

Mineral Reconnaissance Programme

Report No. 98

**Exploration for gold between the
lower valleys of the Erme and Avon
in the South Hams district of Devon**

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Cover photographs

Front cover: The grains of gold are from a drainage sample: the largest are about 1 mm long.

Back cover: Gold grains from overburden have been mounted and polished. The one (top) contains up to 4% of palladium and silver, the amount varying across the section: the different colours may reflect this variation or differences in porosity. The other (bottom) shows what appear to be growth zones and the trace of the probe scan; palladium content (about 5%) varies across the apparent growth zones, and silver (up to 10%) is most abundant on the rim.

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Bibliographical reference

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DATA PACKAGE

This report contains details of some of the geochemical surveys carried out and some other results of general scientific interest derived from the work but much has been omitted. A comprehensive data package is available at a current 1988 cost of 1000 pounds sterling plus VAT. This includes:

- A Consultation with available staff of the British Geological Survey who carried out the work.
- B Examination of borehole core and rock samples and polished thin sections obtained from these.
- C A detailed data package containing the items listed below.
 - 1 Listing of chemical analyses of drainage samples including gold determinations.
 - 2 Map showing location of gold anomalies in drainage.
 - 3 Data and maps showing the results of follow-up drainage sampling.
 - 4 Single element maps and data sets of overburden sampling including distribution of gold.
 - 5 Multivariate statistical treatment of overburden data, plots of multivariate parameters and the geological interpretation of these.
 - 6 Details of mineralogical examination of gold and other minerals from overburden samples and their analysis by electron microprobe.
 - 7 Results and interpretation of ground geophysical surveys.
 - 8 Location, graphic logs and chemical data from 6 boreholes collared to investigate the source of 3 gold overburden anomalies.
 - 9 Petrographical details of sections from the boreholes and chemical information determined on constituent minerals by electron microprobe.
 - 10 Interpretation of geological setting, controls and origin of gold mineralisation.

Enquiries concerning the data package should be made to Dr D J Fettes, British Geological Survey, Murchison House, West Mains Road, Edinburgh EH9 3LA or Mr J H Bateson, British Geological Survey, Keyworth, Nottingham NG12 5GG.

SUMMARY

A programme of exploration for gold within the poorly understood belt of Lower Devonian rocks between the estuaries and lower valleys of the rivers Erme and Avon is described. Interpretation of geophysical data suggests that the upper crustal structure of the area and its relationship with the Start Complex to the south requires reinterpretation.

A geochemical drainage survey of the area using panned concentrate sampling revealed gold anomalies which were subsequently followed up by overburden sampling, geophysical surveys and drilling. The multivariate statistical procedures of principal component analysis and cluster analysis were employed to facilitate recognition of geochemical patterns which reflect mineralisation of different types and major geological boundaries. In addition comparison of the analyses of different size fractions of the concentrate samples was utilised to aid interpretation of the drainage data. This proved useful in detecting anomalies likely to be derived from contamination and in classifying anomaly types. The drainage data strongly suggest the presence of a major fault, trending around WNW, separating two entirely different sequences in the NE of the area.

The use of panned overburden samples from shallow pits in exploration for gold is described and a comparison between these samples and conventional sieved soil samples collected simultaneously is made. Mineralogical examination and chemical analysis of several mineral grains separated from overburden concentrate samples was carried out. This led to the discovery of the very rare mineral potarite (Pd + Hg) in one overburden sample and the recognition of among others, several types of iron oxide, cassiterite and some secondary base metal minerals.

The size and shape of individual grains of gold in both overburden and drainage samples was measured and a significant difference between them discovered. On average the diameter of grains in drainage is three times that in overburden grains whether from background or anomalous sites. To account for this it is proposed that gold grain growth has occurred in head and perhaps more recent alluvium in valley bottoms. The chemical composition of overburden gold grains from a number of sites has been determined with the electron microprobe. Many grains have relatively silver-rich rims while the bulk of the grain is silver-poor, frequently containing a few percent palladium. Other grains are pure gold to the detection limit of the analytical procedure employed.

INTRODUCTION

Previous MRP exploration work in South Devon comprised a drainage survey of the region immediately south of the Dartmoor granite (Jones, 1981) and a detailed survey of the outcrops of volcanic rocks between the valleys of the Yealm and the Dart (Leake et al, 1985). This latter work proved the existence of extensive mineralisation and early hydrothermal activity associated with the volcanic rocks, independent of the later intrusion of the Dartmoor granite. Accordingly, reconnaissance exploration was extended southwards into the poorly understood outcrop of Lower Devonian rocks. As gold grains were detected at two of three sites chosen for orientation work, the reconnaissance survey was planned specifically for the detection of gold mineralisation.

The area surveyed lies to the east of Plymouth and is bounded to the south by the shore of Bigbury Bay and to the east and west by the large tidal indentations of the Erme and Avon estuaries respectively. The area is covered by topographical Ordnance Survey 1:50 000 sheet 202 and by Geological Survey mapsheets 349 and 355 at the 1:50 000 scale though the latter date from 1898 and 1899 and are at present being resurveyed.

PHYSIOGRAPHY

The area forms a low-lying plateau of rounded hills, up to 144 m above sea level, cut by relatively deep stream valleys often occupied by anomalously small streams. These large valleys are locally known as combes. The landforms of the area are considered to be periglacial in origin as major ice sheets are not thought to have reached this part of Devon. A relatively thin veneer of solifluxion deposits thickening to some extent in the valleys is present throughout the area and except on the coastline there is extremely little natural exposure. Often a distinct layer of clay-rich material is found beneath the present drainage sediment which is probably largely of solifluxion origin. The published geological map shows the existence of several sheets of river gravel at various elevations particularly south of the area around Ivybridge. These gravels are thought to have been derived from the Dartmoor granite to the north and therefore to contain a proportion of material derived from the mineralisation associated with both the granite intrusion and its aureole. It is very likely that the larger valleys, especially if running roughly north-south, would contain material derived from this source but the general extent of such deposits over the area is unknown. Overburden sampling has failed to find any evidence of significant amounts of exotic material and in one area sampling showed it to be absent from a flat bench-like feature shown on the published geological map as being underlain by gravel material.

The land is mainly given over to agriculture and there is a complex network of minor roads and sunken lanes over much of the area. Most of the fields are pasture but there are some large tracts on the flatter ground where cereals are grown. In the past there seems to have been addition of a great deal of basic slag to the land as a fertiliser and this leads to contamination of some of the streams, though not with most of the metallic elements of interest. Contaminants specifically identified in the drainage samples are described in a later section.

GENERAL GEOLOGY

A general geological map of the area based on the published 1:250 000 map is shown in figure 1. Much of the area is underlain by the Dartmouth Beds of Lower Siegenian age which are thought to have been deposited in rivers, lakes and deltas. The predominant rock types in this unit are red and grey/green slates with some coarser horizons. Locally basic tuffs and agglomerates comprise a significant proportion of the succession. Overlying the Dartmouth Beds are the marine Meadfoot Beds deposited in a shallow water, high energy environment and the Staddon Grits, which is thought to represent a local facies within the upper part of the Meadfoot Beds (Dinely, 1961). A more detailed account of the Dartmouth Beds along the coast of Bigbury Bay is given by Dinely (1966).

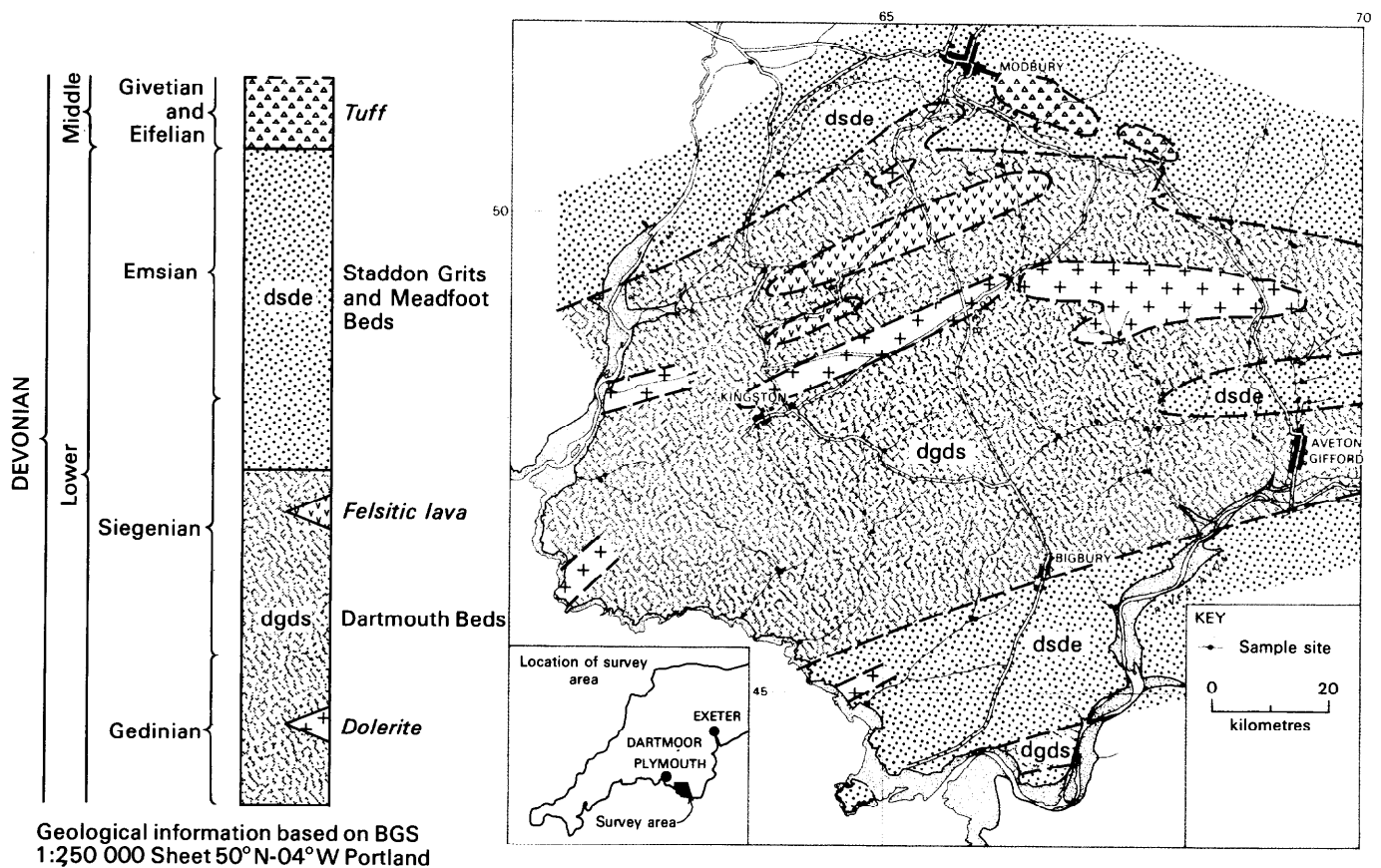


Figure 1 Simplified geological map of survey area.

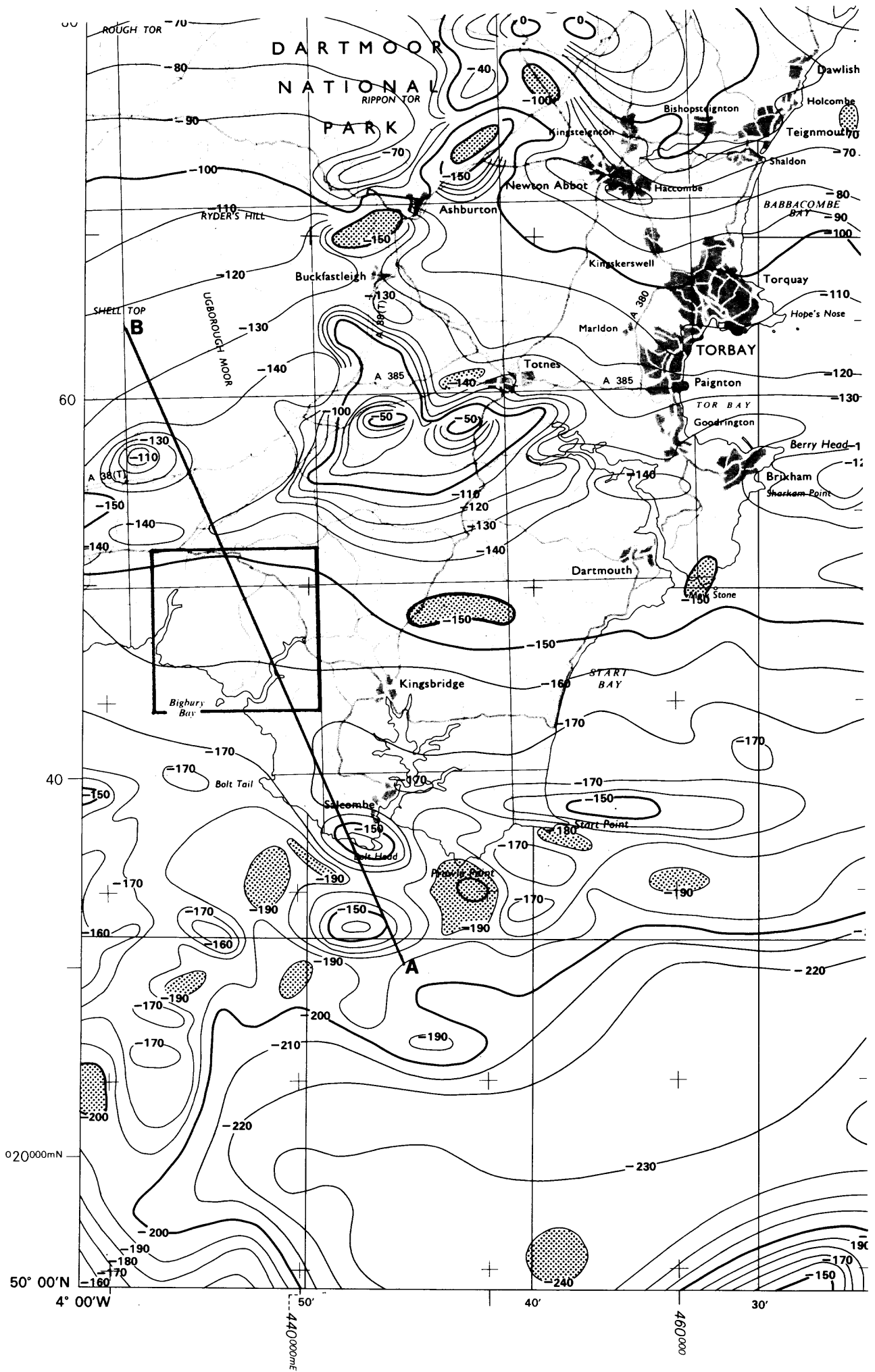
In this work the Dartmouth Beds are divided into four units. The lowest unit, the Warren Sandstones, comprises a rapid alternation of sandstone and slate which is similar to fluvial cyclothems identified in the Lower Old Red Sandstone rocks of the Welsh Borderland (Selwood and Durrance, 1982). Stratigraphically above is the Yealm Formation which is similar to the Warren Sandstones except for the additional presence of pyroclastic horizons and conglomerates with volcanic debris. This is in turn overlain by the massive Scobbiscombe Sandstones which appear to have a restricted outcrop and are interpreted as a fluvial grit deposit (Dineley, 1966). The uppermost unit, the Wembury Siltstones, is similar to the Warren Sandstones but is more finely laminated. Hobson (1976) reinterpreted the stratigraphy of the Dartmouth Beds and reversed Dineley's stratigraphical succession so that the Wembury Siltstones became the oldest unit. The succeeding Meadfoot Beds are thought to have been deposited in a fully marine setting and the general environment of deposition is pictured as an alluvial coastal plain passing gradationally seawards through tidal flats, lagoons and offshore bars to open sea (Selwood and Durrance, 1982).

Descriptions of the very meagre exposures of acid igneous rocks in the area are given by Durrance (1985). Most of the occurrences are within the area mapped originally by Ussher as Dartmouth Beds but there are also some apparently within the outcrop of the Meadfoot Beds. Durrance (1985) describes porphyritic spheroidal and nodular rhyolites and sheared rocks. Elongate outcrops of dolerite or "greenstone" also occur in the area. Their texture is clearly igneous and relatively coarse grained, with plagioclase and clinopyroxene the main

constituent minerals. They appear similar to other greenstones found elsewhere throughout S.W. England and interpreted as intrusive high level sills associated with a pre-granite phase of magmatism of uncertain affinity.

Structurally the area falls within the Dartmouth Zone (Selwood et al, 1982) which is thought to have a complex antiformal nature. This zone lies immediately north of the Start zone comprising schists characterised by a higher grade of regional metamorphism than the Dartmouth Beds. The Start rocks are alternatively interpreted as Devonian rocks which have been buried to a greater depth than the rocks to the north (Edmonds et al, 1975) or pre-Devonian basement (Doody and Brooks, 1986). Three coaxial phases of folding have been recognised by several workers (Selwood et al, 1982), followed by the formation of flat-lying kink bands. Hobson (1976) summarised the major structure of the area as a major D1 fold with the northern limb cut by a large fault modified by later megascopic D3 open folding of cleavage. South of Plymouth the D1 folds are overturned to the north but they become progressively upright and then slightly overturned to the south as they are traced southwards towards the Start boundary. An alternative interpretation of the Dartmouth antiform as a major thrust structure displaced

Figure 2 Part of the 1:250 000 Bouguer Gravity Map Portland, showing the gravity field across south Devon, for a reduction density of 2.70 Mg m^{-3} . The boxed area indicates the zone of detailed geochemical sampling, the section line AB is shown in Figure 4.



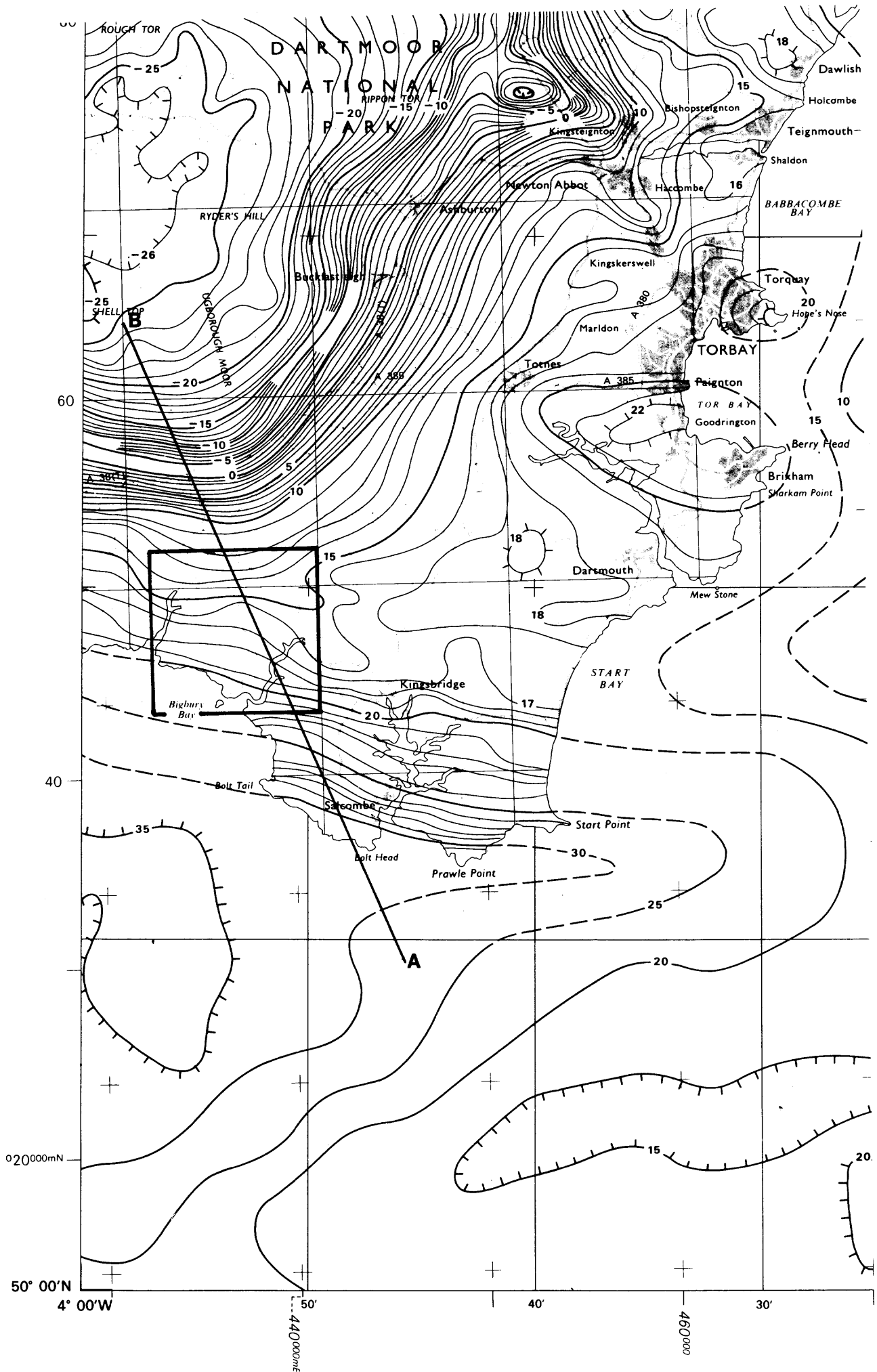


Figure 3 Part of the 1:250 000 Aeromagnetic Anomaly Map Portland, showing total field aeromagnetic anomalies in nT at a mean terrain clearance of 152 m.

several km to the north, rather than a fold, is provided by Coward and McClay (1983) though this interpretation of the field evidence is disputed by Smythe (1984). Clearly further work is required to resolve aspects of the major structure of the area. There is a need to evaluate the geology of the inland unexposed area, which has not been investigated since the original geological survey by Ussher, using a range of geological, geochemical and geophysical techniques.

SCOPE OF MRP INVESTIGATION.

A range of exploration techniques has been applied to the area in consequence of the discovery of a significant amount of gold in orientation drainage samples. A regional geophysical interpretation of the available gravity and other information has been made to assist in the interpretation of the general geological framework of the area. A regional geochemical drainage survey, using panned heavy mineral concentrates and other samples where appropriate, was undertaken both to provide information on the regional distribution of gold and also to provide information on the distribution of other elements of economic interest and to help in production of a geological interpretation of the unexposed inland area.

More closely spaced drainage sampling was carried out in two areas where significant amounts of gold had been found in the initial survey. This was followed by extensive overburden sampling in one area and ground geophysical surveys of part of this. Subsequently 6 holes were drilled to investigate the source of three overburden anomalies.

REGIONAL GEOPHYSICS

Aeromagnetic Data

Analogue aeromagnetic data collected in 1957 along north-south flight lines spaced approximately 400 m apart and with a mean terrain clearance of 150 m have been digitised from 1:63 360 worksheets and are available from BGS. The data for the South Hams region of Devon are shown in Figure 2 contoured at intervals of 10 nT. The main feature in the data is the anomalous zone associated with the Middle Devonian Volcanic rocks where anomalies locally exceed 100 nT. In addition there are local anomalies over the Start Complex and its extension offshore.

