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Mineral Reconnaissance Programme

Exploration for gold in the Crediton Trough, Devon. Part 1 — regional surveys

Department of Trade and Industry

MRP Report 133
Technical Report WF/94/4

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D G Cameron, R C Leake, R C Scrivener,
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SUMMARY

The results of geochemical surveys in the Crediton Trough of Devon, an area of Permian and Carboniferous rocks, north of Dartmoor, are given in two reports. This report (Part 1) describes the broad-scale drainage and lithogeochemical survey carried out mainly in the area from Hatherleigh in the west, to the valley of the River Exe in the east, over the outcrop of Permian red-bed sediments, minor alkaline basalts and lamprophyric lavas and the surrounding Carboniferous sediments. The Permian outliers at Hollacombe (near Holsworthy), Peppercombe (near Clovelly), and Holcombe Rogus (south-west of Wellington) together with parts of the Permian outcrop of the Tiverton Basin and west of Cullompton were also sampled. In addition, the results of an interpretation of Landsat Thematic Mapper (TM) imagery over the survey area are presented. Part 2 contains details of follow-up overburden surveys at Deckport, Solland and Smallbrook.

The area was selected for gold exploration on the basis of the model of precious metal transport developed to account for the widespread gold in south Devon, which suggested that gold mineralisation might be present in the Permian sequence and the contact with underlying Carboniferous rocks.

Drainage surveying confirmed the presence of gold for the first time at numerous localities on the Permian outcrop, and subsequent microchemical mapping of grains demonstrated a number of close similarities with gold from south Devon, strongly suggesting a similar origin.

The analysis of rock samples from the Crediton Trough also showed gold to be locally enriched, up to 1.8 ppm in alkaline basalts and up to 42 ppb in samples of Permian sedimentary breccias.

Extensive manganese and zinc drainage anomalies at the southern boundary of the Crediton Trough can be related to mineralisation within the Permian and Carboniferous, some of which was worked in the vicinity of Newton St. Cyres. Cinnabar was reported for the first time from this area, and detrital tin, copper and lead anomalies, thought to variously reflect ore minerals or contamination, were also recorded by the drainage survey.

The distribution of gold anomalies in the drainage samples indicates that the source is probably associated with the early Permian sediments, the boundary faults between the Permian and Carboniferous sequences, and structures in the Permian, especially where they are underlain by volcanic rocks. Further overburden sampling at three sites is reported in Part 2.

Satellite imagery interpretation showed that all the gold anomalies lie on or near lineaments, usually a set trending north-east, which may be more closely associated with mineralising pathways than other directions.

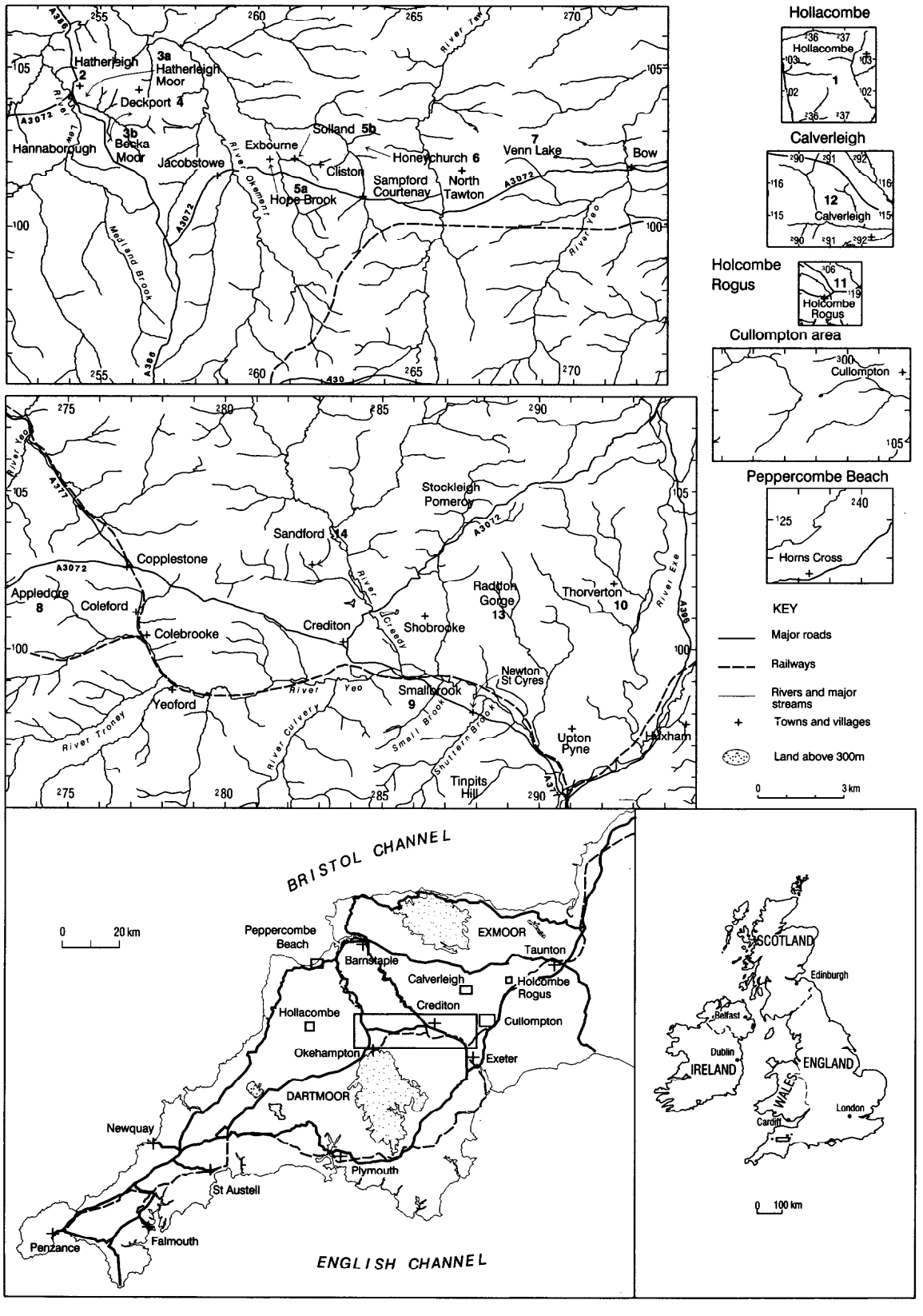

Figure 1 Location of the survey areas

INTRODUCTION

This report describes reconnaissance drainage and lithogeochemical surveys over the Permian and Carboniferous rocks of the Crediton Trough area of Devon, north of Dartmoor, and over small outliers and other areas of Permian New Red Sandstone outcrop to the north and east. The work was carried out for mineral potential assessment and prompted limited follow-up surveys at three localities, described in Part 2. Previous studies in the south of Devon had suggested a Permo-Triassic origin for saline oxidising fluids which transported gold and platinum-group elements (Leake and others, 1988; 1990; 1991; 1992). These solutions penetrated the Devonian basement where reducing conditions caused the precious metals to be deposited along faults and in favourable host rocks. The New Red Sandstone outcrop of Devon and its contacts with older rocks were accordingly selected for the current study, with initial investigations being made in the Crediton Trough and other depositional basins further north. These red-bed basins are post-Variscan in origin and are filled mostly with clastic sediments and minor basaltic and lamprophyric lavas. Primary 1:10 000-scale geological mapping of the Exeter district had indicated the likely presence of sites of previously unknown mineralisation in the area and these were also followed up.

The main survey area lies to the north of the Dartmoor massif, stretching some 40 km from Hatherleigh in the west to Newton St. Cyres and the Exe valley in the east (Figure 1). Sampling, however, was across a narrow band some 8 to 10 km wide as can be seen in Figures 6 ff. Topography differs between the west and east of the area. In the west there is a rolling plateau rising to 181 m in height, cut by the large northwards-draining rivers Lew, Okement, Taw and Yeo which dissect the Lower Permian outcrop. There are some broad valleys running east-west over the Permian outcrop which may be fault-related. There is little but soil colour and field drainage to distinguish areas underlain by the Permian or the Carboniferous strata. East of Colebrook (Figure 1) the major drainage tends to run west-east, in the valley of another River Yeo which joins the lower reaches of the Creedy to run into the Exe. In this area, Late Permian sandstones, breccias and volcanic rocks form low hills, rising from the Exe and Creedy floodplains to an altitude of 62 m (Figure 1). The low, wide Exe valley forms the eastern boundary of the main survey area. To the north, Early Permian breccias form a range of hills which rise to 253 m at Cadbury [ST 91 05] before falling steeply away to the lower ground of the Upper Carboniferous (Westphalian) sandstones and shales of the Bude Formation. In the south, the Upper Carboniferous (Namurian) Crackington Formation shales and sandstones also form a bounding range of hills of a similar height which eventually merge with the Dartmoor foothills.

Much of the area is prime agricultural land, due to the fertile properties of the free draining, red loamy soil 'Red Land' developed on the Permian strata, and mixed farming is widespread. Over the less well drained Carboniferous 'Dun Land' there is more pasturage and conifer planting. There is no extractive industry in the main survey area, although there were some small manganese and base-metal mines active in the last century.

The main area is covered by Ordnance Survey (OS) 1:50 000 Landranger maps 191 (Okehampton and North Dartmoor area) and, with the area west of Cullompton, 192 (Exeter, Sidmouth and surrounding area). Geological Survey (GS) 1:63 360 Sheet 324 (Okehampton) and 1:50 000 Sheet 325 (Exeter) cover the main part of the Crediton Trough; the latter has recently been completely resurveyed on the 1:10 000 scale.

The Hollacombe outlier is on OS Landranger map 190 (Bude, Clovelly and surrounding area) and GS 1:50 000 Sheet 323 (Holsworthy). The Tiverton Basin and Holcombe Rogus areas are covered by OS Landranger Sheet 181 (Minehead and Brendon Hills area), and, together with the area west of Cullompton, 1:50 000 GS Sheet 310 (Tiverton).

At Peppercombe Beach, on the north Devon coast, east of Clovelly, another small outlier of Permian sandstones and conglomerates is covered by OS Landranger sheet 190 (Bude, Clovelly and surrounding area) and by 1:50 000 GS Sheets 329 (Bideford) and 307/308 (Bude).

GEOLOGY

Previous research

The area was geologically surveyed on the one-inch scale by Sir H T de la Beche and maps published between 1835 and 1845. The Okehampton sheet was resurveyed on the six-inch scale by E A Edmonds, J E Wright, K E Beer, E C Freshney, M Williams and M C McKeown and published in 1969, accompanied by an explanatory memoir (Edmonds and others, 1968). The Exeter sheet was resurveyed on the one-inch scale by W A E Ussher and published in 1889. This district has recently been resurveyed on the 1:10 000 scale by staff from the BGS Exeter office under the project leadership of R A Edwards. The 1:10 000 sheets are published and there are several BGS Technical Reports describing the geology in detail (Scrivener, 1983, 1988; Edwards, 1987; Scrivener and Edwards, 1990, 1991). Resurvey of the Holsworthy sheet on the six-inch scale was by M Williams, M C McKeown and A E Edmonds between 1963 and 1966 and the map was published in 1974. The Tiverton sheet was partly resurveyed by Ussher in 1871-97 and a provisional sheet, compiled by J E Wright published in 1969, with the addition of some six-inch scale mapping by J M Thomas and E E Swarbrick.

Other recent work in the area includes Ault and others, (1990), Haslam (1990), Warrington and Scrivener (1990) and Haslam and Scrivener (1991), while Knill (1969) and Fortey (1991) have worked on the igneous rocks in the area. Geophysical work has been reported by Cornwell and others (1990) and Davey (1981).

Relatively little work has been published on the sparse mineralisation of the area. Dewey and Bromehead (1915) covered the manganese workings for the wartime economic memoir. Beer and Scrivener (1982) noted the manganese mineralisation of the Newton St. Cyres and Upton Pyne areas and further work is reported by Scrivener and others (1985).

The Crediton Trough

The Crediton Trough is a post-Variscan basin measuring some 45 km from east to west and up to 8 km from north to south at its eastern end. It is partly fault-bounded and variable in depth up to 900 m (Davey, 1981). Rocks infilling the Crediton Trough are mostly red-bed clastic sediments ('New Red Sandstone') of Permian age (Edmonds and others, 1968; Bristow and Scrivener, 1984; Warrington and Scrivener, 1990; Scrivener and Edwards, 1990) though some of the oldest rocks may be Stephanian (Upper Carboniferous) in age.

There are also smaller volumes of basaltic and lamprophyric lavas of the Exeter Volcanic Rocks, also Permian in age (Edmonds and others, 1968; Knill, 1969; Cornwell and others, 1990; Fortey, 1991). The Crediton Trough is flanked to the north and south, and probably underlain, by the Culm Measures, folded sedimentary rocks of Upper Carboniferous (Namurian and Westphalian) age comprising mostly interbedded sandstone and shale in varying proportions. A simplified solid geological map of the survey area is presented as Figure 2.

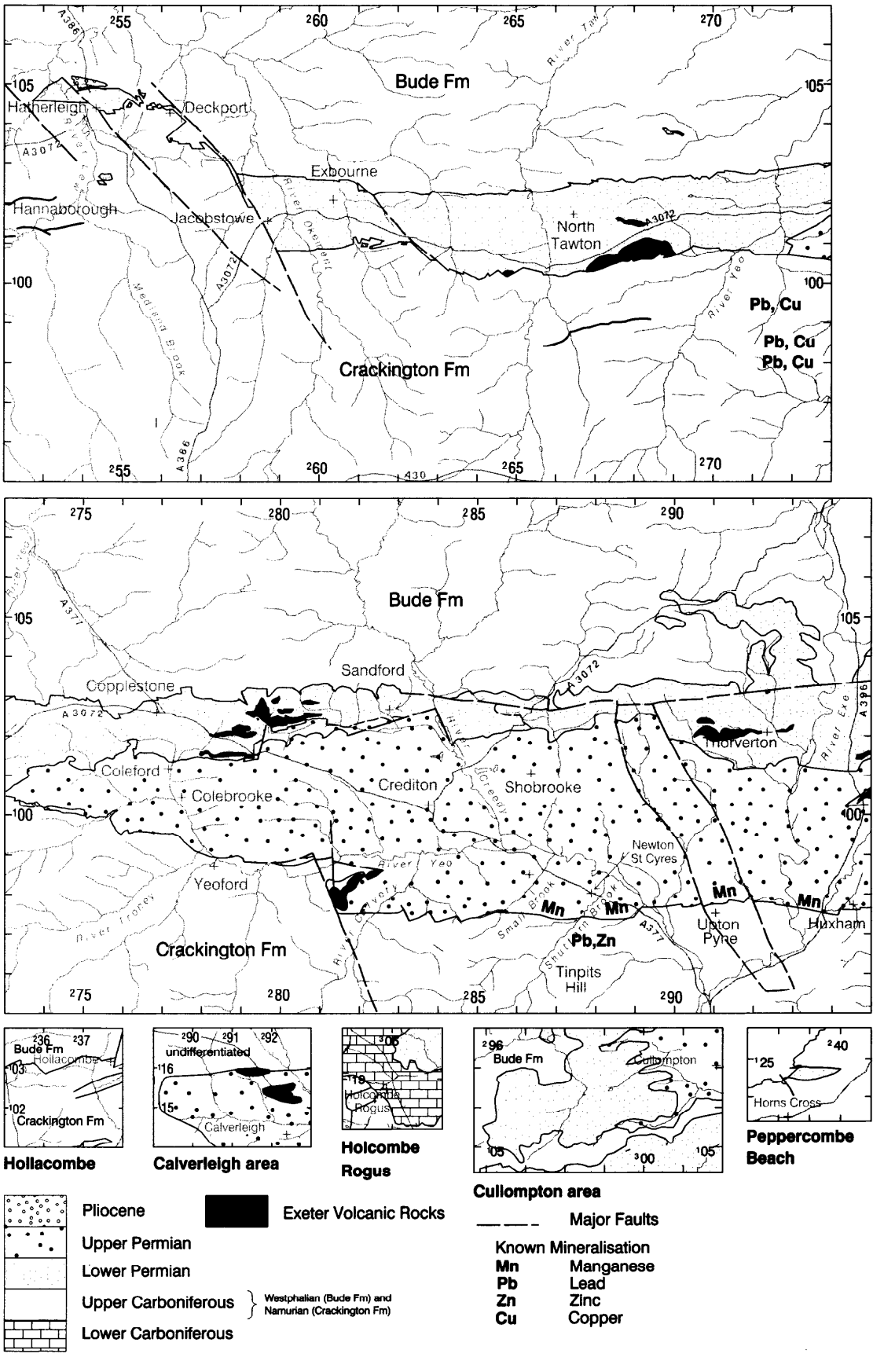

Figure 2 Geology of the survey areas

Crackington Formation

The tightly folded strata outcropping to the south of the Crediton Trough are the oldest (Namurian) representatives of the Upper Carboniferous in south-west England. They comprise grey and dark grey shales with subordinate interbeds of hard, grey, fine-grained sandstone of turbidite origin, mostly < 0.5 m thick (Haslam and Scrivener, 1991). On lithological and palaeontological grounds these rocks are placed in the Crackington Formation of Edmonds and others (1968). In places, typical Crackington Formation lithologies give way to dark grey or black shales with sparse thin beds of grey siltstone and fine, locally flaggy, sandstone. These beds have been shown (Scrivener 1983) to occur at or near the base of the Crackington Formation and to correlate with the Ashton Shale Member of the middle Teign valley (Selwood and others, 1984).

