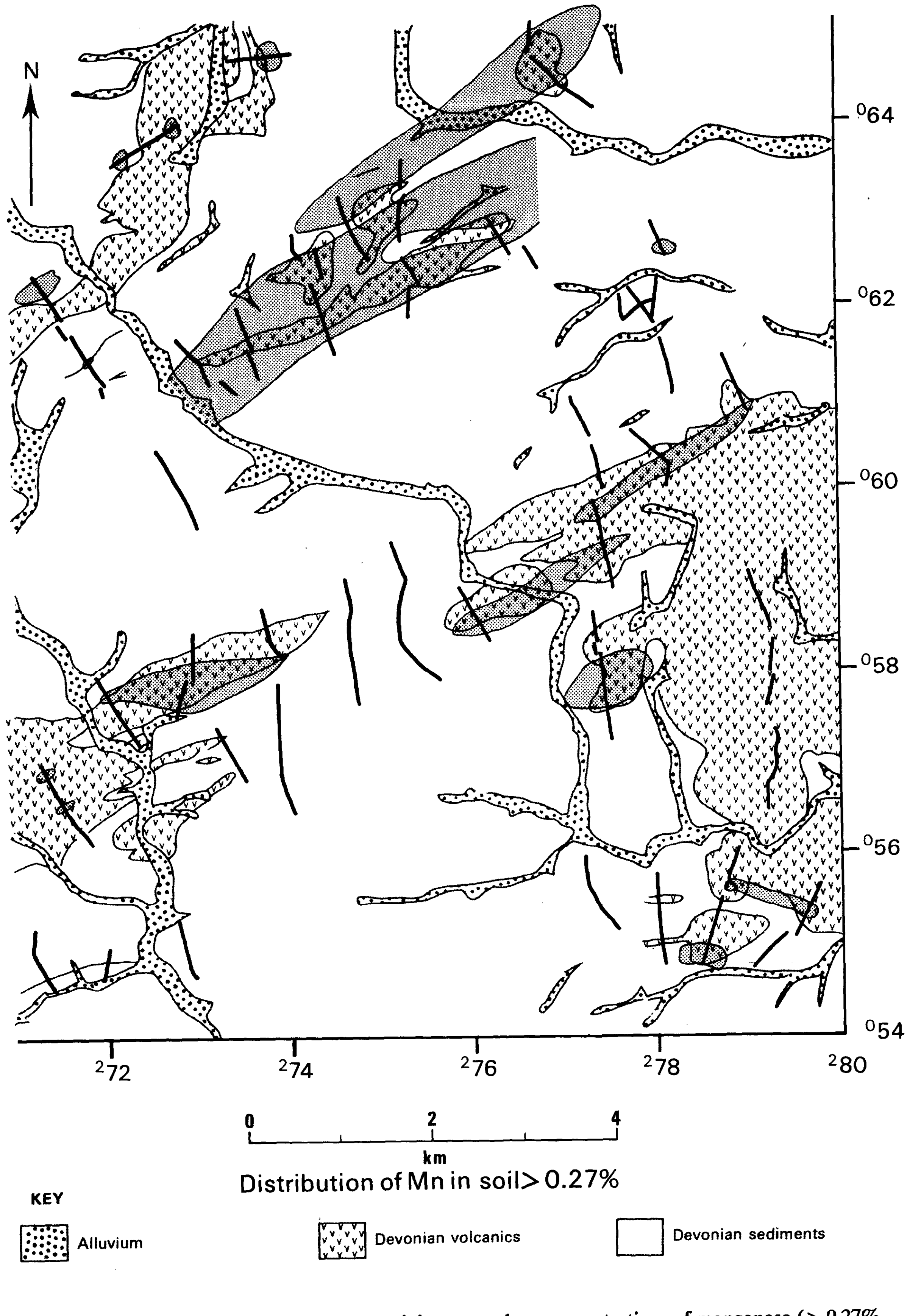

Figure 8 Distribution of soil samples containing anomalous concentrations of manganese (> 0.27% Mn) in north and east of area

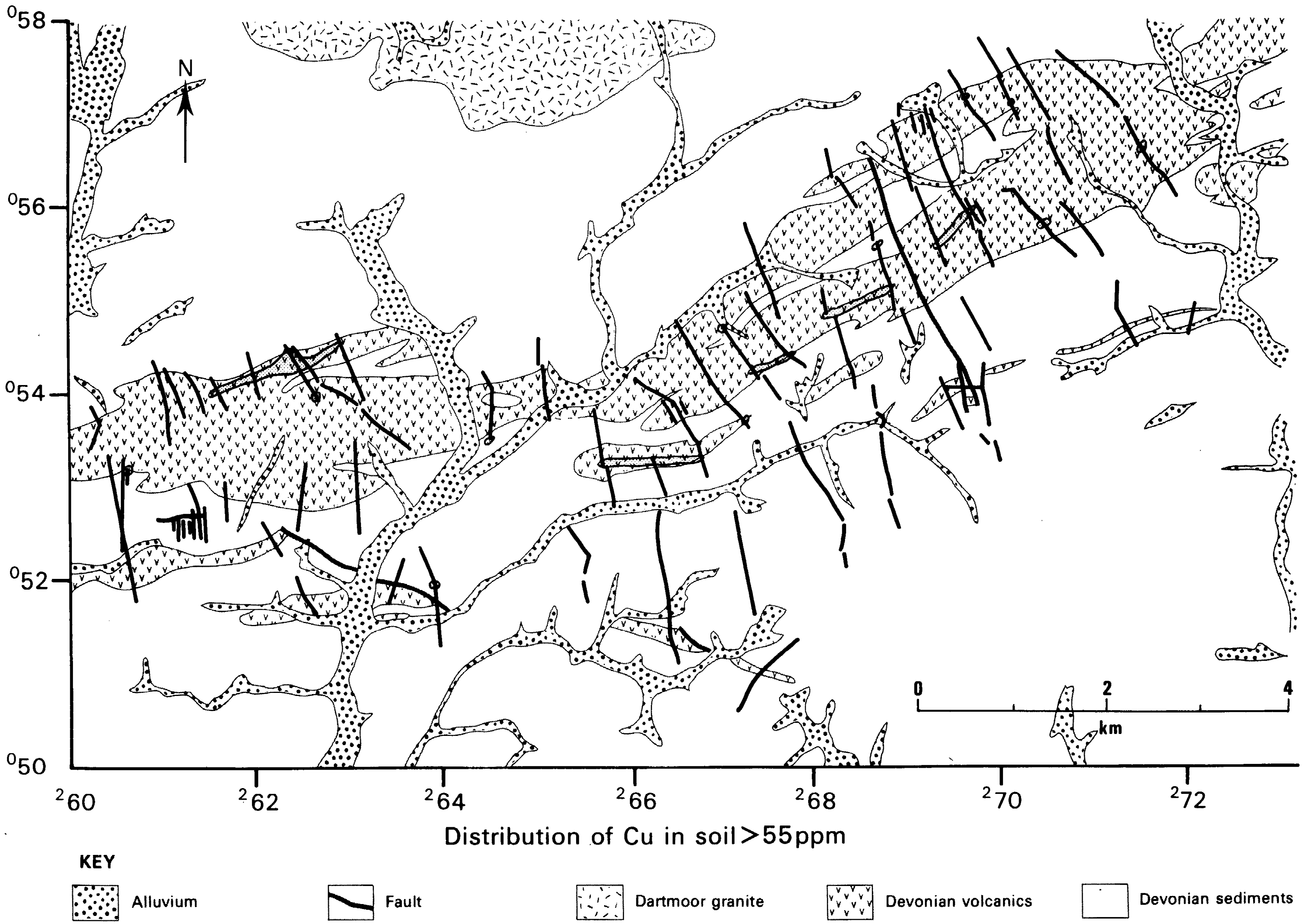

Figure 9 Distribution of soil samples containing anomalous concentrations of copper (> 55 ppm Cu) in south and west of area

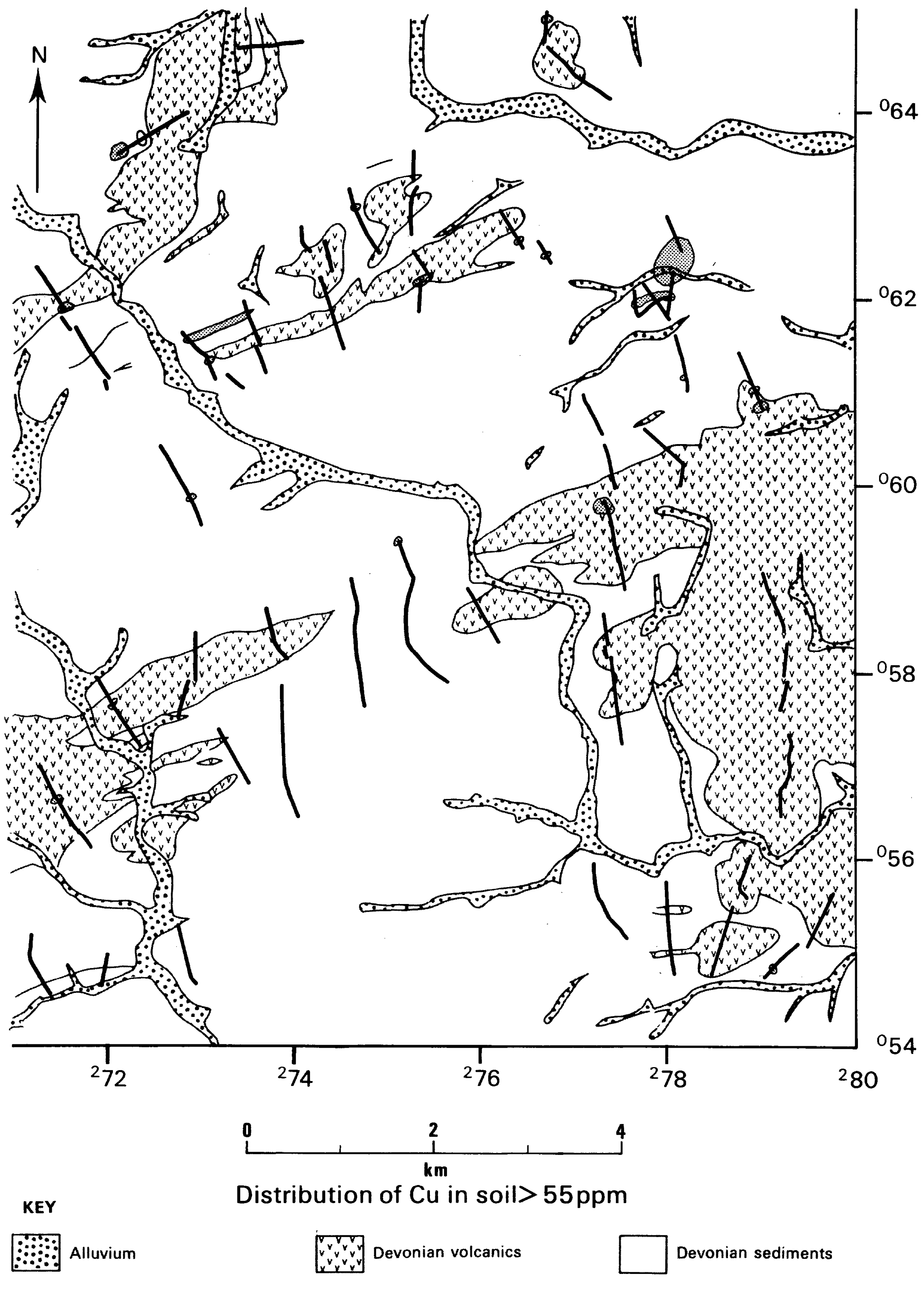

Figure 10 Distribution of soil samples containing anomalous concentrations of copper (> 55 ppm Cu) in north and east of area

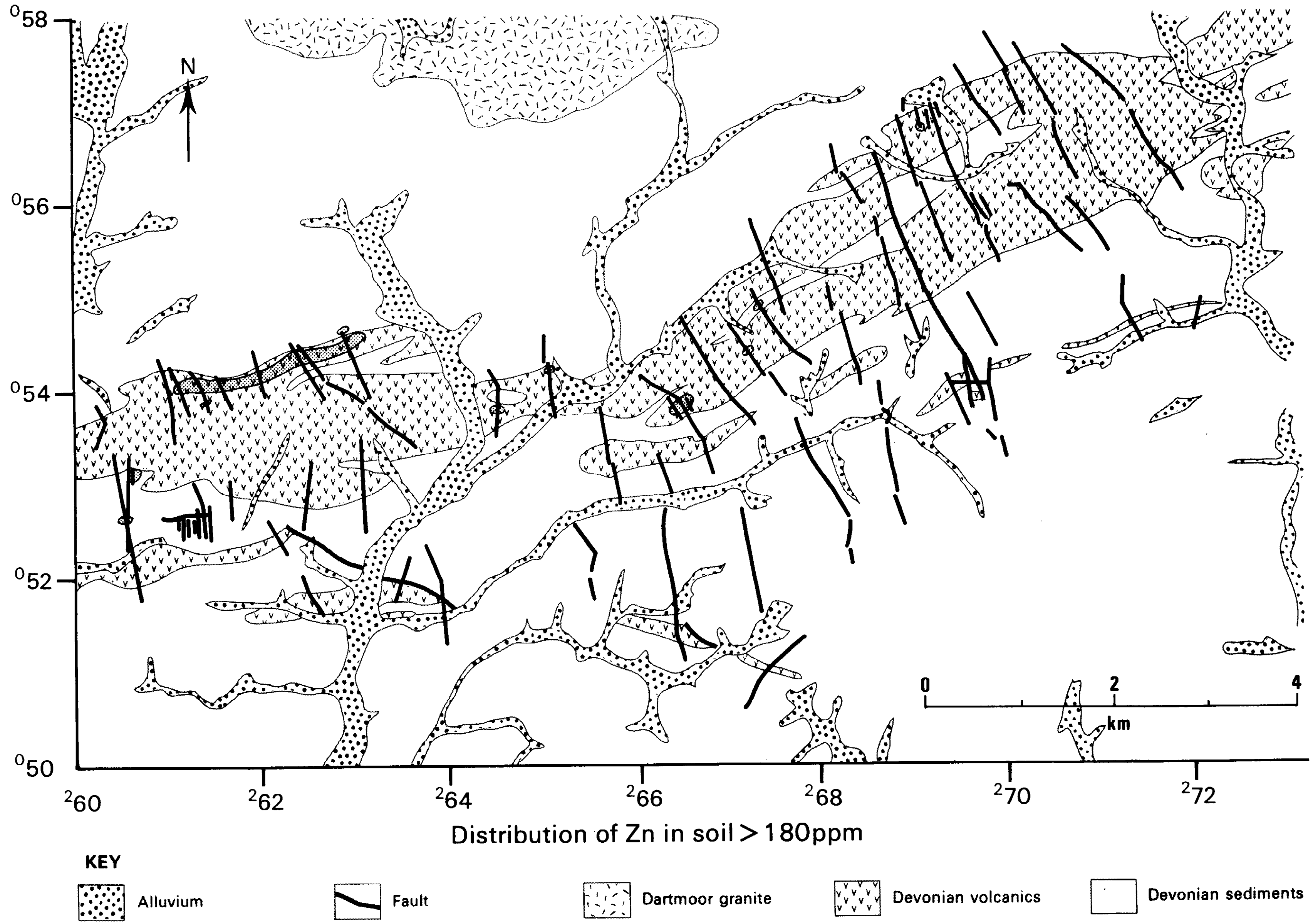

Figure 11 Distribution of soil samples containing anomalous concentrations of zinc (> 180 ppm Zn) in south and west of area

Zinc
The distribution of samples containing relatively high levels of zinc is shown in Figures 11 and 12. The association of zinc with the massive ferroan dolomite horizon in the Higher Ludbrook area (Leake et al., 1985) is reflected in soil anomalies in the area of the drill holes and also along strike to the northeast. The linear zone of anomalies in the northwest of the area is associated with elevated concentrations of As, Mn and Pb. Zinc is associated with Mn, Cu, As, Sb and Pb in the anomalies at the north end of line 12. Further south, on lines 11 and 12, low amplitude Zn anomalies in soil are associated with a zone of sedimentary rocks enriched in Mn and also Pb. There are also two main areas of zinc enrichment in the northeastern part of the area. Two varieties of anomaly are present; in the west of this zone, zinc is accompanied by elevated levels of As and to a lesser extent Cu, Sn, Pb, Mn and Sb. Further east, zinc is associated with Pb, Mn and to a lesser extent Cu; arsenic anomalies are absent.