Seismic Data

The SW England Seismic Experiment SWESE (Brooks et al, 1984, Doody and Brooks, 1986) suggested that the Start schistose metamorphic rocks represent the exposed regional crystalline basement with a velocity above 6 km s⁻¹. The refractor associated with this basement surface extends westwards from the Start Complex at a shallow depth (< 1 km) as far as the Plymouth Bay Fault, where it is downfaulted by about 1 km. Still further west at the Lizard this refractor is at a depth of about 4 km which

suggests that the exposed ultrabasic/basic rocks of the Lizard form a detached slice above the basement. The seismic data can be explained by the overall structural model for SW Devon proposed by Chapman et al (1984) in which the Lower Devonian rocks have been thrust northwards over a crystalline basement and then later displaced by normal faults.

Gravity Data

Regional gravity data are available for all South Devon at a distribution of about 1 per 1.5 km². The land and marine data have been contoured in Figure 3 for a reduction density of 2.70 Mg m⁻³. The main feature of the Bouguer gravity field across SW England is the large negative anomaly associated with the Hercynian granites. To satisfy the observed gravity and heat-flow anomalies these intrusions must extend to depths of at least 10 km, although the gravity data suggest that the Dartmoor intrusion is significantly thinner in the north. The granites have a mean saturated density close to 2.63 Mg m⁻³, while numerous measurements suggest a mean near-surface density for the Devonian strata close to 2.70 Mg m⁻³. The maximum relative gravity anomaly over southern Dartmoor is close to -50 mGal; for this anomaly to be explained by a density contrast of -0.07 Mg m⁻³ then the granites would have to extend to depths of over 17 km, which is inconsistent with the heat flow and seismic data. The density contrast is therefore presumed to be significantly greater at depth and possibly as large as -0.15 Mg m⁻³. This implies that the mean density of the host strata is close to 2.78 Mg m⁻³ which is the mean grain density (i.e. assuming zero porosity) of the Devonian rocks. An alternative interpretation assumes that pre-Devonian basement rocks underlie much of SW England at relatively shallow depths and this hypothesis is supported by the gravity data in South Devon.

Away from the granites a significant feature of the gravity field in South Devon is the positive gradient southwards across the Start peninsula. As noted by Bott et al (1958), the gradient starts abruptly some 4-5 km north of the mapped Start Boundary. Bott and Scott (1964) interpreted this anomaly in terms of a thinning wedge of Start metamorphic rocks of density contrast 0.06 Mg m⁻³, extending north of the exposed schists and assumed to be about 4 km thick. In the light of the suggestion that the Start rocks form the regional basement in South Devon, this interpretation needs reconsideration.

If the onset of the positive gradient indicates the northern boundary of the Start Complex basement, then the gravity data suggest that this basement extends from the coast at Torcross (5 km north of Start Point) through Kingsbridge and possibly NW as far as Jennycliff Bay in Plymouth Sound. A slight trough in the gravity data extending from near Aveton Gifford NW towards Modbury could reflect the fault postulated from geochemical and geological data (see below) if this displaces the basement. SW of this fault, basement could be closer to the surface.

There is also some evidence in the gravity data for significant basement structure in the Torbay area. The outcrops of Lower Devonian Staddon Grit and the Meadfoot Group around Torbay and Hope's Nose are associated with significant local positive gravity anomalies of about 5 mGal. Coward and McClay (1983) suggest that these outcrops have been downfaulted from a higher structural level, a postulated upper thrust sheet. The gravity data do not support this structural interpretation however. The local positive anomalies are best inter-

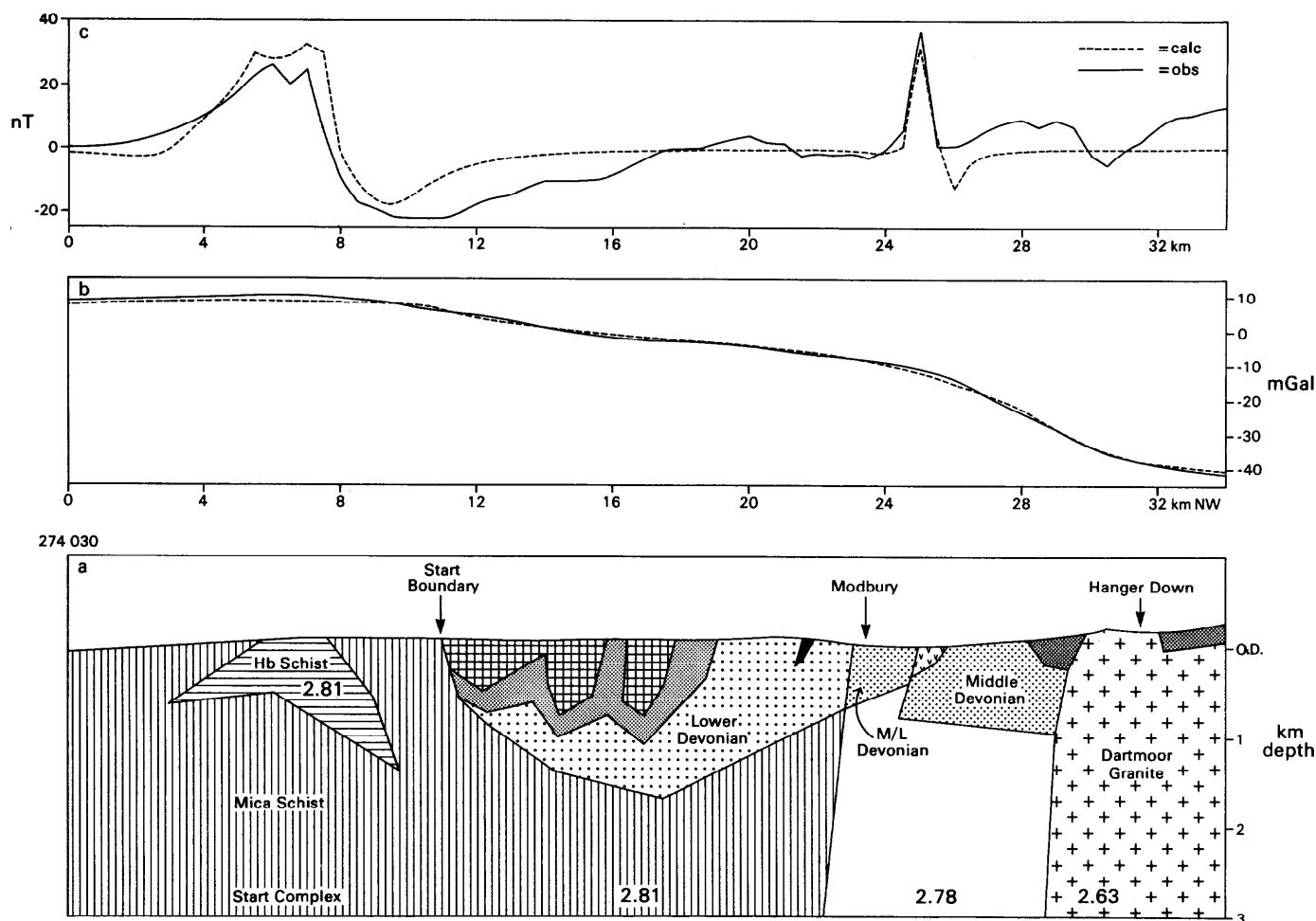


Figure 4 A 2.5D model (a) of the gravity and magnetic anomalies along part of section of line AB (Figure 2). Magnetic anomalies (c) can be modelled by hornblende schist within the Start Complex, and by Devonian volcanics. The gravity data (b) has been modelled by assuming crystalline basement at shallow depth, south of the Dartmoor granite. The Start Complex might extend beneath the Lower Devonian as far north as Modbury. Unlabelled formations have been assumed to have a density of 2.70 Mg m^{-3} .

preted as reflecting crystalline basement, possibly Start like, close to the surface around Torbay.

The structural interpretation of the Lower Devonian of South Devon by Hobson (1976) with its northern boundary of the Dartmouth slates marked by a major fault truncating the northern limb of an antiform, has been extended with the two and a half dimensional modelling of gravity and magnetic fields to provide an interpretation of the upper crust across South Devon (Figure 4) from Shell Top [260 064] on Dartmoor to offshore of Bolt Head. Crystalline basement is presumed to underlie all the Devonian rocks south of Dartmoor; south of Modbury this basement has affinities with the exposed Start Complex. The nature of the basement to the north of this is uncertain but gneissic rocks with no positive gravity or magnetic expression are a possibility.

RECONNAISSANCE GEOCHEMICAL DRAINAGE SURVEY

Following the discovery of a significant amount of gold in an orientation drainage sample, the whole area was sampled systematically. The design of sampling programmes for the detection of gold mineralisation is particularly difficult, firstly, because of the low levels that can

be of significance (in the ppb range) and secondly, because gold tends to occur in discrete grains of various size up to a few mm. In order to obtain an effective sample of material which may contain gold grains up to 2 mm diameter, using an effective sampling algorithm (Gy, 1984), in excess of a tonne of material would be required, clearly impractical at the exploration stage. A further constraint is provided by the maximum weight of sample that is digested in a single gold determination, i.e. 60 gm. Accordingly, sampling methods were developed to overcome these problems as far as practicable and additionally to provide material for multi-element analysis to investigate the possible existence of pathfinder elements.

Sampling Methods

At each site a panned heavy mineral concentrate was obtained by panning approximately 12 kg of minus 2 mm material down to 150 ml of concentrate. Gold grains observed during panning were noted. After drying, the concentrates were in many cases sieved into 3 or 4 size fractions prior to a superheavy fraction being obtained on a Mozely shaking table or Superpanner. Individual gold grains were picked from the superheavy concentrate, measured and weighed where possible, and retained for subsequent work. Gold concentrations were then

calculated back to the original weight of concentrate, assuming a 100% Au content in the grains, which probe analyses had shown to justifiable within 10%. An estimate of weight was obtained from the grain dimensions in the case of the smallest grains, which were too small to weigh directly satisfactorily. In addition 60 gm of several recombined fractions or complete samples (minus the extracted gold grains) were submitted for a chemical analysis of gold. This was achieved by acid digestion followed by solvent extraction and determination by atomic absorption by Caleb Brett Laboratories, St Helens, Merseyside. This enabled an estimate of gold present in either composite grains, or as inclusions or trace amounts within other minerals to be obtained. Gold found by analysis was then added to the previous figure to give a total concentration. In addition 12 gm subsamples of either size fractions or complete concentrates minus gold grains were analysed for the elements Mg, Al, P, S, Ca, Ti, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Y, Zr, Ag, Sn, Sb, Te, Ba, La, W, Pb and Bi by XRF at MESA, Nottingham University after grinding in a Tema swing mill.

A conventional field wet-sieved minus 100 mesh BSI sample was also obtained at a number of sites and gold determined on a 60 gm subsample taken after fine grinding in a Puerisette 5 agate planetary ball mill. A range of elements were also determined by XRF. In addition a suspended fraction sample (Leake and Smith, 1975) was obtained at several sites and this was subsequently sieved to provide a minus 240 mesh BSI (<63 micrometres) fraction for preparation and analysis in the same way as the minus 100 mesh samples.

A comparison of gold levels in different samples from the same site is shown in Table 1.

Table 1 Comparison of Au levels in contrasting sample types from the same site

Panned concentrate	- 100 mesh sieved	Suspended fraction
4054		< 10
1632		< 10
1337		< 10
267		< 10
564		< 13
124	29	
219	176	
35	< 10	
171	< 10	
< 10	54	
193	< 13	
308	241	
42000	234	
< 10	5	
90	105	
< 10	12	

all values in ppb

Comparison of levels of gold in panned concentrate and suspended fraction samples indicates that significant amounts of very fine-grained gold, which cannot be retained in panning, are not present. Rather, dispersion of gold is as discrete grains of native metal, mostly above the 63 micrometre size or as components of relatively coarse grains (e.g. limonite) or as composite grains with other

minerals. In view of this, there is nothing to be gained by analysis of minus 100 mesh samples, as the sampling precision for grain counting/weighing (+ analysis) from the concentrate of an original 12 kg sample is much better than analysis of a 60 gm split of a minus 100 mesh fraction sample (generally about 100 gm in all). The concentrate sample also gives an estimate (with decreasing precision with grain size increase) of the amount of gold in grains coarser than 100 mesh. This is particularly important as the mean diameter of 162 grains that have been measured is 190 micrometres and only 30% of the grains are smaller than 150 micrometres (100 mesh). The poor agreement between gold levels in the panned concentrate and minus 100 mesh samples in Table 1 is therefore only to be expected given that one spherical grain of 150 micrometre diameter would contribute over 2 ppm Au to the sieved sample.

Results

Summary statistics of the drainage data are given in Table 2.

Table 2 Summary statistics of drainage data

	N	Mean	SD	Min	Max
MgO%	67	1.96	0.67	0.41	3.53
Al ₂ O ₃ %	30	9.39	1.62	5.95	12.98
P ₂ O ₅ %	37	0.14	0.07	0.06	0.40
S ppm	67	311	229	64	1350
K ₂ O%	26	2.15	0.59	1.11	3.24
CaO%	67	1.12	1.13	0.14	5.08
TiO ₂ %	67	3.25	5.49	0.60	33.95
Cr ppm	67	149	61	74	325
MnO%	67	0.17	0.17	0.06	0.90
Fe ₂ O ₃ %	67	10.36	5.14	5.52	30.64
Co ppm	30	20	6	11	40
Ni ppm	67	46	11	30	77
Cu ppm	67	42	55	9	290
Zn ppm	67	98	54	52	306
As ppm	67	16	12	< 1	81
Rb ppm	41	50	17	16	98
Sr ppm	30	89	43	36	189
Y ppm	41	25	5	18	49
Zr ppm	67	254	118	132	727
Ag ppm	67	1	1	< 1	6
Sn ppm	67	509	1056	1	7354
Sb ppm	67	5	6	< 1	38
Ba ppm	67	277	119	< 10	552
La ppm	41	45	58	11	373
W ppm	67	11	17	< 1	93
Au ppb	67	413	1917	< 10	15000
Pb ppm	67	164	339	10	1558
Bi ppm	37	2	2	< 1	5

N = number of samples; SD = standard deviation

Only the elements where the data set is complete have been plotted in class-interval map form. These are discussed in turn in order of atomic number. Silver results are not presented in map form as the levels are too close to the detection limit of the analytical method. The gold results are included in the data package and therefore a gold distribution map is not included in this report. The complete drainage data set is available as part of the data package, which includes the follow up samples which have been omitted from the data set presented in this report.

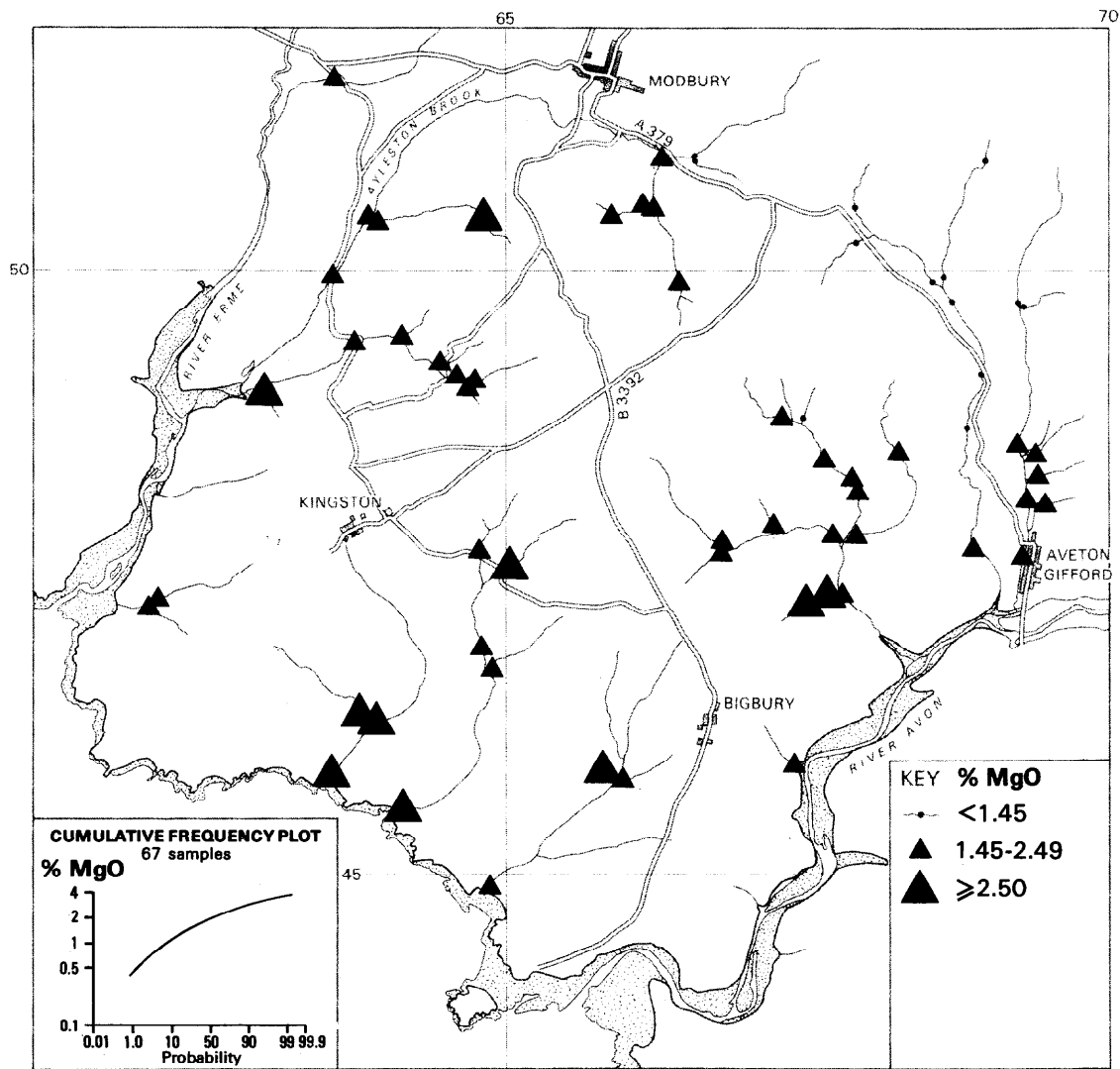


Figure 5 Distribution of magnesium in drainage panned concentrates.

Magnesium

The most distinct feature of the MgO map (Figure 5) is the grouping of samples with relatively low MgO around and to the NE of the road between Modbury and north of Aveton Gifford. This suggests a fundamental difference between rocks on either side of a line roughly followed by the road. This line probably marks a major WNW-trending fault, the presence of which can also be deduced from the original geological mapping of Ussher. According to the mapping of Dinely (1966) the relatively Mg-rich samples could be derived from the Wembury siltstone unit of the Dartmouth Slates, perhaps on average finer in grain size than the other units.

Table 3 Oxide and sulphide minerals identified in drainage samples

Mineral	Elements	Comments
Ilmenite	Fe Ti	Locally abundant.
Oxide Ball	Fe	Both rough and smooth varieties locally conspicuous.
Cassiterite	Sn	Widespread, locally common; red and yellow varieties.
Goethite/ after pyrite	Fe	Cubes.
Goethite/ fibrous	Fe	
Hematite	Fe	
Limonite	Fe	
Earthy gossan	Fe	Red hydrous Fe oxides.
Pyrite	Fe S	Local.
Pyrrhotite	Fe S	Rare.
Chalcopyrite	Fe Cu S	Rare.

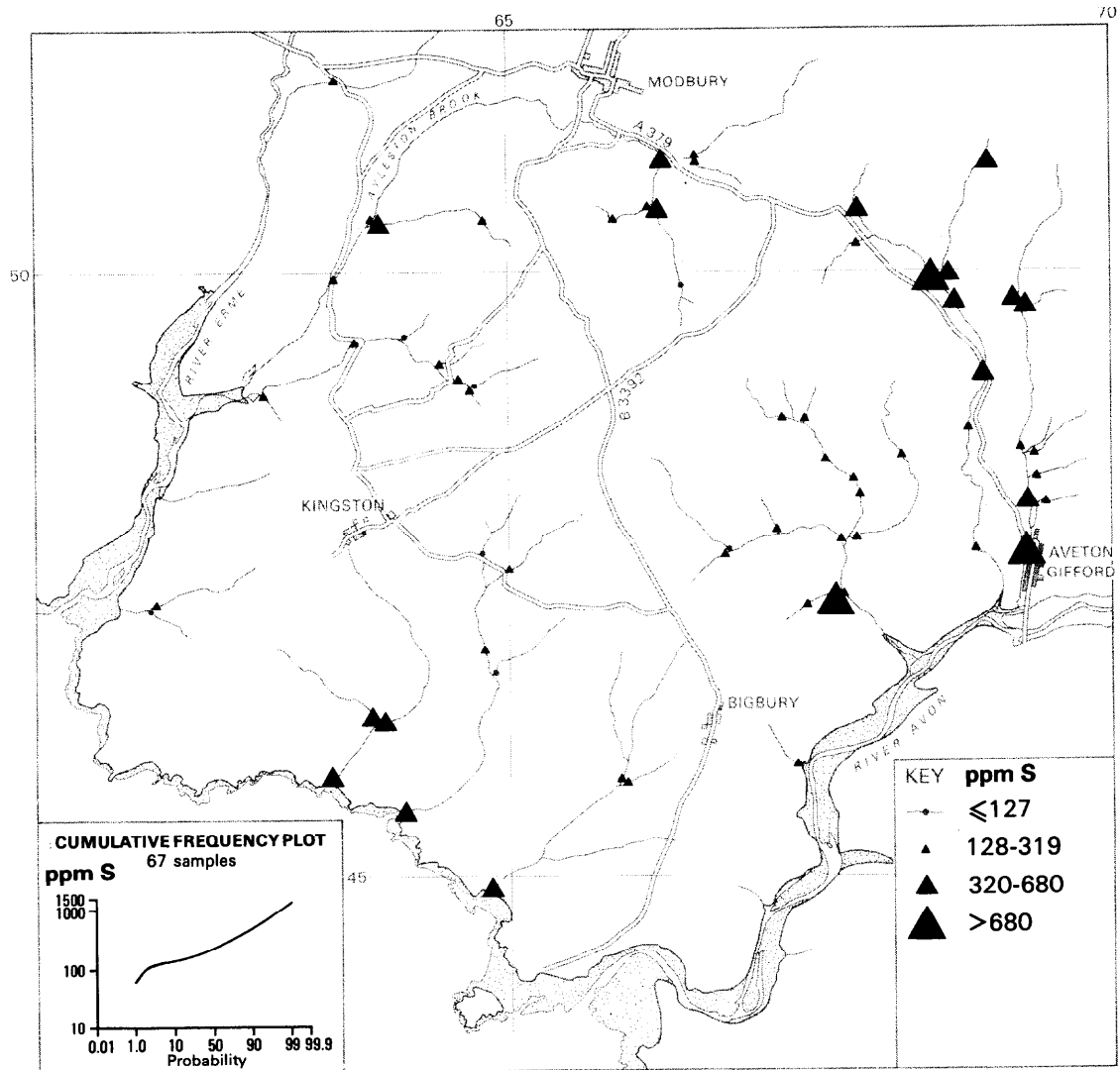


Figure 6 Distribution of sulphur in drainage panned concentrates.