Bude Formation

To the north of the Crediton Trough, the Upper Carboniferous strata are dominated by sandstone and siltstone, with subordinate interbeds of shale (Haslam and Scrivener, 1991). Individual sandstone beds may be several metres thick. Sparse faunal evidence indicates that these rocks range in age from the upper part of the Namurian into the Westphalian; they were named the Bude Formation by Edmonds and others (1968). In general the Bude Formation is more competent and is less tightly folded than the Crackington Formation.

Lower Permian

The undeformed infill of the Crediton Trough can be divided into two units on the basis of age. To the west and along the northern margin of the basin, where the New Red Sandstone rests on the underlying Culm Measures at a disconformity, a sequence of Lower Permian, and possibly Stephanian, age includes the Cadbury Breccia, Bow Breccia, Knowle Sandstone and Thorverton Sandstone (Edmonds and others, 1968; Edwards, 1987; Scrivener and Edwards, 1990).

The Cadbury Breccia is typically unbedded, consisting of very poorly sorted, red-brown, gritty loam with angular to subrounded pebbles and cobbles, mostly of Culm sandstone and vein quartz. The overlying Bow Breccia is a bedded deposit of fine and coarse conglomeratic breccias with subordinate beds of red sandstone which increase in abundance towards the top of the formation. Clasts in the Bow Breccia include Culm sandstone, vein quartz, shale and hornfels, together with a few of pebbles of acid igneous rock including quartz-porphyry and rhyolite. Occurrences of Devonian limestone pebbles have also been recorded, e.g. at Solland Quarry [SX 615 021].

Above the Bow Breccia are the red-brown Knowle Sandstones in the west and Thorverton Sandstones in the east of the district; at a number of places they, and also the Bow Breccia, are interbedded with lamprophyric and basaltic lavas of the Exeter Volcanic Rocks. The six-inch scale survey of the Okehampton district (Edmonds and others, 1968) and the recent 1:10 000 scale survey of the Exeter district (Scrivener and Edwards, 1990) both indicate that lamprophyric lava extrusion predated the basalt flows.

Upper Permian

A considerable disconformity above the Exeter Volcanic Rocks and the Knowle and Thorverton Sandstones separates the Lower Permian sequence from Upper Permian strata (Warrington and Scrivener, 1990; Scrivener and Edwards, 1990) which form the bulk of the basin infill east of Bow. At the base of the Upper Permian sequence, the red clayey sand of the Creedy Park Sandstone is locally developed, while elsewhere the Crediton Breccia (Scrivener and Edwards 1991) is the basal formation. The Crediton Breccia comprises poorly sorted red-brown silt, sand and clay with pebbles and cobbles of sandstone, slate, shale, vein quartz, hornfels, chert and variable amounts of acid igneous material. In the lower part of the Crediton Breccia, igneous pebbles include quartz-porphyry, rhyolite and tuff; they are

untourmalinised, though pebbles of vent or hydrothermal breccia with a tourmaline cement are present in places. Higher up the formation, some of the igneous clasts are tourmalinised and these increase in abundance upwards.

The overlying Newton St. Cyres Breccia (Scrivener, 1988) is characterised by the presence of locally abundant cleavage fragments of K-feldspar (murchisonite) and by a relatively sandy and well-cemented matrix. Apart from murchisonite, other clasts in the Newton St. Cyres Breccia are similar in variety to those found in the higher levels of the Crediton Breccia, with acid igneous pebbles and tourmalinite particularly abundant in places. Near the top of the Newton St. Cyres Breccia, pebbles of granite and microgranite occur. In the eastern part of the Crediton Trough, the Crediton and Newton St. Cyres Breccias pass laterally into clayey and silty red-brown sandstones.

At the highest levels of the Upper Permian sequence of the Crediton Trough, the breccias and their fine-grained lateral equivalents are succeeded by the relatively well sorted, predominantly aeolian sands of the Dawlish Sandstone. Within the Dawlish Sandstone there are two argillaceous members and beds of sandy breccia with clasts similar in range and type to those of the Newton St. Cyres Breccia.

Pliocene

To the north of Hatherleigh, a small patch of southerly dipping brown, purple and green gravels with minor clays is exposed in two streams. Edmonds and others (1968) suggest that this deposit is Pliocene in age and predates the present river system.

Pleistocene and Recent

No glacial effects are seen in the survey area and it is thought that only periglacial conditions prevailed during the Pleistocene. Apart from river deposits, little long distance transport has occurred.

Head. Deposits of head cover much of the area. This is taken to include rock debris in situ as well as solifluxion material, as it is difficult to separate the two. Edmonds and others (1968) note 2–3 m of head developed over the sandstones and lavas of Permian age. This is composed of gravelly sand; usually the clay content is only high on the lower ground.

Alluvium. Small alluvial deposits occur in most of the valleys developed in the Permian outcrop. They comprise mainly clays, silts and sands, and are pebbly in places. Edmonds and others (1968) suggest that this is reworked head material and has not been moved very far.

Structure

Geophysical evidence (Edmonds and others, 1968; Davey 1981) suggests that the Crediton Trough is essentially a graben with faulted boundaries to north and south, dipping at moderate angles into the structure. Locally, for example to the north of Crediton and Thorverton, the boundary between the Culm Measures and the New Red Sandstone is a disconformity, so that the basin in that area has the form of a shallow half-graben with the faulted contact to the south. The New Red Sandstone strata dip mostly to the south, but westwards from the Exe Valley towards Crediton the southern part of the trough is occupied by a shallow syncline and thus the beds at the southern margin dip gently to the north. At least three groups of faults occur within the Crediton Trough (Figure 2). These comprise north-west-trending structures and their conjugate fractures, north–south faults and strike faults trending roughly east-west. Of the first group, the most significant structure is the Sticklepath–Lustleigh Fault which has a dextral wrench displacement of up to 4.8 km (Edmonds and others, 1968). Other faults of similar trend cutting the rocks of the eastern part of the Crediton Trough, have smaller wrench displacements; some of these and their conjugate fractures appear to have controlled the distribution of stratabound manganese

mineralisation along the southern margin of the Crediton Trough between Newton St. Cyres and the Culm Valley (Scrivener and others, 1985).

Permian outliers and sub-areas

Hollacombe outlier

Some 16 km west of the Crediton Trough, near Holsworthy, a fault-bounded outcrop of Bow Breccia, the Hollacombe outlier, is surrounded by Crackington Formation and Bude Formation strata (Figure 2). The latter are as described above. The BGS Hollacombe No. 1 Borehole [SS 3758 0256], drilled in 1968, penetrated 119.28 m of Permian breccia with some beds of sandstone and siltstone, above a faulted contact with Crackington Formation strata.

Calverleigh area, near Tiverton

The Tiverton Basin around Calverleigh is filled with sedimentary breccias of Permian age with, in the northern part, some interbedded basic lavas of the Exeter Volcanic Rocks. The northern edge of the basin is marked by a disconformity where Permian strata are underlain by folded shale and interbedded sandstones of the Culm Measures (probably Crackington Formation) (Figure 2).

Holcombe Rogus area, near Wellington, Somerset

In this area folded Upper and Lower Carboniferous strata are partially overlain by undeformed mudstone and sandstone of Permian age. The Lower Carboniferous black shales are overlain by Dinantian shaley limestones which are succeeded in turn by more black shales and siltstones of Namurian age, then by interbedded shale and sandstone of Culm Measures (Crackington Formation). The Permian cover is of red sandstone to the north-east (possibly equivalent to the Dawlish Sandstone) and of red mudstone with marginal breccia in the south-west (Figure 2).

Cullompton

West of Cullompton, Culm Measures, probably Bude Formation, are overlain by red Lower Permian breccias and conglomerates, which are in turn patchily overlain by red sandstone. The age of the sandstone is uncertain, probably Upper Permian or Lower Triassic (Figure 2).

Peppercombe Beach

On the north Devon coast, east of Clovelly, a partly fault-bounded outlier of coarse breccias and marly sandstones, probably of Lower Permian age, lies within a sandstone facies of the Bude Formation (Edmonds and others 1979). Gayer and Cornford (1992) note that the major fault direction parallels that of the Sticklepath Fault zone, but however, suggest that this outlier may be of Triassic age (Figure 2).

Mineralisation

Little mineralisation has been recorded from the area surveyed. Small-scale manganese workings were situated in the Permian outcrop near the southern boundary of the Crediton Trough at Upton Pyne, Huxham and near Newton St. Cyres (Beer and Scrivener, 1982; Scrivener and others, 1985). The deposits take the form of concentrations of nodular masses of manganite, other manganese oxide minerals and rhodochrosite, which have replaced the host rock rather than infilling fractures. Minor barite and kaolinite are recorded in the deposits.

Also south of Newton St. Cyres, at Tinpits Hill [SX 878 965], within the Crackington Formation, are small workings for lead and zinc. These consist of galena with brown sphalerite in a quartz and siderite gangue, with traces of fluorite and barite (Scrivener and others, 1985).

Other small lead deposits are noted in the Crackington rocks south of Bow, at Spreyton, Wheal Maria [SX 712 989] and Bowbeer Farm [SX 716 984 and SX 715 978]. Edmonds and others (1965) report that they consist of galena with chalcopyrite in a gangue of quartz and siderite.

LITHOGEOCHEMISTRY

Igneous rocks

Some twenty three igneous rocks were collected from various exposures of the Exeter Volcanic Rocks: four samples of lamprophyric lava (olivine minette) from two sites, twelve samples of basaltic lava or dolerite from Thorverton quarry [SS 909 102] and isolated samples of basalt from four other sites within the Crediton Trough. In addition, three acid lava boulders from within the Crediton and Newton St. Cyres Breccias were also analysed. The analytical results are summarised in Table 1.

The rock samples were crushed and a subsample was milled; the resulting powders were further subsampled to produce a 12 g pellet for analysis of a wide range of elements (Table 1) by X-ray Fluorescence Spectrometry (XRF) at BGS Analytical Geochemistry Laboratories, Keyworth. An additional split was analysed for gold by acid digestion followed by solvent extraction and Atomic Absorption Spectrophotometry (AAS) finish at Analabs, Caleb Brett, St. Helens.

Table 1 Composition of Permian igneous rocks from the Crediton Trough

		Lamprophyric			Basaltic			Acid		
		mean	min.	max.	mean	min.	max.	mean	min.	max.
CaO	%	4.33	2.25	6.19	8.16	1.26	12.43	0.08	0.06	0.11
TiO_2	%	1.07	0.99	1.23	1.72	1.42	2.60	0.28	0.12	0.47
MnO	%	0.12	0.07	0.19	0.36	0.16	0.60	0.06	0.04	0.07
Fe_2O_3	%	6.86	6.26	7.21	10.17	8.26	12.85	2.46	1.83	3.06
V	ppm	106	96	112	145	87	231	21	7	33
Co	ppm	29	27	30	33	15	64	5	4	6
Ni	ppm	123	96	150	87	43	206	7	6	9
Cu	ppm	43	8	124	49	14	120	18	6	33
Zn	ppm	114	55	158	216	48	584	26	19	33
As	ppm	9	2	22	6	<1	14	19	11	25
Rb	ppm	156	145	168	40	10	82	452	364	507
Sr	ppm	1072	1024	1179	145	82	243	387	15	1018
Y	ppm	23	21	26	23	16	32	14	7	21
Zr	ppm	442	424	465	159	107	248	100	36	178
Nb	ppm	23	21	25	18	13	30	14	12	15
Sn	ppm	<1	<1	2	1.2	<1	3	28	12	47
Ba	ppm	2687	2525	2961	351	198	625	200	61	367
Pb	ppm	50	46	54	48	31	60	20	15	29
U	ppm	4.5	3	6	3.0	1	7	4.6	4	6
Au	ppb	<10	<10	15	192	<10	1778	<10	<10	<10
		n=4				n=16			n=3	

Seventeen analyses of samples covering the full range of composition within the Exeter Volcanic Rocks are given in Fortey (1992) together with a compilation of all previously published analyses, 52 in all. Three of these analyses are of samples from Thorverton quarry and these fall within the range shown in Table 1 for all elements except V, Cu and As which are slightly higher in one or two samples compared with the present data.

The lamprophyric lavas can easily be distinguished chemically from the basaltic lavas in a greater abundance of Zr and especially Sr and Ba (Table 1). There is considerable variation in the composition of the basalts from Thorverton quarry, reflecting different degrees of evolution. Ni levels reach 206 ppm in the most primitive types, while in the most evolved type the Ni content is 43 ppm. Similarly, TiO_2 reaches 2.60 % in the most evolved type, compared with 1.42 % in the least evolved type. In contrast, the lamprophyric lavas show a relatively small range of compositions. The lead content of both types of volcanic rock are relatively high, probably reflecting significant lead levels in the potassium feldspar present in these rocks.

The fragments of acid lava from the breccias are also variable in composition, ranging from rhyolite to dacite, but all show considerable enrichment in Rb and Sn. In these respects, they resemble the granite porphyrys or 'elvans' associated with the Dartmoor Granite.

Origin of gold in alkali basalts

Gold was detected in five of the twelve samples from Thorverton quarry, (three samples containing significant amounts, 0.37 ppm, 0.45 ppm and 1.78 ppm) but not in the samples of basalts from other localities. The gold-rich samples are relatively evolved in composition, but in other respects there is no clear enrichment of any other element in association with the gold. Petrographical descriptions of rock from the quarry (Fortey, 1991) show that alteration is intense and primary minerals have been replaced by hematite, carbonate, chlorite and clay, while vesicles are filled with silica, carbonate and a deep green clay. Enrichments in Mn and Zn are present in some samples from Thorverton quarry, but there is no clear indication of a positive correlation with gold. This suggests that the association of gold with some varieties of basalt may be a primary one as was indicated for the highly evolved mafic rocks exposed in the Erme Estuary in South Devon (Leake and others, 1992). However, a detailed and systematic study of the basalts and surrounding Thorverton Sandstones in the quarry is required before the question of the origin of the gold and its possible significance can be answered with any confidence.

Sedimentary rocks

Samples were collected from most of the main stratigraphical units of the New Red Sandstone in the Crediton Trough. However, the coverage is not adequate to give a truly representative picture of the variation both within and between the units, as many of the samples came from different points along one section. Nevertheless, the results, summarised in Table 2, demonstrate probably genuine differences in chemistry with age, which must reflect differences in source material of these rocks. The samples were taken mostly in shallow road cuttings except for those from the Lower Permian Bow Breccia, which were obtained in a disused quarry, and the probable Lower Permian samples which come from cliff sections at Peppercombe Beach, on the north Devon coast. That near-surface leaching of the porous rocks which make up the succession in the Crediton Trough has taken place is shown by the fact that only the samples from the quarry or sea cliffs contain carbonate. In these samples, calcium contents are within the range 9.45 % to 52.0 % CaO. In contrast, calcium contents of samples from near surface exposures reach only 0.35 % CaO.

There are only minor differences in the contents of Co, Ni, Cu, Zn, Mo, and Ag in the different sedimentary units and these elements are not shown in Table 2. Major differences in composition are apparent between the rocks above and below the unconformity beneath the Crediton Breccia. Thus the units above the unconformity are enriched in Ti, V, Fe, Rb, Sr, Y, Zr, Nb, Sb, Ba, U and especially Sn compared with those below. The differences in Sn content are similar to those reported for a minus 106 micrometre fraction of rock samples from the various units (Ault and others, 1990). The above spread of

elements suggests that the source of the upper units contained more feldspathic rock and a suite of heavy minerals typically associated with alkali rocks and, in view of the high Sn content, extensive hydrothermally altered and mineralised material of the greisen type. A few of the samples of sedimentary rock contain detectable gold, to a maximum of 42 ppb in a sample of the Upper Permian Crediton Breccia. No preferential association of detectable gold with any of the units is apparent.