Lead
The distribution of lead anomalies (Figures 13 and 14) is generally similar to that of zinc in the west of the area. However, lead is not enriched in samples derived from the Higher Ludbrook area. There are low amplitude lead anomalies derived from the sedimentary rocks to the south of the volcanic belt, particularly on lines 51 and 57. A similar group of lead anomalies occurs on lines 102 and 103. There is moderate agreement in the location of Pb and Zn anomalies in the area covered by lines 111-121 but lead is much subordinate to zinc further to the northwest.

Arsenic
Arsenic anomalies (Figures 15 and 16) are concentrated mostly in two zones in the west of the area between lines 1 and 28 and one area in the northeast (lines 123 and 124). Arsenic is also associated with the anomalies on the north of lines 10-12 but to a lesser extent than in the north. Elsewhere, arsenic anomalies are scattered and isolated. Arsenic is not generally enriched in association with the exhalative style mineralisation around Higher Ludbrook. The signature of the two main zones of As anomalies are different, particularly in the proportion of Zn and Pb.

Antimony
The source of the highest amplitude antimony anomalies which occur in an elongate zone between lines 58 and 69 (Figures 17 and 19) was investigated with the aid of two further boreholes at Ladywell Farm, described below. Antimony is also enriched in the area of Ba and Mn anomalies around Higher Ludbrook, between lines 35 and 41 (Figure 17). There are also a group of Sb anomalies north of this zone, between lines 36 and 43 which may be a continuation of the high amplitude anomalies further to the northeast. Elsewhere, anomalies are scattered and isolated (Figures 17 and 18). Antimony is associated with the polymetallic anomalies on line 12.

THE ADDITIONAL LADYWELL BOREHOLES

The locations of the three boreholes in the Ladywell area are shown in relation to the overburden antimony anomalies in Figure 19. Borehole 1, described in Leake et al., 1985, failed to intersect rocks with sufficient enrichment in antimony to account for the surficial anomalies. Accordingly boreholes 2 and 3 were drilled on either side to provide a more complete control of the underlying geology. The locations of the holes were constrained by the presence of a gas pipeline through the

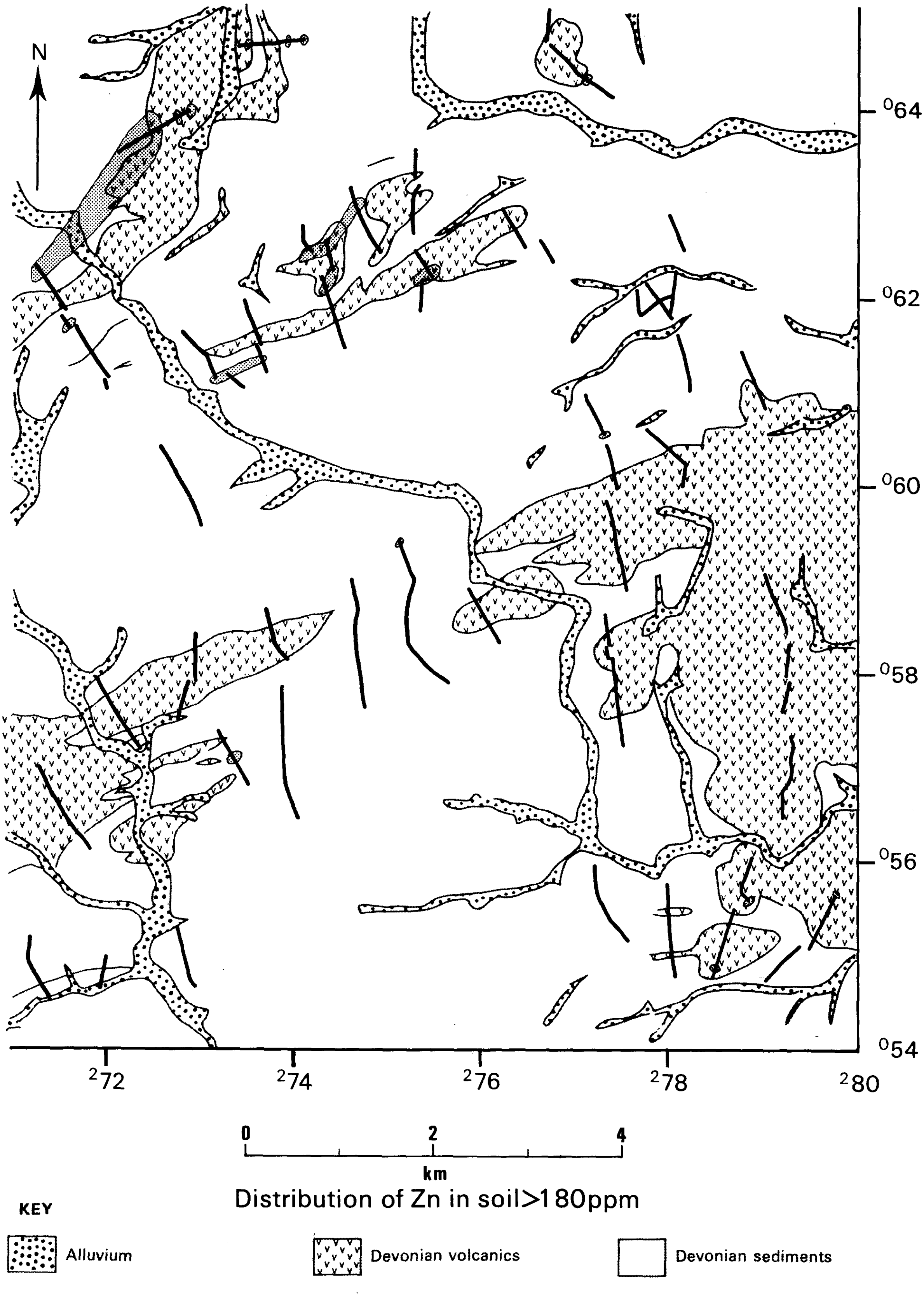

Figure 12 Distribution of soil samples containing anomalous concentrations of zinc (> 180 ppm Zn) in north and east of area

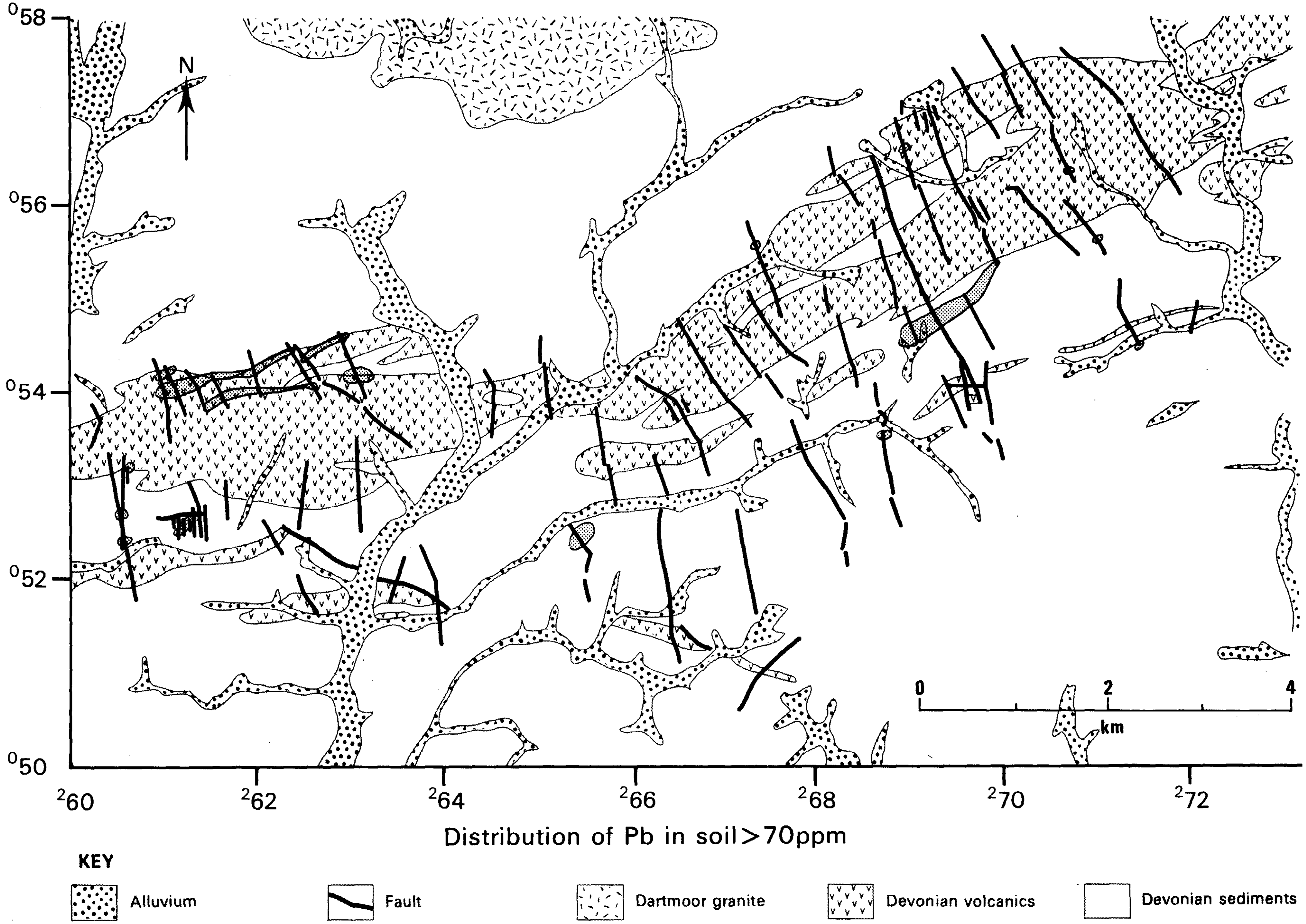

Figure 13 Distribution of soil samples containing anomalous concentrations of lead (> 70 ppm Pb) in south and west of area

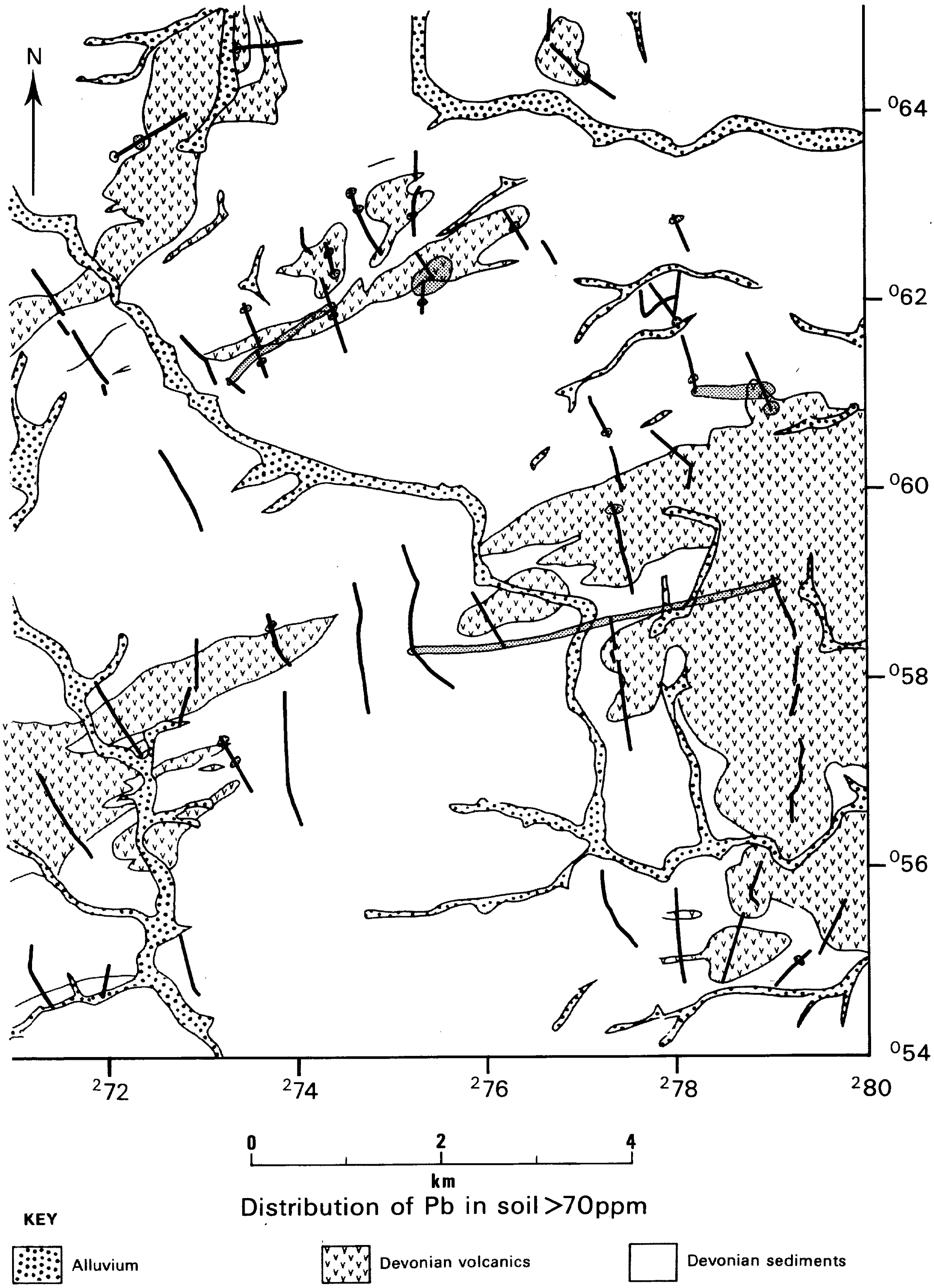

Figure 14 Distribution of soil samples containing anomalous concentrations of lead (> 70 ppm Pb) in north and east of area