Sulphur

The range in sulphur levels (Figure 6) is quite low compared with similar samples from other areas in Britain. This is consistent with the observation of the relative scarcity of grains of pyrite or other sulphides identified in samples examined mineralogically (Table 3). On the other hand goethite/limonite pseudomorphs after pyrite are sometimes quite conspicuous. The relatively low sulphur levels are therefore a consequence of the widespread oxidation of rock in the near surface environment which is a feature of the area. Relatively sulphur-rich samples are concentrated in a group NE of the Modbury to Aveton Gifford road and in a group near to the coast. Several other elements associated with mineralisation e.g. Zn and As are also enriched in samples from the former group.

Table 4 Silicate minerals identified in drainage samples

Mineral	Elements	Comments
Epidote	Si Al Ca Fe	Locally common.
Composite rutile and epidote	Si Ca Fe Ti	
Leucoxene	Ti Fe Si Al	
Chlorite	Fe Si Al Mg	Locally common.
Pyroxene?	Si Ca Mg Fe	
Albite	Si Al Na	
Biotite	Fe Al Si K	
Amphibole	Si Fe Al	
Tourmaline	Si Al Fe B	Locally common.
Muscovite	Si Al K	
Zircon	Zr Si	Both rounded and euhedral forms.

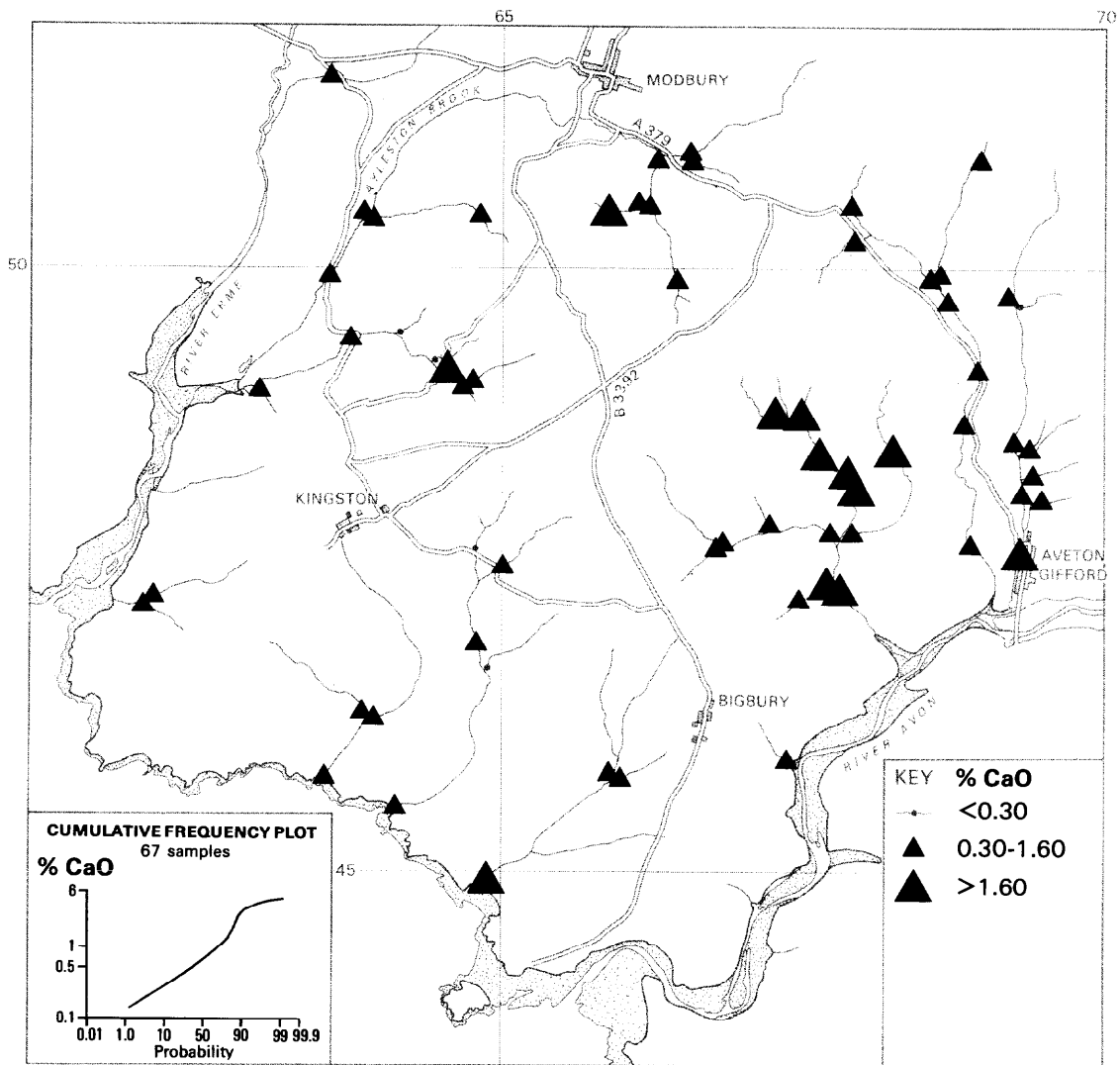


Figure 7 Distribution of calcium in drainage panned concentrates.

Calcium

Samples richest in calcium (Figure 7) are concentrated to the NW of Aveton Gifford and are derived from greenstone bodies. Mineralogical examination of the concentrate samples reveals that much of the Ca is accommodated in clinopyroxene and perhaps epidote (Table 4).

Table 5 Contaminants identified in drainage samples

Material	Elements
Battery plate	Pb
Brass	Cu Zn
Aluminium metal	Al
Alloy	Ni Fe
Glazed pottery	Si Pb
Ball bearing	Fe Cr
Lead Shot	Pb Sb
Amalgam?	Sn Hg
Iron	Fe

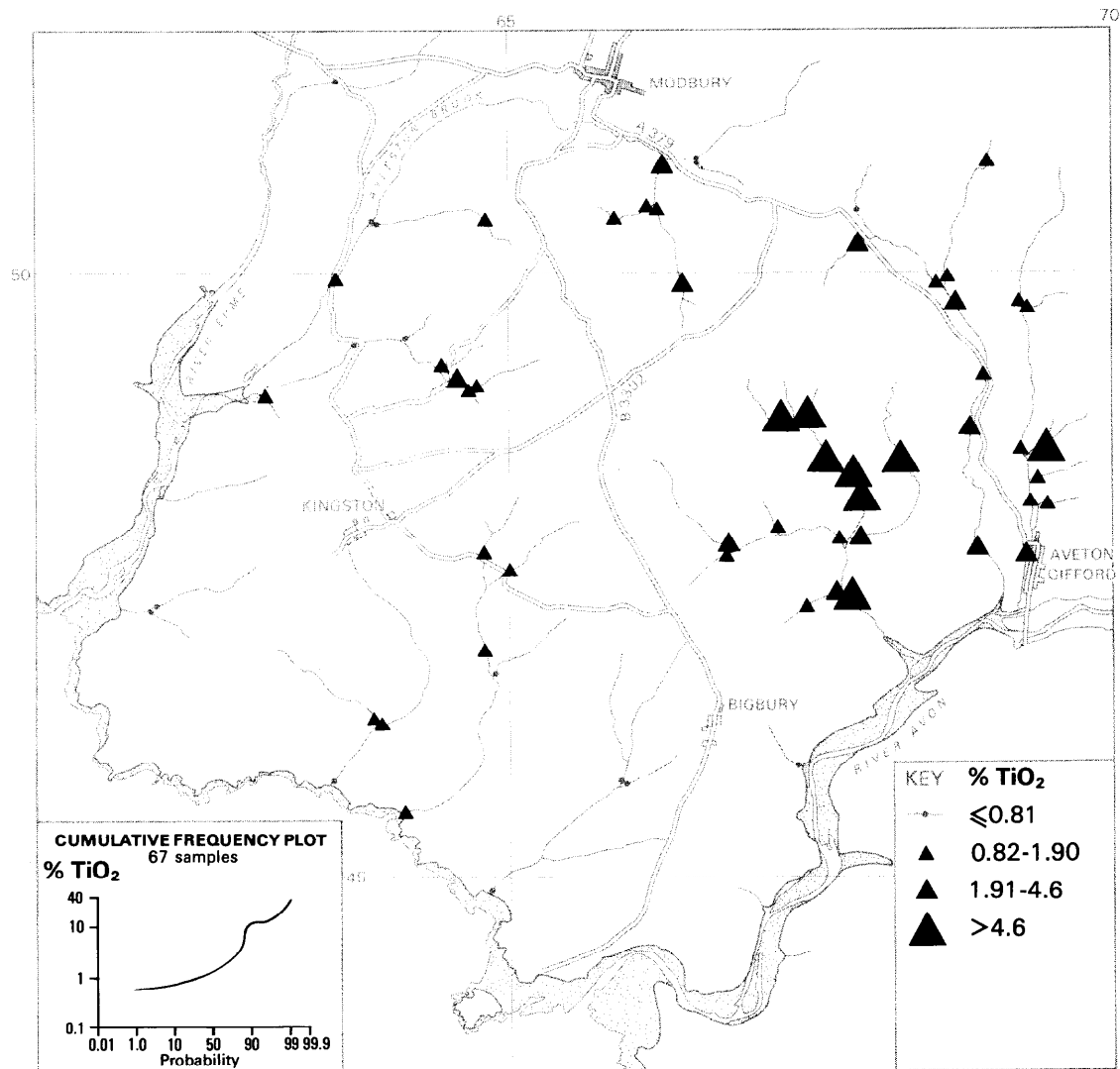


Figure 8 Distribution of titanium in drainage panned concentrates.

Titanium

There is a relatively large range in the titanium contents of the concentrate samples (Table 2). A distinct group of samples contain the highest Ti levels and are derived from bodies of greenstone to the NW of Aveton Gifford (Figure 8). The drainage samples also support the original geological mapping of the area by Ussher, dating from

1898, which shows greenstone to the east of the main road north of Aveton Gifford but in much smaller amounts than to the west of the road. Mineralogical examination shows ilmenite to be the main form of Ti in samples derived from the greenstone but leucoxene and rutile as additional minerals derived from other sources.

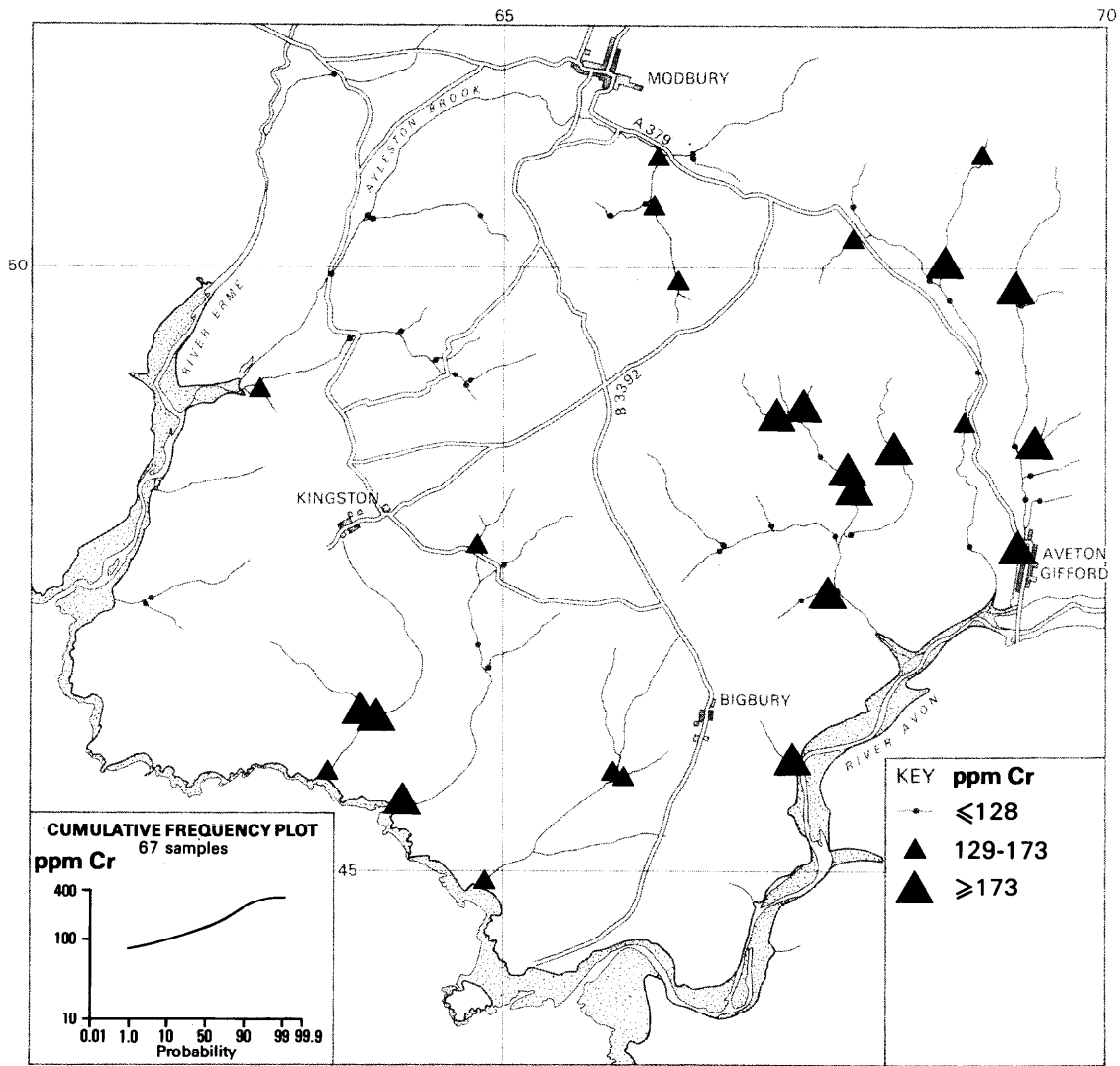


Figure 9 Distribution of chromium in drainage panned concentrates.

Chromium

Four groups of relatively chromium-rich samples can be discerned (Figure 9). The largest group, from NW and just north of Aveton Gifford are derived from the greenstone bodies. A further group correlate to some extent with Mg-rich samples in the south of the area. Two sites, at Aveton Gifford and west of Aveton Gifford, are

contaminated with a significant amount of metallic rubbish and Cr is probably a component of this. A chrome-steel ball bearing has been identified as one Cr-containing contaminant grain (Table 5). In addition to the NE of the Aveton Gifford to Modbury road there are two relatively Cr-rich samples but the origin of the chromium in these is not known.

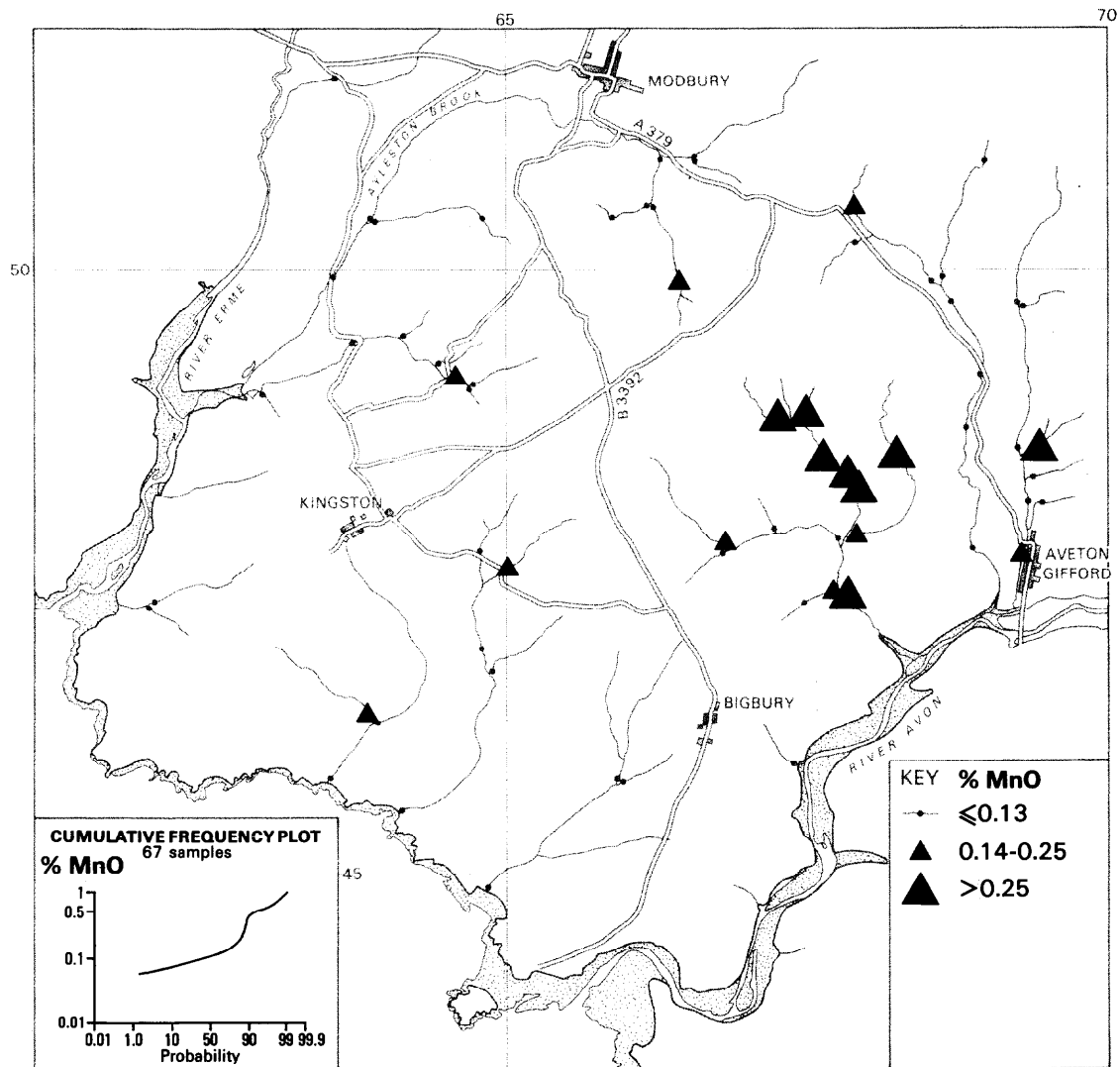


Figure 10 Distribution of manganese in drainage panned concentrates.

Manganese

Samples with the highest levels of manganese are all derived from the greenstone bodies to the NW and north

of Aveton Gifford (Figure 10). In these samples much of the Mn is accommodated in ilmenite which is a minor constituent of these rocks.

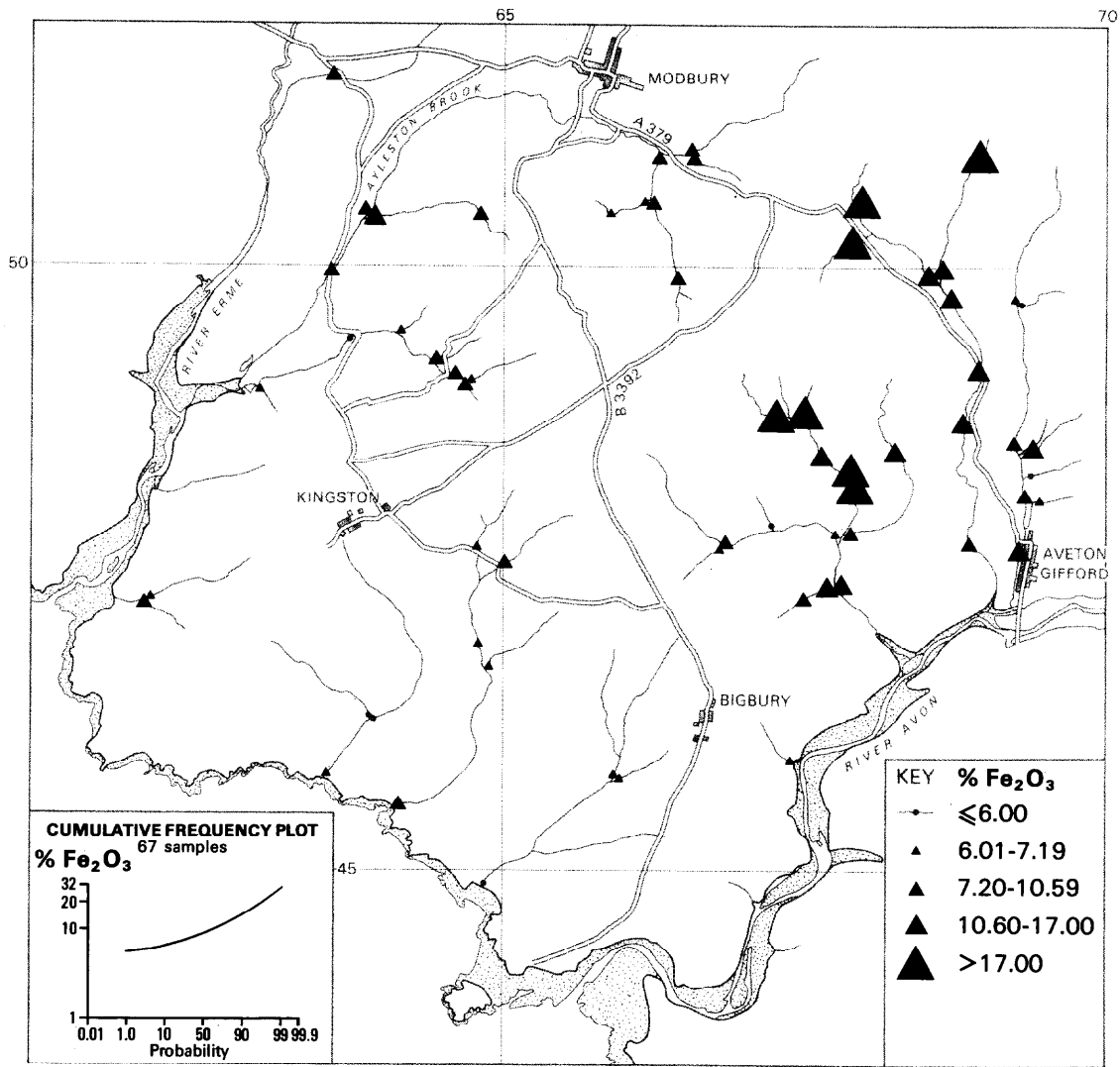


Figure 11 Distribution of iron in drainage panned concentrates.

Iron

There is a considerable range in iron contents of the concentrate samples (Table 2). Within the most iron-rich samples, two varieties are apparent. The group of samples from NW of Aveton Gifford (Figure 11) are derived from the greenstone bodies and ilmenite is the main iron mineral present. In contrast the Fe-rich

samples from the vicinity of the Modbury to Aveton Gifford road and the area to the NE of this are geochemically quite different, with a close association of Fe with Ni, As and Sb. The chemical analysis of a fraction very rich in iron, in the form of goethite/hematite grains from one of these sites is 62.4% Fe₂O₃, 0.54% TiO₂, 163 ppm Ni, 223 ppm As and 72 ppm Sb.