Table 2 Composition of sedimentary rocks from Crediton Trough (mean content of stratigraphic units)

		Bow Breccia	Knowle Sandstone	Thorverton Sandstone	Crediton Breccia	Newton St. Cyres Breccia	Peppercombe Beach Breccia
TiO_2	%	0.35	0.36	0.49	0.61	0.60	0.48
MnO	%	0.13	0.09	0.09	0.08	0.19	0.46
Fe_2O_3	%	4.86	3.57	4.34	5.40	5.51	2.83
V	ppm	45	37	51	82	83	51
As	ppm	26	7	17	30	35	59
Rb	ppm	55	94	110	184	201	61
Sr	ppm	94	67	51	250	155	145
Y	ppm	16	12	20	24	24	29
Zr	ppm	149	161	247	205	183	285
Nb	ppm	7	7	8	14	15	11
Sn	ppm	1	2	2	17	20	<1
Sb	ppm	1	4	3	6	6	2
Ba	ppm	179	160	223	320	377	315
Pb	ppm	11	16	21	20	17	8
U	ppm	2.6	1.2	3.7	3.9	4.5	0.6
Au	ppb	11	<10	<10	11	<10	<10
		n=9	n=6	n=3	n=9	n=10	n=5

REGIONAL DRAINAGE SURVEY

Sampling

Drainage samples were collected in the same manner as in the survey of South Devon (Leake and others, 1988, 1990). Briefly, at most sites both a panned concentrate of stream alluvium and a 'fines' fraction of suspended material were obtained, but the latter were not collected at repeat and follow-up sampling sites. The majority of sites were over Permian catchments, except in the west of the Crediton Trough area where both the narrowness and the break up of the outcrop of Permian rocks leads to some catchments having a Carboniferous component. In the south-east of the area, adjacent to the southern boundary of the Crediton Trough, part of the Crackington Formation outcrop, thought to be mineralised, was also sampled.

Isolated samples were obtained at the Hollacombe Outlier, a small outcrop of Permian rocks near Holsworthy, some 16 km west of the western end of the Crediton Trough. Small groups of samples were also taken near Cullompton and to the north-west of Tiverton, in the northern part of a further east-west elongate trough of Permian rocks, the Tiverton Basin. Both these areas have a Carboniferous component in their catchments. One isolated sample was obtained west of Wellington, where New Red Sandstone rocks are underlain by calcareous Lower Carboniferous rocks. A total of 186 panned concentrates and 135 'fines' samples were obtained.

Chemical analysis

Gold grains were removed from the panned concentrate samples before chemical analysis. This was achieved, after drying and sieving to produce a -0.5 mm fraction, by use of a Superpanner, followed by magnetic separation of the heavy concentrate into four or five fractions and hand picking of individual grains. The separated gold grains were first weighed, before being mounted in resin on a glass slide and polished for microchemical mapping studies. The weight of gold grains was subsequently combined with the value obtained by chemical analysis to give the levels shown here. The samples were recombined and ground in a Tema swing mill with a Cr-steel pot prior to subsampling for chemical analysis.

Gold was determined chemically in a 60 g subsample by acid digestion followed by solvent extraction and AAS finish at Analabs Caleb Brett, St Helens. A 12 g pellet was prepared for analysis by X-ray Fluorescence Spectrometry (XRF) at the BGS Analytical Geochemistry Laboratories at Keyworth, and Ca, Ti, V, Mn, Fe, Ni, Cu, Zn, As, Y, Zr, Nb, Mo, Ag, Sn, Sb, Ba, Ce, W, Pb, Bi and U were determined. The 'fines' fraction samples were also analysed for Mn, Fe, Ni, Cu, Zn, As, Rb, Ag, Sb, Ba, Pb and U by XRF at BGS and for gold by Analabs Caleb Brett using the same chemical method as the panned concentrate samples.

Table 3 Summary statistical data for drainage samples

		Panned concentrate			'Fines' fraction			Crossover	
		med.	max.	min.	med.	max.	min.	percentile	conc.
Fe	%	9.1	46.4	1.2	5.0	9.1	1.9	6	2.8
Ti	%	0.33	4.58	0.11	-	-	-	-	-
Mn	ppm	1010	18170	100	1800	10790	320	-	-
Zr	ppm	330	3730	78	-	-	-	-	-
Ba	ppm	295	16660	54	420	1140	175	80	510
Sn	ppm	110	>20000	<1	-	-	-	-	-
Zn	ppm	102	14870	15	145	505	42	55	120
Rb	ppm	120	178	35	-	-	-	-	-
V	ppm	90	550	18	-	-	-	-	-
Pb	ppm	52	1130	3	32	115	9	2	12
Ce	ppm	51	2315	24	-	-	-	-	-
As	ppm	40	475	7	23	87	10	5	12
Cu	ppm	34	430	7	28	85	8	32	24
Ni	ppm	30	175	6	40	190	13	62	44
Y	ppm	16	172	7	-	-	-	-	-
Nb	ppm	10	114	3	-	-	-	-	-
Mo	ppm	4	24	<1	1	7	<1	-	-
U	ppm	3.0	53	<1	2.4	29	<1	-	-
Sb	ppm	2.5	42	<1	-	-	-	-	-
W	ppm	1	35	<1	-	-	-	-	-
Bi	ppm	<1	41	<1	-	-	-	-	-
Au	ppb	<10	13440	<10	-	-	-	-	-

Population characteristics

Cumulative frequency plots of each element in panned concentrate and 'fines' fraction samples are shown in Figures 3 to 5, and the corresponding numerical data in Table 3. For panned concentrates there are marked increases in gradient in the plots for Y, Pb, Ce, Zn, Ba, U and to a lesser extent for Ti, Zr, Nb and perhaps Cu. This signifies the existence of well-defined anomalous populations for these elements, reflecting their presence of minerals or contaminants containing these elements in significant amounts, superimposed on populations reflecting the background composition of common minerals and rock fragments.

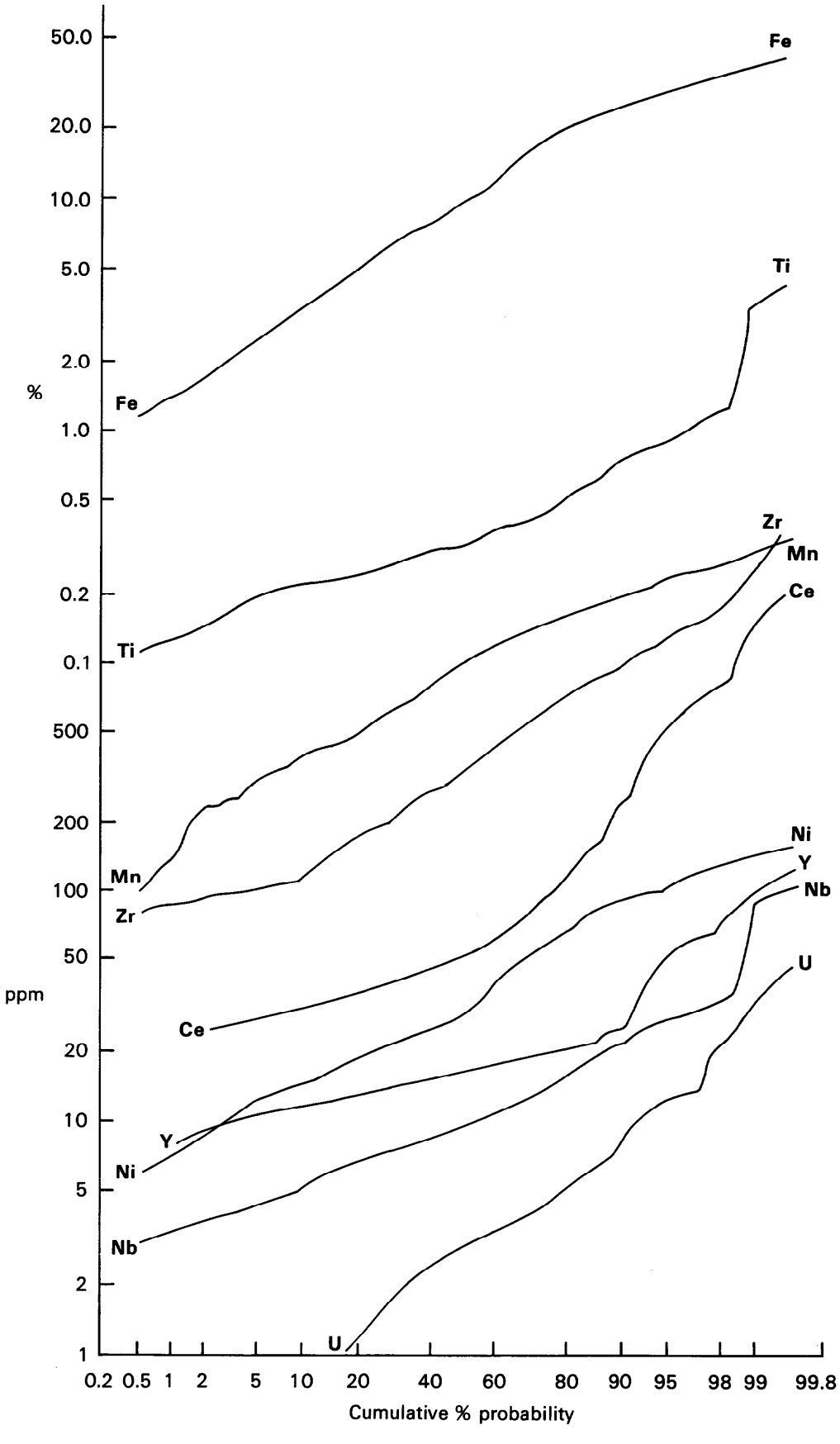

Figure 3 Combined cumulative frequency plots of Fe, Ti, Zr, Mn, Ce, Ni, Y, Nb and U in panned concentrate samples

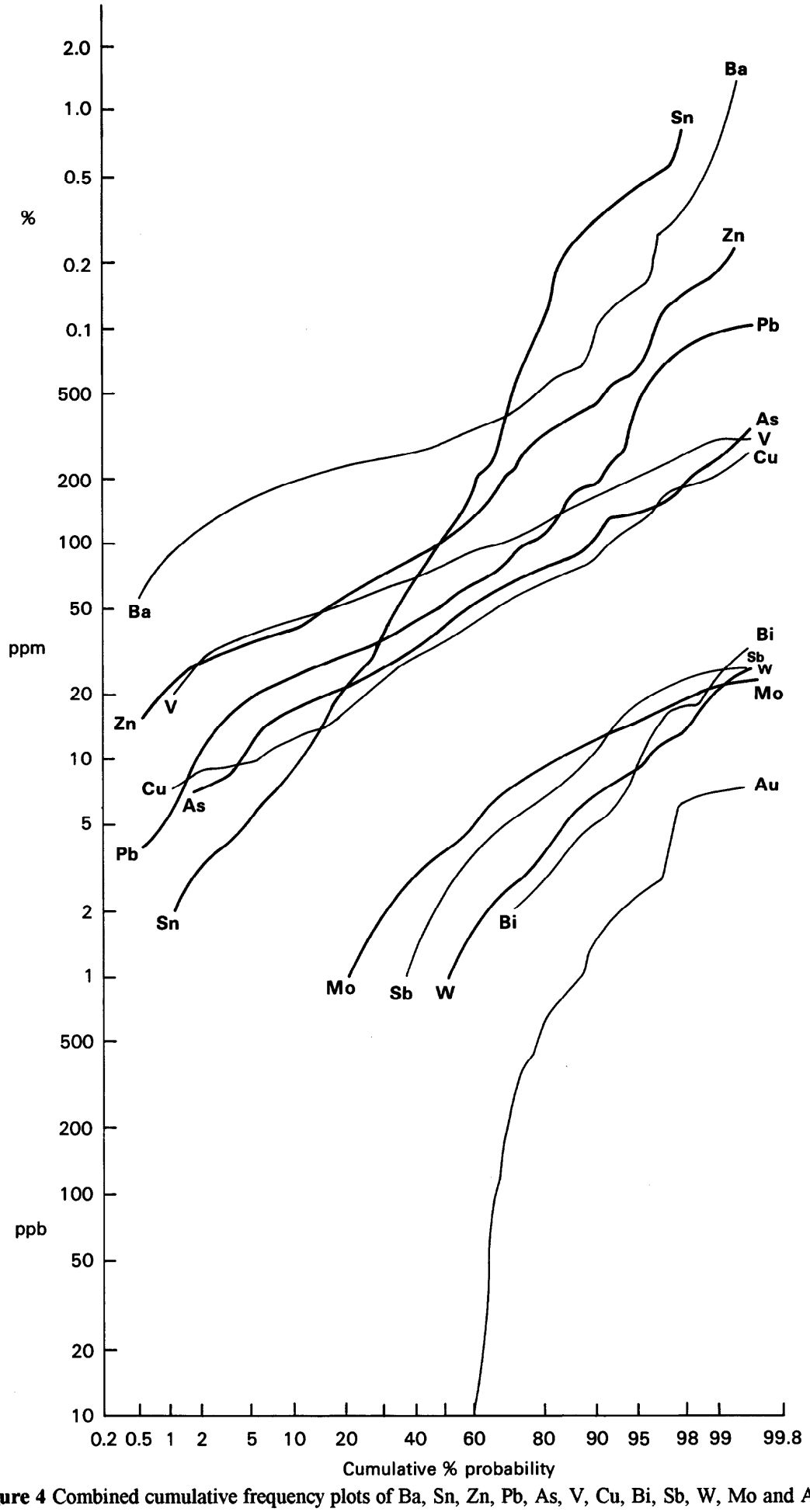

Figure 4 Combined cumulative frequency plots of Ba, Sn, Zn, Pb, As, V, Cu, Bi, Sb, W, Mo and Au in panned concentrate

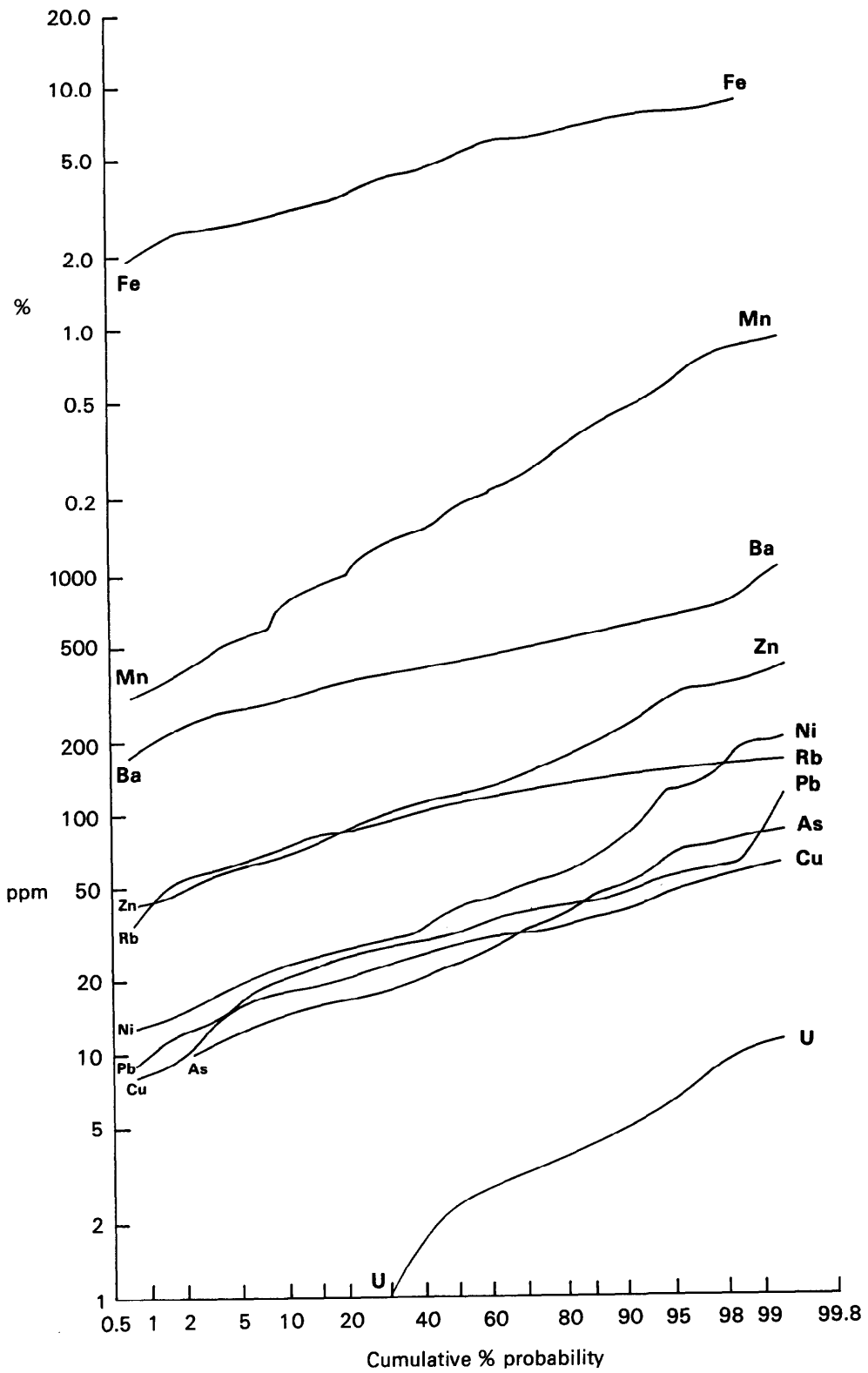

Figure 5 Combined cumulative frequency plots of Fe, Mn, Ba, Zn, Ni, Rb, Pb, As, Cu and U in 'fines' fraction samples

The distributions of Fe, Mn, V, As and Ni are relatively flat, which suggests that these elements are likely to be accommodated in common minerals and rock fragments throughout the area. For example, As is likely to be finely dispersed in iron oxide and in rock fragments rather than present in some samples as arsenopyrite or other As-rich minerals.