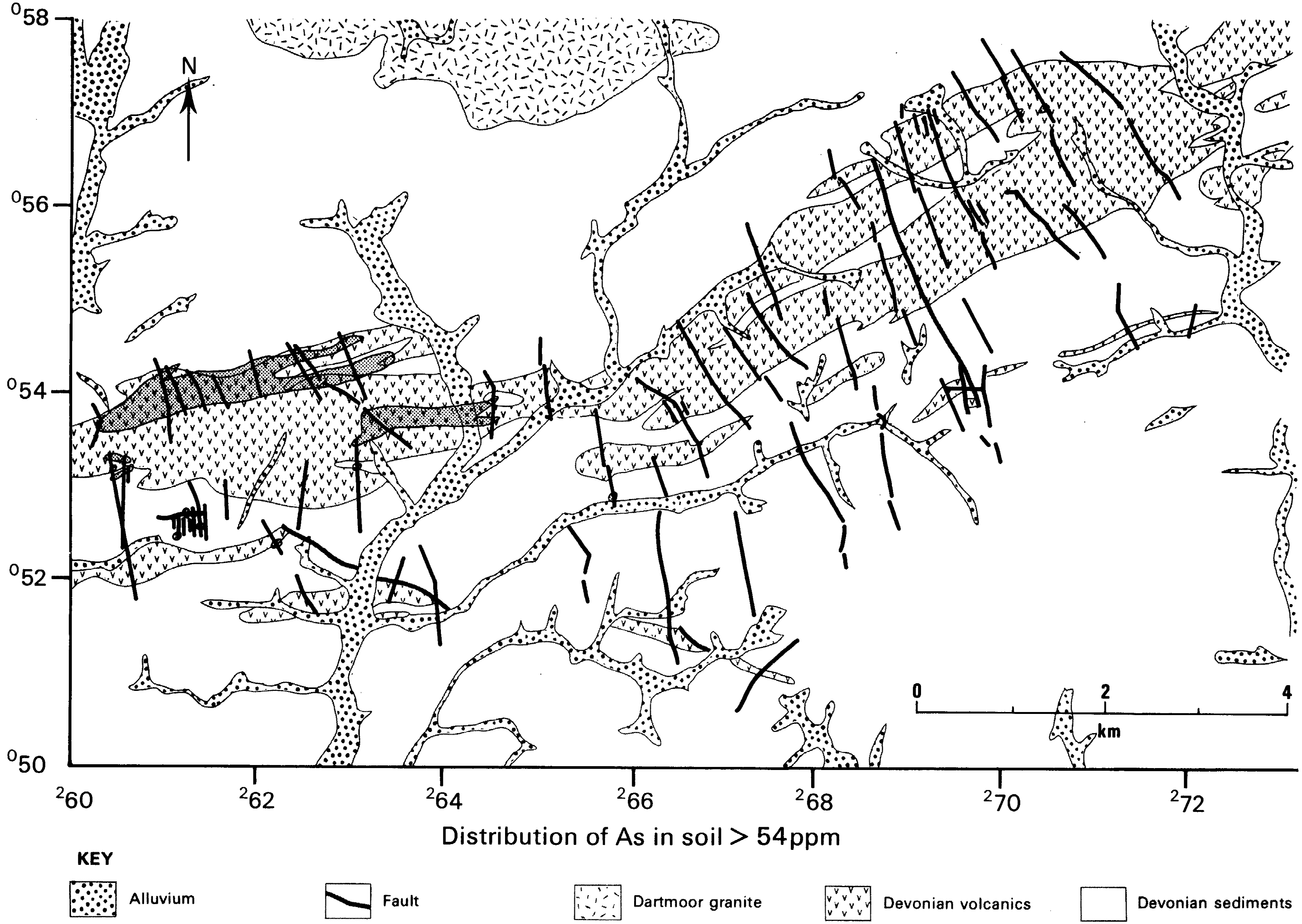

Figure 15 Distribution of soil samples containing anomalous concentrations of arsenic (> 54 ppm As) in south and west of area

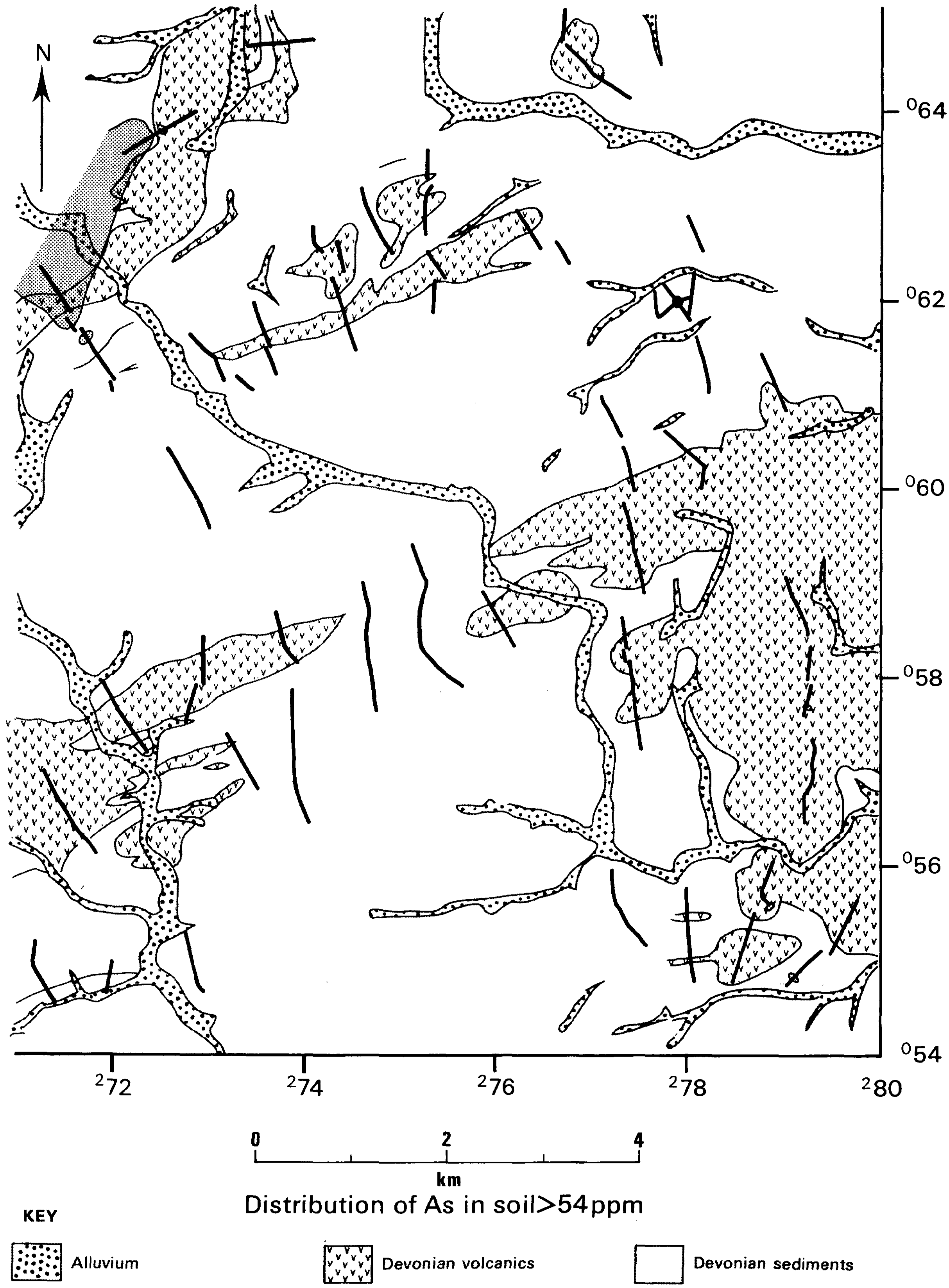

Figure 16 Distribution of soil samples containing anomalous concentrations of arsenic (> 54 ppm As) in north and east of area

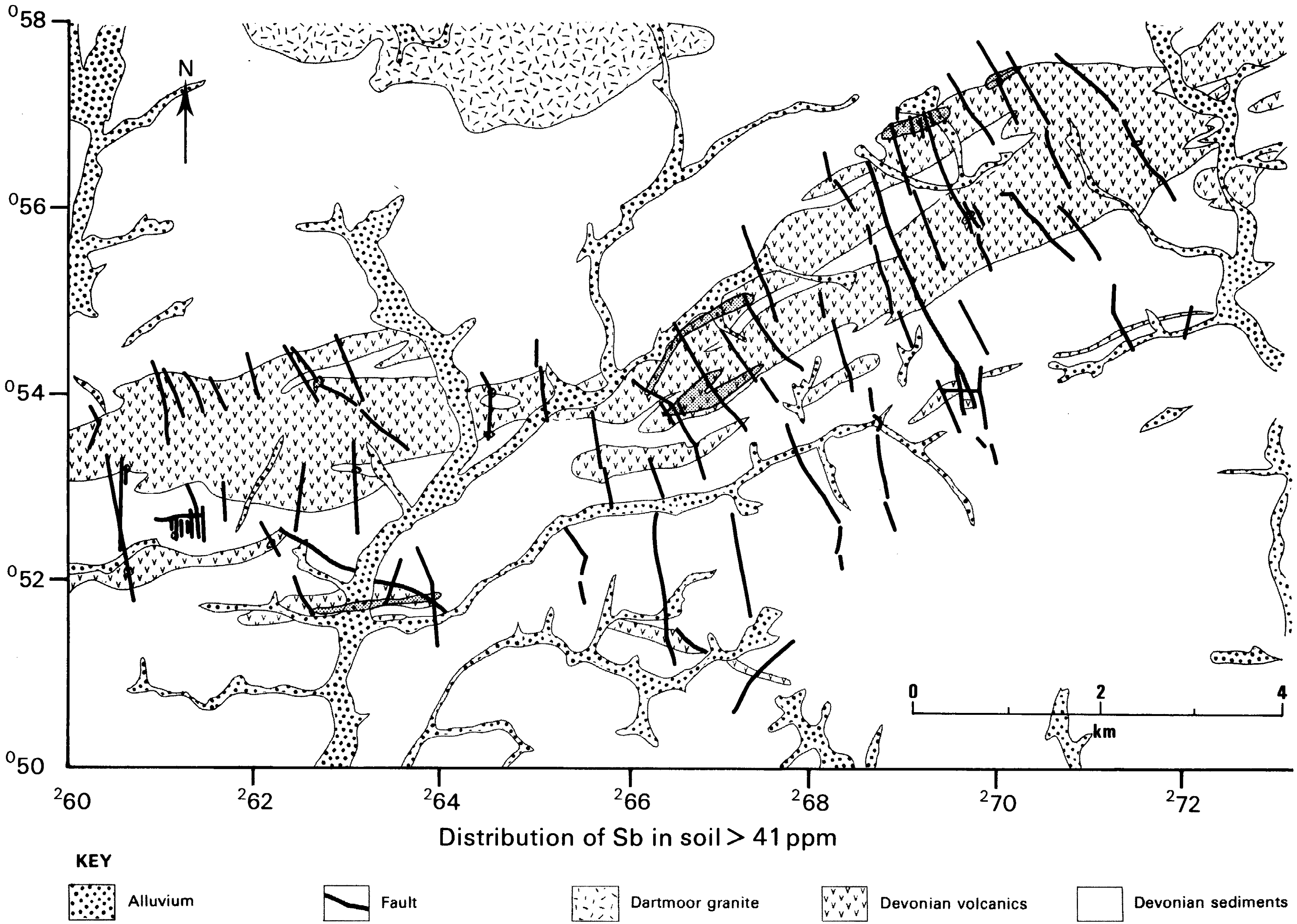

Figure 17 Distribution of soil samples containing anomalous concentrations of antimony (> 41 ppm Sb) in south and west of area

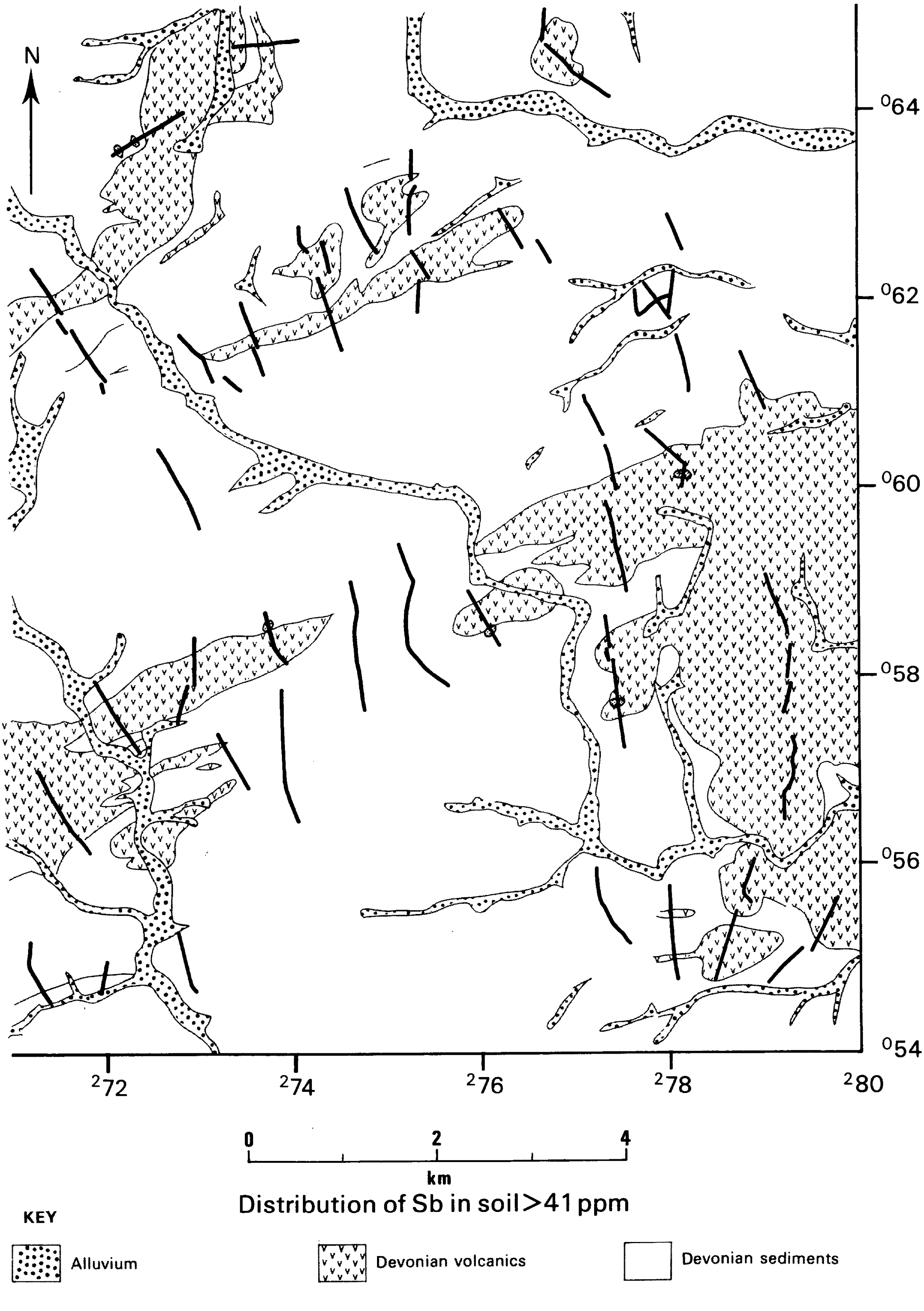

Figure 18 Distribution of soil samples containing anomalous concentrations of antimony (> 41 ppm Sb) in north and east of area