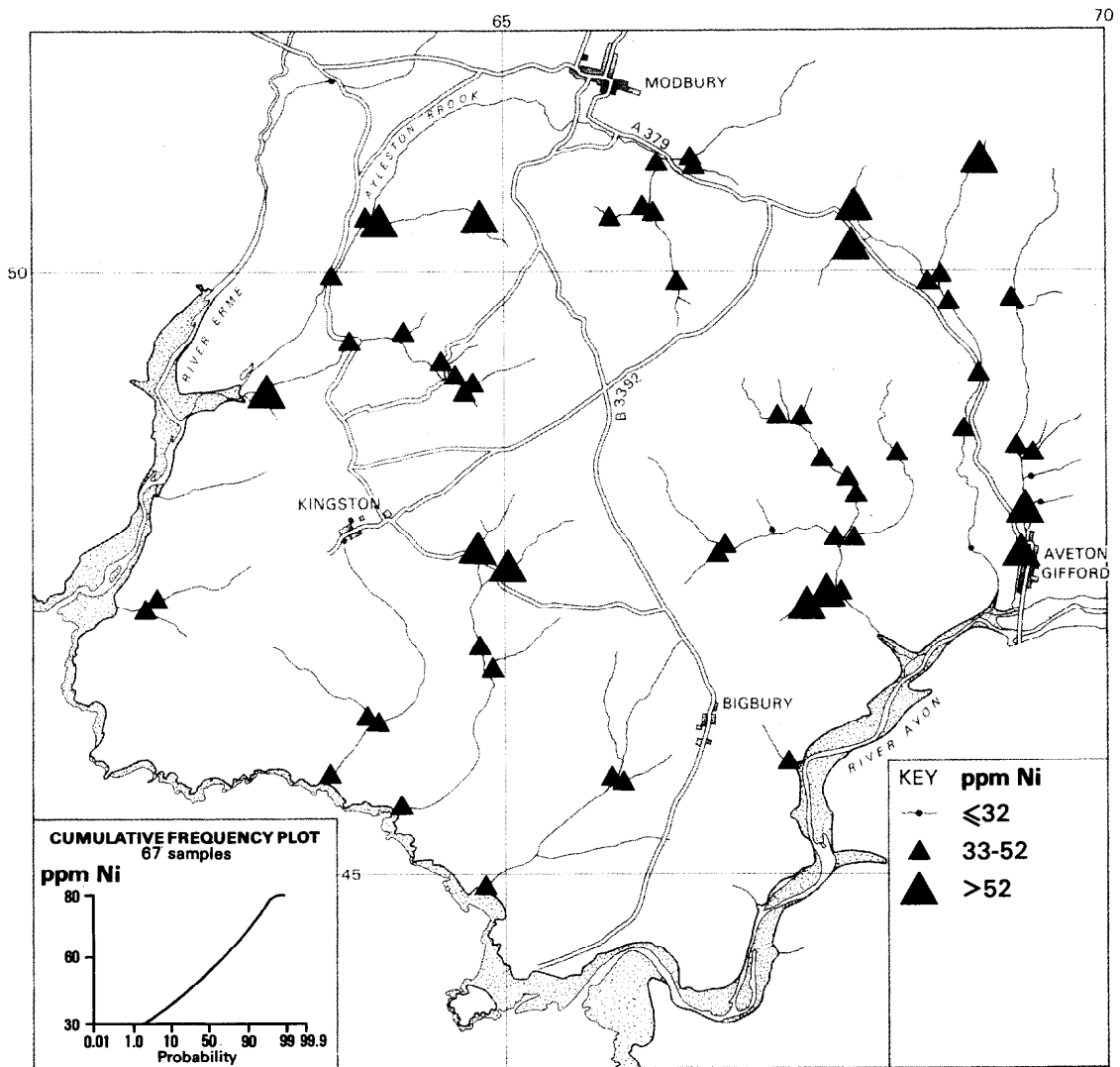


Figure 12 Distribution of nickel in drainage panned concentrates.

Nickel

Apart from the Ni-rich samples mentioned previously, relatively high levels of Ni are a feature of samples from sites with a significant amount of metallic contamination e.g. at Aveton Gifford, and a fragment of Ni-rich alloy

has been identified in one of these samples (Table 5). The cause of the relative Ni enrichment in other samples e.g. from east of Kingston and in the NW of the area (Figure 12) is not clear.

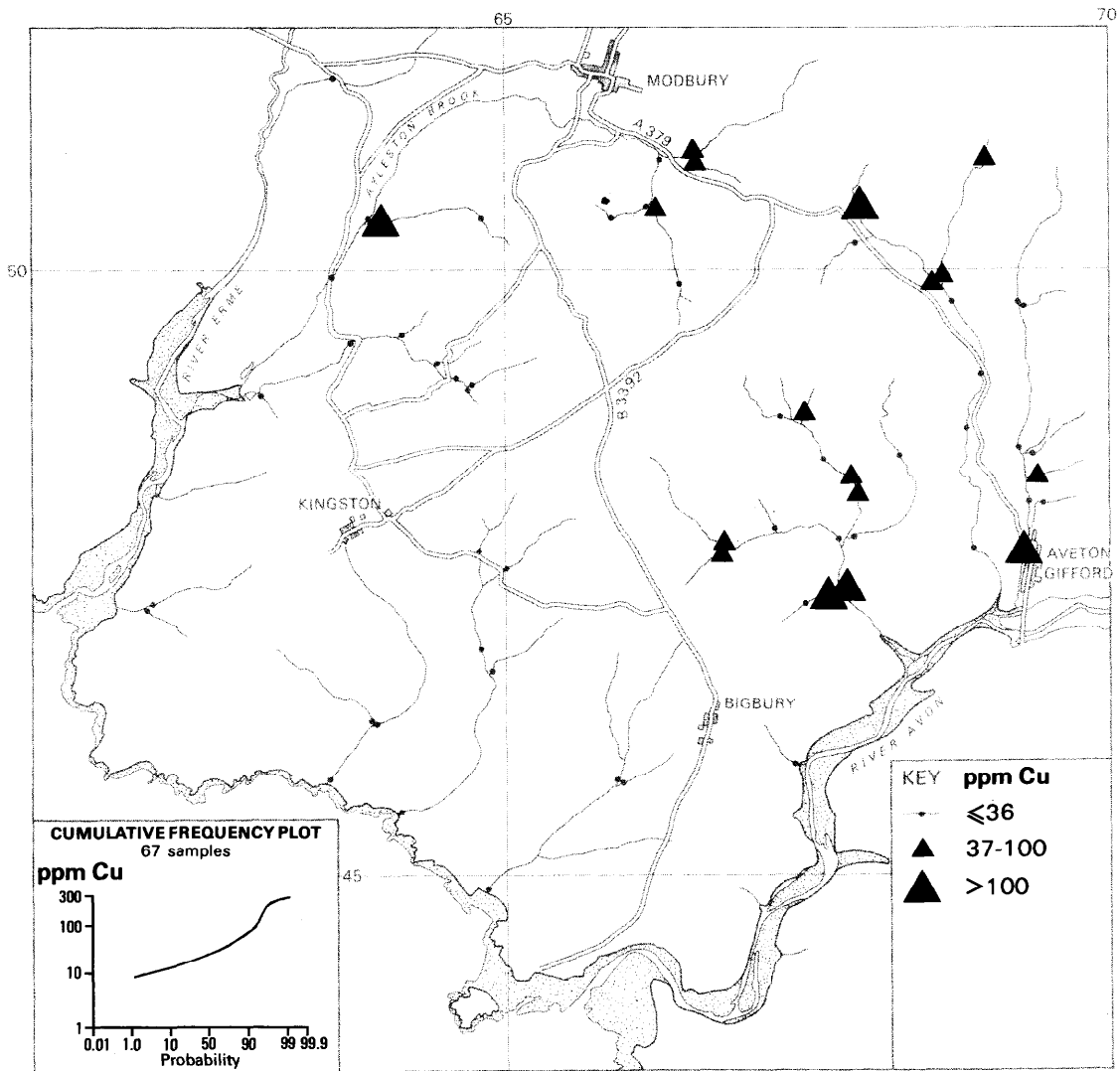


Figure 13 Distribution of copper in drainage panned concentrates.

Copper

At the three sites with the highest levels of copper in the south of the area (Figure 13), metallic contamination is probably the chief source. A piece of brass has been identified in one sample and this could represent a widespread contaminant derived from cartridge cases. In contrast, the relatively enhanced level of Cu in the sample from the NE part of the area is possibly natural in origin as there is

a correlation between Cu and the greatest abundance of the goethitic iron oxide material. Elsewhere, a few grains of chalcopyrite have been identified as a natural form of copper. The source of the Cu anomaly in the NW part of the area (Figure 13) is less clear. Though the sample shows some contamination with metallic material, in analysed size fractions from the site there is some positive correlation between Cu and S concentrations.

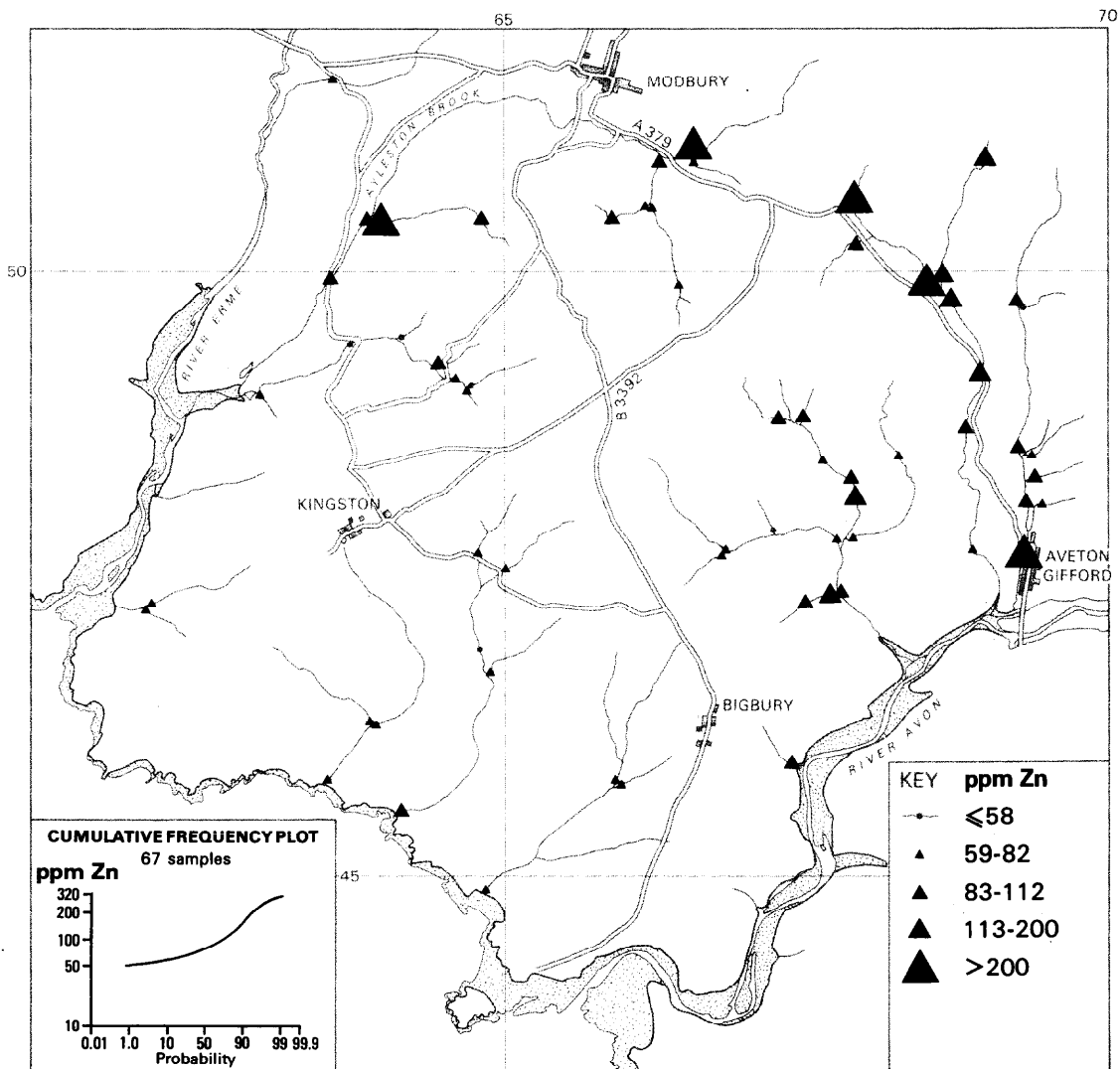


Figure 14 Distribution of zinc in drainage panned concentrates.

Zinc

Apart from contaminated sites at Aveton Gifford and in the NW of the area, samples containing the highest levels of zinc are from the vicinity of the road between Modbury and Aveton Gifford (Figure 14) which in turn is considered to be close to the line of the major fault discussed

previously. In these samples, there is some correlation between Zn and Fe levels but this is not as high as that between Fe and Ni, As and Sb. The form of this zinc is not known but it is unlikely to be mostly brass as the Zn/Cu ratio in these samples is relatively high.

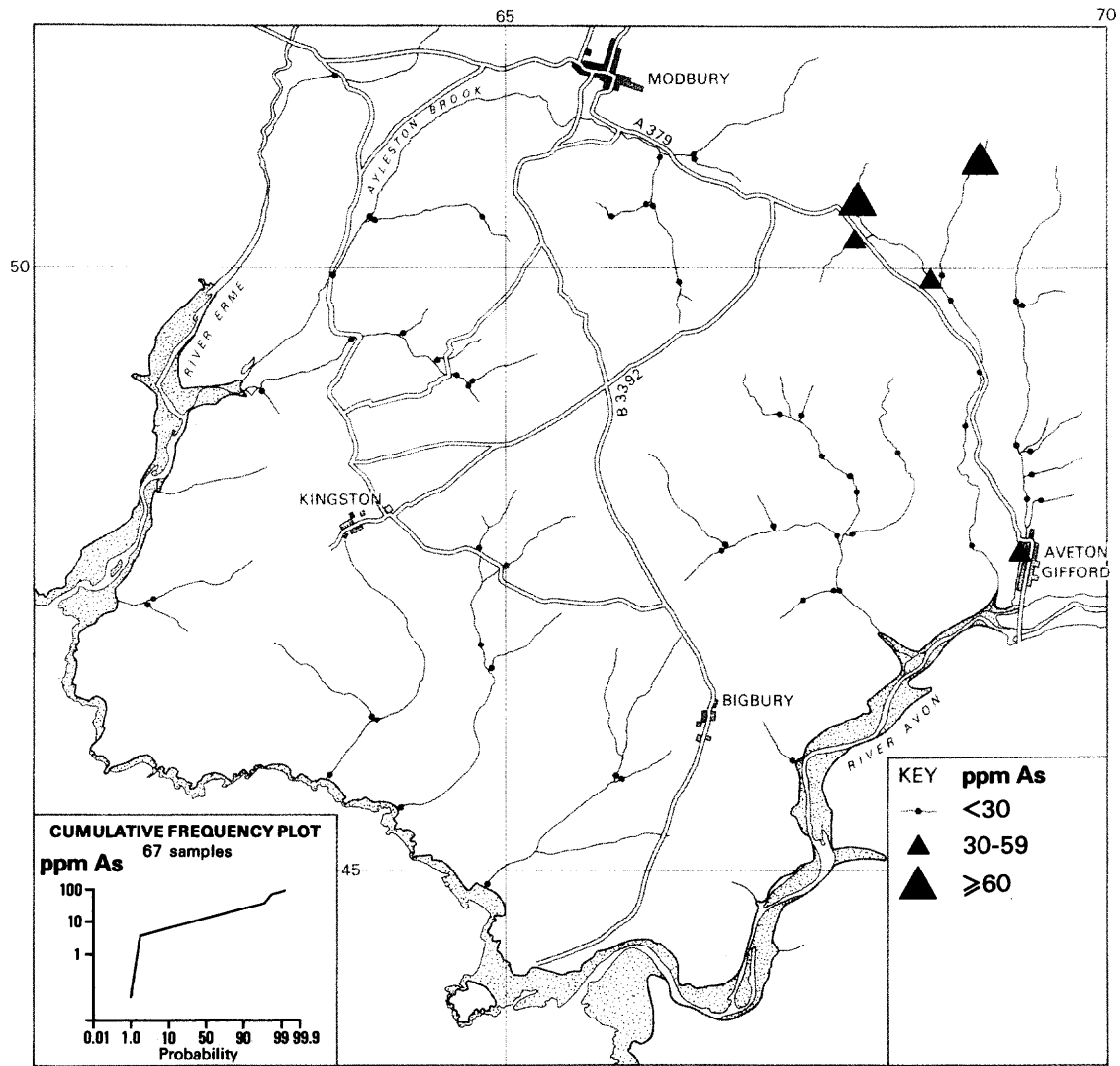


Figure 15 Distribution of arsenic in drainage panned concentrates.

Arsenic

With the exception of the contaminated sample from Aveton Gifford, concentrates containing relatively high levels of arsenic are derived from the vicinity of the A379 road (Figure 15) or the area to the NE of this. Since there

is a very close association between As and Fe in these samples, it is likely that the arsenic is in intimate association with the iron oxide which is abundant in these samples.

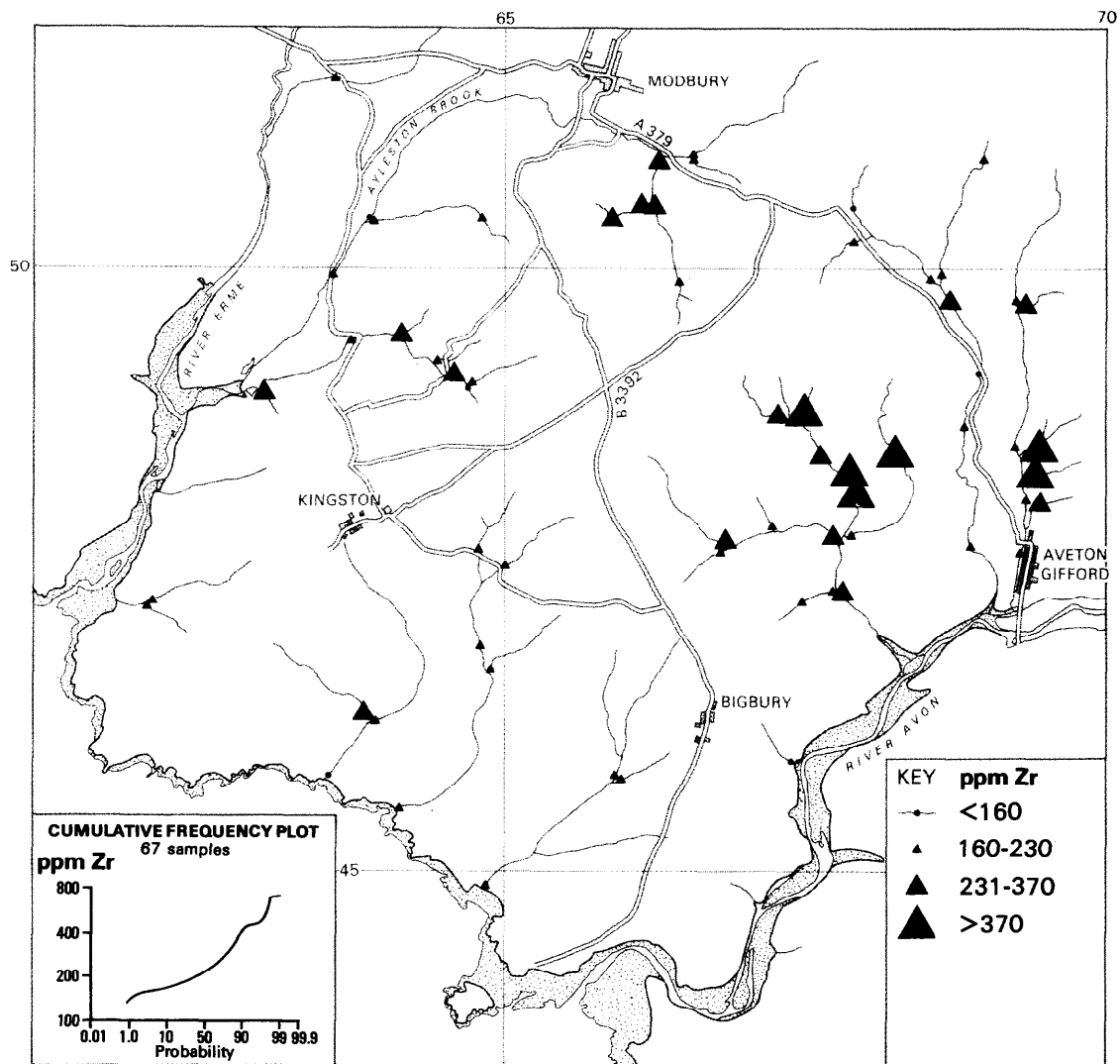


Figure 16 Distribution of zirconium in drainage panned concentrates.

Zirconium

There is a relatively small range in zirconium contents in the drainage samples (Table 2). Nevertheless samples with the highest Zr levels can be recognised as a group which are derived predominantly from the greenstone bodies to the NW and north of Aveton Gifford (Figure

16). In addition, there is a zone of less pronounced Zr enrichment traceable from south of Modbury SW to the Erme. This corresponds roughly to the outcrop of felsite mapped by Ussher and shown more diagrammatically in Figure 1.

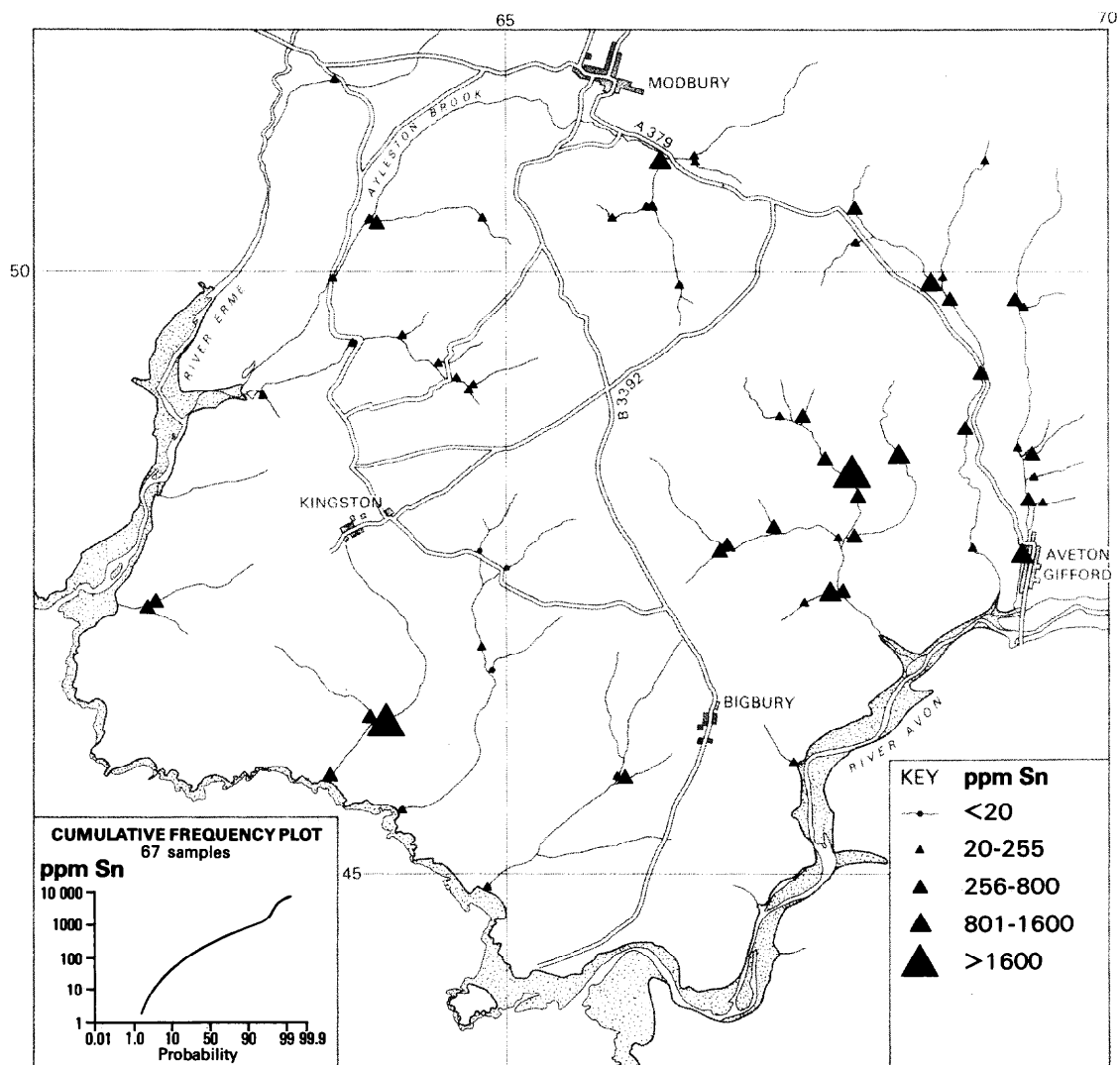


Figure 17 Distribution of tin in drainage panned concentrates.