The distributions of Sn and Au, though irregular, have generally higher gradients than the other elements. This reflects their occurrence entirely as high-density metal-rich grains which are preferentially collected by the panning process and which may also have been upgraded naturally in overburden and subsequently in drainage alluvium because of their high density and mechanical and chemical stabilities. High Sn levels may indicate sites where upgrading of heavy minerals, including gold, has been most effective, although there may also be a more fundamental association between the two elements in bedrock. The relatively high gradient of the Bi distribution may also indicate an association between that element and Au.

The gradients of the Sb, W and Mo distributions are intermediate between those of Sn and elements such as Mn. This again suggests some possible association between these elements and either Sn or Au. In the distribution of the elements in the 'fines' fraction (Figure 5) most elements show a relatively flat gradient. The higher gradient for Mn, Zn, Ni and Pb probably reflects the presence of mineralisation involving these elements in Namurian rocks adjacent to the Crediton Trough.

Element distribution

Gold

The distribution of Au in panned concentrates, determined by weight and chemical analysis, is shown in Figure 6, and the distribution of gold grains recorded in the pan is shown in Figure 7. Analysis of the 'fines' samples showed only two samples above the detection limit of 10 ppb (maximum 13 ppb). This demonstrates that gold is not being dispersed as very fine-grained material but is present in alluvium as detrital grains, a conclusion similar to that arrived at in South Devon (Leake and others, 1988).

Gold was detected in 77 panned concentrate samples, 40 % of the total, and in amounts in excess of 200 ppb in 30 % of the total, to a maximum concentration of 13.4 ppm. The presence of gold grains was recorded in the field at 60 sites, not all of which were confirmed by later microscopic examination, this may be due to gold grains not being extracted from dried samples after transit, if they get attached to lighter grains, particularly iron oxides.

In eleven areas major Au enrichment was evident from both numbers of gold grains present and Au reported by chemical analysis (Figure 6). In these areas there is considerable variation in the elements associated with Au, and consideration of this provides useful information for the interpretation of the origin of Au at each site. These locations are discussed in detail below together with some localities with lesser enrichment (numbers refer to Figures 6 & 7 and subsequent element distribution plots).

1. Hollacombe, Holsworthy. Only two orientation sites were sampled at the 3.5 km long outlier of Permian rocks near Hollacombe to the south-east of Holsworthy, and both streams have a large proportion of Culm in their catchments. One of these sites gave a high-amplitude Au anomaly but no other element enrichments except barium (1157 ppm) and vanadium (224 ppm). None of the samples from the area show significant enrichment in tin.

2. North-west of Hatherleigh. This anomalous area contains two sample sites about 400 m apart in the same stream. The area is underlain by a small outcrop of gravels with clay, of supposed Pliocene age, in contact with New Red Sandstone rocks to the south. The samples also contain low-amplitude anomalous levels of Pb_p* , As_p, V_p and, in one sample, Ba. Tin does not show any significant enrichment in the samples.

3a. Hatherleigh Moor. This anomalous locality lies south and east of the north-west-trending, faulted contact between the Permian and the Crackington Formation. There are three Au-bearing samples derived from Hatherleigh Moor and the main stream draining from the south-east. The Au anomaly in the main stream is probably derived from anomalous locality 3b further upstream. The samples draining Hatherleigh Moor show slight enrichment in As_p and Sn_p and have the highest Ba_p anomaly (1.7 %).

3b. Becka Moor. Primarily draining Crackington Formation rocks, south of the contact, this locality comprises three anomalous samples from the Merryland Stream and its tributary, two of which are high-amplitude, and a low-amplitude anomaly in the Dunsland Brook draining from the south.

The anomalous samples are marked by enrichments in Zn_p, Cu_p and, especially, As_p (476 ppm). Tin levels are low in one sample but much higher in the sample from 400 m further east. The richest Au_p anomaly is in the sector of the stream which drains from the north, where there is an outcrop of New Red Sandstone rocks.

4. Deckport. At this locality there were eleven Au-bearing samples from a 800 m stretch of stream draining northwards from Deckport and one sample from the headwaters of an east-draining stream about one kilometre east of Deckport. All samples are enriched in tin, some especially so. Moderate to high-amplitude Zn_p anomalies, often accompanied by elevated levels of Cu_p, are also present in most of the samples. Moderate-amplitude As_p enrichment occurs in most Au-bearing samples, to a maximum of 134 ppm. In addition, Yp, Ce_p, U_p, Ba_p, Nb_p, Sb_p and Ti_p are also enriched here.

The source of these base-metal anomalies is probably not directly related to the source of the Au as there is a distinct cut-off in Zn some 250 m north of the cut-off for Au. They could be derived from a north-trending structure which is followed by the stream in its mid reaches as the cut-off is situated where the stream changes direction slightly. This structure could also carry Au but a further source must also be present and this could be in the outcrop of New Red Sandstone rocks which lies just to the south. The Au anomaly further to the east is underlain by Bude Formation rocks cut by west-north-west-trending faulting. Cinnabar was identified from the lower reaches of the main north flowing stream.

5a. Hope Brook, Exbourne. Two Au-bearing samples occur in the drainage basin of the north-flowing Hope Brook, to the east of Exbourne. The northern sample is highly anomalous in Au and tin with some enrichment in Cu_p, Mo_p and As_p. It was collected near the northern margin of the New Red Sandstone rocks. The southern sample is only slightly enriched in Au and the stream drains a thin satellite outcrop of New Red Sandstone just south of the main outcrop and about 1.4 km away from the northern sample on the main stream.

5b. Solland. At this locality there are nine sites in a stream draining north-west and then west past Solland towards Exbourne, and its west-flowing tributary. Gold anomalies are moderate to high-amplitude in the south-east stretch of stream and decrease somewhat to the north-west.

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* For simplicity, elements in panned concentrate are given subscript $_p$, those in 'fines' fraction, $_f$.

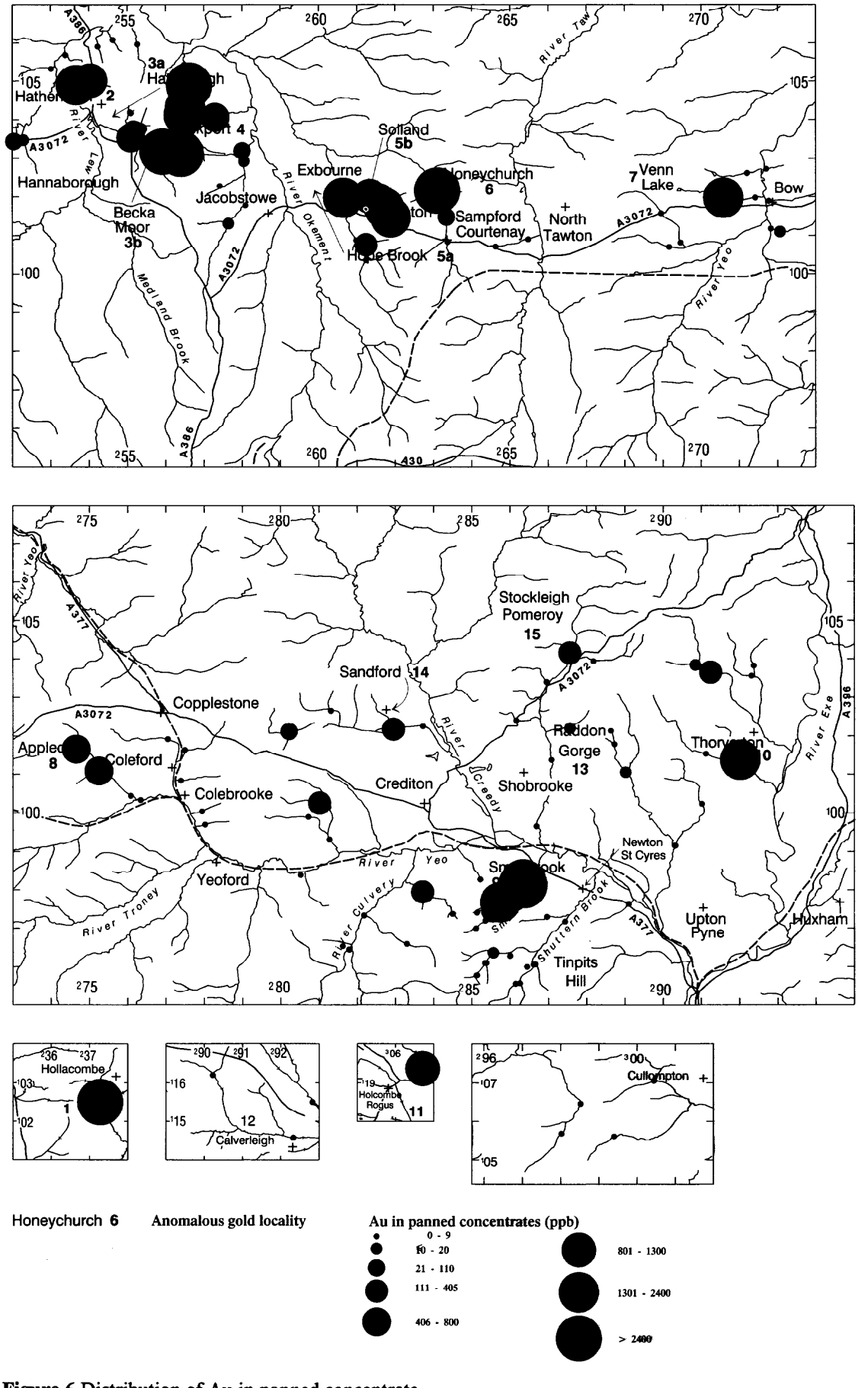


Figure 6 Distribution of Au in panned concentrate

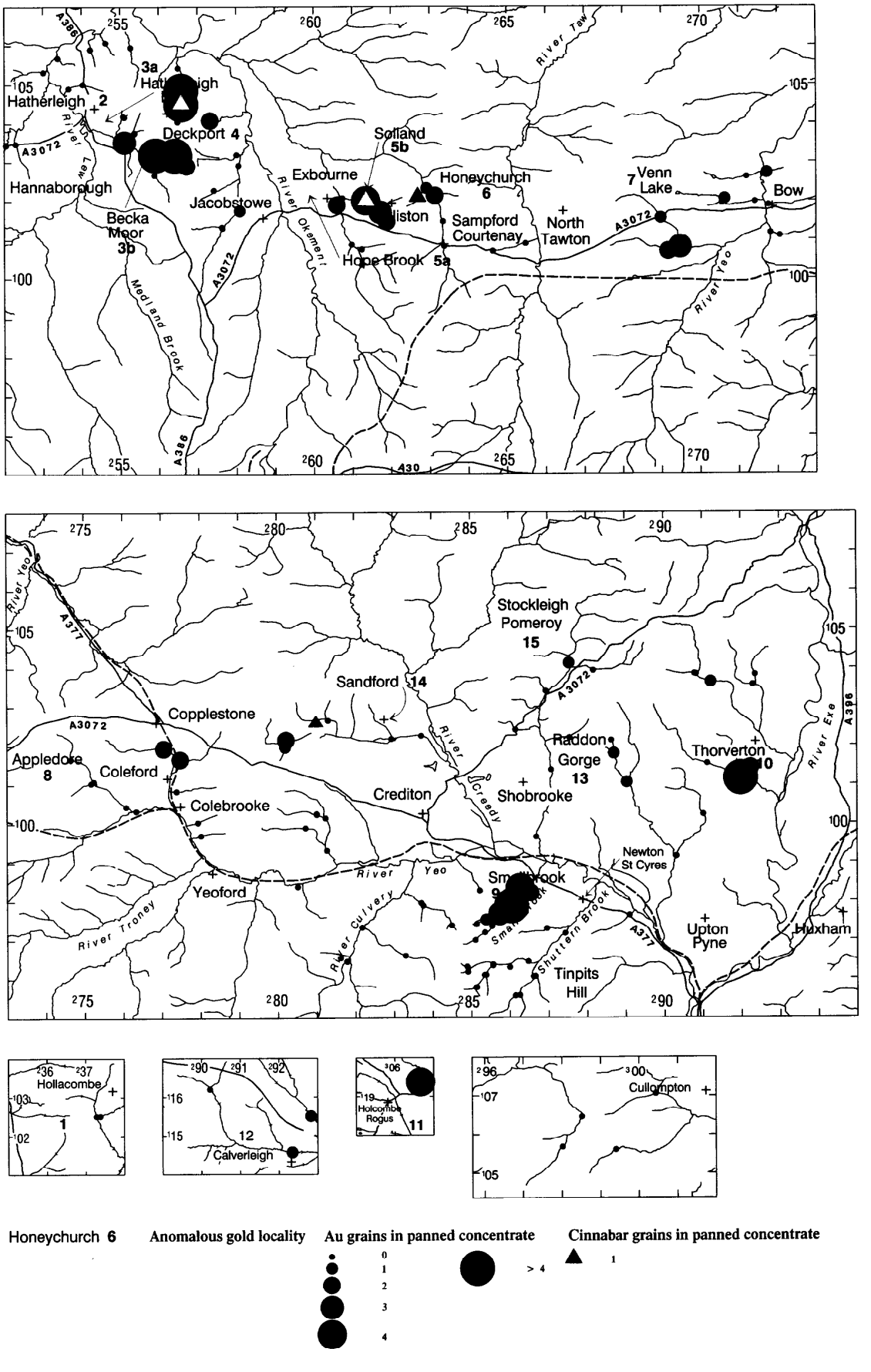


Figure 7 Distribution of gold and cinnabar grains in panned concentrate

Samples are rich in tin and show some enrichment in W_p, Mo_p, Y_p, Ce_p, U_{pf}, Nb_p, Zr_p, Ti_p and Cu_p. Arsenic levels are only slightly elevated and there are sporadic lead anomalies which, in part at least, are probably due to contamination. The high-amplitude uranium anomaly in 'fines' samples is associated with one of the sites in the main stream. Cinnabar was recorded at this locality (Figure 7). The data suggest that the source of the Au is either towards the south contact of the New Red Sandstone rocks or is in the north-west-trending structure which is followed by the upper reaches of the stream.

6. Honeychurch. A group of three Au-bearing samples, one of which is high-amplitude, occur at this locality. Two samples were obtained from the stream draining Lower Permian and Crackington Formation rocks northwards from Sampford Courtenay towards Honeychurch, and the high-amplitude anomaly from the tributary draining the northern contact of the New Red Sandstone to the east. The anomalous samples show moderate enrichment in Sn and slight enrichment in Fe_p, As_p and Mo_p and perhaps Pb_p, though this last may be a contaminant. A grain of cinnabar was recorded in the pan from the small stream which follows a north-east–trending fault from Cliston (Figure 7).

7. Venn Lake. A stream draining the central part of the New Red Sandstone subcrop west of Bow, contains a moderately high-amplitude Au anomaly. This is accompanied by slight enrichment in As_{pf} and high levels of Ti_p, Ce_p, Y_p U_p, Pb_p Cu_p and Nb_p, but only moderate quantities of Sn_p.

8. Appledore. Three low to medium-amplitude Au anomalies from adjacent streams draining the centre of the Crediton Trough to the west of Coleford mark this locality. No other elements except Zr_p are particularly enriched in these samples and the tin content of two samples is very low.

9. Smallbrook. Eight Au-rich samples, including the highest amplitude anomaly in the survey area, have been obtained from the Small Brook and a tributary. There is a sharp cut-off for Au as the contact between the Permian rocks and the Crackington Formation strata to the south is approached. The two streams forming the headwaters of the Small Brook, which drain the Carboniferous rocks, do not contain Au.

As_p and Bi_p are enriched in all the Au-bearing samples and there are more local enrichments in Ba_p, Pb_p, U_p, Sb_p, Mn_p, Fe_p, Zn_p, V_p, Mo_p, Zr_p, Pb_p and Ni_p. Sn concentrations resemble those of gold, being generally high in the samples anomalous for Au and decreasing towards the Au cut-off. The auriferous samples are also relatively enriched in vanadium compared to iron (Figure 9).