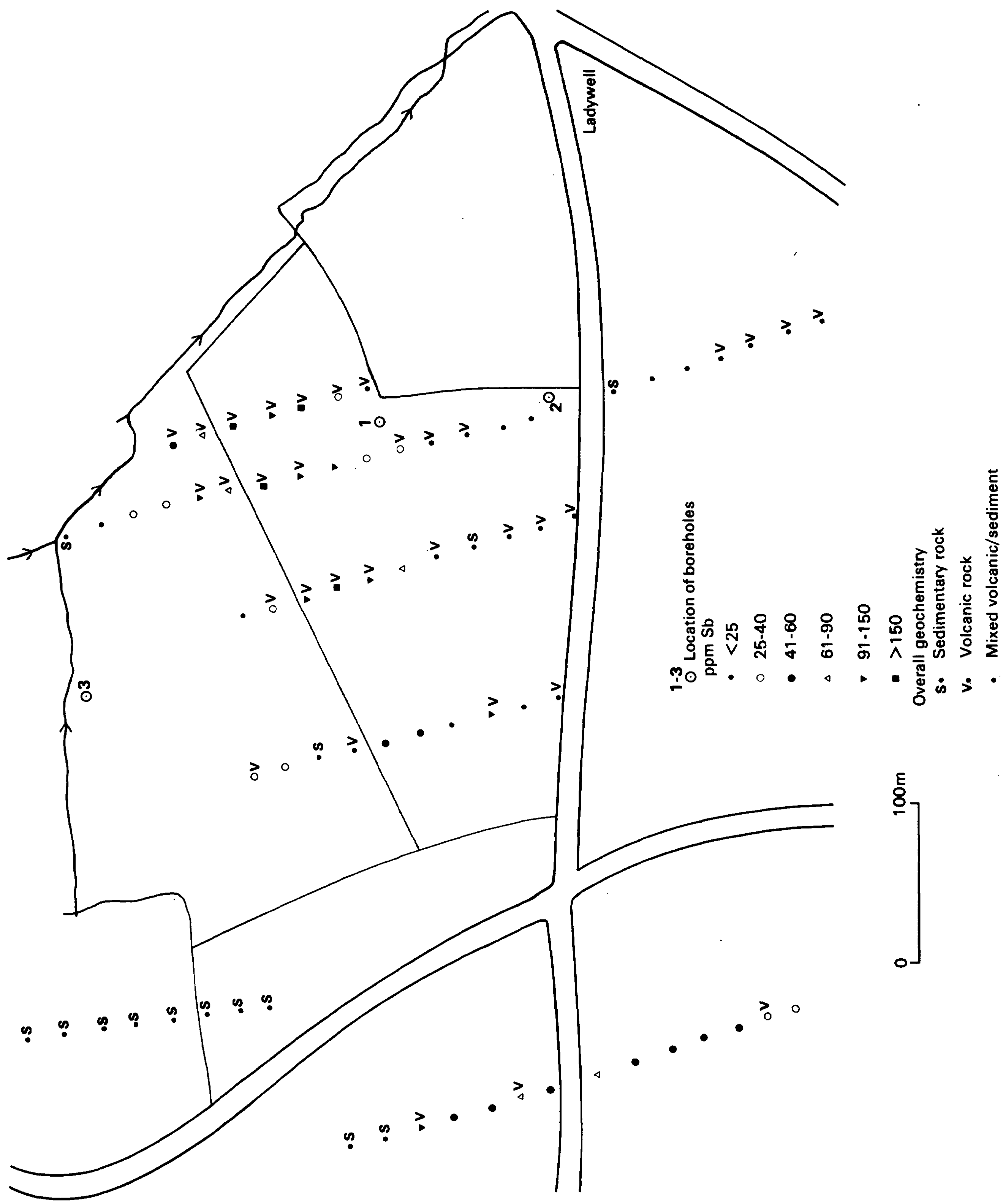

Figure 19 Locations of Ladywell boreholes in relation to overburden antimony anomalies and geology deduced from geochemistry of residual soil samples

area in the vicinity of the anomalous zone and by the desire to limit disturbance to agricultural activity.

Lithology

Borehole 2

The graphic log of the simplified lithology of borehole 2 is shown in Figure 20. In much of this hole volcanic and sedimentary material is intimately intermingled. Typically thin partings and lenses of dark slate occur within the volcanic rocks. In places the slate is predominant with thin volcanic layers. There are also areas of core in which volcanic rock is intimately associated with probable siliceous chemical sediment. Most of the volcanic rock is fine-grained but there are also relatively coarse layers with conspicuous feldspar crystals. The volcanic rock is usually sheared and sericitic but in some sections it is intensely brecciated. Although some of the brecciation is probably fault related, some is syngenetic due to autobrecciation during extrusion or reflects laharic or other debris flows. Most, if not all, of the volcanic material in this hole appears to be fragmental and clear evidence for the existence of lavas is lacking. Slump structures are visible where thin volcanic horizons are interlayered with slate. The volcanic rocks are intensely and variably altered to give red, pink, flesh, grey and greenish varieties. There is a distinct zone between about 77 and 89 m where the rocks are generally red-stained and altered.

Borehole 3

The graphic log showing the simplified lithology of borehole 3 is shown in Figure 21. In this borehole there is a sharp transition between volcanic and sedimentary material at about 58 m depth. This contact is marked by brecciation in the slates and is probably tectonic. Much of the volcanic material is relatively massive. Small pillows of lava can be seen in some sections with interfingered layers of mud. Siliceous chemical sediment in irregular lenses or layers is more conspicuous than in borehole 2.

Mineralisation

Borehole 2

Fine disseminated pyrite is uncommon in this hole. Sparry baryte occurs in one veinlet. Sulphides and sulphosalt minerals occur in minor amounts as fracture coatings and in association with carbonate veinlets. Sphalerite is most frequent together with lesser millerite, bournonite, tetrahedrite, stibnite, chalcopyrite and galena. The concentration of antimony reaches 186 ppm over 0.7 m in individual samples within the red altered zone but the form of this antimony is probably a secondary mineral since no sulphides or sulphosalts can be seen. Mercury is enriched to a maximum of 10.4 ppm against a background of around 0.5 ppm immediately adjacent to the red altered zone and may be accommodated in sulphosalt minerals. No detectable silver (> 0.5 ppm) or gold (> 10 ppb) was found in 15 analysed samples from borehole 2.

Borehole 3

Pyrite is more abundant in borehole 3 both in disseminations and in association with quartz and carbonate veining. Unlike borehole 2 sulphosalt minerals appear to be absent or very rare. Fracture coatings of galena are more conspicuous and there are a few occurrences of galena and sphalerite in association with carbonate veinlets. The form of the Zn which is enriched in some sections of the sedimentary rocks (up to 1580 ppm Zn over 1 m) is unclear.

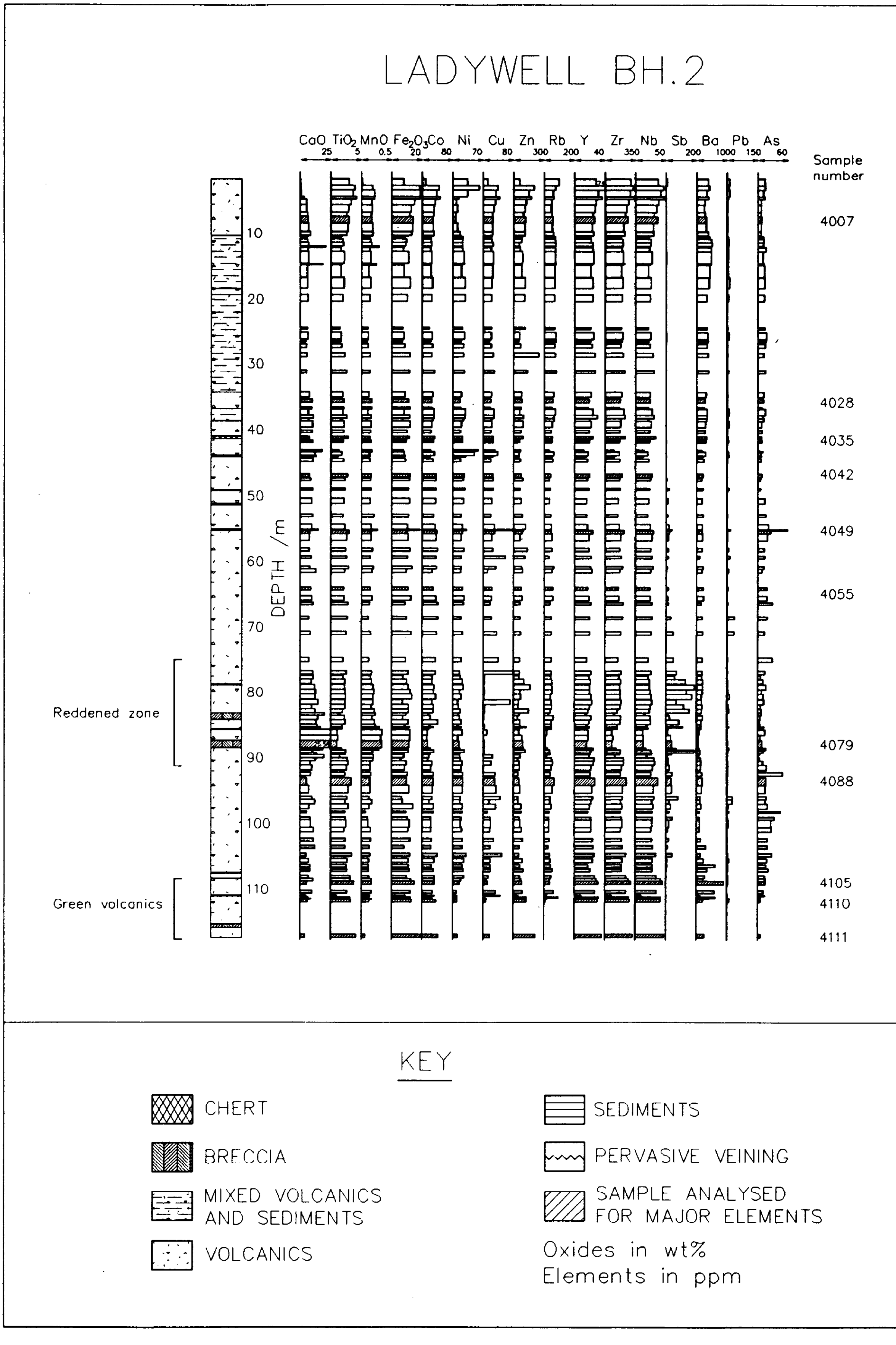

Figure 20 Graphic lithological and chemical log of Ladywell borehole 2

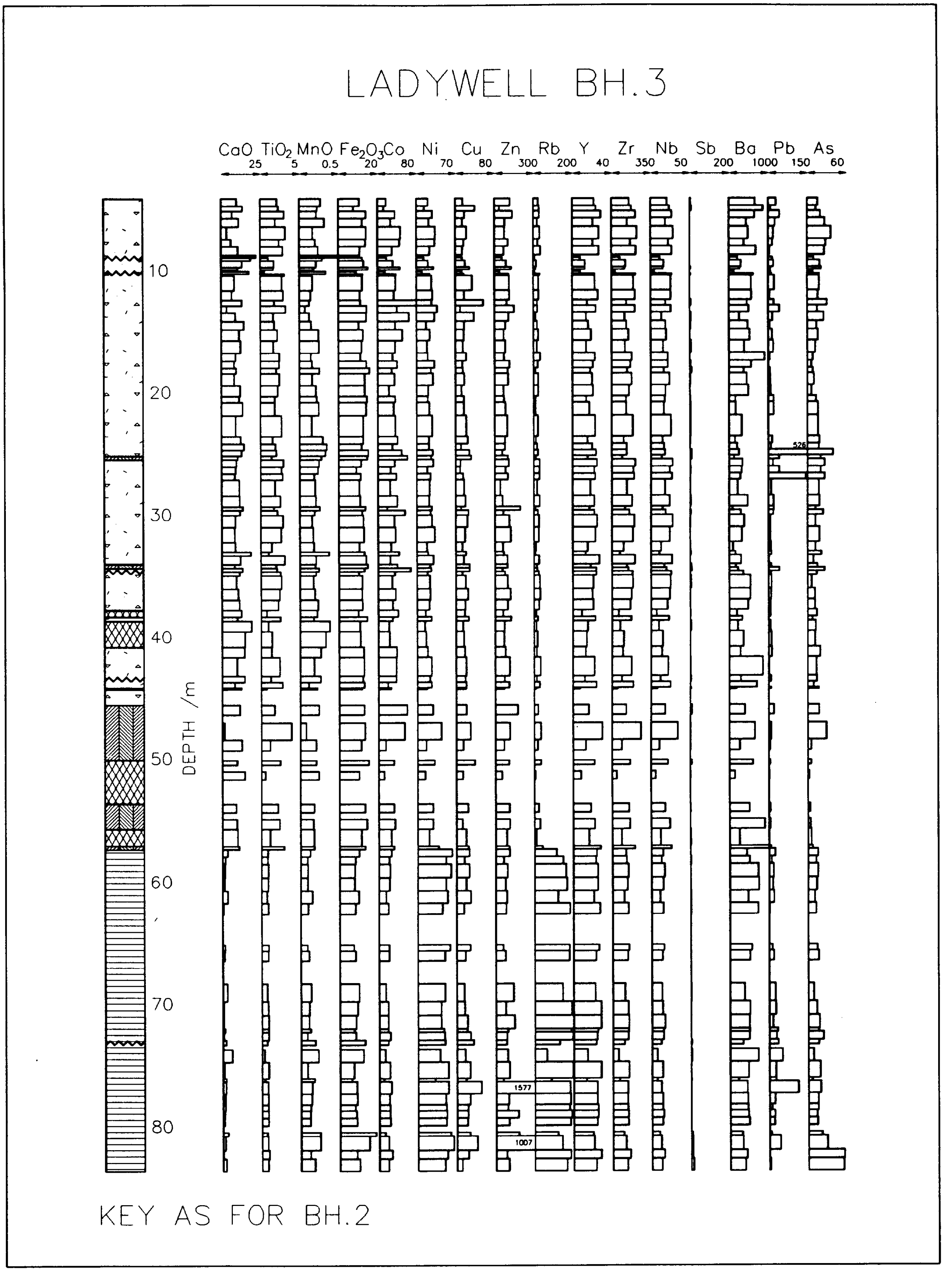

Figure 21 Graphic lithological and chemical log of Ladywell borehole 3

Chemistry of borehole core

Original nature of volcanic rocks

Knowledge of the source and plate-tectonic setting of volcanic rocks can be of importance in the assessment of potential for associated volcanogenic mineralisation. Discriminant diagrams using ratios of the more immobile elements can be used to identify the nature and possible environment of origin of altered volcanic rocks. On the Zr/TiO_2 against Nb/Y plot of Winchester and Floyd (1977), shown in Figure 22, samples from borehole 2 and 3 plot within the alkali basalt field. In samples from borehole 2 there is some scatter towards the andesite field (Trend A, Figure 22) which reflects admixture with sedimentary material. Some samples also show scatter towards the andesite/basalt field which probably reflects some addition of yttrium during alteration associated with carbonate veining and brecciation. The volcanic rocks from both holes plot within the field of intraplate basalts in the triangular Ti-Zr-Y plot of Pearce and Cann (1973), shown in Figure 23, with spread towards relatively high Zr reflecting sediment admixture and a tenuous trend towards the Y apex reflecting addition of Y in association with carbonate alteration.