Tin

Tin in the form of cassiterite is relatively abundant in several samples and the range in Sn concentrations is very large (Table 2). There appear to be considerable concentration gradients with large contrasts between adjacent samples (Figure 17). Particularly low Sn levels are associated with samples from east of Kingston, whereas one of two samples from south of Kingston contains a very high level. These distribution patterns suggest either local sources of tin or local sites of cassiterite accumulation. Some cassiterite is undoubtedly exotic in origin and is derived ultimately from the Dartmoor area to the north but the proportion of this to material that may be more locally derived is difficult to assess. If most of the cassiterite were derived from a Dartmoor source then an association of Sn enrichment with roughly north-south valleys might be expected, especially as large gravel sheets

are shown on Ussher's geological map in the region south of Dartmoor. However, the distribution of tin in the drainage does not support this model. Alternatively there may be a correlation between tin enrichment and height above sea level, especially as several Pleistocene platforms and raised beaches have been recognised in SW England (Cam and Hosking, 1985). Though this model could fit the distribution of tin in drainage better, there are several examples of adjacent samples collected at essentially the same height containing substantially different tin levels. Some local sources of tin are also likely, as cassiterite has been identified in several overburden samples and enhanced levels of tin have been found by analysis in several rock samples. At one locality a few grains of a Sn + Hg alloy have been detected by energy dispersive electron microprobe. It is difficult to relate this to a likely contaminant material and so its origin remains problematical.

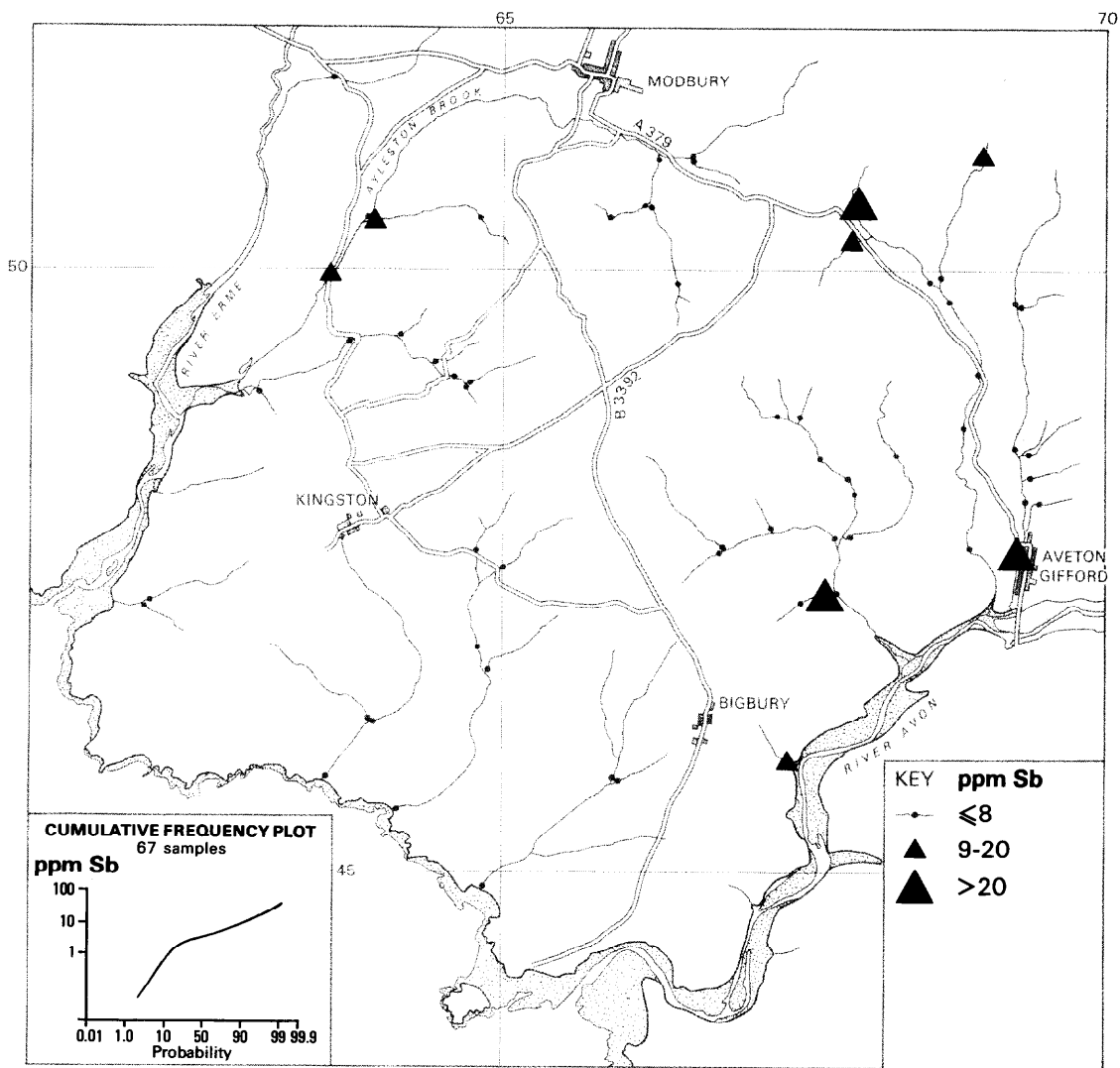


Figure 18 Distribution of antimony in drainage panned concentrates.

Antimony

Relatively few samples contain detectable levels of antimony (Figure 18). In one group of such samples, from around and to the NE of the A379 road, the Sb is closely associated with iron oxide together with Ni and As as

discussed above. With the exception of the sample from near the road to the north of Kingston all other Sb-rich samples are also rich in Pb. At these sites the Sb is thought to be associated with Pb in contaminants such as lead shot (Table 5).

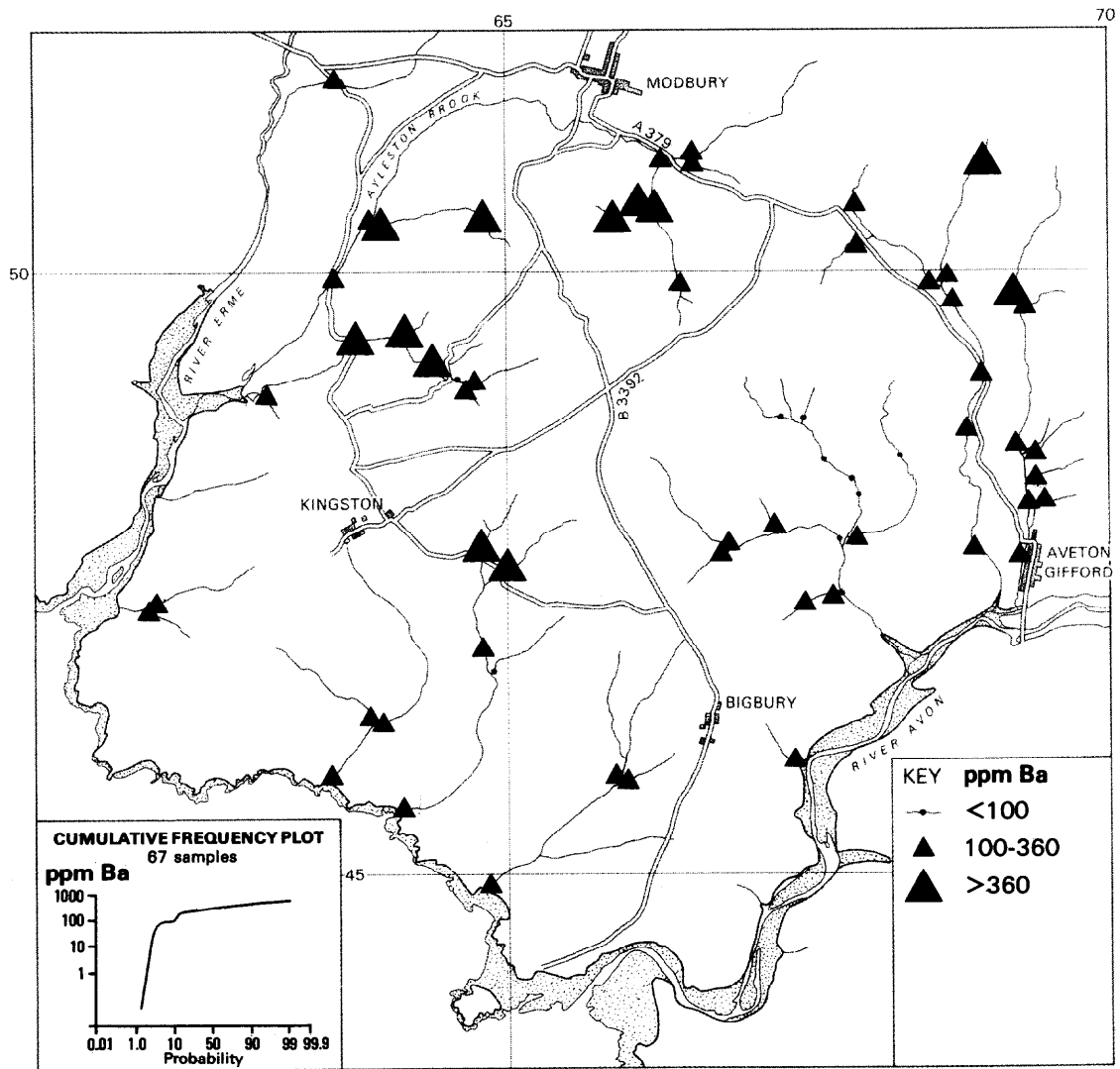


Figure 19 Distribution of barium in drainage panned concentrates.

Barium

The range in barium contents is relatively low compared with many areas in Britain (Table 2). The maximum level of Ba in the samples is insufficient to suggest the presence of any significant amount of baryte, which concentrate sampling is usually very sensitive in detecting. The lowest

levels of Ba are associated with samples derived from the greenstone bodies NW of Aveton Gifford (Figure 19). The highest levels are concentrated in a belt running SW from south of Modbury which corresponds roughly with the outcrop of the felsite mapped by Ussher and shown more diagrammatically in Figure 1.

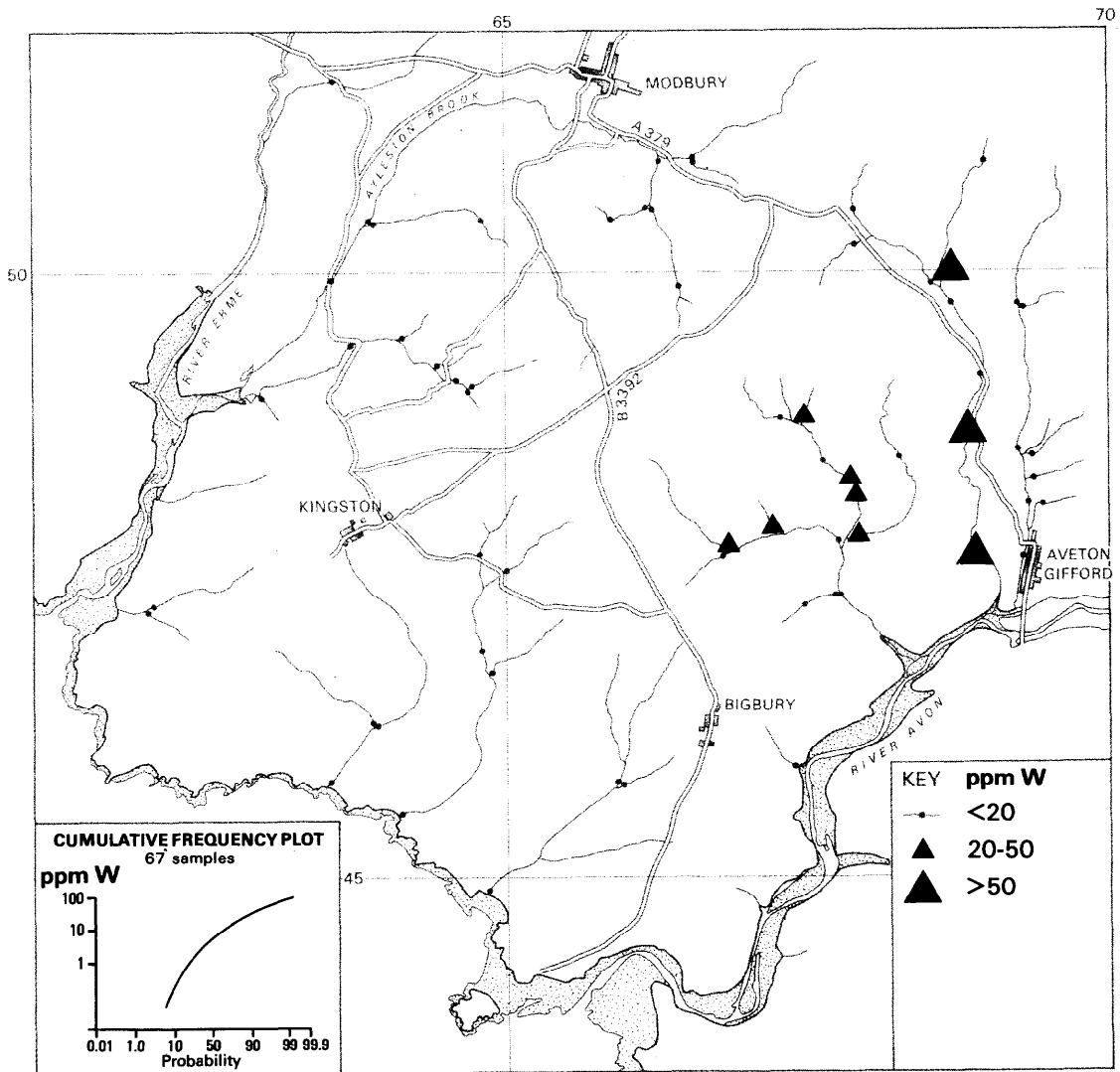


Figure 20 Distribution of tungsten in drainage panned concentrates.

Tungsten

All samples containing relatively high levels of tungsten occur to the west and NW of Aveton Gifford (Figure 20). One group correlates with samples derived from the

greenstone bodies though the form of the W in them is not known. The source of the higher levels of W in the stream immediately west of Aveton Gifford is not clear.

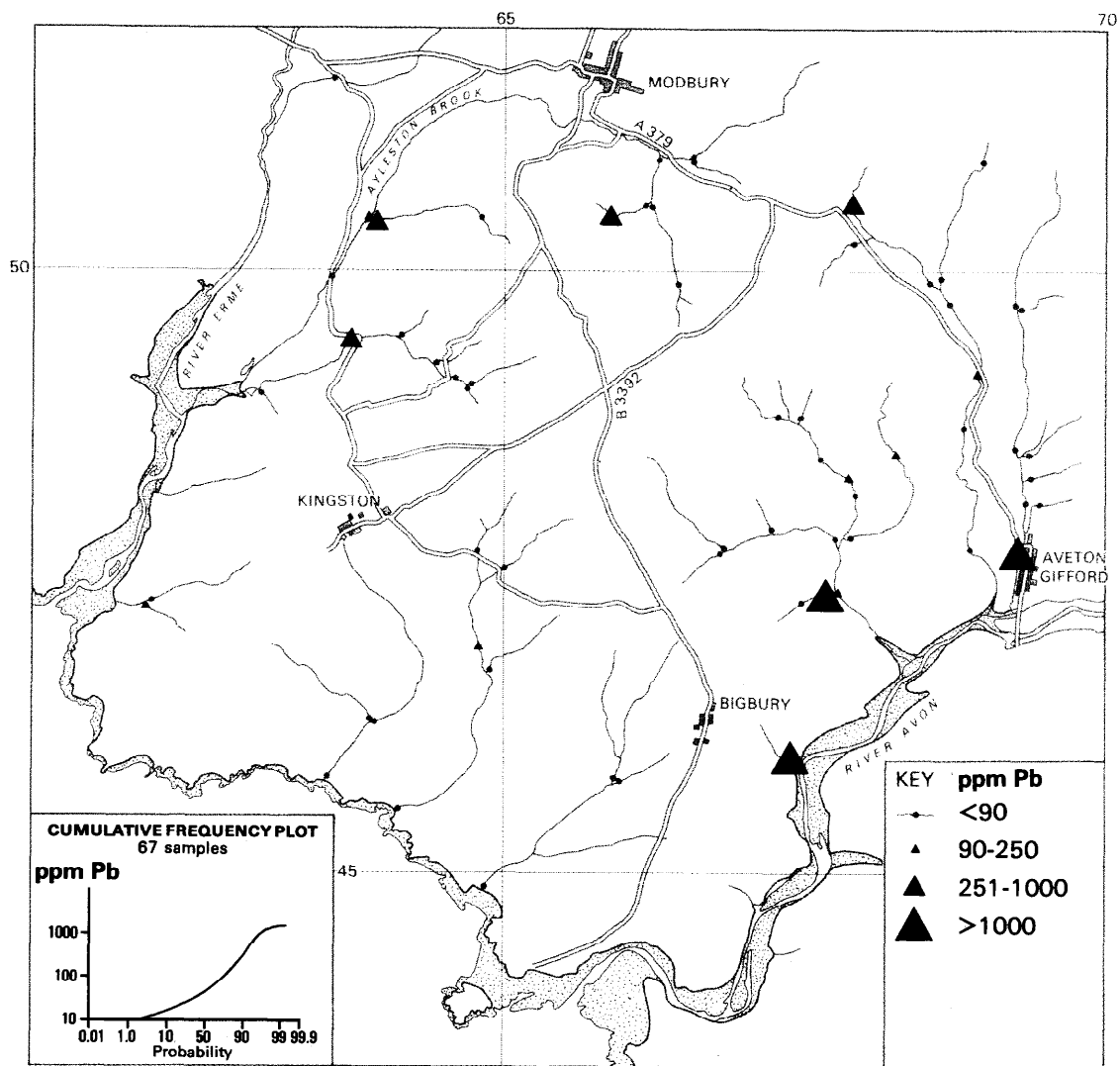


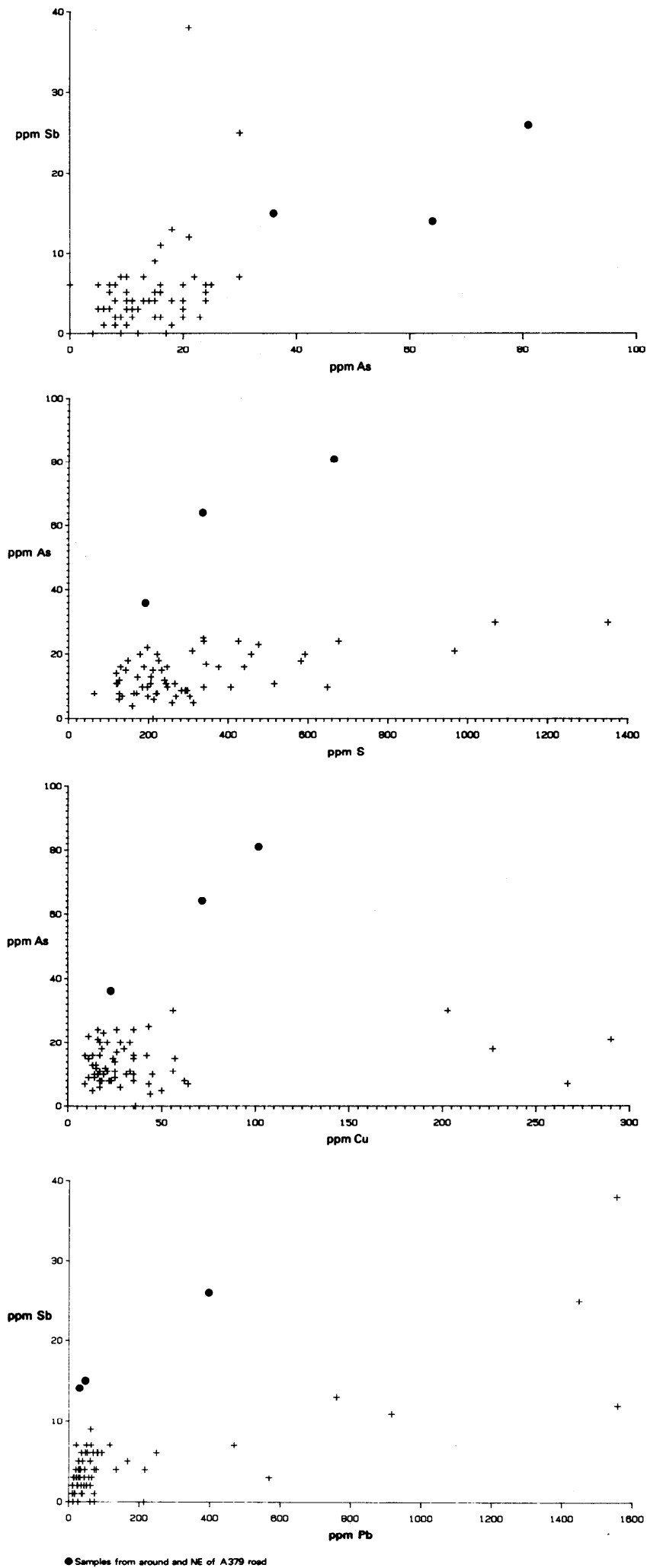
Figure 21 Distribution of lead in drainage panned concentrates.

Lead

The distribution of lead (Figure 21) is dominated by the frequent presence of contaminants like lead shot, battery plate and lead glaze (Table 5). No natural lead minerals have been observed in the drainage samples but small

amounts of both cerussite and anglesite have been identified in overburden. The sample from north of the A379 road is most likely to contain lead of natural origin in view of its enrichment in the other hydrothermal associated elements Fe, As, Zn, Cu, Sb and S.