10. Thorverton. This locality, to the south of Thorverton, comprises two anomalous samples derived from well within the outcrop of Permian rocks of the Crediton Trough. A low-amplitude Zn_p anomaly accompanies one anomaly but the content of other elements, including tin, is generally low.

11. Holcombe Rogus. This anomalous locality comprises one orientation site sampled from a stream draining an outlier of New Red Sandstone resting on Dinantian dark shales and limestones to the north of the Tiverton Basin. The sample's relatively high calcium content reflects the calcareous nature of the nearby Carboniferous rocks. The sample is enriched in As_p, Mo_p and Pb_p but the tin content is low. This sample is particularly significant as it extends the zone of Au anomalies well to the north of the Crediton Trough.

12. Calverleigh. Four orientation sites were sampled in this New Red Sandstone basin containing basalts and sedimentary breccias. Gold (Figure 7), noted in the pan but not confirmed by chemical analysis, was accompanied by enrichments in Zn_p, Mo_p and As_p (Figure 7).

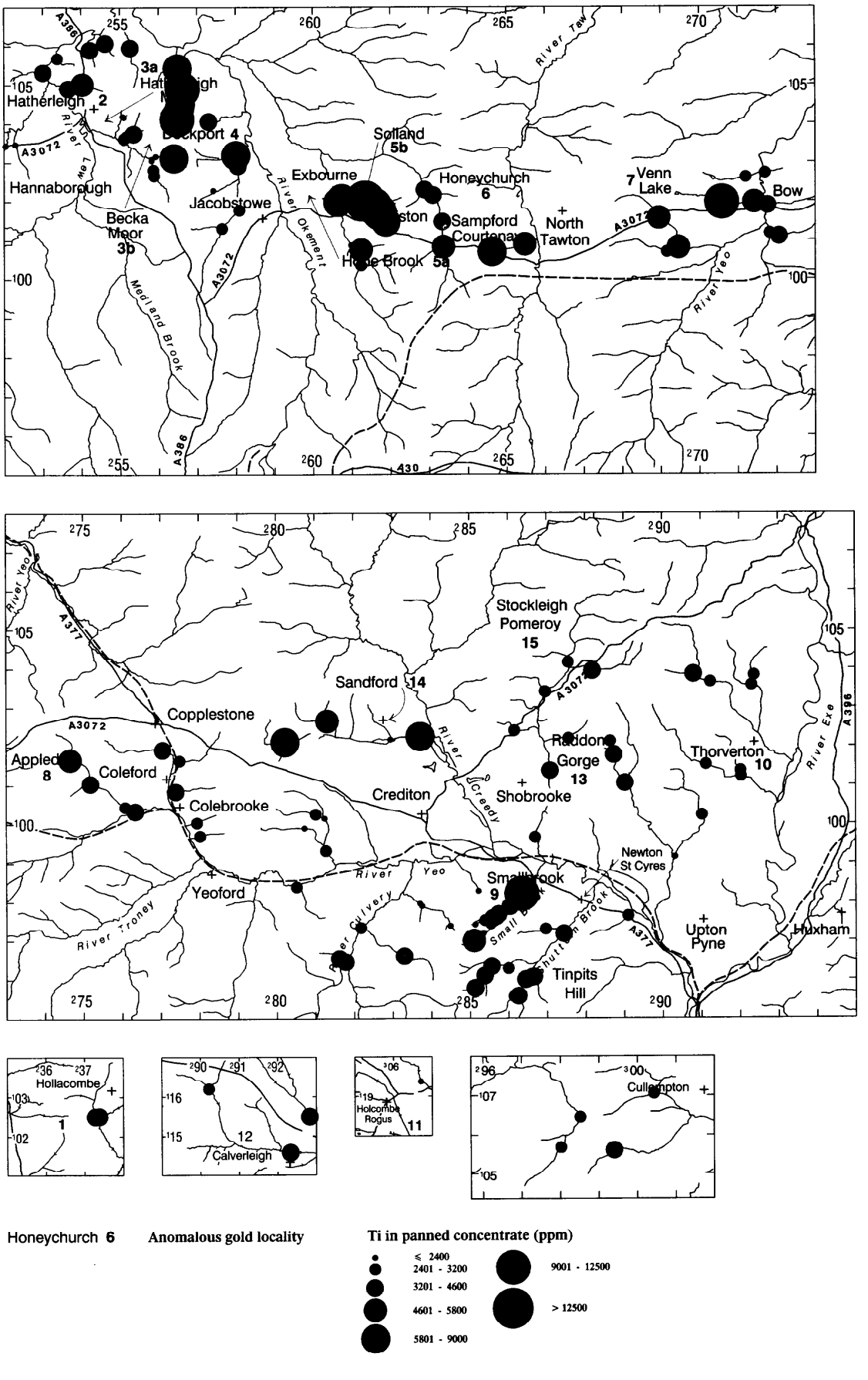


Figure 8 Distribution of Ti in panned concentrate

13. Raddon Gorge. Minor Au occurrences in this area of Upper Permian Breccias are accompanied by U_p, Bi_p, Sb_p, Mn_p and Mo_p enrichments.

14. Sandford. This auriferous catchment, draining eastwards in Upper Permian breccias and basaltic lavas, had minor Mo_p enrichment and cinnabar was recorded from one site.

15. Stockleigh Pomeroy. One site with Au recorded is also enriched in Cu_p. The stream drains an area underlain by Bude Formation rocks.

Titanium

Ti_p contents are higher in samples derived from the lower sequence of New Red Sandstone rocks which occupy the western part of the Crediton Trough (Figure 8). Lower Ti_p levels are generally a feature of samples derived from the upper sequence of New Red Sandstone rocks which occupy the south and east of the Crediton Trough, with the exception of samples from the Smallbrook area, which are relatively enriched. The drainage data thus differs from the chemistry of the sedimentary rocks, which indicates that rocks from the upper group are more enriched in the element. There is no correlation between relative enrichment in Ti_p and proximity to outcrops of mafic igneous rock and nowhere do samples contain sufficient Ti_p to suggest that mafic rocks form a significant proportion of the source material.

The close association of niobium with Ti suggests that much of the Ti may be present as rutile, a mineral in which niobium is frequently present in minor amounts, rather than ilmenite. Such rutile is unlikely to be derived from ordinary mafic rocks but could be derived from alkali rocks. Rutile and its TiO_2 polymorphs, anatase and brookite, are very common in hydrothermally altered rocks in the Cornubian granites. Most samples with Ti_p >1 %, including the sample with the maximum Ti content (UDP 1069, [SS 6134 0201], 4.58% Ti) are associated with the Solland area (Figure 8).

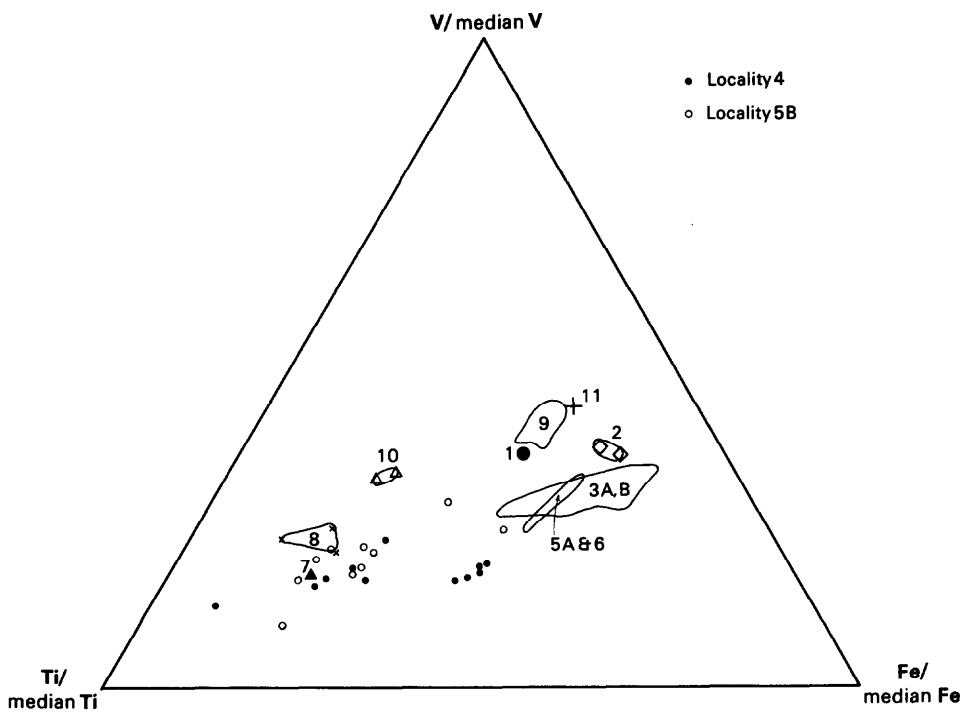


Figure 9 Relative proportions of Ti, V and Fe in gold-bearing concentrates, standardised against median line for each element