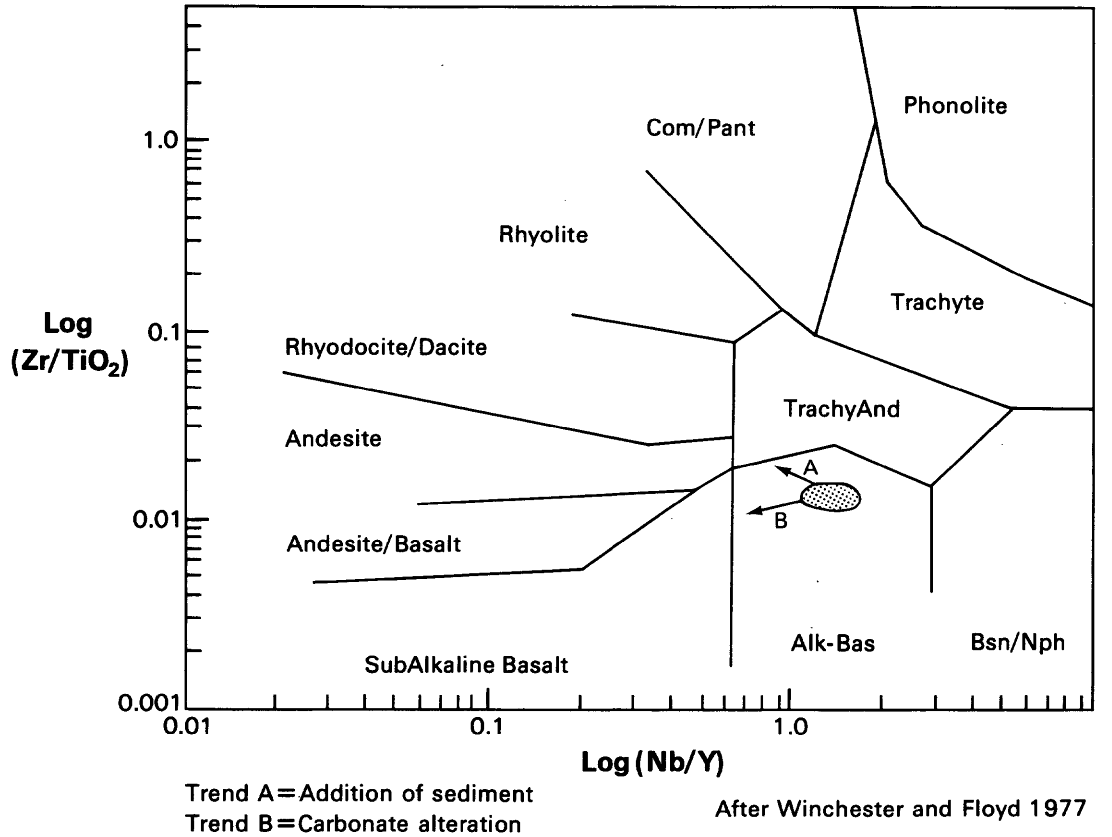

Figure 22 Plot of log (Zr/TiO_2) against log (Nb/Y) showing the field occupied by Ladywell volcanic rocks (shaded) superimposed on the fields of common volcanic rocks; after Winchester and Floyd (1977). Additional points along trend A and trend B reflect admixture of sedimentary material with the volcanics and hydrothermal addition of yttrium respectively.

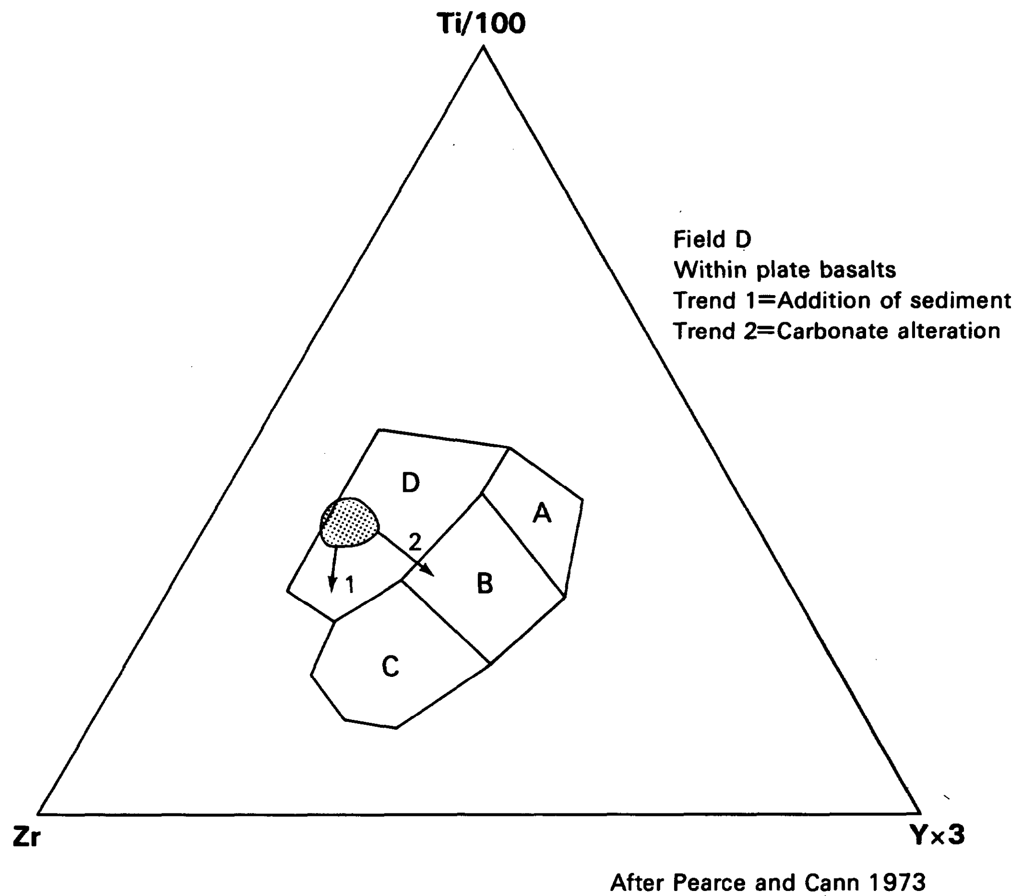

Figure 23 Triangular plot of Zr-Ti/100-Yx3 showing field of Ladywell volcanic rocks (shaded) superimposed on fields of basalts from different plate tectonic settings; after Pearce and Cann (1973). Field A = predominantly arc basalts , field B = predominantly mid-ocean ridge basalts, field C = predominantly arc calc-alkali basalts and field D = intraplate basalts. Additional points along trend 1 and trend 2 reflect admixture of sedimentary material with the volcanics and hydrothermal addition of yttrium respectively

The intimate mixing of sedimentary and volcanic rocks in borehole 2 is more clearly shown on a plot of the two immobile elements Ti and Zr (Figure 24a). The TiO_2/Zr trend of the volcanic rocks is typical of alkali basalts and similar to that shown for Upper Devonian volcanic rocks in Southwest England by Floyd (1982a). However, there is greater variation of the TiO_2/Zr ratio for samples from borehole 2 than borehole 3 and higher absolute values of both elements. This suggests that borehole 2 volcanics are more highly differentiated than borehole 3 volcanics. The brecciated and silicified rocks have similar TiO_2/Zr ratios to the volcanic rocks suggesting that the matrix of these hydrothermal rocks is volcanic.

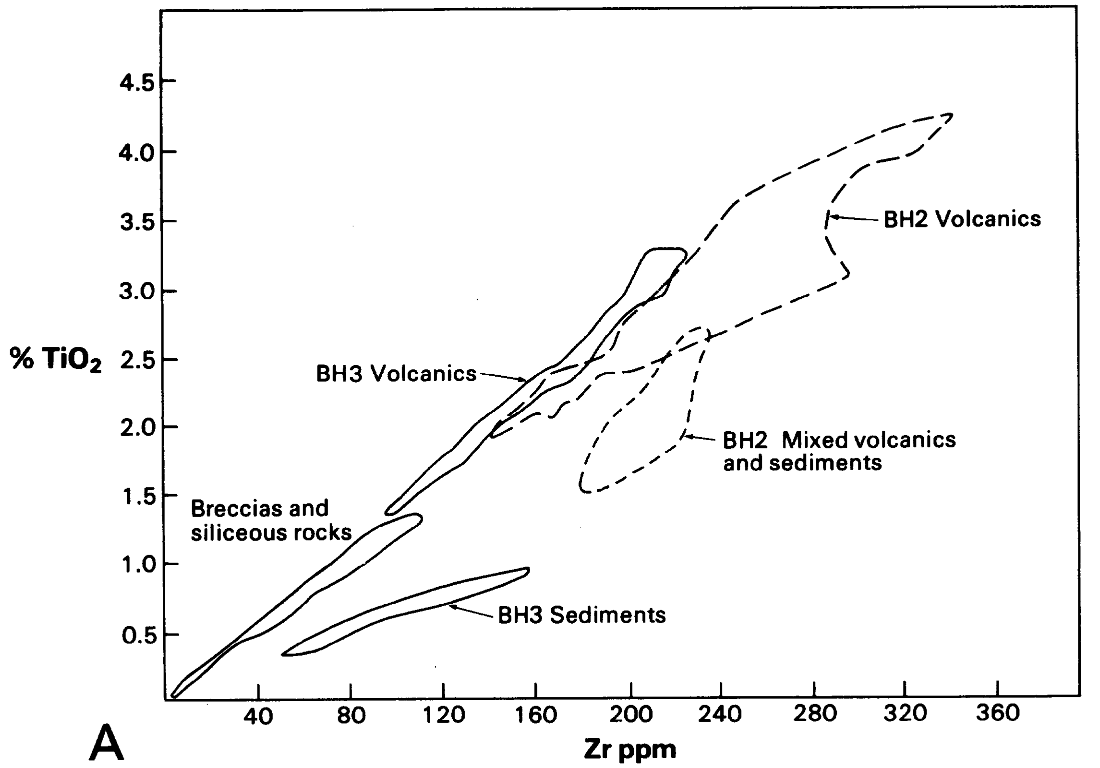

Figure 24a Plot of TiO_2 against Zr showing fields occupied by different rock types in Ladywell boreholes 2 and 3.

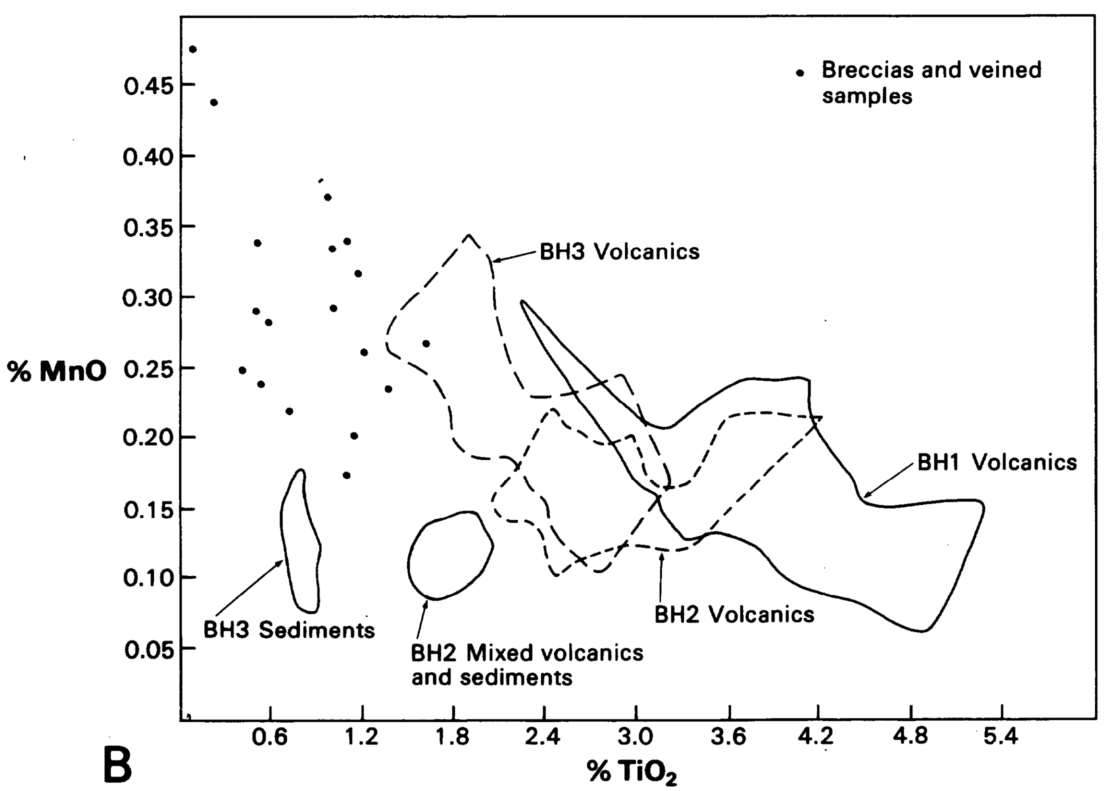

Figure 24b Plot of MnO against TiO_2 showing fields occupied by volcanics and other rocks types from all three Ladywell boreholes

Hydrothermal alteration

The variety and extent of hydrothermal alteration of both volcanic and sedimentary rocks is a striking feature of the boreholes. At least three varieties can be recognised on the basis of mineralogy and chemistry.