Figure 22 Plots of element pairs As-S, As-Cu, Sb-As and Sb-Pb in drainage panned concentrates.



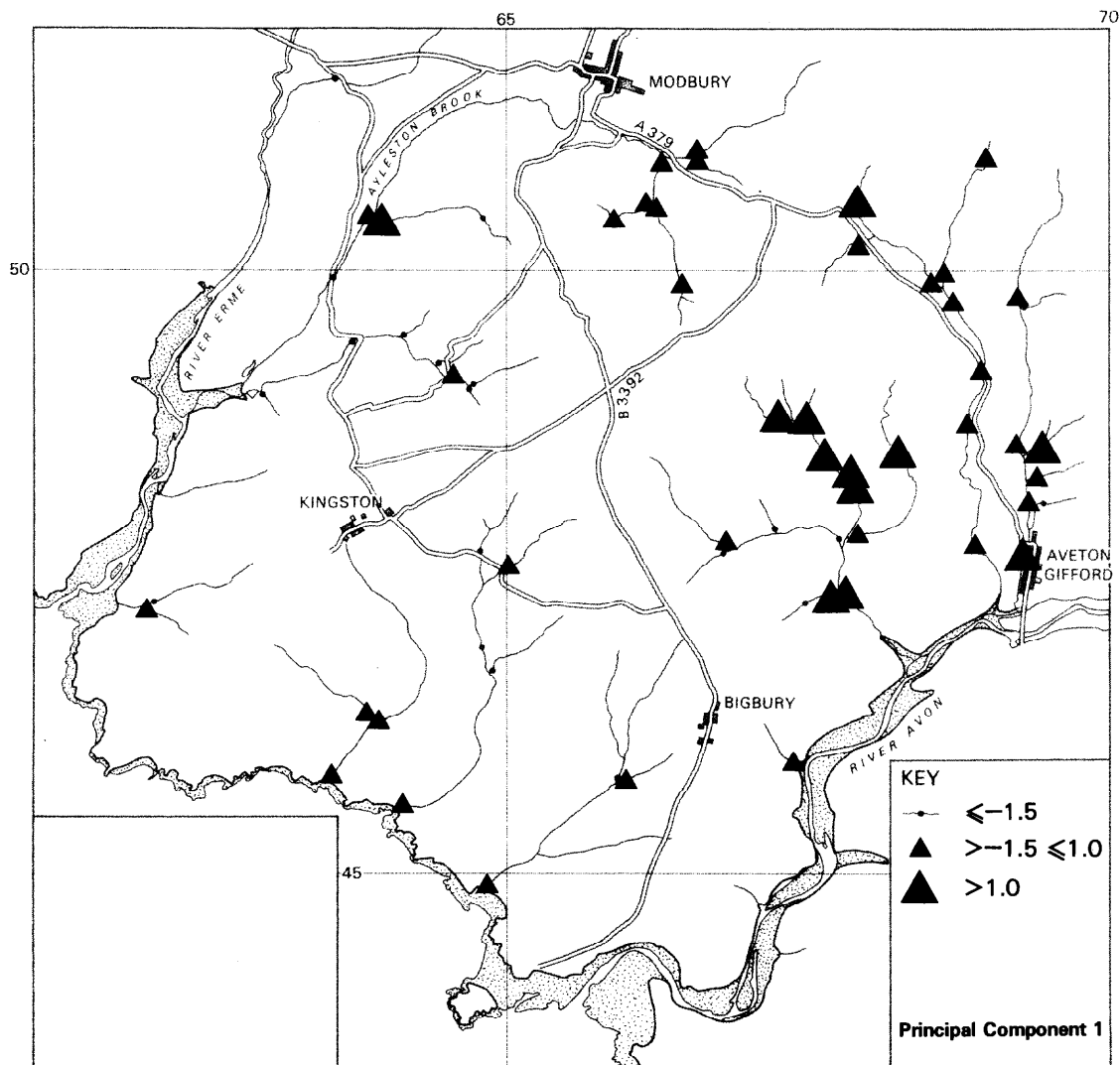


Figure 23 Distribution of principal component 1 of drainage panned concentrates.

Multivariate treatment of drainage data

Plots of pairs of elements As-S, As-Cu, Sb-As and Sb-Pb are given in Figure 22. These clearly demonstrate the significant difference between the anomalous samples derived from the area around and to the NE of the A379 road between Modbury and Aveton Gifford and all the other samples. The approximately straight line correlation between S, As, Cu, Sb and perhaps Pb in these three samples suggests a common source material. They are also much richer in Sb relative to Pb than other Pb-rich samples which are thought to be contaminated with metallic material of artificial origin.

A principal component analysis was carried out using the SAS Princomp Procedure on a VAX 8600 computer under VMS. The five eigenvectors with eigenvalues greater than 1.0 calculated by this procedure are given in Table 6.

Table 6 Principal component analysis drainage data

	Eigenvectors				
	Principal components (Eigenvalue > 1)				
	1	2	3	4	5
MgO	-0.07	-0.04	0.66	-0.10	-0.04
S	0.11	0.33	-0.00	0.16	-0.29
CaO	0.34	-0.07	0.15	-0.10	-0.17
TiO ₂	0.35	-0.21	-0.01	-0.13	0.05
Cr	0.25	-0.07	0.21	-0.06	0.08
MnO	0.35	-0.20	0.05	-0.12	0.06
Fe ₂ O ₃	0.36	0.08	-0.21	-0.07	0.21
Ni	0.07	0.31	0.23	-0.11	0.49
Cu	0.21	0.28	0.12	-0.01	-0.29
Zn	0.16	0.36	-0.16	0.08	0.05
As	0.03	0.33	-0.32	0.05	0.30
Zr	0.26	-0.23	0.02	-0.14	0.02
Ag	0.33	0.07	-0.03	-0.24	0.17
Sn	0.18	-0.07	0.18	0.62	0.16
Sb	0.15	0.40	-0.04	-0.02	-0.13
Ba	-0.26	0.19	0.18	-0.02	0.26
W	0.13	-0.11	-0.30	0.26	-0.33
Au	0.14	-0.13	0.13	0.59	0.26
Pb	0.12	0.29	0.29	0.10	-0.32
Eigenvalue	6.03	4.34	1.88	1.53	1.19

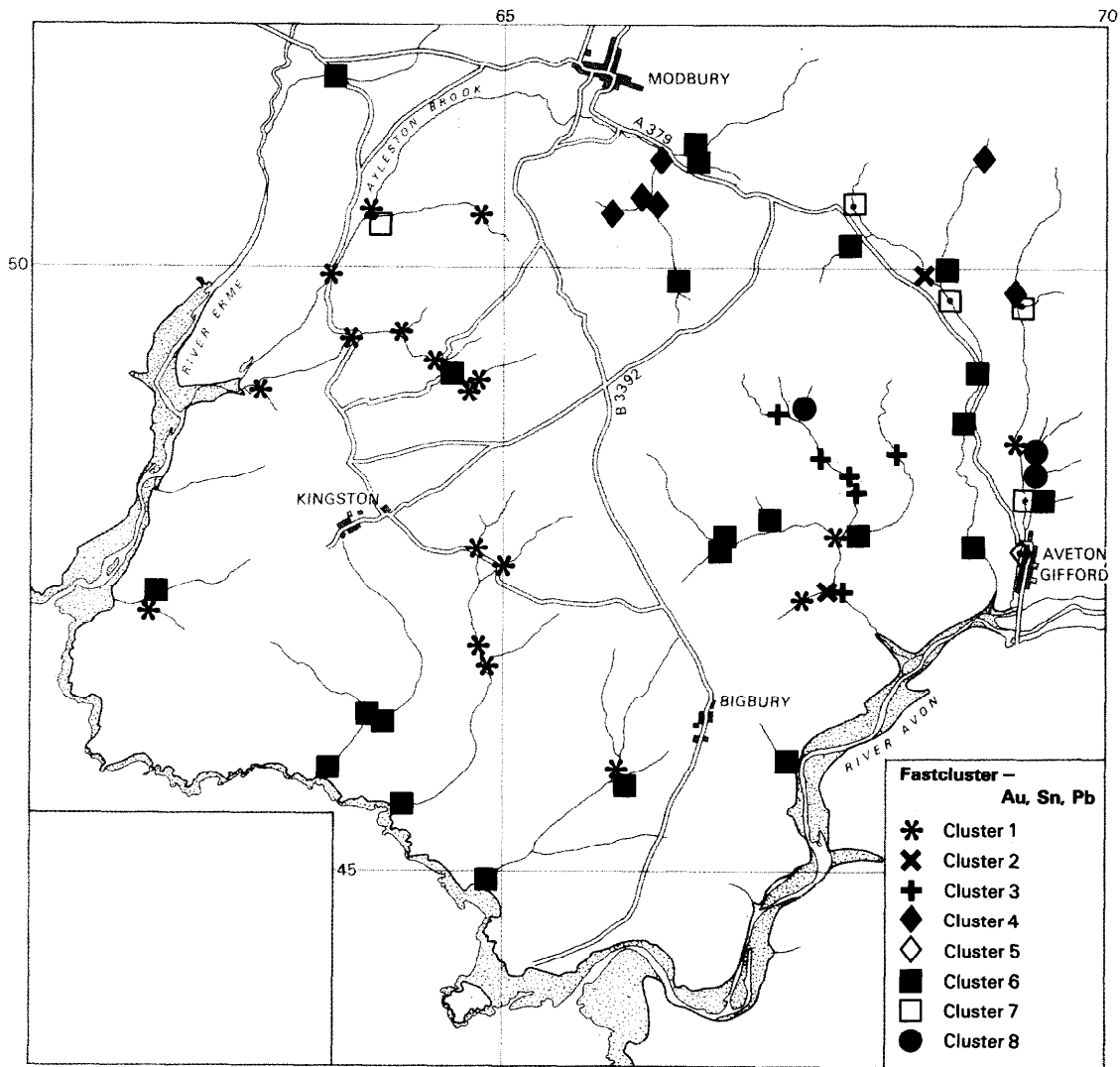


Figure 24 Distribution of clusters from fastcluster procedure on drainage concentrate raw element data with elements Au, Sn and Pb omitted.

A class interval plot of values of the first principal component for the drainage concentrates is shown in Figure 23. In general the highest values of this principal component correspond either to samples derived from the greenstones or to samples where a significant amount of heavy metal contamination is present. Overall it appears that values of the principal components when plotted individually, do not provide information which is not equally apparent from the single element maps.

In addition cluster analysis was carried out using the SAS Fastclus procedure on a VAX 8600 computer under VMS. Two options were applied in the clustering. Firstly raw data was clustered after removal of the elements Au, Sn and Pb which showed much greater variance than

other elements. In the second case the principal components were clustered instead of raw data as a means of reducing variance and standardising the data.

A plot of samples classified into 8 clusters using the raw data with the elements Au, Sn and Pb removed is shown in Figure 24. In addition the samples defined by clusters are shown on Ba-Ca and Ti-Fe plots in Figure 25. Samples with a significant greenstone component are clearly defined as clusters 3 and 8. Barium exerts a strong influence on the separation of cluster 6 from clusters 1 and 4, differences which could reflect the presence of different sedimentary rock units with the east and centre contrasting with the rest of the area.

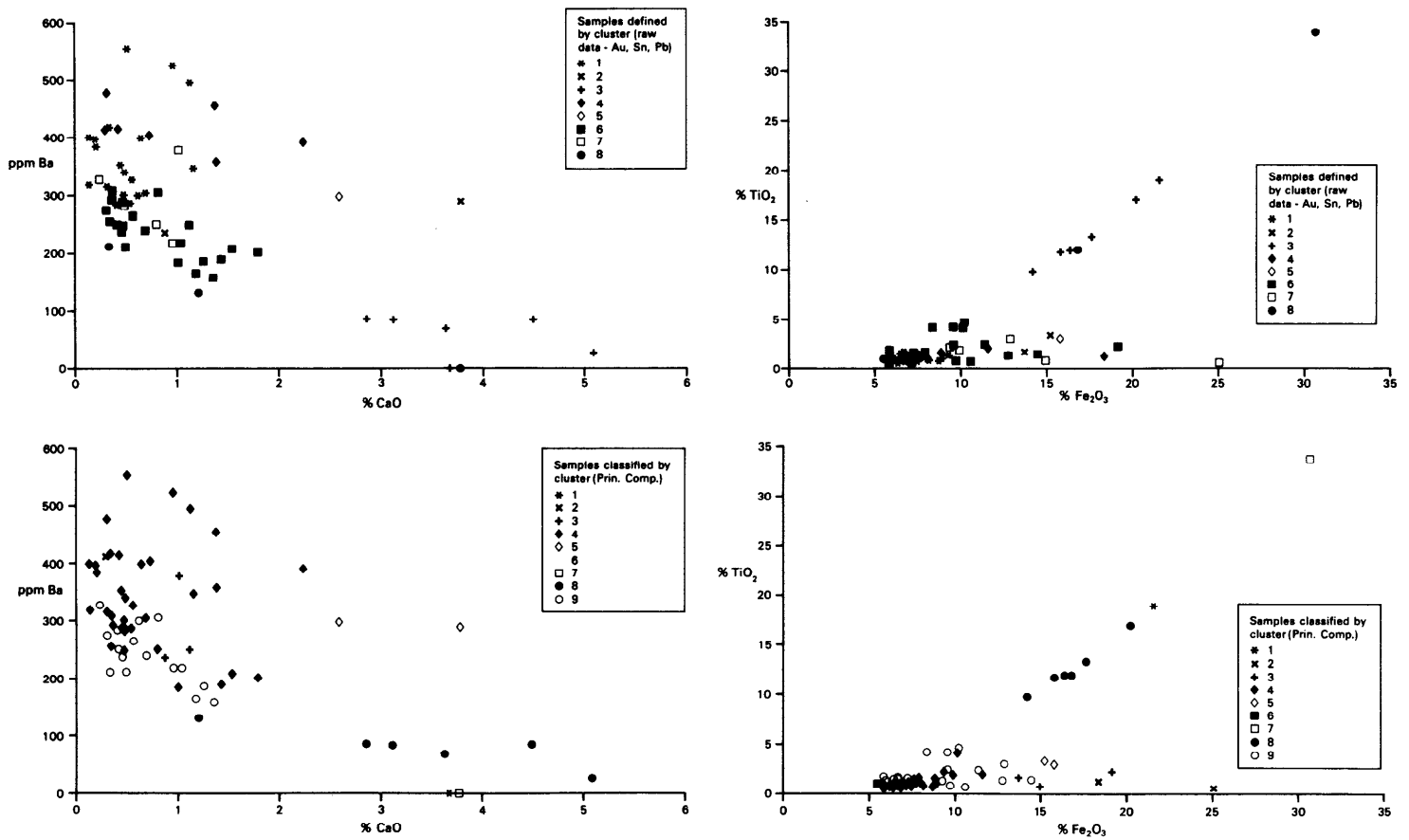


Figure 25 Plots of element pairs Ba-CaO and TiO₂-Fe₂O₃, with samples classified by raw element cluster and by principal component cluster.

A complementary plot of samples classified into 9 clusters using the first 5 principal components is shown in Figure 26. The samples defined by these clusters are also shown on Ba-Ca and Ti-Fe plots in Figure 25. There are some clear differences between the two clustering procedures, the use of principal components accentuating some differences and reducing others compared with the raw data. Some of these differences result from the inclusion of the extra three elements Au, Sn and Pb in the principal components data set c.g. a better separation of

the two highly contaminated sites (cluster 5, Figure 24) by virtue of the high lead levels present in these samples. In addition samples from around and to the NE of the A379 road are more clearly separated from others within the principal component data set than the raw element data set. In contrast differences between clusters 1, 4 and 6 in the raw data set have to a large extent been removed with most of these samples assigned to a single cluster (cluster 4) in the principal component data set.

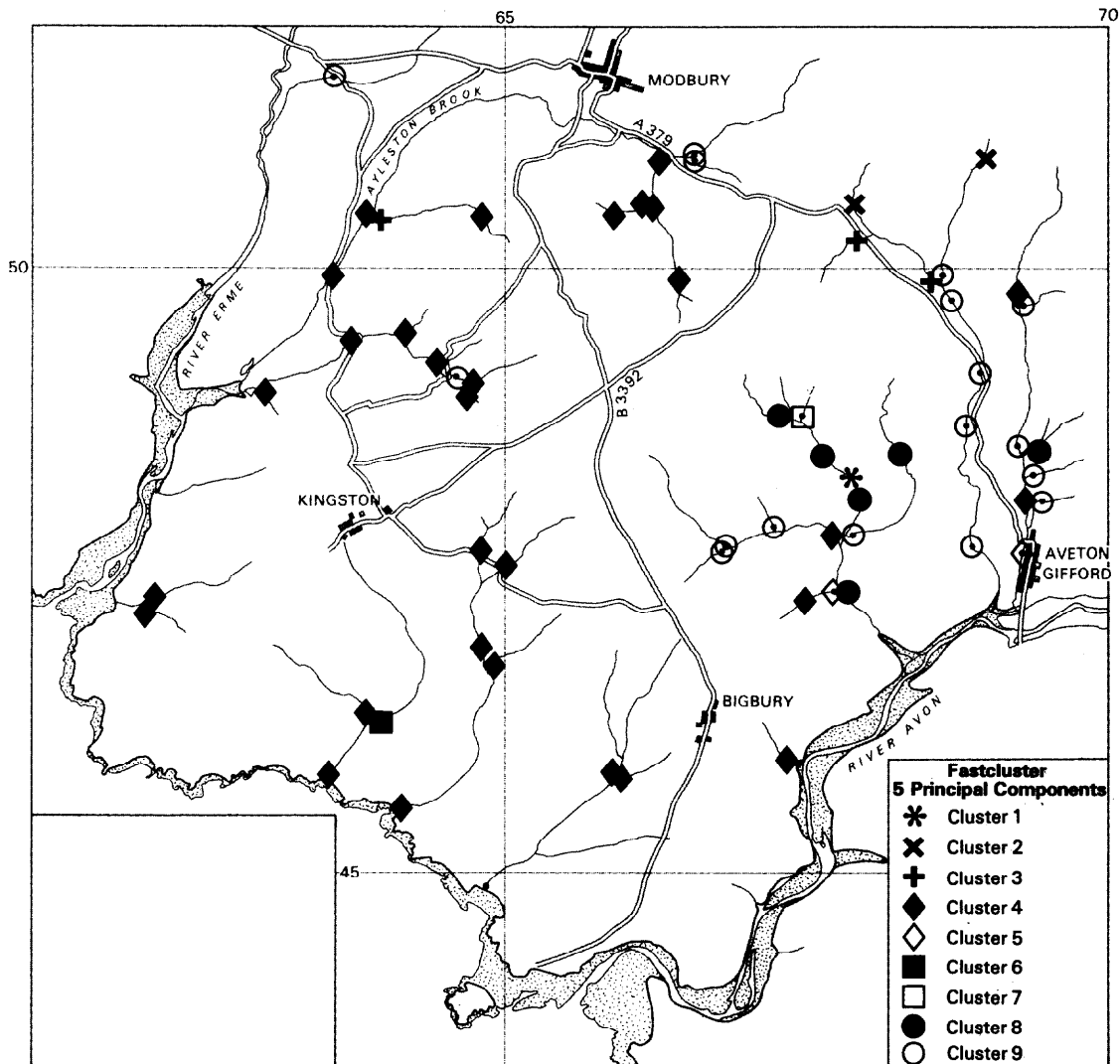


Figure 26 Distribution of clusters from fastcluster procedure on drainage concentrate principal component data.

Size distribution of elements in drainage samples

A consideration of the grain size distribution of a particular element in a drainage sample can provide significant information about the nature and significance of an anomaly which may not be apparent from bulk chemical analyses. To investigate such grain-size factors three size fractions of some panned concentrate samples, obtained after sieving at 500 micrometres and 250 micrometres, have been analysed for a range of elements by XRF as

described above. In Figure 27 the compositions of three fractions are compared on triangular diagrams on which 5 samples are specifically identified to serve as interpretive illustrations. For each element, points are elongated into a rough line but the trends of the line for Ti and Zr differ markedly from those for Fe, Zn, Mn and P. For Ti and Zr the variation is principally in the proportion of these elements in the finest fraction relative to the other two. This is due to the relative fine size of grains of ilmenite