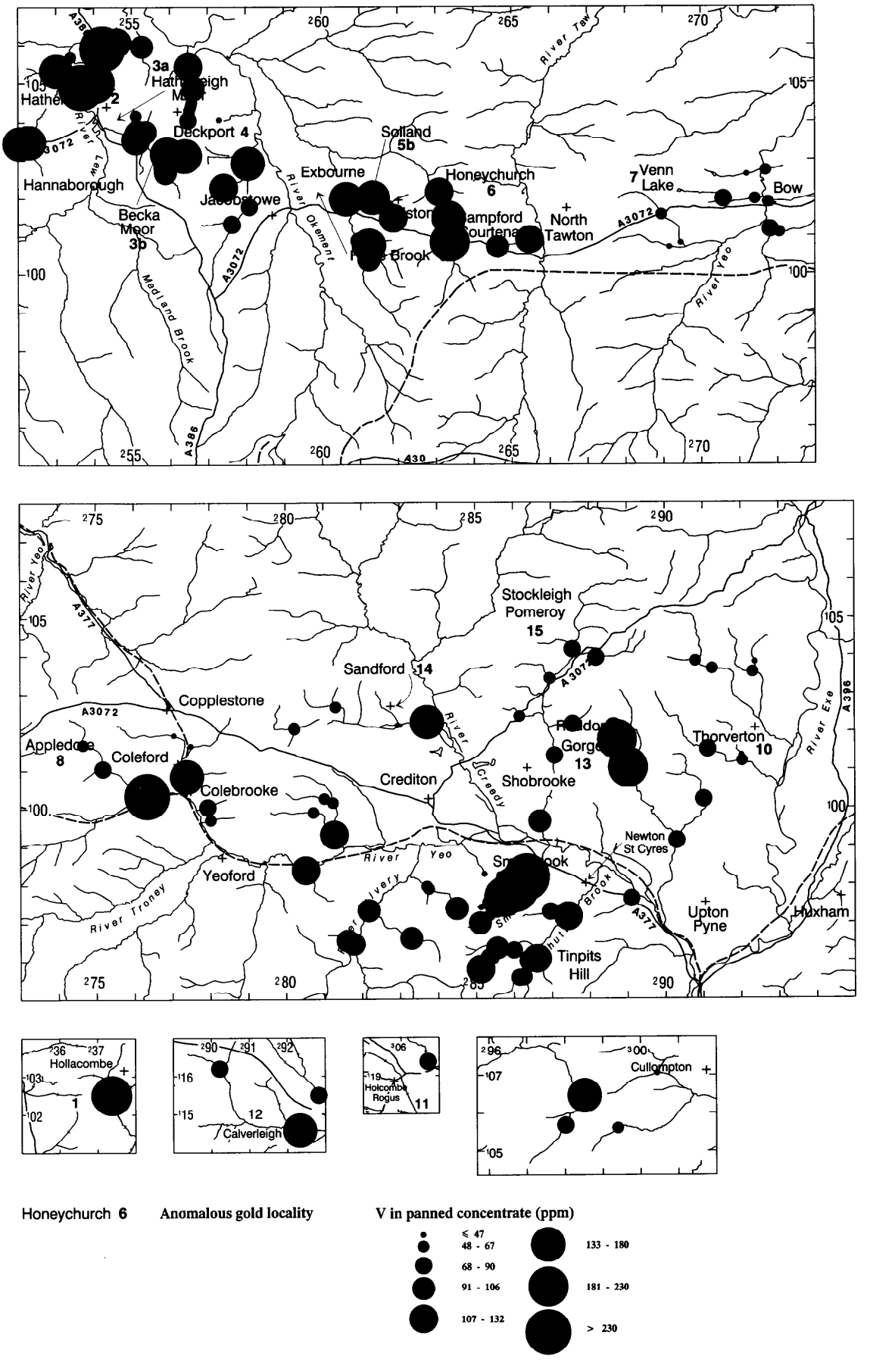


Figure 10 Distribution of V in panned concentrate

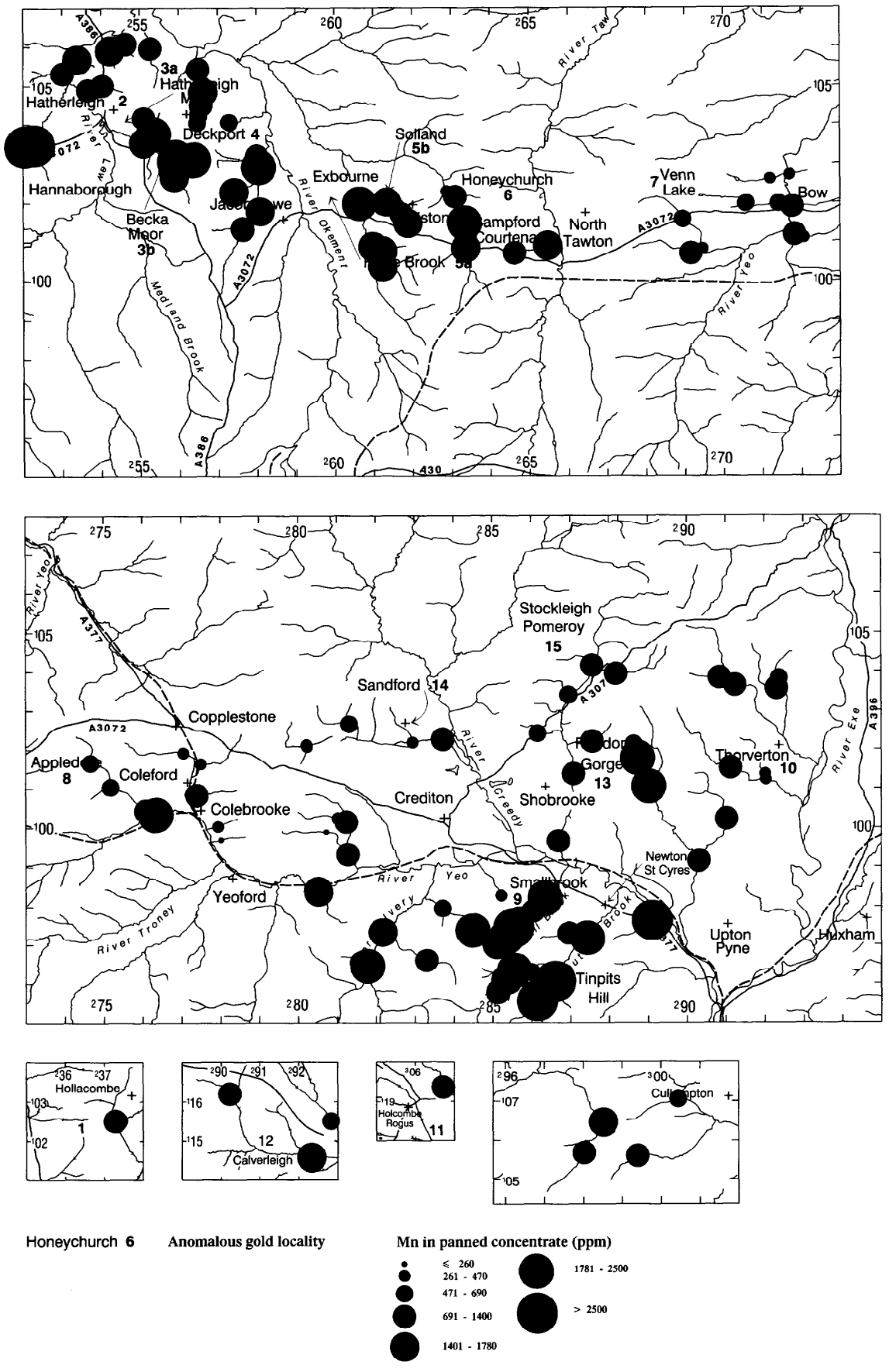


Figure 11 Distribution of Mn in panned concentrate

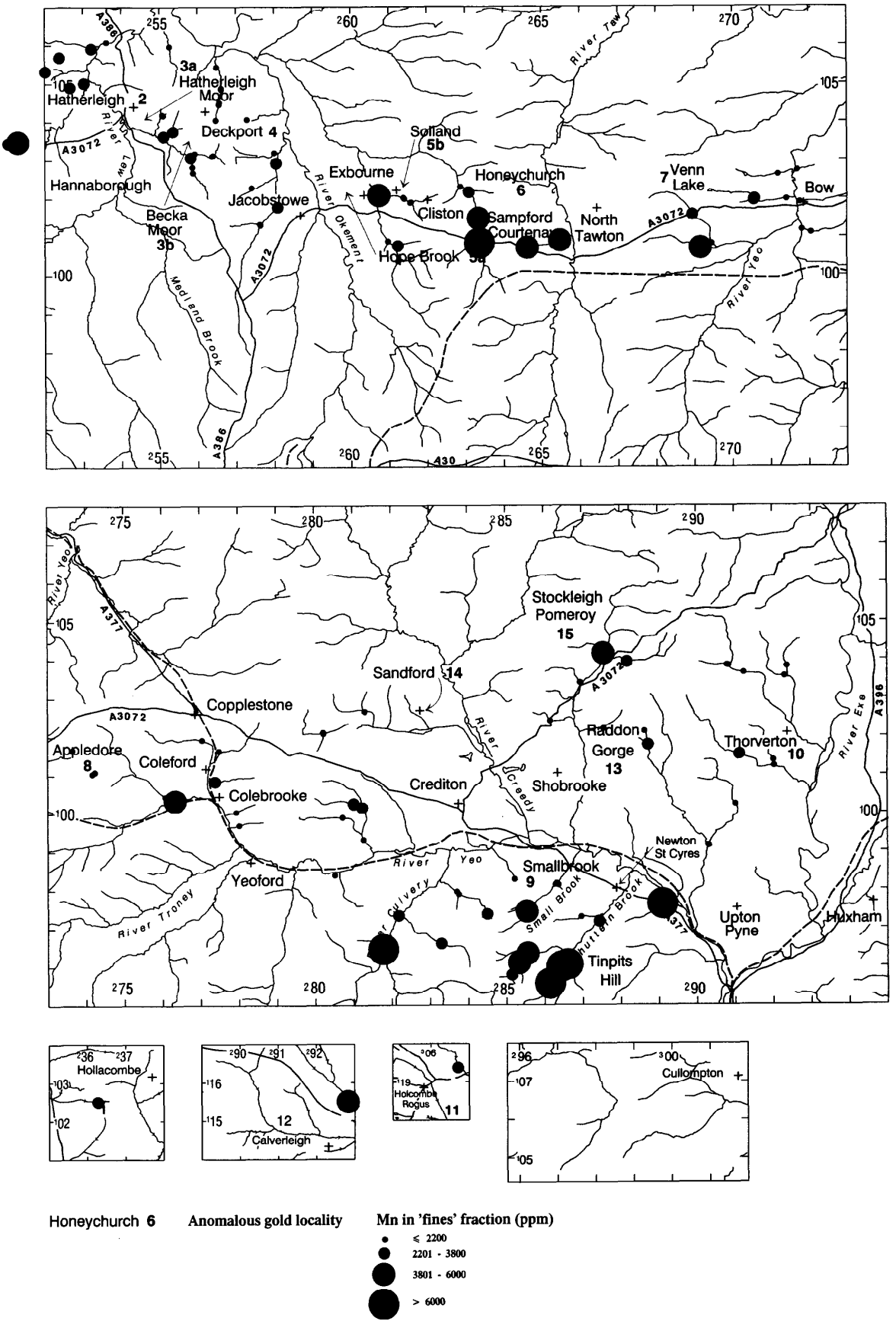


Figure 12 Distribution of Mn in 'fines' fraction

Gold concentrations in general show no clear association with Ti_p, which might have been expected if there was a primary association between precious metals and the mafic volcanic rocks of the Permian succession. Thus some anomalous Au sites (localities 7, 8, 4, 5b on Figure 8) are marked by relative enrichment in Ti_p in the Ti_p-Fe_p-V_p (Figure 9) while others are not.

Vanadium

The distribution of V_p (Figure 10) is more complex than that of Ti_p and resembles that of Fe_p. High V_p is a feature of samples derived from Smallbrook and the Hatherleigh area (Figure 10). At Hatherleigh the streams drain the Carboniferous Crackington Formation, small outcrops of the Bow Breccia and the Pliocene gravel. Other areas of high V_p include the Holsworthy area in the extreme west (Figure 10), the Colebrook area in the centre of the Trough and the area to the west of Thorverton. In last two areas there is no great accompanying enrichment in Au. Gold-rich samples from Holcombe Rogus (Figure 10) and Smallbrook show the greatest enrichment in vanadium relative to Ti_p-Fe_p-V_p plot (Figure 9).

Manganese

High Mn_p levels are seen in the south and west of the Crediton Trough, in catchments which have high proportions of Crackington Formation rocks. This contrasts with the low levels present in the Knowle Sandstone and Crediton Breccia outcrops (Figure 11). However, Mn_p values are generally higher than Mn_f values (Figure 12 and Table 3). This can partly be explained if most of the Mn is present as a minor component in carbonate which on weathering produces fine-grained Mn oxide. Since gold mineralisation may be associated with carbonate, as in the mineralisation in South Devon at Hope's Nose, the Mn_f anomalies have potential as a pathfinder. Mn_p anomalies probably reflect crystalline Mn oxide as well as magnetite and ilmenite.

One sample from near Newton St. Cyres containing high levels of Mn_{pf} (UDFP 1076 [SX 8910 9764] Mn_p 1.82 %, Mn_f 1.08 %) probably reflects Mn oxide mineralisation at the southern boundary of the Crediton Trough, similar to that which occurs in a similar geological environment at Upton Pyne, some 2 km to the east. Other large-amplitude Mn_f anomalies (Figure 12) and, to a lesser extent, Mn_p anomalies are located in streams draining the Crackington Formation to south and west of Smallbrook, in association particularly with base-metal anomalies. These may partly represent secondary Mn enrichment in these poorly drained areas, together with extensions of the known mineralisation near this contact. Within the Crediton Trough there are isolated Mn_f anomalies (Figure 12), especially within the outcrop of the Bow Conglomerate. In three localities moderate Au anomalies are also present.

Smaller amplitude Mn_p anomalies accompanied by Mn_f anomalies at Hannaborough (Figure 11), both c. 0.3 %, are in streams which drain mainly Crackington Formation rocks but which also have lamprophyric lavas in their catchments, e.g. UDFP 1070 [SS 5204 0343] (Mn_f, 3190 ppm Mn_p 2980 ppm). Other small-amplitude Mn_p anomalies not associated with Mn_f anomalies occur in the Deckport area with anomalous Au, and in the east of the area (Figure 11).

Iron

Fe is present in the stream bed mainly as detrital grains, with only low concentration in the 'fines' samples (Table 2). The low gradient of the cumulative frequency plot for the 'fines' samples (Figure 5) indicates that recent weathering products of iron-rich sulphide material are unlikely to be present. This conclusion is not surprising for samples derived from the Permian red beds but is perhaps more surprising for samples derived from Carboniferous strata. Maps showing the distribution of Fe_p and Fe_f are given in Figures 13 and 14 respectively.