The most visually obvious type of alteration is the extensive and, in parts, intensive carbonate veining and pervasive alteration. A plot of MnO against TiO_2 for samples from all three Ladywell boreholes (Figure 24b) shows relatively high levels of Mn to be characteristic of veined and brecciated rocks. The reddish tinge of some of the carbonate also suggests that it contains a significant amount of the rhodochrosite end-member. A concentration of 0.2% MnO (average MnO in alkali basalt 0.15%) represents a threshold above which Mn has been introduced into the volcanic rocks as a result of hydrothermal alteration. Samples from boreholes 1 and 2 mostly plot in a high Ti and low Mn field (Figure 24b) indicating relatively little carbonate alteration. In contrast, several samples from borehole 3 have a distinctive bleached colouration and plot in a field with lower Ti and higher Mn, reflecting the carbonate alteration.

A second and more pervasive type of alteration which causes significant variation in the alkali elements is also present in the volcanic rocks. The existence of this alteration can be demonstrated principally in borehole 1 since few samples were analysed for Na_2O and K_2O in borehole 2 and none in borehole 3. Two fields are apparent in the Na_2O-K_2O plot in Figure 25a. All samples showing relative enrichment in sodium are greenish in colour. In contrast, samples showing relative enrichment in potassium and depletion in sodium are pinkish in colour. As the field of the green volcanics is close to the average composition of alkali basalts (Figure 25a) it is probable that a phase of hydrothermal alteration was responsible for addition of potassium and depletion of sodium in the pinker volcanics. The degree of potassic alteration in the Ladywell holes is not as intense as that found in volcanic rocks from Ludbrook and Burraton (Leake et al., 1985). The majority of samples from borehole 2 that have been analysed for the alkali elements plot within or close to the field of altered volcanics. The two borehole 2 samples with a higher sodium content than the field of green volcanics in borehole 1 may represent a different style of alteration. The greater general abundance of Rb in borehole 2 volcanics compared with borehole 3 volcanics (Figure 25b) is probably due to a combination of (1) a more highly differentiated initial composition, (2) admixture of several samples with minor amounts of sediment and (3) potassic alteration.

A third variety of alteration produced the zone of oxidised rock enriched in antimony that was intersected in borehole 2. This conspicuously red zone is completely depleted in Cu as a consequence of destruction of any sulphide or sulphosalt minerals. There appears to be little introduction of iron into this zone. It is possible that the antimony is remobilised and enriched locally in the red zone due to the oxidation of part of a wider zone showing lower amplitude enrichment in antimony, mostly in the form of sulphosalt minerals.

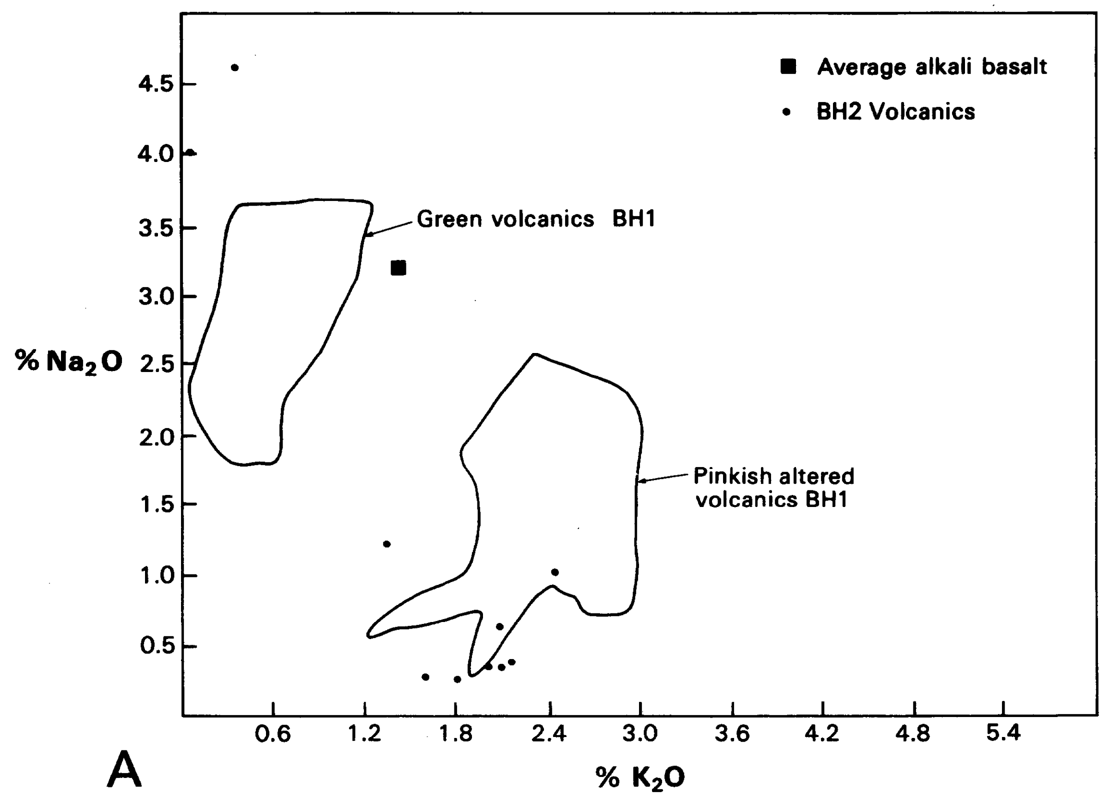

Figure 25a Plot of Na_2O against K_2O in mafic volcanic rocks from Ladywell boreholes 1 and 2 showing fields of greenish and pinkish altered varieties.

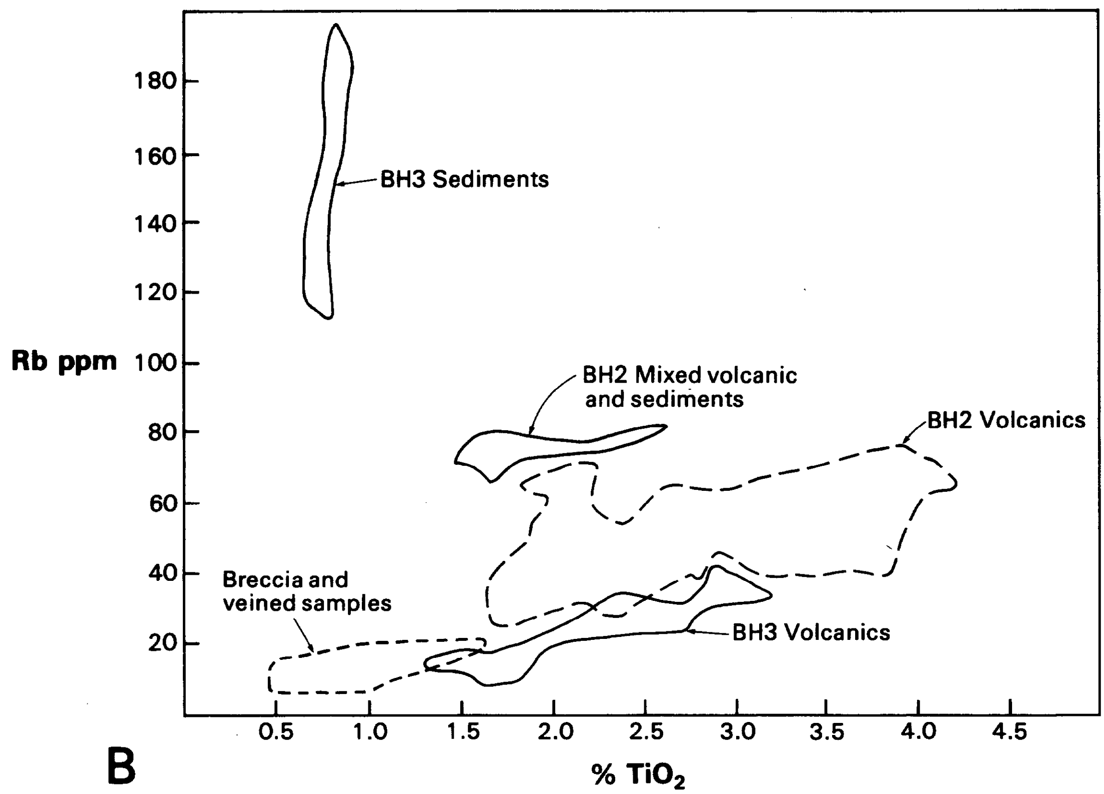

Figure 25b Plot of Rb against TiO_2 showing fields occupied by various rock types in Ladywell boreholes 2 and 3

Relationship of overburden anomalies to mineralisation in core

The locations and lithologies of boreholes 1 and 2 are shown in relation to the area of anomalous antimony in soil in Figure 26. Borehole 3 which was sited to the north of the anomalous zone (Figure 19) did not intersect rocks with any degree of enrichment in antimony and it is possible that it is separated from the anomalous zone by faulting. Boreholes 1 and 2 have similar lithologies and chemistry and the presence of sediment mixed with volcanics in the upper part of borehole 2 correlates with the chemistry of overburden samples to the south of the collar of borehole 1. The zone of antimony enrichment intersected in borehole 2, at 120 ppm Sb over 6.4 m or 75 ppm over 21 m, is comparable in width and magnitude with the surface soil anomalies. However borehole 1, which would be on the downward projection of the anomaly, shows only minor amounts of antimony-bearing mineralisation.

Two interpretations of the relationship between the surface anomalies and boreholes are possible. Firstly, the surface anomaly and the mineralisation intersected in borehole 2 could reflect two distinct mineralised structures dipping steeply to the north. Against this is the absence of any antimony anomalies in overburden to the south of borehole 2. A second possibility is that of two separate shallow north-dipping mineralised structures, the one intersected in borehole 2 having no surface expression.

THE CLASSIFICATION OF VARIETIES OF MINERALISATION

An attempt to classify the types of soil anomaly and their mineralisation sources has been made in multicomponent space using cluster analysis (SAS Fastclus procedure). This is valuable as different mineralisation types have different elemental signatures, which in some cases can be diagnostic. Particular attention has been paid to the question of evidence for stratabound enrichment in base metals which may be related distally to the centres of exhalative mineralisation previously investigated by drilling (Leake et al., 1985).

Exhalative mineralisation

The soils derived from the area of exhalative mineralisation around Higher Ludbrook generally have a distinct signature, with enrichment principally in Ba, Mn, Zn and Sb. In soils derived from volcanic rocks, (relatively high Ti contents) samples with an exhalative mineralisation signature occur within a recognisable field within a Mn-Fe-Ba triangular diagram using concentrations ratioed to the median element level of the total population of soil samples (Figure 27). This exhalative field shows enrichment in Ba with some accompanying enrichment in Mn. Samples derived from sedimentary rocks with an exhalative signature also show Ba enrichment but less marked enrichment in Mn than the volcanic rocks, as illustrated in the corresponding Mn-Fe-Ba diagram for sedimentary rocks (Figure 28). On the equivalent Cu-Zn-Pb diagram (Figure 29), which includes only samples with greater than 50 ppm Cu or 180 ppm Zn or 70 ppm Pb, samples from around Higher Ludbrook mostly plot towards the Zn apex but with some samples showing some parallel enrichment in Cu. In contrast, the samples derived from the Burraton area plot towards the Pb apex in the same diagram. This difference probably reflects the much greater abundance of mafic volcanic rocks in the Higher Ludbrook area which would represent a reservoir of Zn and Cu rather than Pb.

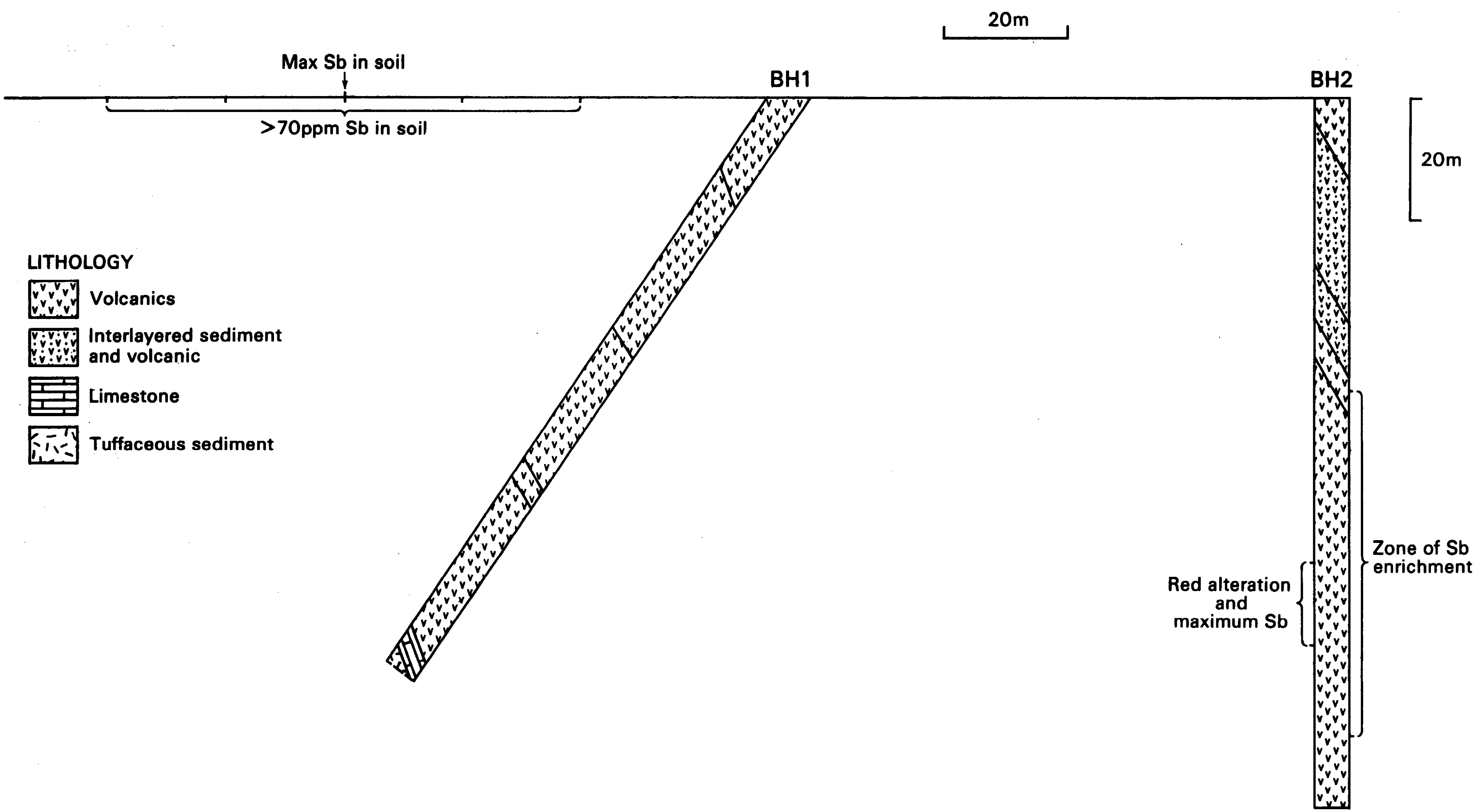

Figure 26 Section through boreholes 1 and 2 showing relationship between lithology and dip of strata in holes holes and surface antimony anomalies