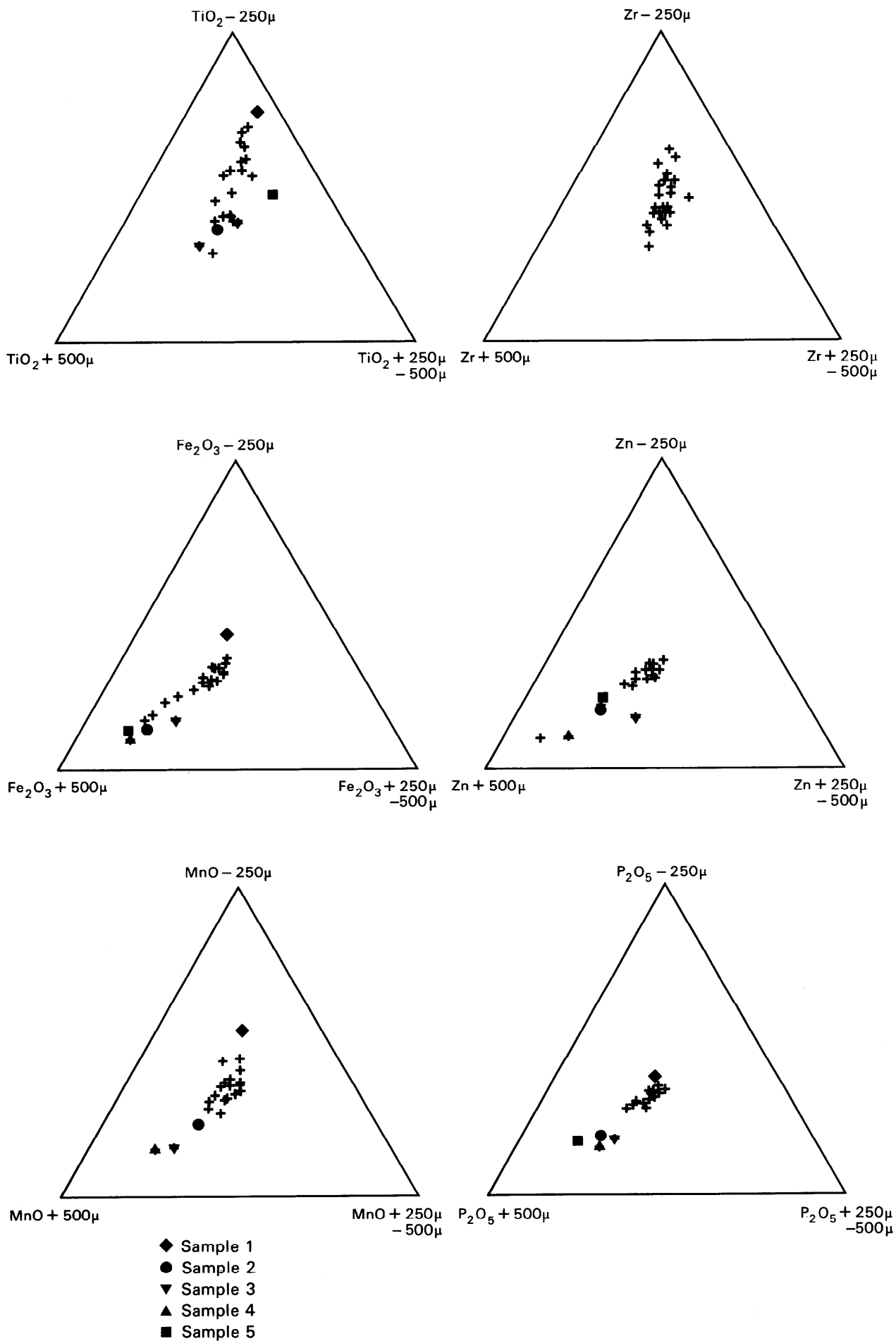
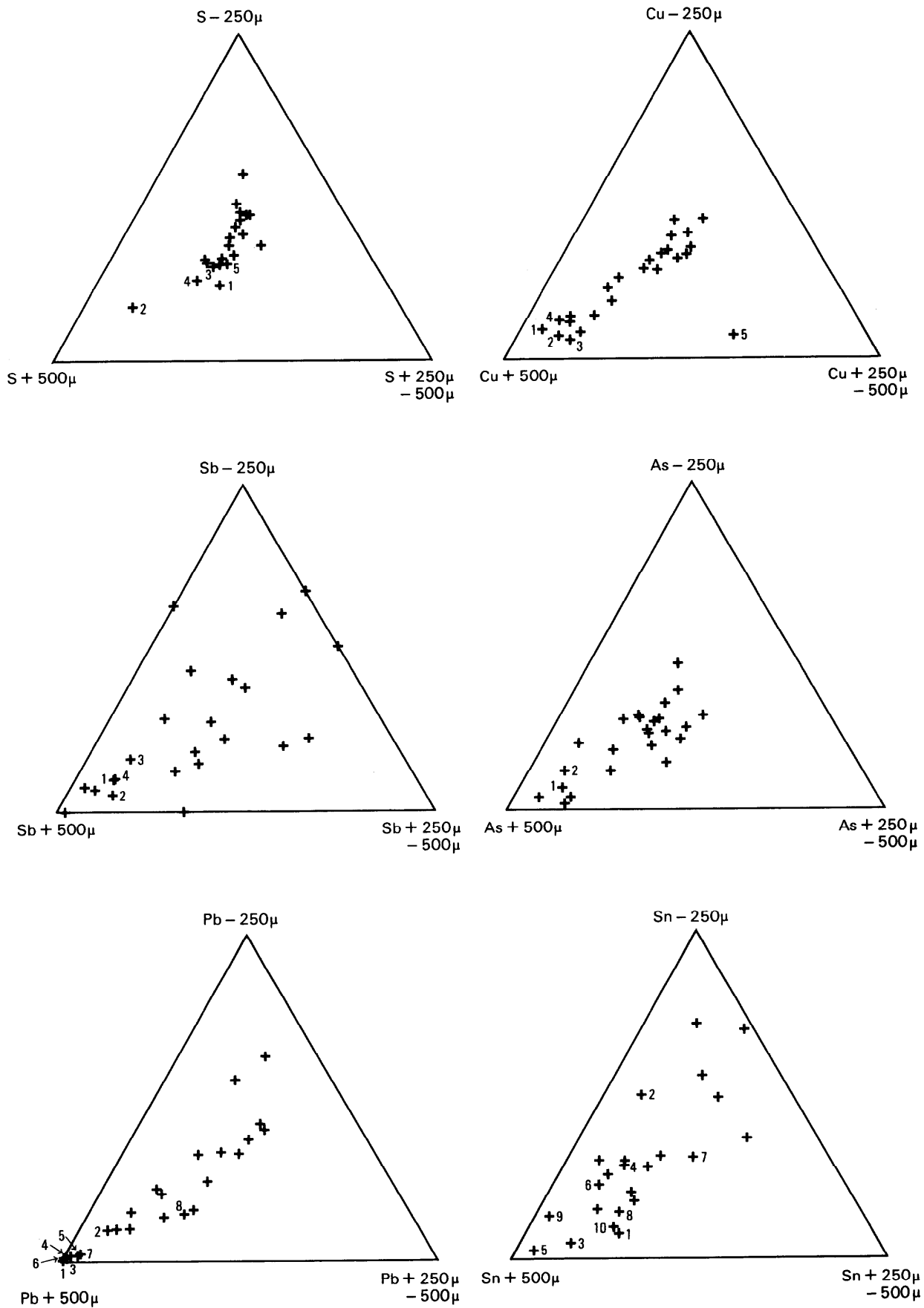


Figure 27 Triangular plots of proportions of Ti,Zr,Fe,Zn,Mn and P in three size fractions of drainage panned concentrates (partial data set).



Numbers refer to samples containing highest overall levels of each element

Figure 28 Triangular plots of proportions of S,Cu,Sb,As,Pb and Sn in three size fractions of drainage panned concentrates (partial data set).

and zircon which are the chief hosts of Ti and Zr respectively in addition to rock fragments. Thus sample 1 is the most Ti-rich of those for which size data are available and is derived to some extent from greenstone from which relatively fine grains of these minerals are released into the drainage sediment.

In contrast the variation is principally in the proportion of the coarsest fraction to the other two for Fe, Zn, Mn and P. Samples 2 to 5 are all from the vicinity of the A379 road between Modbury and Aveton Gifford. They all show iron to be concentrated predominantly in the coarsest material with the pattern for phosphorus almost identical. In two of these samples the overall level of Fe and P is much less than in the other two to such an extent that they do not appear to be closely related in either the single element or multivariate parameter plots described above. Nevertheless mineralogical examination confirms that all contain distinctive coarse grains of goethitic iron oxide which are clearly from one type of source, though in two samples it is much more conspicuous than in the others. The relative position of the same four samples on the Zn diagram is similar but not identical to that on the Fe diagram. This suggests that the association of Zn is not quite as close as P with this iron oxide material. The additional sample which is rich in coarse-grained Zn is quite unlike the four marked samples in the other elements and therefore is not derived from a similar source, a fact confirmed by mineralogical examination of the sample. For Mn, one of the marked samples does not exhibit a concentration of Mn in the coarse fraction. This suggests that Mn has a separate, though perhaps related, source than the iron oxide.

Similar size data for the elements S, Cu, Sb, As, Pb and Sn are plotted in triangular form in Figure 28. For these elements the samples containing the largest overall concentrations of each element are identified so that the size distribution of individual anomalies can be assessed. This information is extremely valuable in assessing the likely significance of an anomaly and especially in detecting anomalies derived from metallic material of artificial origin.

It is clear that for lead most anomalies are present only in the coarsest fraction and are therefore likely to be contaminant derived since any natural lead mineral would have undergone at least some mechanical breakdown and so appear in the finer fractions also. Sample 2 and especially sample 8 contain finer-grain Pb-rich material in addition to the coarse. Lead of natural origin is therefore much more likely to be present in these samples.

Overall, samples on the Pb diagram trace a line towards the coarsest grain-size apex as do all the other elements except sulphur after allowance for scatter resulting from levels being close to the detection limit for some elements (e.g. Sb) in some samples. For sulphur the trend of the points is towards the finest apex. This indicates that S levels do not correlate with those of the metallic elements, due in part to the absence of sulphide minerals like pyrite in the surficial environment in this area and in part to the importance of metallic contamination. One sample stands out on the S diagram (i.e. no. 2) as relatively enriched in coarse grained sulphur. As this sample is also enriched in Cu, Zn, Fe and Pb it is possible that at least some of the anomalous levels of metallic elements are of natural origin.

The association of metallic elements with either coarse-grained iron oxide or contaminants will account for the concentration of points near the coarse apices of the Cu, Sb and As diagrams. Sample 5 on the Cu diagram is

clearly different, with Cu most enriched in the middle fraction which suggests a different type of source, perhaps natural.

The Sn diagram does not show the close association between anomalous levels and coarse grain size. Several samples show marked enrichment in tin in other fractions. These patterns must largely be natural in origin since cassiterite is the commonest form of tin identified in these samples. Sample 5 is unusually enriched in tin of coarse grain size and since this is also rich in coarse Pb the two elements may be closely associated in a contaminant like solder. Similar arguments may apply to samples 3 and 9 but to a lesser extent.

FOLLOW-UP DRAINAGE SAMPLING

Follow-up drainage sampling was carried out in two areas to test the persistence of drainage gold anomalies found during reconnaissance sampling and to look for possible cut-off sites. The results of this work are presented in the data package.

OVERBURDEN SAMPLING

An extensive programme of overburden sampling was carried out in one area to trace the source of drainage gold anomalies. Initial sampling was carried out on traverse lines at 20 m intervals by digging small pits to 0.5 to 0.8 m depth and filling a bucket of 10 l capacity with material from its base. The bucket of overburden, weighing around 22 kg, was then sieved through a 2 mm screen and the minus 2 mm fraction collected in a pan. A representative collection of oversize rock fragments were retained for subsequent examination and identification. The minus 2 mm fraction, commonly between 4 and 5 kg in weight, was then carefully washed and panned to produce a clay-free heavy mineral concentrate of constant volume (150 ml). This material was then put into a Gold Genie spiral concentrator and a small, very heavy, concentrate obtained. Gold grains were then counted and picked from the Gold Genie concentrate under a binocular microscope. Other grains of interest were also picked out and mounted on a slide for subsequent microscopic or electron microprobe investigation. Residual material minus the gold grains was then recombined with the original heavy mineral concentrate for grinding prior to chemical analysis. At each site an orthodox soil sample was taken from the base of the pit so as to fill approximately a 10 × 20 cm Kraft paper bag giving a sample weighing 150–200 gm after drying. Since it was impractical to cover all the area with pit samples much of the later sampling took the form of orthodox soil sampling using a hand auger, with pitting at regular intervals. In addition pits were also dug in areas thought to be promising by virtue of their soil colour or because rock fragments within the soil resembled those from gold-rich samples already found. After chemical analyses had been obtained, further pit sampling was carried out in areas thought to have chemical characteristics similar to gold-rich sites previously found.

The concentrates were ground in a Tema swing mill and 12 gm subsamples analysed by X-Ray Fluorescence at MESA, Nottingham for S, Ti, Cr, Fe, Ni, Cu, Zn, Rb, Zr and Pb. The element list was chosen to provide data which could be used to provide a geochemically-derived geological map of the area so that the geological setting of

the gold anomalies could be assessed and also to investigate possible pathfinders. A greater number of additional elements viz. Mg, P, K, Ca, V, Mn, Co, As, Se, Sr, Y, Mo, Sn, Sb, Te, Ba, La, W, Hg, Tl and Bi were determined in a few gold-rich samples. In addition gold was determined in 50 gm splits of some of the concentrates as described above at the laboratories of Caleb Brett Ltd, Merseyside. All orthodox soil samples were analysed for the same 10 elements as listed above for the concentrates after drying, disaggregating and sieving to obtain a minus 85 BSS fraction (180 micrometres).

Summary statistics of the chemical analyses of the panned overburden samples are given in Table 7.

Table 7 Summary statistics panned overburden samples

	N	Mean	SD	Min	Max
S ppm	175	152	546	38	7266
TiO ₂ %	175	1.65	1.11	0.24	5.77
Cr ppm	175	97	77	<2	388
Fe ₂ O ₃ %	175	9.60	6.06	2.13	28.32
Ni ppm	175	26	23	4	147
Cu ppm	175	26	19	4	209
Zn ppm	175	86	67	17	618
Zr ppm	175	750	548	131	2989
Pb ppm	175	27	20	7	200

N = number of samples SD = standard deviation

At least one grain of gold was detected in 114 of the 175 panned overburden samples. In most cases gold grains were removed from the concentrate and mounted on slides for shape and size measurement and for investigation with the electron microprobe. In 43 samples gold determinations were made on the residual concentrate samples after removal of the gold grains. For a further 58 samples any gold grains identified were returned to the sample prior to its fine grinding and chemical analysis of a 50 gm split as described above. These data are included in the data package. In general where Au grains were observed in the sample, additional gold was found by chemical analysis and there is a general rough correlation between number of grains and analysis level. A few exceptions were noted and in 10 cases gold levels of between 14 and 209 ppb were obtained by analysis though no grains were observed.

Table 8 Summary statistics of soil data

	N	Mean	SD	Min	Max
S ppm	978	535	328	77	2481
TiO ₂ %	978	1.27	0.58	0.13	4.14
Cr ppm	978	101	59	3	481
Fe ₂ O ₃ %	978	8.87	3.01	2.36	23.54
Ni ppm	978	38	24	3	186
Cu ppm	978	20	11	4	177
Zn ppm	978	86	42	15	591
Rb ppm	978	142	27	30	288
Zr ppm	978	407	158	143	944
Pb ppm	978	23	9	6	132

N = Number of samples SD = standard deviation

The summary statistics for the orthodox soil samples are given in Table 8.

Agreement between the two sample types is good for most elements and this is illustrated by the plot of Zn concentrations in Figure 29. Agreement is less good for titanium compared with other elements, perhaps a consequence of grain size factors since the soil samples are sieved at 180 micrometres. There is also considerable scatter on the corresponding plot for sulphur (Figure 29) and this element differs from others in its much greater, general concentration in the sieved soil sample compared with the panned overburden sample. This can be accounted for if sulphur is present predominantly not as sulphide grains but in very fine grain material that is preferentially lost during panning. In contrast the presence of sulphide grains can be inferred in the two samples where S is relatively enriched in the panned samples.

Single element plots for both sieved soil and panned overburden samples are provided as part of the data package. Some of the elements are of considerable importance in delineating geological boundaries in the absence of any exposure over most of the area. This operation is a vital step in the assessment of the geological environment and potential controls of the gold anomalies. To facilitate the production of a geological map, multivariate statistical procedures have been employed. The results of the application of principal component analysis and cluster analysis using the methods employed for the drainage data are also included in the data package. The cluster analysis with raw data has been particularly useful in the delineation of geological units and their boundaries, many of which were subsequently confirmed as a result of drilling. The best results were obtained with the element sulphur omitted as there seemed little relationship between S levels and the underlying geology.

MINERALOGY OF OVERBURDEN PANNED CONCENTRATES

A number of grains other than gold were also taken from several overburden concentrates and mounted for electron probe analysis to investigate whether it was possible

Table 9 Silicate minerals identified in overburden samples

Mineral	Elements	Comments
K Feldspar	K, Al, Si	
Albite	Na, Al, Si	
Sodic Plagioclase	Na, Ca, Al, Si	
Clay	Fe, Al, Si	greenish
Muscovite	K, Al, Si	
Biotite	K, Fe, Mg, Al, Si	
Clinozoisite	Ca, Al, Si	
Chlorite	Fe, Al, Si	
Garnet	Fe, Mn, Ca, Si, Al	
Amphibole?	Fe-rich	
Tourmaline	Fe-rich	black, some euhedral
Zircon	Zr, Si	euhedral and rounded forms
Monazite	P, RE	reddish or yellow or beige

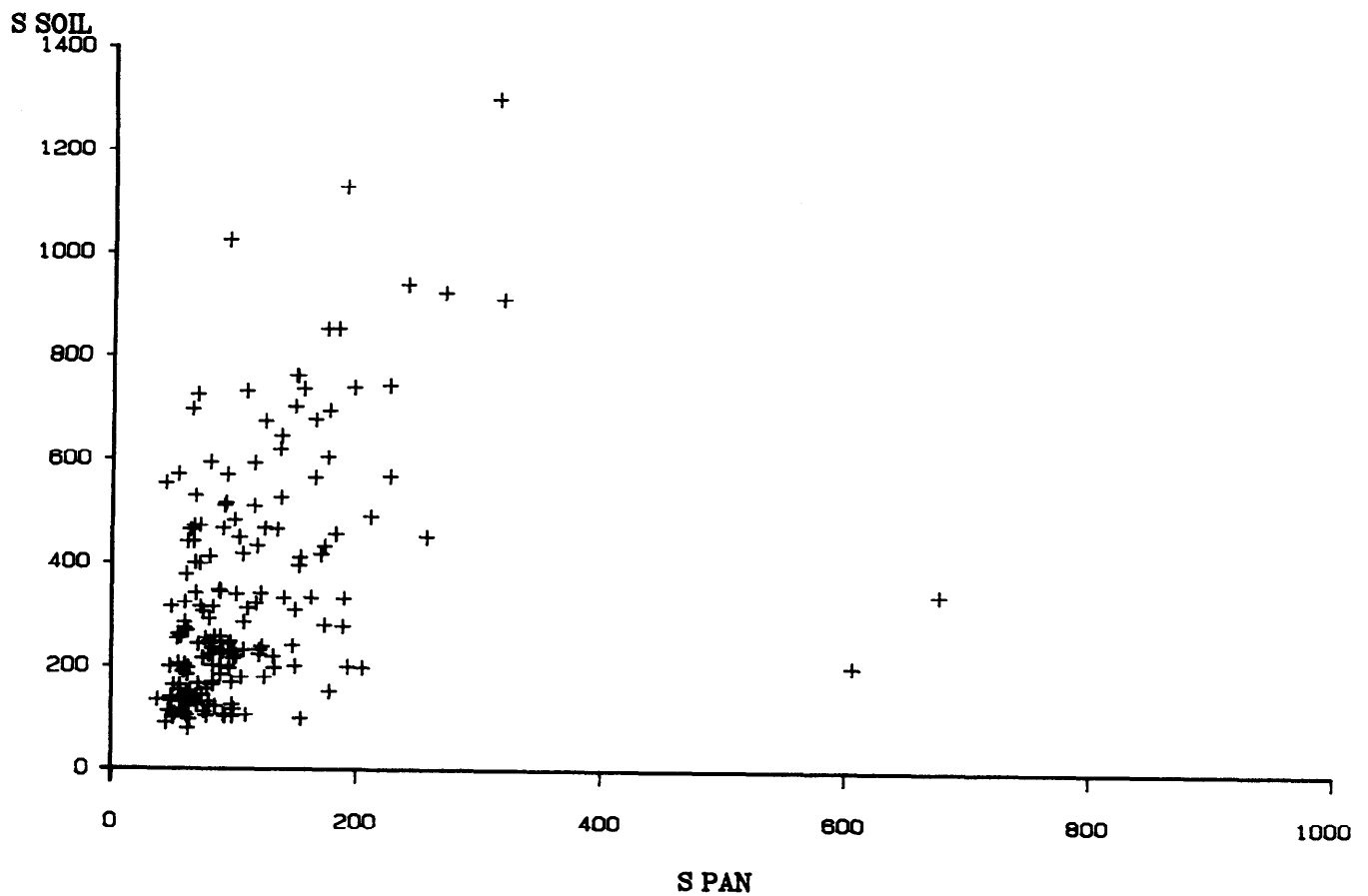
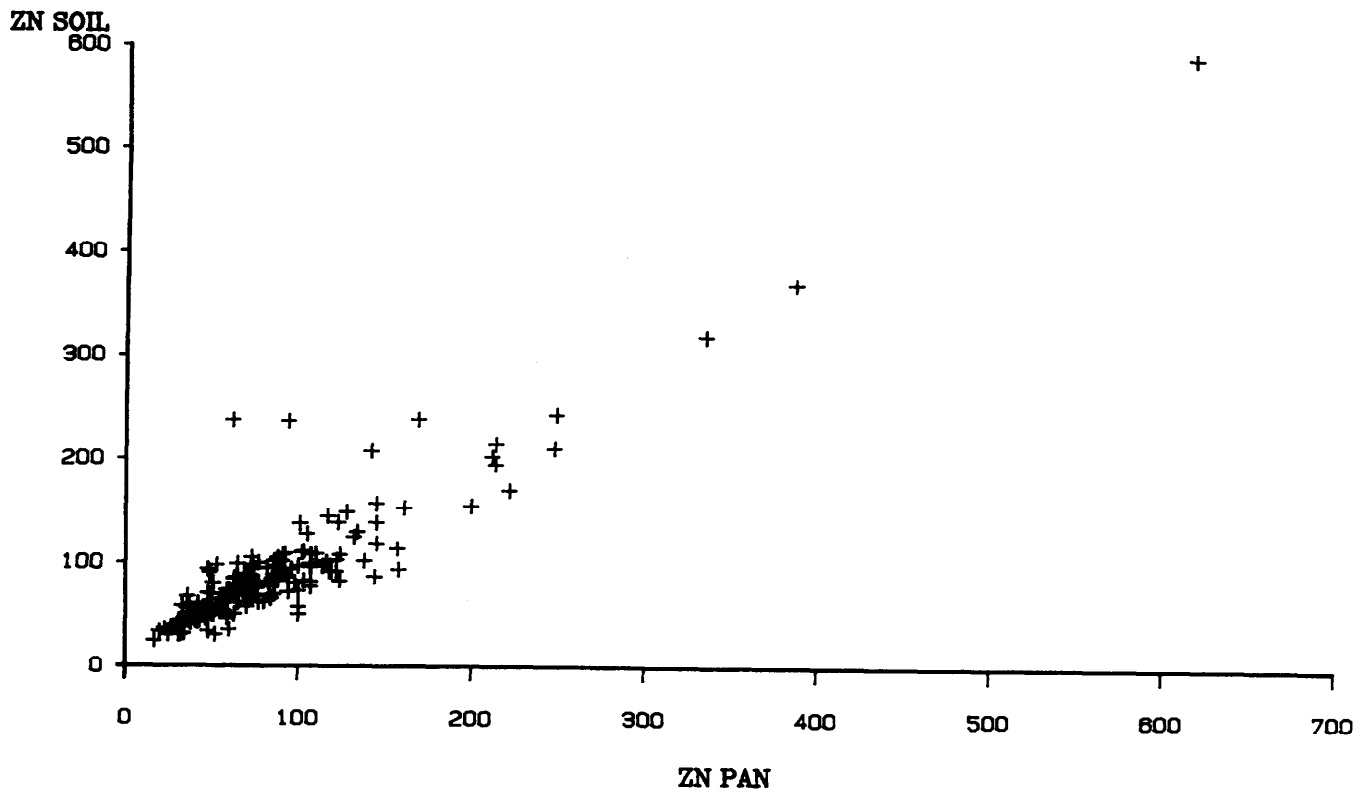


Figure 29 Comparison of zinc and sulphur concentrations in sieved (minus 85 BSS fraction) overburden and panned overburden samples from the same site. All axes in ppm.

to identify mineralogical pathfinders associated with the gold. These comprised representatives of common minerals and also grains of more unusual appearance. Silicate minerals identified are included in Table 9.

The ore minerals identified are included in Table 10. The most unusual grain identified was of potarite, an alloy of palladium and mercury. It occurs in the form of an elongate knobby crystal aggregate with a dull bronze-brown colour. The grain which weighed 0.20 mg gave a composition of 55% Hg, 37% Pd and perhaps about 3% Te by XRF. Other exotic mineral grains may be present as a few smaller aggregate grains of rather similar appearance and inconspicuous colour were noted in some other samples but these were not retained for electron microprobe examination.