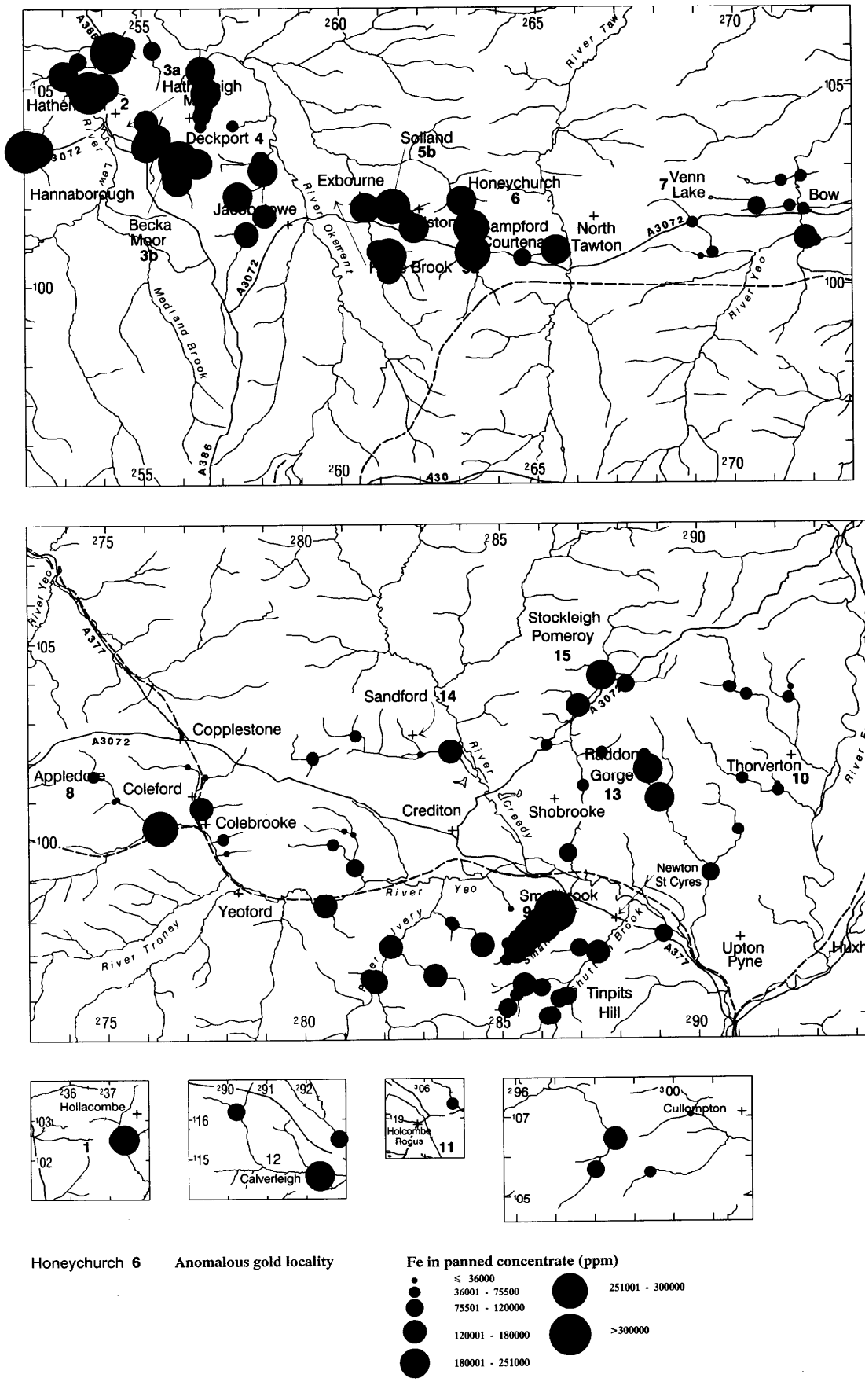


Figure 13 Distribution of Fe in panned concentrate

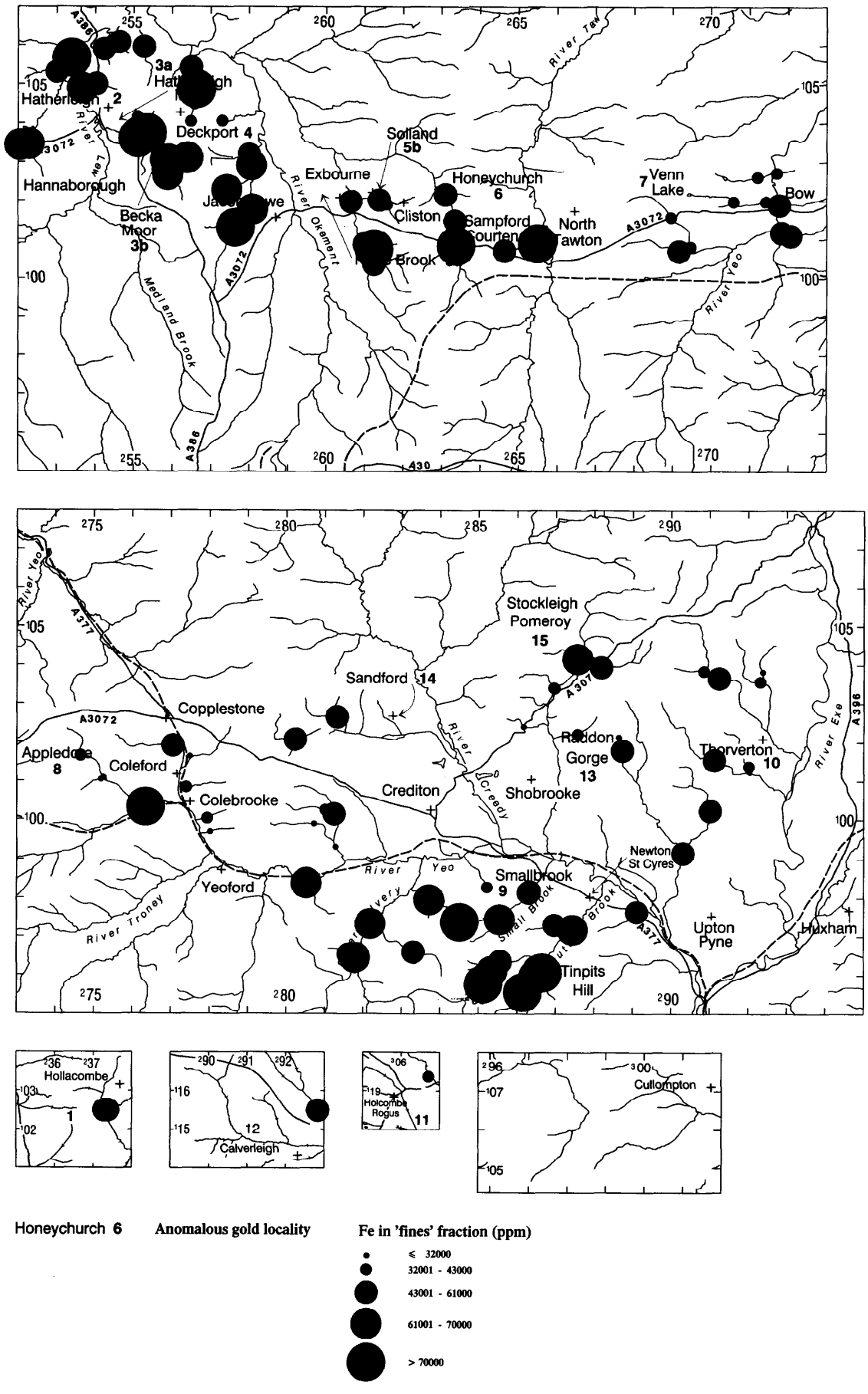


Figure 14 Distribution of Fe in 'fines' fraction

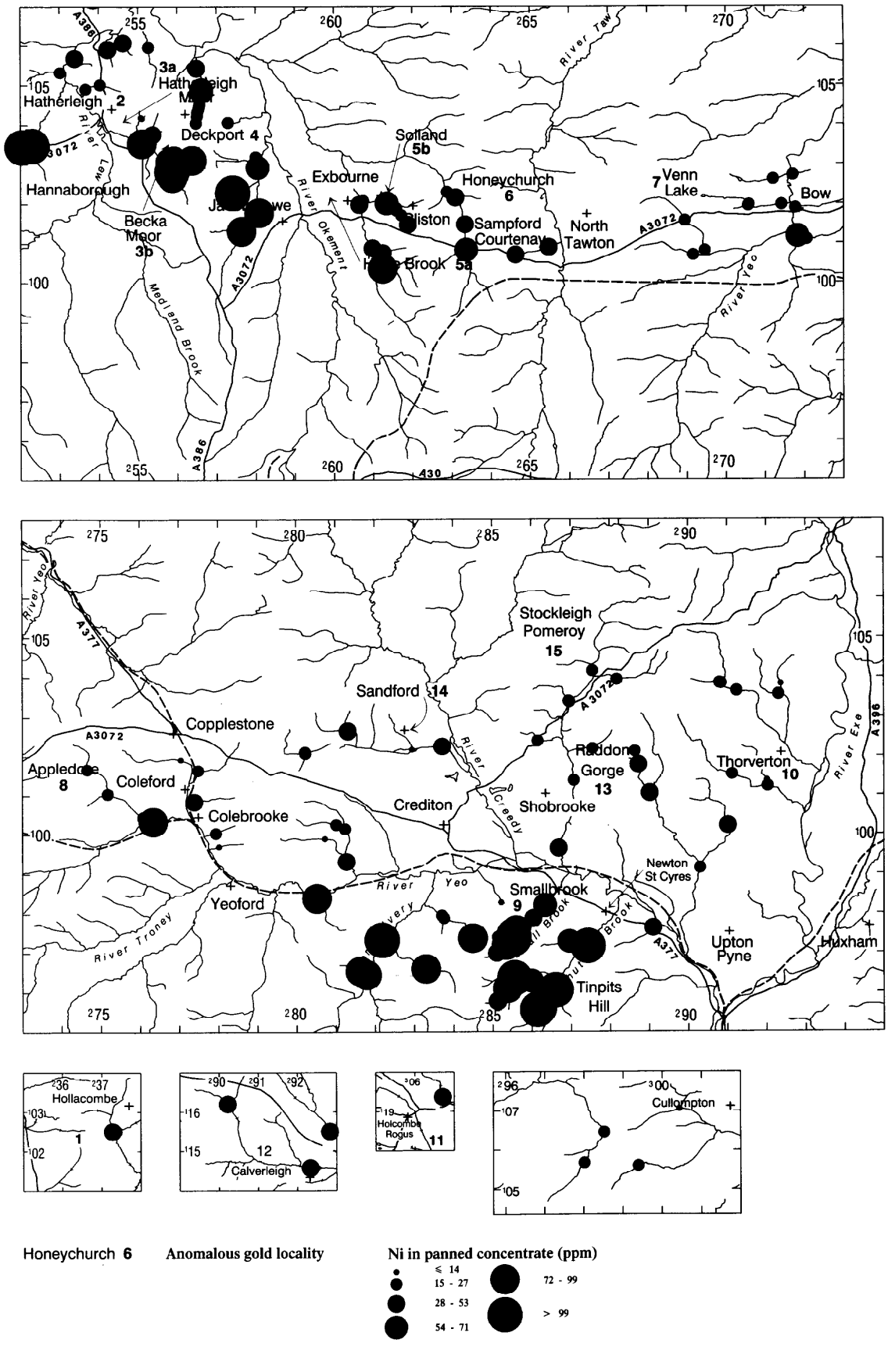
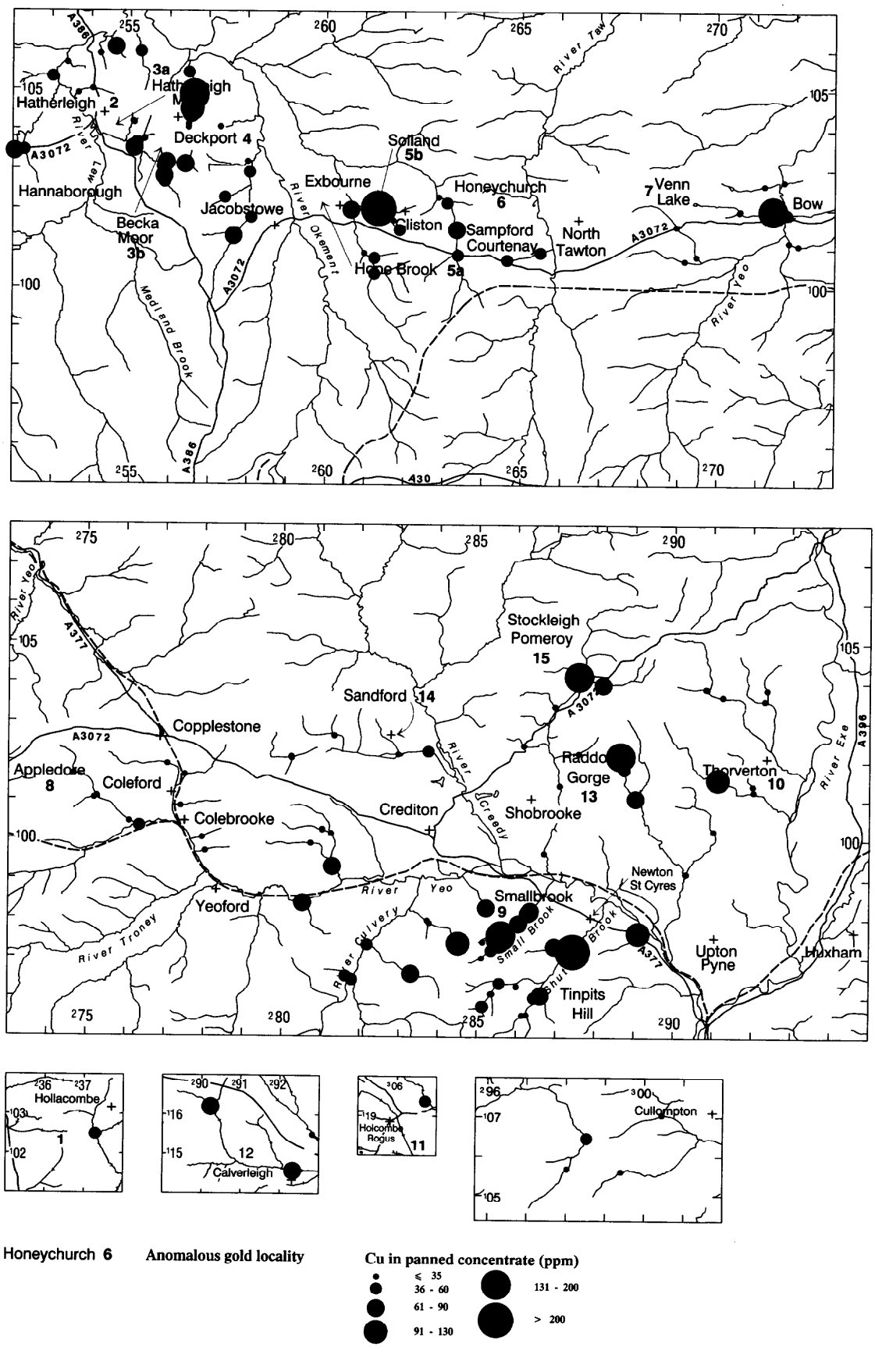


Figure 15 Distribution of Ni in panned concentrate



Honeychurch 6 Anomalous gold locality

Cu in panned concentrate (ppm)

- ≤ 35
- 36 - 60
- 61 - 90
- 91 - 130
- 131 - 200
- > 200

Figure 16 Distribution of Cu in panned concentrate

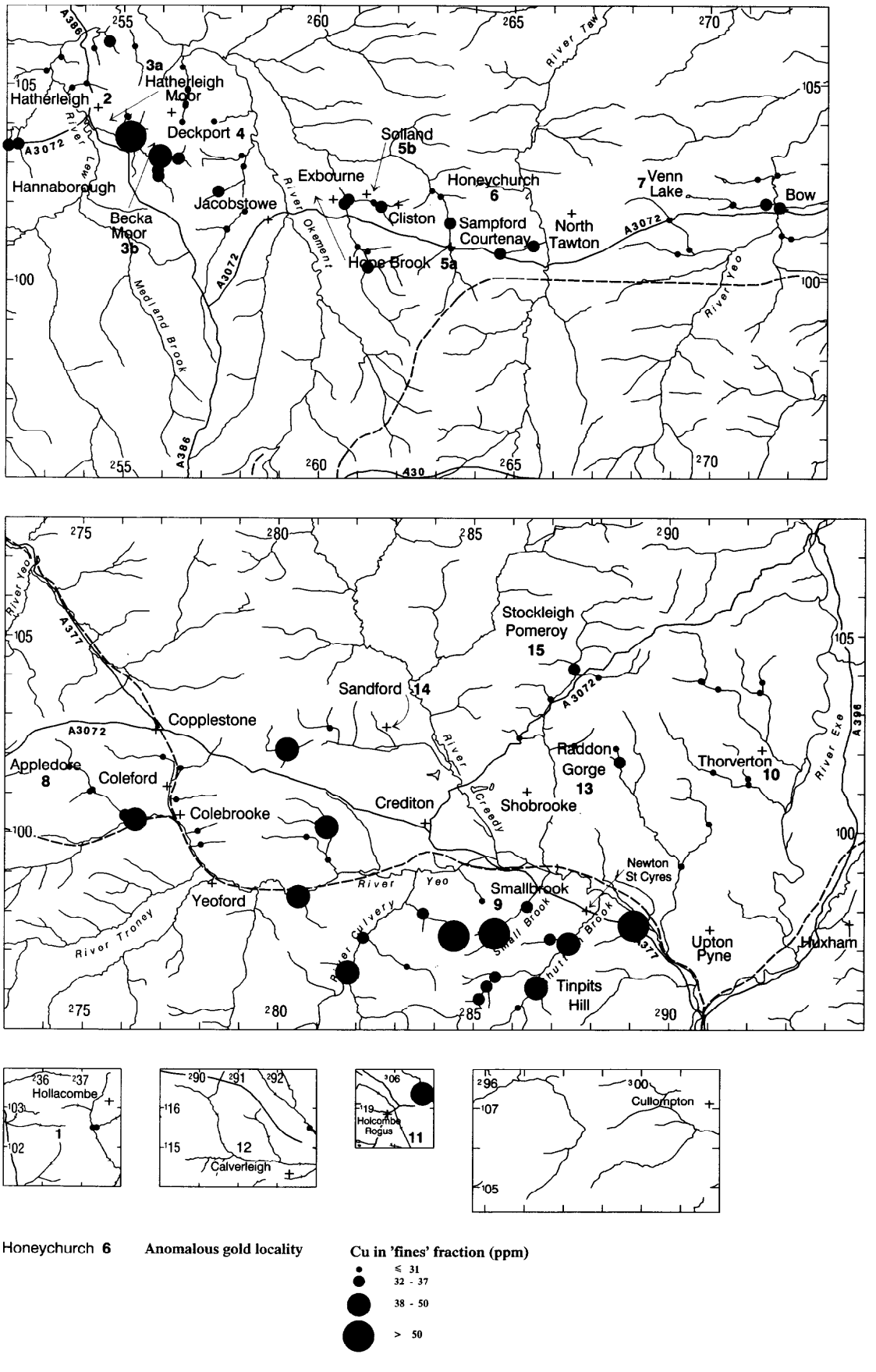


Figure 17 Distribution of Cu in 'fines' fraction

There is a marked contrast between the western and eastern parts of the Crediton Trough in terms of Fe_p distribution, with several of the highest Fe_p values occurring around Hatherleigh, in the extreme west of the main outcrop of the New Red Sandstone. Relative enrichment in Fe_p is also shown in the Ti_p-V_p-Fe_p diagram (Localities 2, 3A and 3B, Figure 9) for samples containing anomalous Au from the same area.

Samples containing the highest concentrations of Fe_f are also concentrated in the area to the south-east of Hatherleigh (Figure 14). Elsewhere, similar enrichment occurs over parts of the Crackington Formation subcrop to the south of Smallbrook and at isolated sites within the central section of the Crediton Trough. No general correlation between enrichment in Fe in either sample type and the presence of Au is evident, though at each locality Au tends to follow Fe due to the effect of variable upgrading in concentrates of Au and heavy Fe oxide minerals. This is probably the reason for the large Fe_p anomaly, 46 % at UDP 1084 [SX 8634 9820] in the Small Brook.

Nickel

The cumulative frequency plots for Ni_p and Ni_f are similar and relatively flat (Figures 3 and 5). Furthermore, there is general agreement in concentration levels between the two sample types. Samples with relatively high Ni_p (Figure 15) and Ni_f contents are found over the outcrop of the Namurian Crackington Formation to the south of the Crediton Trough, in the area to the south and south-west of Smallbrook and south-east of Hatherleigh. The largest Ni_p anomaly is again in one of the streams draining lamprophyres at Hannaborough (UDP 1070 [SS 5204 0343] 175 ppm) although most of the catchment is Crackington Formation. The largest Ni_f anomaly is in the upper reaches of the Small Brook. This enrichment probably reflects a background enrichment in the Crackington Formation rocks as a whole. Within the outcrop of Permian rocks only one site, north-west of Crediton, has an enriched Ni_f level, possibly reflecting the nearby outcrops of mafic volcanic rocks.

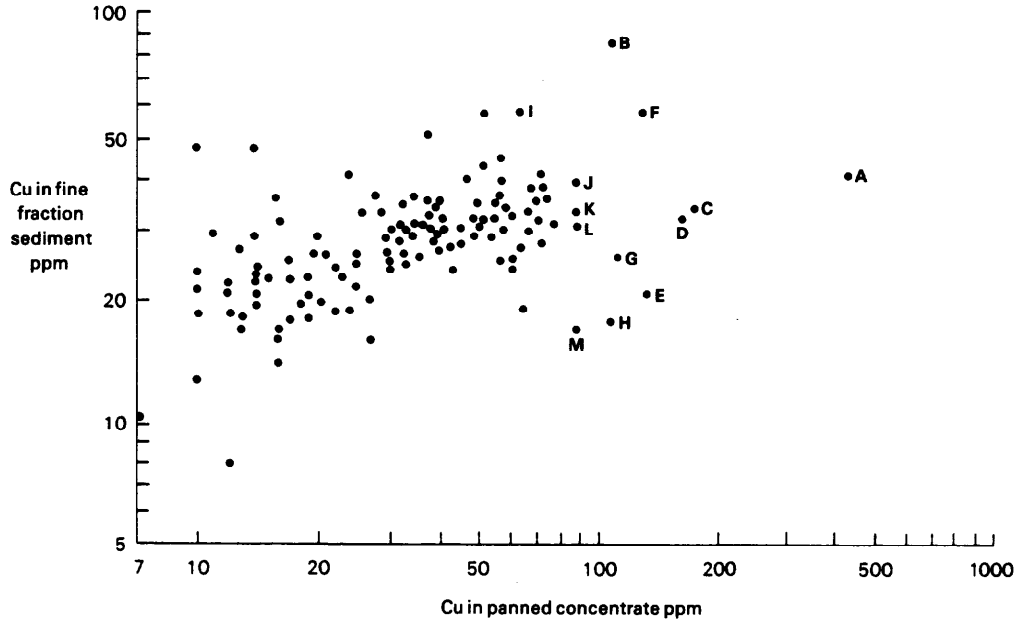


Figure 18 Comparison of Cu values in panned concentrate and 'fines' fraction. See text for explanation

Copper

The cumulative frequency plot for Cu_p samples has a higher gradient than that of the Cu_f samples (Figures 4 and 5), suggesting that the element is present largely in detrital grains. Since Cu can occur as contaminants in drainage sediment, especially in intensively farmed areas like the Crediton Trough, it can be instructive to compare the distribution of Cu_p and Cu_f (Figures 16 and 17) as well as Cu levels in both sample types at individual locations (Figure 18).

Some Cu_p anomalies are found in the area around the Small and Shuttern Brooks, the highest Cu_p anomaly being UDP 1077, 432 ppm, in the latter stream [SX 8743 9717]. This sample (A, Figure 18) is also very rich in Zn_p (14868 ppm) and, in view of the relatively low metal content of the corresponding 'fines' sample, is probably derived from dump material from the nearby old base-metal working on Tinpits Hill. Sample B (Figure 18), from the same general area, shows relative enrichment of Cu_f probably because of its high Mn_f content. Samples I, F and L (Figure 18) are also from the same general area and probably reflect previously unknown Cu-bearing mineralisation around the contact between Permian and Carboniferous rocks. Cu is a component of the anomalous Au samples from Deckport (samples M and H, Figure 18). Samples K, Hatherleigh, and L, Solland, are also anomalous in Au. UDP 1158 [SS 8755 0416] Cu_p 174 ppm (C, Figure 18), also somewhat anomalous in Au (240 ppb), is in a stream draining Bude Formation rocks (Figure 16), possibly in a similar environment to the anomalous samples from the Smallbrook area.

It is difficult to account for the two anomalies (Figure 16) around Thorverton, UDP 1137, 133 ppm [SS 8863 0214] and UDP 1163, 119 ppm [SS 9112 0154] (E and G, Figure 18). These, like the isolated Cu_p anomaly at Venn Lake, UDP 1029, 163 ppm [SS 7141 0198] (D, Figure 18), are probably caused by contamination, in view of the association with high lead content and the absence of other elements normally associated with mineralisation. Moderate Cu_p levels in the Calverleigh area are accompanied by slight As_p and Pb_p enrichment. No clear indication of a general association of Cu_{fp} with Au is evident. This is apparent on the Cu_p-Zn_p-As_p diagram in Figure 19, which demonstrates that different Au localities have different signatures in terms of these three elements.