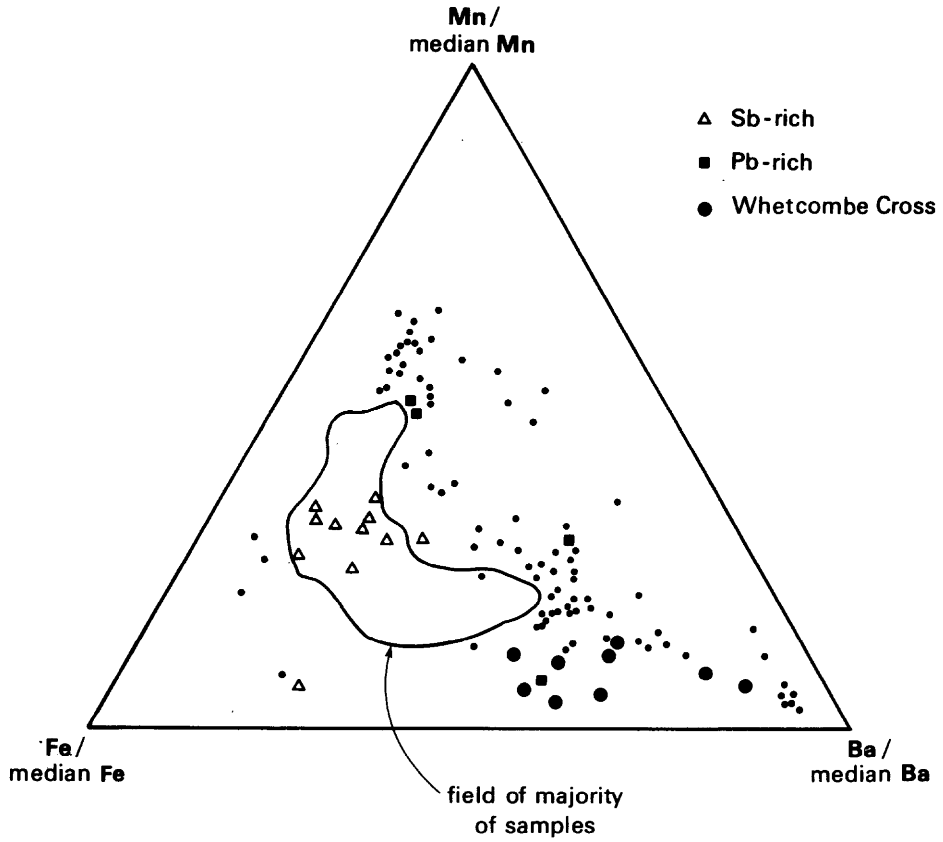

Figure 27 Triangular plot of Mn, Fe and Ba in soils derived from volcanic rocks ratioed against the median level for each element in the complete soil sample dataset. Soils derived from probable vein baryte mineralisation at Whetcombe Cross are distinguished

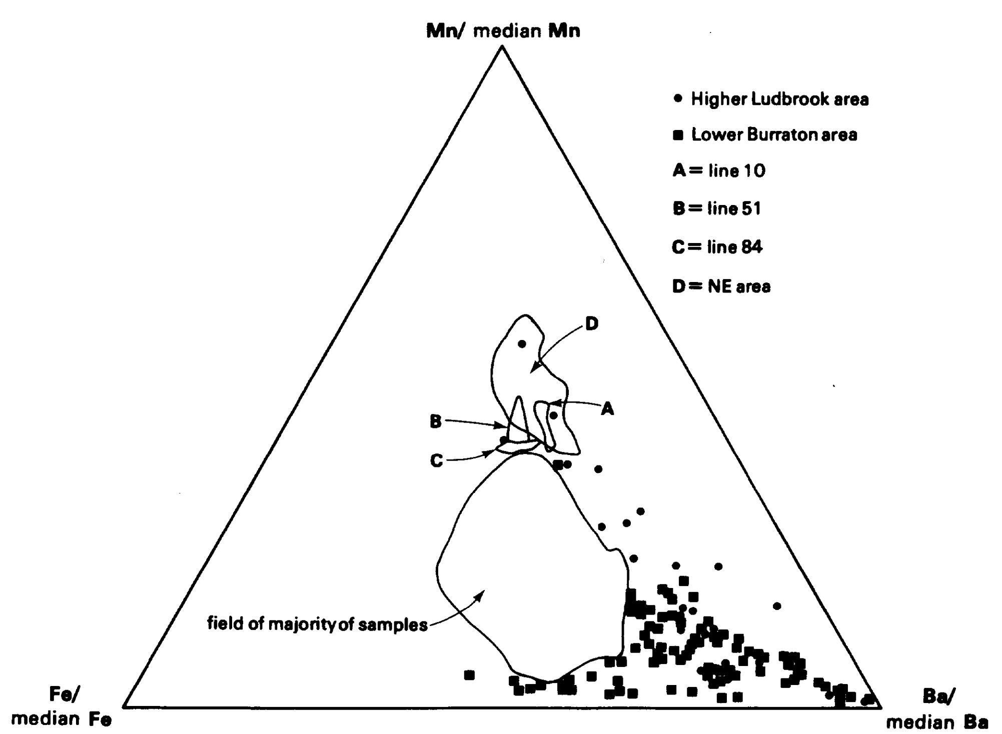

Figure 28 Triangular plot of Mn, Fe and Ba in soils derived from sedimentary rocks ratioed against the median level for each element in the complete soil sample dataset. Fields of four areas of Mn enrichment shown

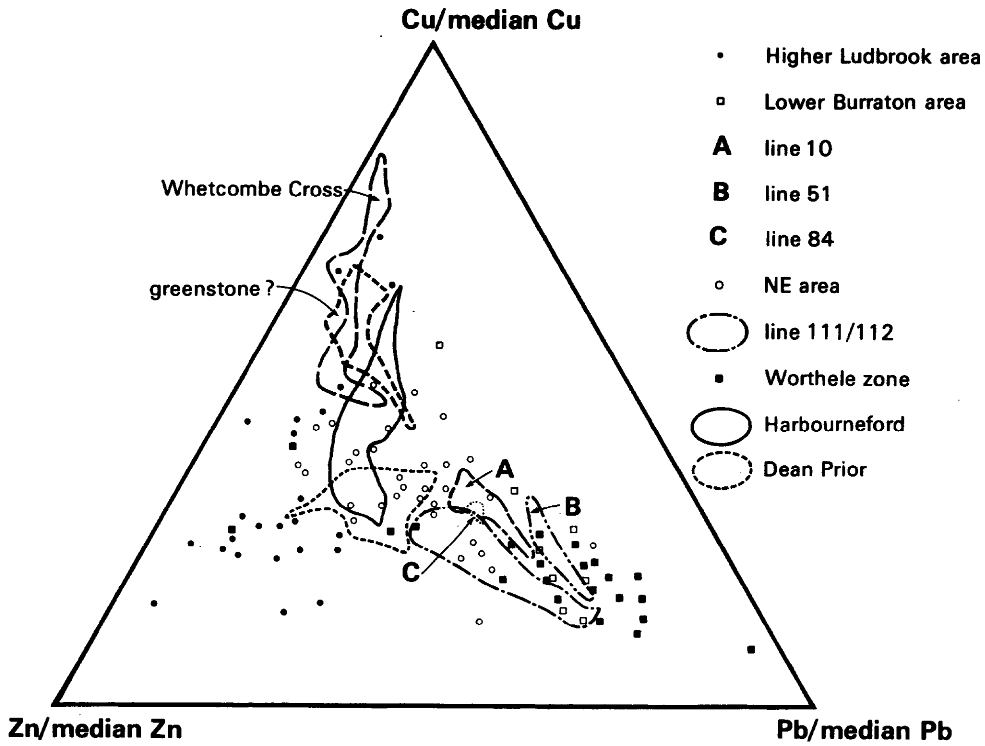

Figure 29 Triangular plot of Cu, Zn and Pb contents in anomalous soil samples (> 50 ppm Cu, > 180 ppm Zn and > 70 ppm Pb) ratioed against the median level for each element in the complete soil sample dataset

There is no evidence of continuity between the mineralisation at Higher Ludbrook and that at Burraton. The Burraton anomalous zone extends only between lines 10 and 21 with peripheral anomalies that are narrow and relatively low amplitude. On the basis of the existing geological mapping on the 1:50,000 Geological Survey Ivybridge mapsheet and charcteristics of satellite images, a major fault zone trending around west-north-west separates the two areas. However, the two anomalous zones do not terminate against this fault zone, being separated by about 4 km. Nevertheless, there is considerable overlap in chemistry between the anomalous soils derived from sedimentary rocks in the two areas, suggesting similar types of source mineralisation.

There are a number of areas where soil samples indicate that sedimentary rocks are enriched in metals, some of which could be distal equivalents to exhalative mineralisation. The locations of these are shown in Figures 30 and 31 and they are discussed in turn below.

A group of samples on lines 10 and 11 outline a zone about 100 m wide in which Mn and base metals are somewhat enriched compared with typical sedimentary rocks. Thus Mn reaches 2920 ppm and the samples plot further towards the Mn apex (field A) in the Fe-Mn-Ba triangular diagram of sedimentary rock derived samples in Figure 28 than the field of the majority of sedimentary rocks. The samples are slightly enriched in Cu, Zn and Pb (maxima 54 ppm, 204 ppm and 104 ppm respectively) so that they plot in a distinct field in the Zn-Cu-Pb diagram in Figure 29, adjacent to the field of Burraton samples.

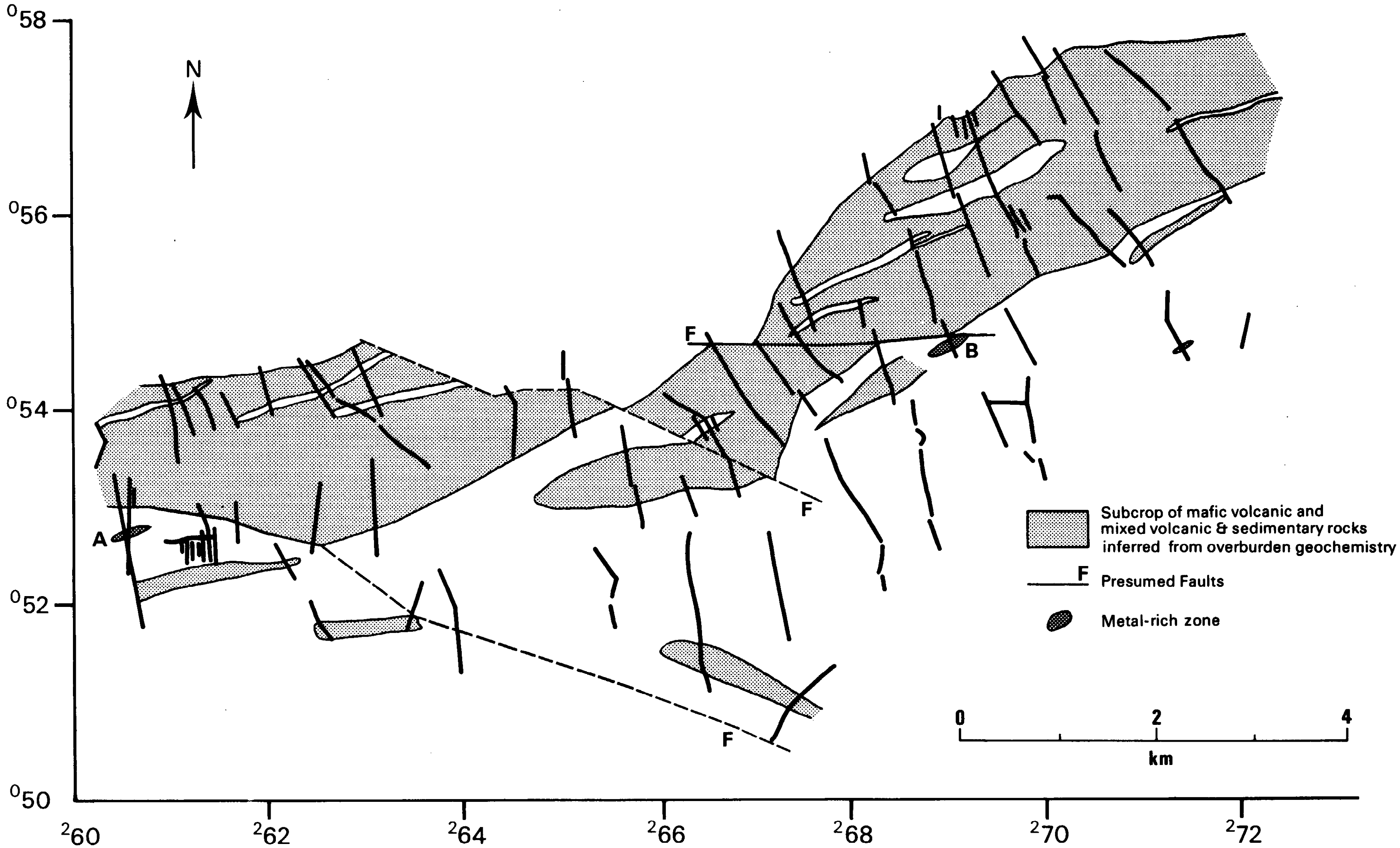

Figure 30 Locations of soils derived from metal-enriched sedimentary rocks in the south and west of the area