Table 10 Alloys, sulphides, oxides and other ore minerals identified in overburden samples

Mineral	Elements	Comments
gold	Au, Pd, Ag, (Hg, Cu, Fe)	3 major varieties
silver	Ag	1 grain
potarite	Pd, Hg	1 dendritic grain
pyrite	Fe, S	rare
magnetite	Fe	octahedra
hematite	Fe	
Fe oxide balls	Fe	some magnetic, others not
goethite	Fe	
pyrite pseudomorph	Fe	
Cr Spinel?	Fe, Cr	
ilmenite/leucosene	Fe, Ti	
rutile	Ti	
anatase	Ti	octahedron
cassiterite	Sn	mostly amber but reddish and black varieties also
limonitic Fe oxide	Fe, Mn (5–14%)	
Mn oxide	Mn	
malachite	Cu	often as balls
smithsonite	Zn	
cerussite	Pb	rare
anglesite	Pb	rare

Contaminants identified in overburden samples include metallic fragments from digging implements, pieces of basic slag and small iron needles perhaps also derived from slag and a fragment of blue paint of unknown origin. The basic slag was probably applied to the land in the past as a fertiliser.

SIZE AND FORM OF GOLD

A large proportion of the gold grains in overburden samples, especially from anomalous sites, are subspherical, octahedral or elongate octahedral in shape with a slightly rough or crazed surface. In this respect they differ markedly from the majority of gold grains in drainage which are much more irregular in shape and are frequently flattened, with a smooth surface. The size of a number of gold grains has been estimated by measurement under the microscope of the two largest axes or by measurement from photographs. A cumulative frequency

plot of the size data from one anomalous site and from a combination of background and anomalous sites throughout the area investigated is shown in Figure 30. There seems to be little difference in grain size between gold from anomalous and background sites with a 50 percentile mean diameter size of about 60 micrometres. In contrast gold grains measured from drainage samples are much coarser as shown by the corresponding cumulative frequency plot also in Figure 30. For drainage grains the 50 percentile mean diameter size is about 190 micrometres. Though part of the apparent size difference is a result of the generally more flattened nature of grains from drainage, the weights obtained of individual grains substantiates their coarser nature.

A few overburden sites contain gold of similar shape and size to that in drainage samples, though in less rounded forms. Some of the grains are delicate in shape with thin necks or small projections. These sites are situated on a bank or terrace of head adjacent to a small stream or on alluvium and are therefore different from typical overburden sites, where material is clearly residual in origin and locally derived.

The difference in gold grain size between the two sample types is clearly of fundamental importance and requires interpretation. It is assumed that the size differences are not the result of preferential removal of fine gold from the drainage sediment by winnowing as overburden samples adjacent to streams, derived from head or terrace deposits also contain predominantly relatively coarse-grained gold. One possibility to account for the difference would require the material in the drainage and head to be derived from a different and undiscovered type of source to the gold found in the residual overburden samples. This is unlikely given the varied topography of the area covered by overburden sampling and the small size of the streams within it. Alternatively if almost all the drainage sediment were derived from head concentrated in stream valleys and now under active erosion, then a different source could be possible depending on the origin of the head. Both the topography of the area and the mineral and chemical composition of the drainage samples suggests that the material is of very local derivation in most cases. It is therefore concluded that recrystallisation and growth of gold must have occurred in the solifluxion debris or head which filled the valleys and may still be taking place in the stream sediment. The chemical processes that could lead to such gold crystallisation are not understood but it is possible that organic matter and its decay products could play a part.

At some of the anomalous sites a significant proportion (around 10%) of the gold is intergrown intimately with subrounded goethitic iron oxide grains. Examination of these oxide grains with the electron microprobe show that iron is the only element detectable. In a very few cases gold is intergrown with a chloritic mineral which is very rich in iron (26–27% Fe). In other grains clay material can be observed adhering to gold grains but it is impossible to show that gold is actually intergrown with it.

COMPOSITION OF GOLD GRAINS

The composition of 55 gold grains from 22 sites has been estimated using a LINK energy dispersive analyser on the electron microprobe. The majority of the analyses are of polished grain mounts and up to 10 spots may have been analysed from one grain. A few probe analyses have been made on unpolished grain mounts and these effectively

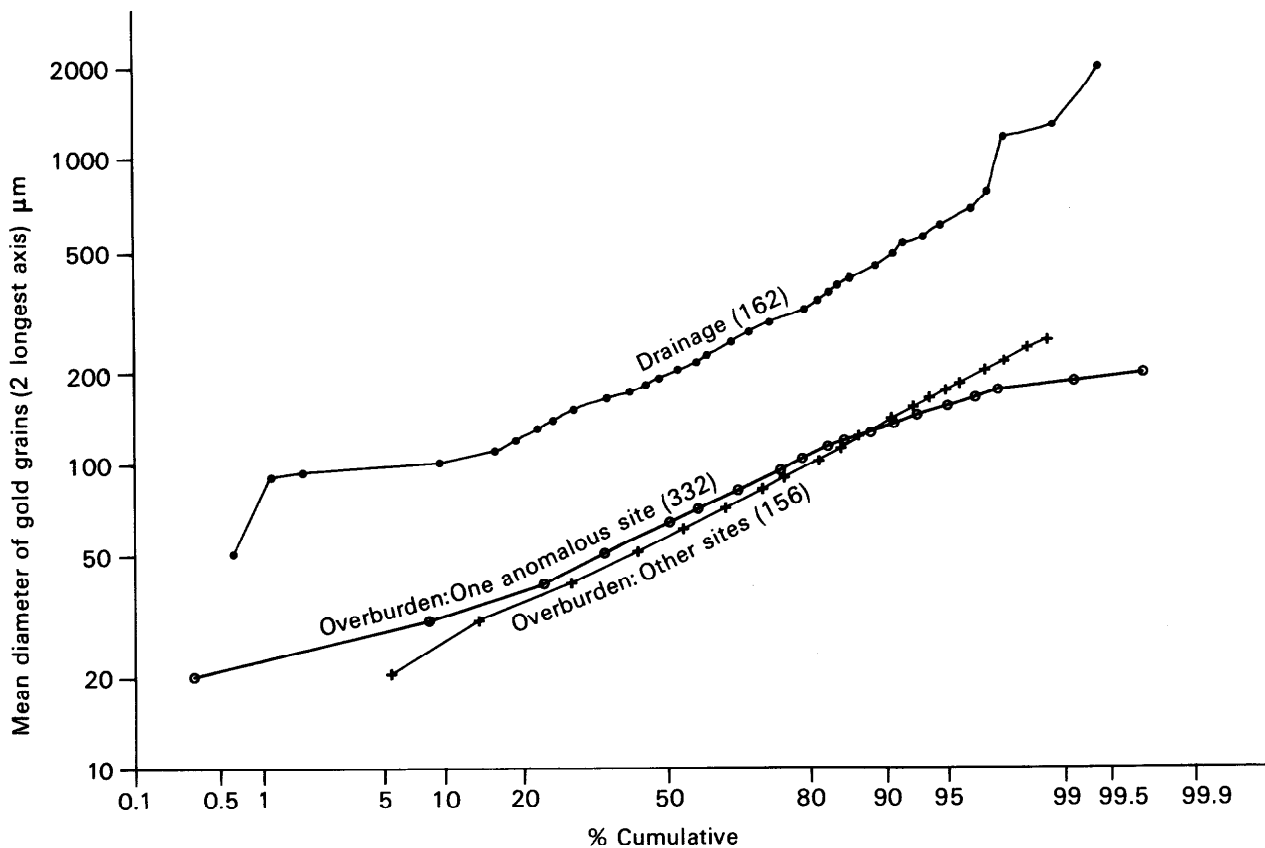


Figure 30 Cumulative frequency plots of the range of grain size of gold grains in drainage and in overburden. Numbers in brackets refer to grains measured.

are only of the edge of a grain since 90% of the Ag L X-rays detected are derived from the top 0.6 microns of the sample. In addition a few of the largest grains were analysed by XRF. Levels of Au, Ag, Pd, Cu and Fe were determined and in a few examples there was a possibility that mercury was also detectable though no quantitative data were obtained. Detection limits on the microprobe are about 0.8% of the element.

A total of 34 analyses from 15 grains showed no detectable levels of any element except gold. The range of Ag, Pd and Cu levels in all the analyses is shown in cumulative frequency form in Figure 31. This shows that levels of Pd are generally slightly lower than Ag and that Cu contents are lower still. A separate population of Cu-rich samples is discernable as is a Ag-rich population. Maximum contents of the minor components are 20.5% Ag, 17% Pd and 10.3% Cu respectively.

The composition of gold grains is also expressed on an Au, Pd, Ag triangular diagram in Figure 32; centres of grains are distinguished from grain edges and boundaries of cracks. There is a tendency for the edges of grains to be relatively rich in silver and poor in palladium, though there are some analyses which are Ag-poor throughout. Though only few grains with relatively high copper contents were found, they are all Pd-poor and some are richer in Ag than other types. The variability in composition of

grains from the same site ranges from little to almost the complete span of compositions. There are indications in the data of an association between composition and location and hence geological environment but further work is required before this can be substantiated.

The composition of two grains, both from a site adjacent to stream, has been investigated in more detail because of evidence of compositional zonation which became apparent after etching with a cyanide solution. A scan was carried out on the electron microprobe across each grain and the Pd and Ag levels monitored continuously. The results are shown in Figures 33 and 34 with the scan line marked on a line drawing of each grain. The compositional scale is not known accurately and so is left blank. In Figure 33 the visible signs of the growth zonation are very clear and some boundaries can be correlated with abrupt changes in Pd levels. Except for sharp small peaks silver was detected only at the edge of the grain and there was no corresponding decrease in Pd but some evidence of a slight increase. In Figure 34 a chevron-like zone with smoother appearance is discernable in the centre of the grain but the overall composition is different with no detectable Pd except in association with the edge of a small hole. Similarly silver is only detectable around this hole and in one other very sharp peak in the middle of the grain.

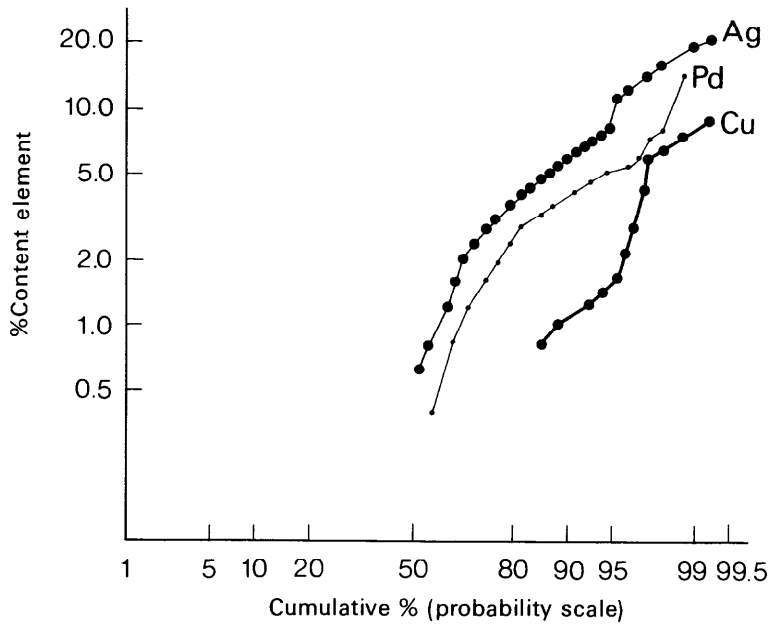


Figure 31 Cumulative frequency plots showing range of silver, palladium and copper contents of gold in overburden samples.

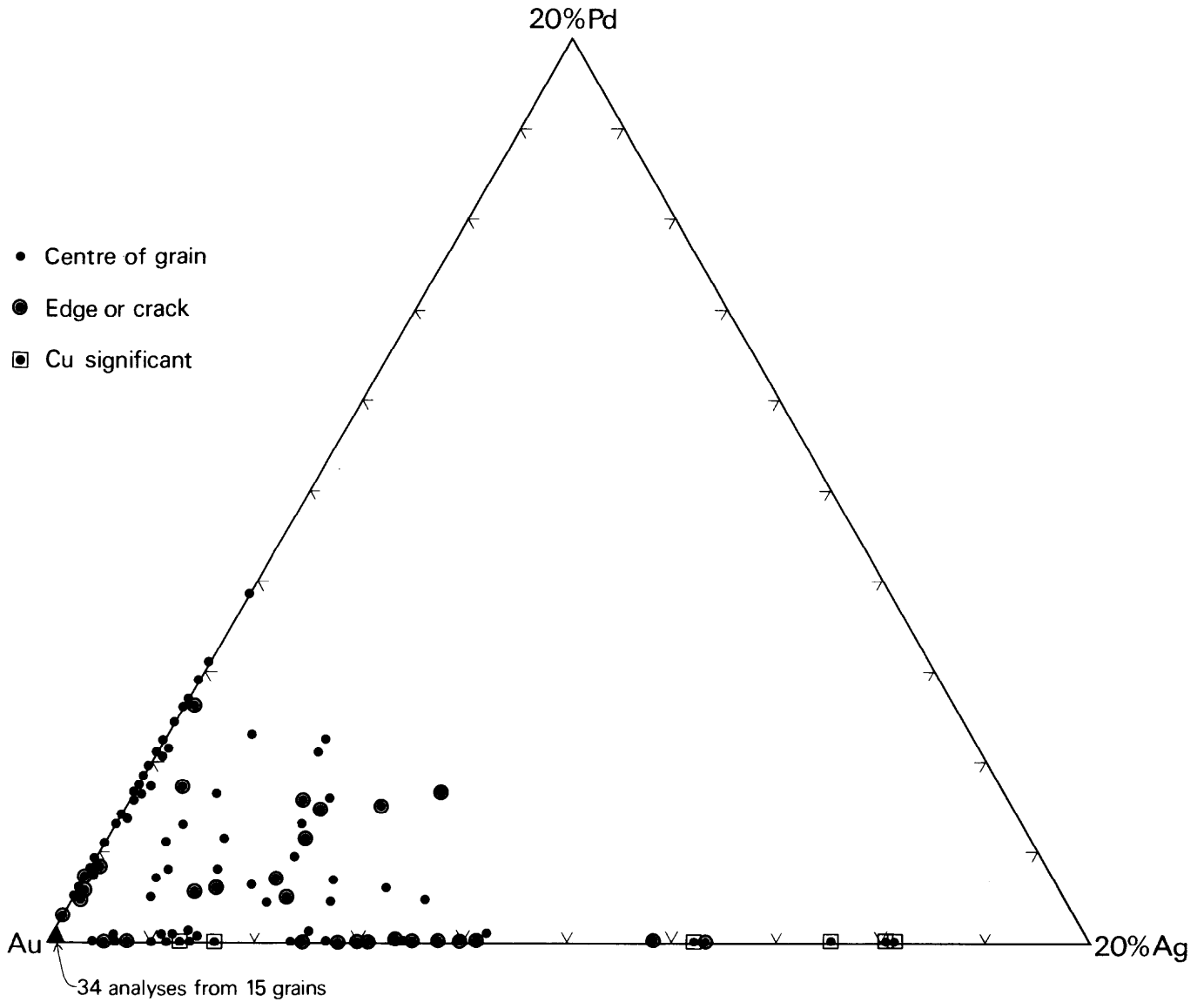


Figure 32 Triangular plot of composition of gold grains in overburden in terms of Au, Ag and Pd determined from spot electron microprobe analyses.

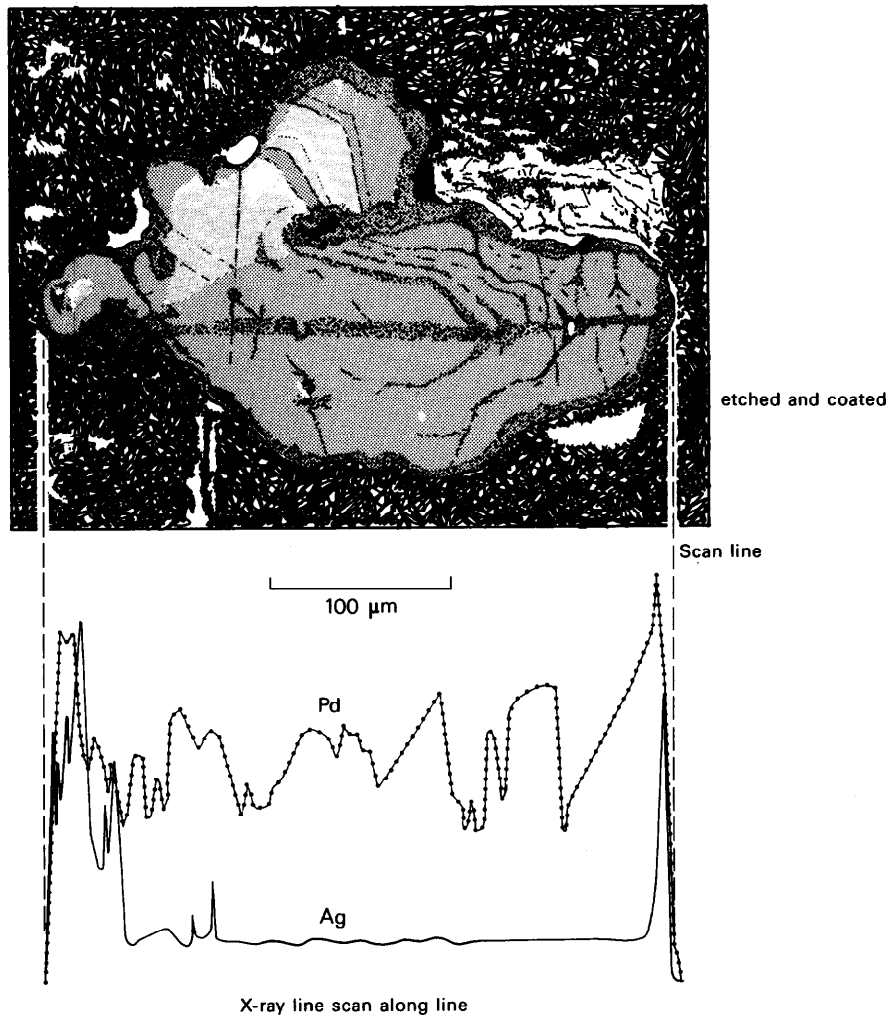


Figure 33 Silver and palladium concentrations along an electron microprobe scan of an overburden gold grain showing colour zoning.

A recognisable relationship between gold grain composition and origin or source has been suggested many times and several generalities have emerged, though some of these have been questioned by more recent work which suggests a greater complexity of factors. It has been claimed that gold from oxidised zones generally contains less Ag and other elements than gold from primary ores but this is not always the case (Chisholm, 1979). Silver-rich rims have been recorded from a wide variety of gold deposits, from unoxidised ore to eluvial concentrations (Chisholm, 1979), though it is generally recognised that silver is much more mobile in the oxidised environment than gold. Reports of palladium-bearing gold are rare, except perhaps for gold associated with platinum group minerals, as in the Stillwater complex (Cabri and Laflamme, 1974), though it was originally found at various localities in Brazil. Some genetic association with the gold mineralisation from Hopes Nose (Scrivener et al, 1982) is likely in view of the presence there also of both relatively pure gold and palladium-bearing varieties.

DETAILED GEOPHYSICAL SURVEYS

Detailed ground geophysical surveys were carried out in one area with anomalous levels of gold in overburden. Techniques employed consisted of VLF-EM and VLF-R measurement using a Geonics EM16 instrument tuned to GBR (16 kHz) and M-VLF (magnetic VLF) and E-VLF (electric VLF) measurement with a Scintrex IGS-2 module allowing simultaneous digital recording. Magnetic measurements were also made with an Elsec proton precession magnetometer and then with the IGS-2 module. Galvanic resistivity and time-domain induced polarisation (IP) measurements were made using a Schlumberger array. The results of this work are included in the data package.

DRILLING

A total of 6 diamond drill holes were collared to test the source of three overburden gold anomalies. One of the holes was relatively short and was terminated due to drilling problems. Locations and petrographical and chemical information on the rocks encountered in the holes is included in the data package.

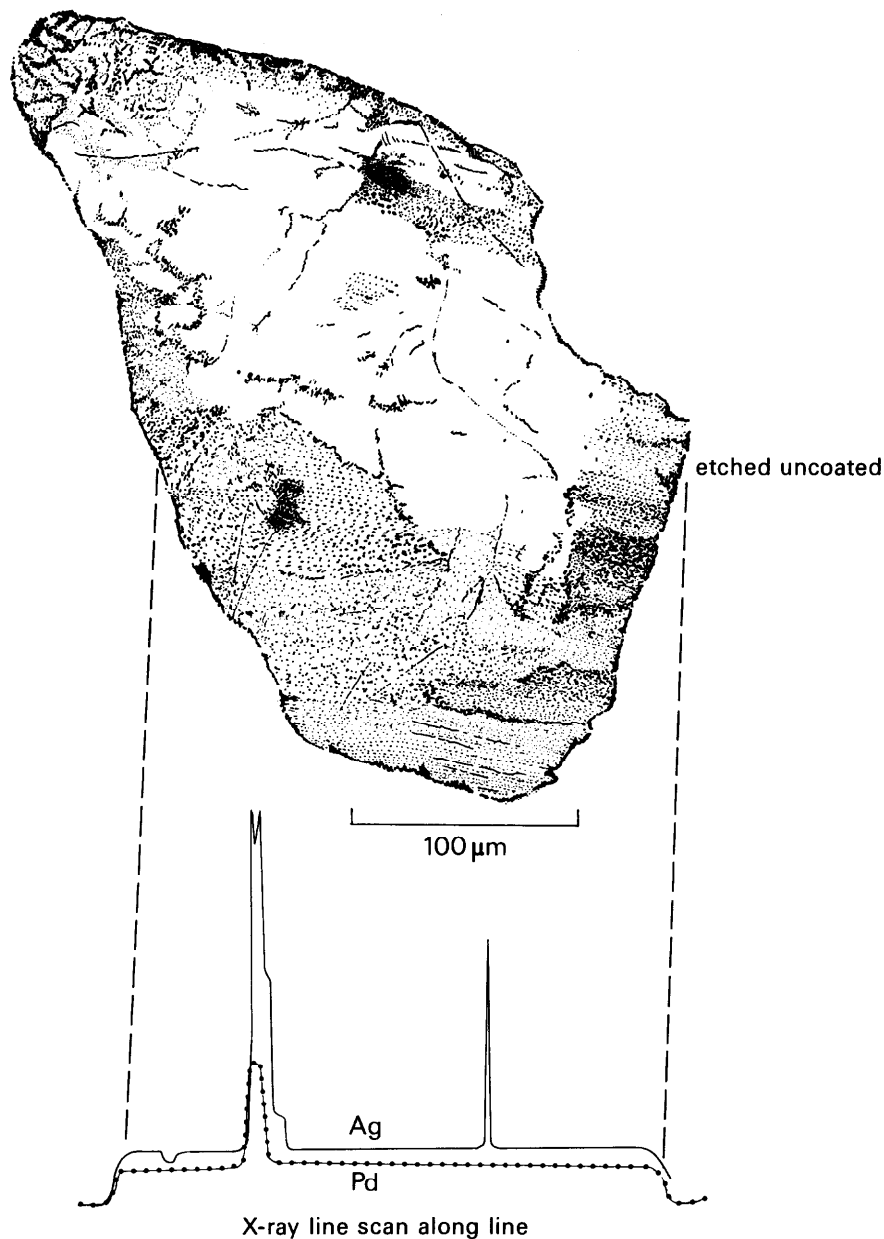


Figure 34 Silver and palladium concentrations along an electron microprobe scan of another overburden gold grain from the same site.

ACKNOWLEDGEMENTS

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