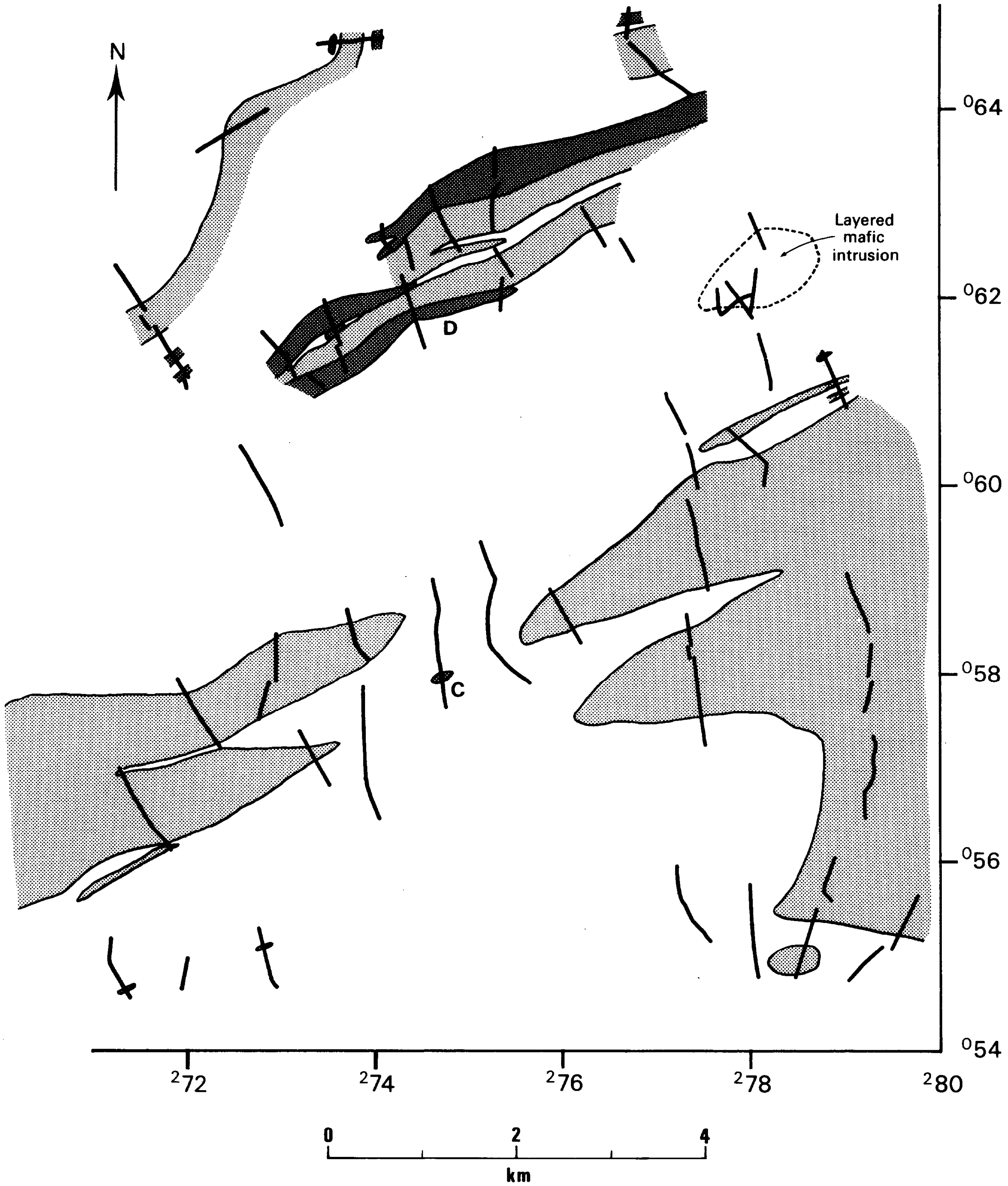

Figure 31 Location of soils derived from metal-enriched sedimentary rocks in the north and east of the area. Ornament as in Figure 30

A zone within sedimentary rocks around 120 m wide is outlined by a group of samples on line 51 in which concentrations of Mn, Zn and Pb are relatively high, reaching 2920 ppm, 195 ppm and 171 ppm respectively. These samples show relative enrichment in Mn compared with the majority of samples derived from sedimentary rocks, plotting within field B in the Mn-Fe-Ba diagram (Figure 28). In the Zn-Cu-Pb diagram (Figure 29) they plot (field B) within the field occupied by samples derived from the Burraton area. The soil data indicate that the metal-rich zone in sediments can be traced to the southwest into a lensoid mass of volcanic rocks south of the main volcanic outcrop (Figure 30).

A group of samples on line 84 also outline a zone about 100 m wide of sediments showing evidence of slight enrichment in Mn, Zn and Pb (maxima 2370 ppm, 160 ppm and 66 ppm respectively). This zone is situated between two lensoid outcrops of volcanic rock within the main belt (Figure 31). The relative enrichment in Mn is only marginal (field C in Figure 28) and the proportion of Cu, Pb and Zn is similar to that shown by the metal-rich samples from line 10.

By far the greatest concentration of samples reflecting sedimentary rocks enriched in metals occur in three zones adjacent to the volcanic rocks in the northeastern part of the area (Figure 31). The concentration of manganese frequently reaches much higher levels than in the other zones described above, as demonstrated by the greater extent of field D in Figure 28. The samples occupy a relatively large field between the Ludbrook and Burraton fields in the Zn-Cu-Pb triangular plot in Figure 29. The southernmost zone is apparently the most anomalous with concentrations reaching 6220 ppm Mn, 225 ppm Zn and 96 ppm Pb. This zone terminates to the east against the 200 m wide zone of metal anomalies in volcanic rocks on lines 111 and 112 (maxima of 7630 ppm, 83 ppm, 760 ppm, 613 ppm for Mn, Cu, Zn and Pb respectively). The field occupied by the anomalies on lines 111 and 112 in the Zn-Cu-Pb diagram (Figure 29) overlaps with that of the sedimentary rocks in the area but extends further towards the Pb apex.

Vein baryte

Volcanic host rocks

At the eastern end of the main zone of Ba enrichment (Figure 5), around Whetcombe Cross (Figure 2), in soils derived from the volcanic rocks there are a series of samples which are geochemically distinct from the Higher Ludbrook type. They are marked by Ba enrichment but relative depletion in Mn (Figure 27) and by higher levels of Cu than the Higher Ludbrook samples (Figure 29). On this basis it can be speculated that the mineralisation is of vein type, probably postdating the exhalative mineralisation and characterised by solutions which leached the Mn-enriched carbonate already pervasively present within the volcanic rocks of the area.

Sedimentary host rocks

Within the zone of Ba anomalies in the Lower Burraton area there are some soil samples where elevated Ba levels are accompanied by low contents of Mn (Figure 28). Similar samples also occur to the west on lines 10 and 11. It is possible that these samples reflect vein baryte.

Polymetallic mineralisation

Worthele zone

This zone is a broad (500 m) elongate group of anomalies at least 3 km long from line 1 to line 9, trending approximately parallel to the strike of the local rocks which are predominantly volcanic. Arsenic is the most prominent anomalous element, reaching a maximum of 220 ppm. Anomalies of Pb, Zn, Mn and Cu are also present (maxima 350, 655, 4850 and 110 ppm respectively) but they are less extensive than the As anomalies. The thinner zone of Pb, Zn and Cu anomalies appears to mark the centre of the anomalous zone which also decreases laterally from between lines 6 and 7. Antimony contents are anomalous in a regional context (generally 10-24 ppm and locally up to 44 ppm) but not compared with other parts of the area.

The signature of the Worthele zone within rocks of Middle Devonian age is very similar to that of the broad anomalous zone around Churchill Farm some 16 km southeast, and to mineralisation exposed on the south coast at Wadham Rocks, some 7 km to the southwest (Leake et al., 1992). At Wadham Rocks, gold is associated closely with elevated levels of arsenic which is largely present as As-enriched pyrite overgrowths on As-poor pyrite (Leake et al., 1992).

The mineralised zone at Churchill Farm is structurally controlled and epigenetic within the recently recognised northern segment of the Start complex containing mafic volcanic rocks, while the mineralisation at Wadham Rocks comprises a zone of veining and pervasive alteration within sedimentary and mafic volcanic rocks of Lower Devonian age (Leake et al., 1992). At Wadham Rocks the mineralised zone has been deformed within the Hercynian orogeny. The age of this mineralisation is therefore either Upper Devonian or Lower Carboniferous, forming in response to a period of tensional stress regime.

Dean Prior and Harbourneford

The other main region of polymetallic mineralisation is in the Dean Prior and Harbourneford areas, intersected on lines 123 and 124. Arsenic is particularly anomalous in the zone, reaching a maximum of 786 ppm. The similar proportions of elements in these two areas, though separated by 1.5 km, suggest that the sources of the soil anomalies are similar in character. Thus the samples from both areas plot roughly along a straight line in the Zn-As-Pb triangular diagram in Figure 32. Though the above anomalous zone and the anomalous zone at Worthele in the west of the region are both marked by considerable enrichment in arsenic, the proportions of the metallic elements are significantly different. The Dean Prior and Harbourneford anomalies are richer in Zn and poorer in Pb than in the Worthele zone to the extent that they plot within a different field on the Zn-Cu-Pb and Zn-As-Pb diagrams in Figures 29 and 32 respectively. In addition, antimony contents are much lower than at Worthele and there are several samples with appreciable tin contents (maximum 49 ppm Sn) near Harbourneford.

It is suggested that the mineralisation which produced the anomalies in the Dean Prior and Harbourneford areas is different in character from the polymetallic mineralisation at Worthele and elsewhere in south Devon. The presence of Sn and the proximity to the Dartmoor granite, 2 km away from part of line 123, suggests that the mineralisation could be related to the contact aureole of the granite, particularly as the aureole is relatively wide in this area. Alternatively the mineralisation could be associated with an intrusive greenstone with an outcrop up to 500 m wide about 500 m southwest of the anomalies at Harbourneford. Samples derived from greenstone

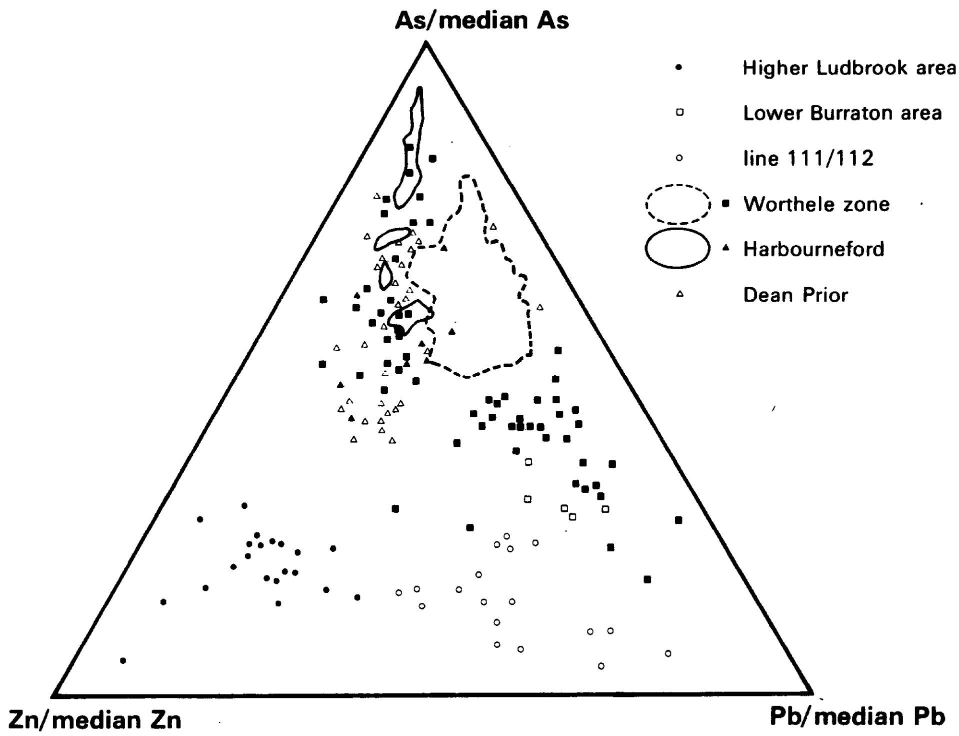

Figure 32 Triangular plot of As, Zn and Pb contents in anomalous soil samples ratioed against the median level for each element in the complete soil sample dataset

bodies elswhere in the area are marked by relatively high Cu contents (Figure 29) as well as elevated Ni concentrations. As the anomalies at Dean Prior occur at a position roughly equivalent along strike to the greenstone, but only a few hundred metres away from the granite contact, both interpretations are possible.

COMPARISON BETWEEN SOUTH DEVON AND RHENISH BASIN

Similarities in the geology and mineralisation between south Devon and the Rhenish basin of Germany are striking. The Fe carbonate and pyrite mineralisation associated with the top of the volcanic sequence at Higher Ludbrook is similar to volcanic related mineralisation of the Lahn Dill type from the Rhenish basin. The stratiform baryte mineralisation at Lower Burraton within shales and minor volcanics (Leake et al., 1985) is similar to the low base metal type of baryte mineralisation of Middle and lower Upper Devonian age in the Rhenish basin (Werner, 1989). All the mineralisation of the Rhenish basin, including the very significant Meggen SEDEX deposit, is thought to reflect a long period of high heat flow and a tensional stress field with major deep faults (Werner, 1989). This is contrasted with the rocks of similar age to the west of the Rhine where evidence of high heat flow is lacking and evidence of exhalative mineralisation much less. Since the geology of south Devon is much more like the Rhenish basin than the area to the west of the Rhine, the potential for the occurrence of SEDEX mineralisation of the Meggen type remains.

CONCLUSIONS AND RECOMMENDATIONS

The overburden geochemical data and the nine BGS boreholes drilled in the Middle Devonian volcanic belt indicate that extensive hydrothermal systems were associated with the volcanic activity. There is also evidence of metal-enriched sedimentary rocks which suggests that submarine hydrothermal activity took place during at least some of the Devonian. The presence of baryte at Lower Burraton, away from the main outcrop of volcanic rocks, and the analogy with the Rhenish basin suggests that SEDEX mineralisation may occur remote from the outcrop of volcanic rocks. Parts of south Devon more remote from the volcanic rocks and especially the continuation of the belt westwards into Cornwall have not been explored and remain highly prospective. Since work in the Rhenish basin (Werner, 1989) indicated that growth faulting played an important part in the control of exhalative mineralisation, a better structural understanding of southwest England may provide crucial information to focus exploration within the belt towards the most favourable sectors.

The controls and environment of the enrichment in antimony found in surface soils and drill core at Ladywell is poorly understood. Local mobilisation of pre-existing diffuse antimony-bearing mineralisation may account for the high amplitude antimony anomalies within a zone of oxidative alteration. In the more diffuse mineralisation antimony is present mostly as sulphosalt minerals and this may reflect a primary enrichment in the element associated with some episode of the volcanic activity. Further evidence of a primary association between antimony amd mafic magmatism is provided by the association of antimony enrichment with intrusive dolerite bodies within a sequence of similar age containing chemically similar volcanic rocks in north Cornwall (Leake et al., 1989)

Several centres of epigenetic hydrothermal activity and polymetallic mineralisation with gold, superimposed on Devonian rocks of various ages, have been located in south Devon. This hydrothermal activity is poorly understood and adequate information on the potential for significant gold content is lacking. At least one of these centres needs to be investigated by drilling to establish the extent and zonation of hydrothermal activity and to establish whether gold concentrations are likely to reach economically interesting levels.

ACKNOWLEDGEMENTS

The authors wish to thank landowners in south Devon for allowing access for geochemical sampling. We are especially grateful to Mr Mitchell for allowing drilling at Ladywell. K E Beer, D G Cameron and R Thompson are thanked for arranging and supervising the collection of overburden samples. Drilling was carried out by H Wilson and A Barnes. Diagrams were prepared by staff of the Drawing Office, Keyworth under the supervision of R J Parnaby.

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