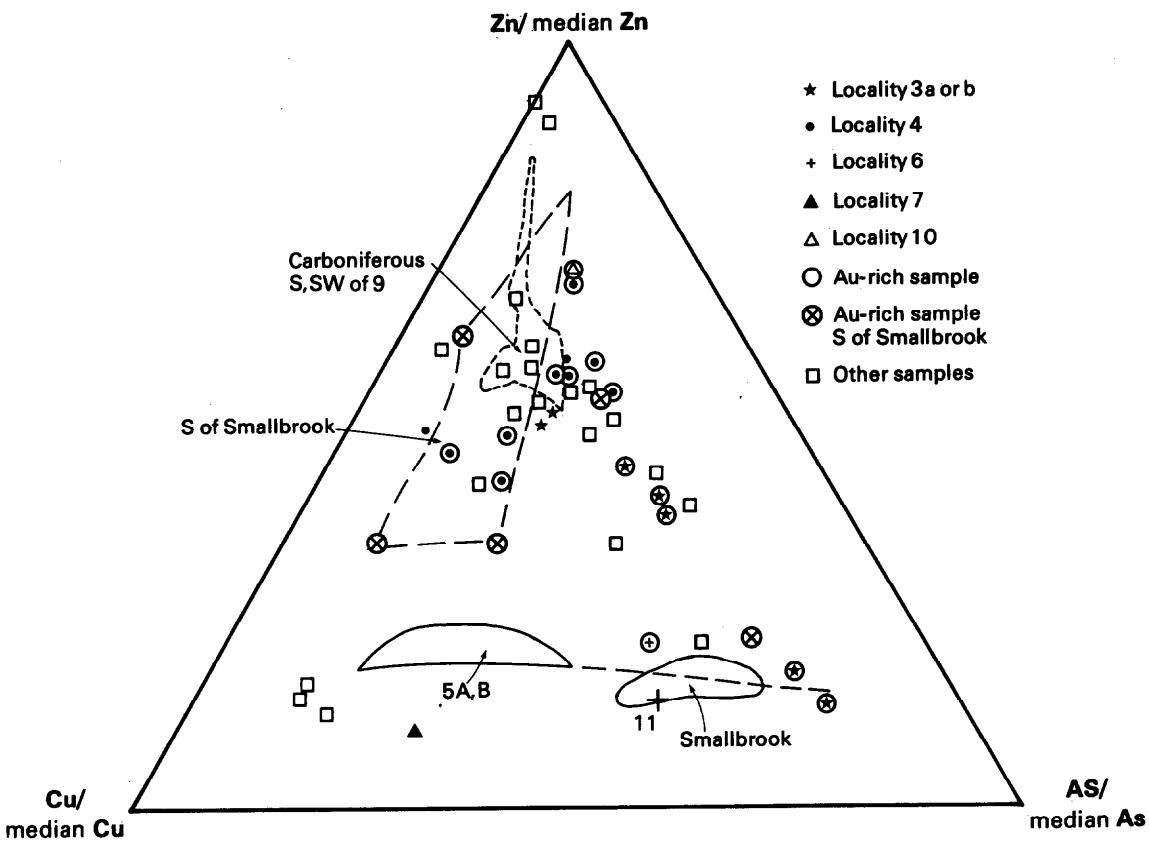
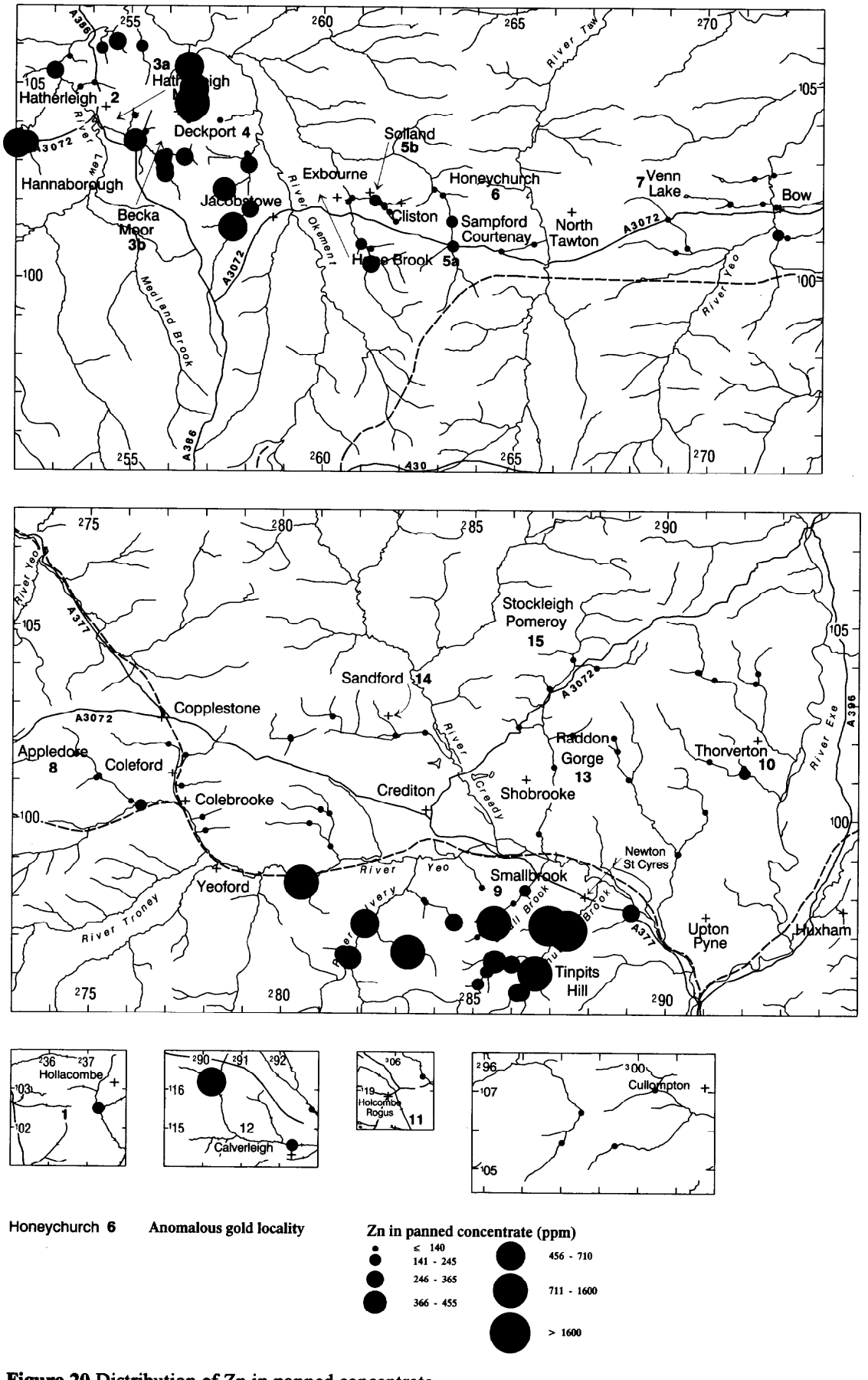


Figure 19 Relative proportions of Cu, Zn and As >median level in metal-rich concentrate samples



Honeychurch **6** **Anomalous gold locality**

Zn in panned concentrate (ppm)

≤ 140	456 - 710
141 - 245	711 - 1600
246 - 365	> 1600
366 - 455	

Figure 20 Distribution of Zn in panned concentrate

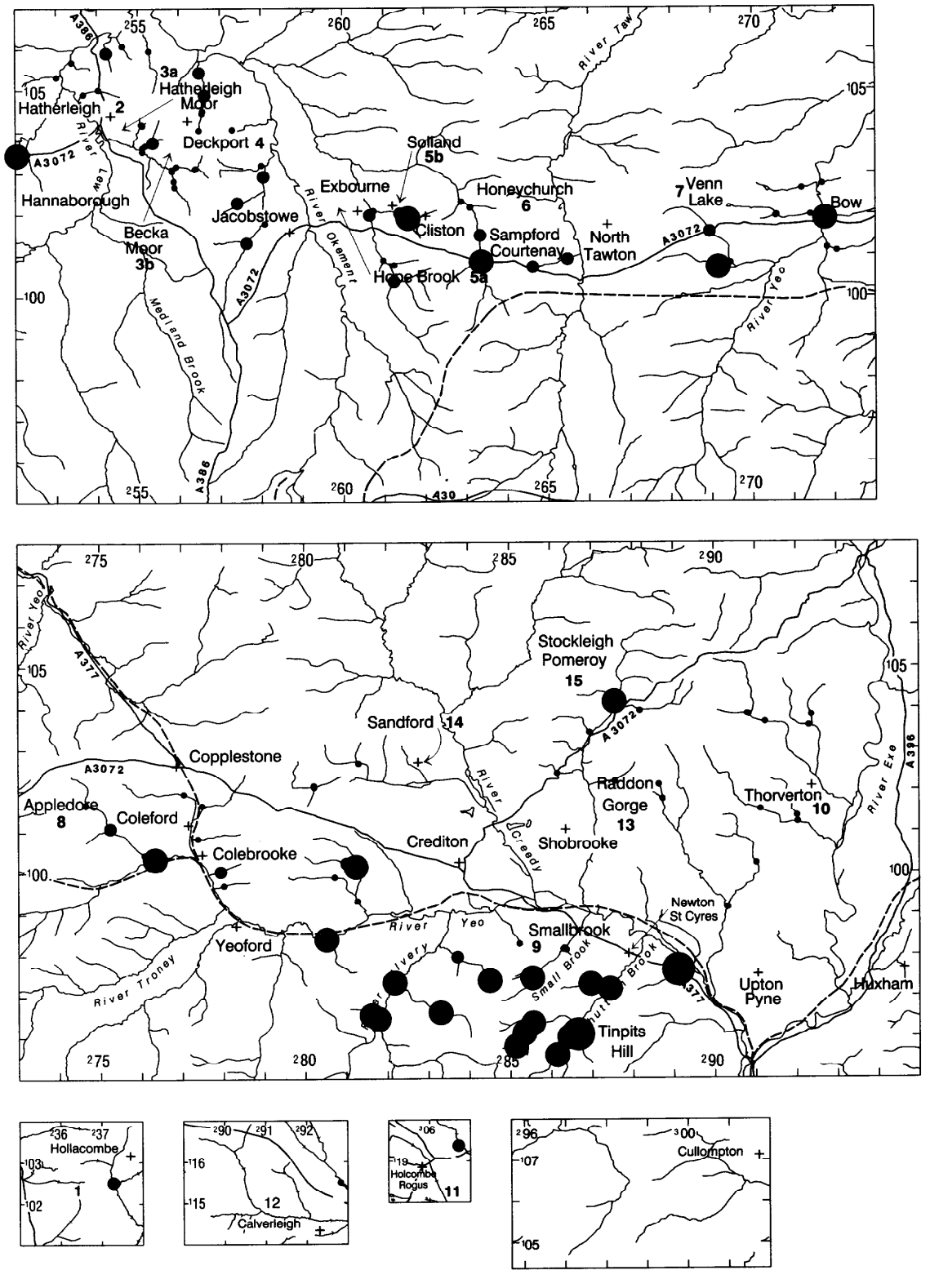


Figure 21 Distribution of Zn in 'fines' fraction

Zinc

Comparison of the cumulative frequency plots for Zn_{pf} (Figures 4 and 5) suggests that detrital dispersion of mineral grains derived from mineralisation is more important than hydromorphic dispersion and fixing of the element on the finest fraction. However, an increase in gradient at the 62 percentile level for Zn_f indicates that hydromorphic dispersion is not negligible. Zn_{pf} anomalies (Figures 20 and 21) are concentrated over the Crackington Formation rocks to the south and east of Smallbrook. The largest Zn_p anomaly (UDP 1077 [SX 8743 9717] 1.49% Zn_p) is probably derived from dump material from old base-metal workings on Tinpits Hill to the south-east. The zone of anomalies extends some 7 km along strike to the west of this locality, the limit of sampling over the Crackington Formation rocks.

There are two possible zones of mineralisation to the south of Smallbrook. The first occurs in Crackington Formation rocks immediately adjacent to the faulted contact with the Permian rocks. To the south of this is a separate zone of anomalies over the Carboniferous, marked by generally equal enrichment in Zn_p and Zn_f (Figures 20 and 21). Though some of the enrichment in Zn_f can be related to parallel enrichment in Mn_f reflecting scavenging by hydrous oxide, the existence of corresponding Zn_p enrichment indicates that there is Zn mineralisation to the west of the known site and the area is worthy of further study. A comparison between Zn_p and Zn_f (Figure 22) shows a general increase in Zn which may relate to mineralisation. The 1:50 000 satellite image indicates that north-east-trending lineaments (and north-west-trending) are prominent in the zone of anomalies.

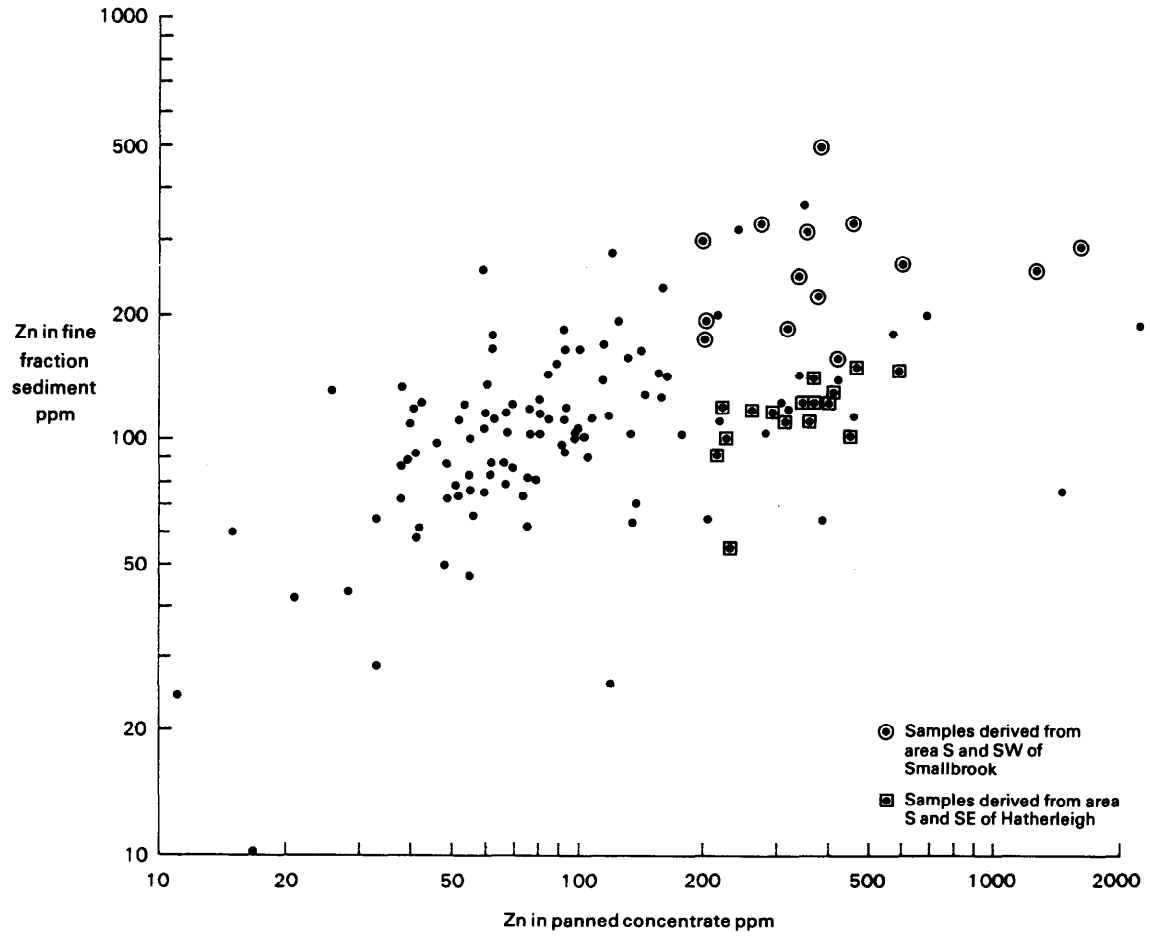


Figure 22 Comparison of Zn values in panned concentrate and 'fines' fractions

Another group of Zn_p anomalies occurs in Crackington and Lower Permian rocks in the extreme west of the Crediton Trough. The relatively low Zn_f content of samples from this area (Figures 21 and 22) distinguish these anomalies from those south of Smallbrook and indicate that dispersion is largely

detrital: lineaments here also trend north-east. Zn_p anomalies are also associated with highly anomalous Au at Deckport (Figure 20), e.g. UDP 1117, 1439 ppm, [SS 5657 0450]. An isolated Zn_p anomaly is also associated with the northern boundary of the Tiverton Basin Permian rocks (Figure 20) i.e. UDP 1158, 580 ppm [SS 8755 0416]; other elements enriched here are Mo_p, As_p and Au_p. Neither Zn_p or Zn_f shows a general association with Au.

Arsenic

The shape of the cumulative frequency curves for As_p and As_f (Figures 4 and 5) are similar, suggesting dispersion both as detrital grains and in the finest fraction of drainage sediment, and the agreement between As_p and As_f contents (Figure 23) is generally better at higher levels than is the case for other elements. Arsenic is clearly enriched in the samples derived from New Red Sandstone rocks of the Crediton Trough compared with those derived from the Carboniferous strata, (Figures 24 and 25). However, within the Trough arsenic enrichment is patchy, with generally lower values derived from the breccias east of Crediton, except for the Smallbrook area.

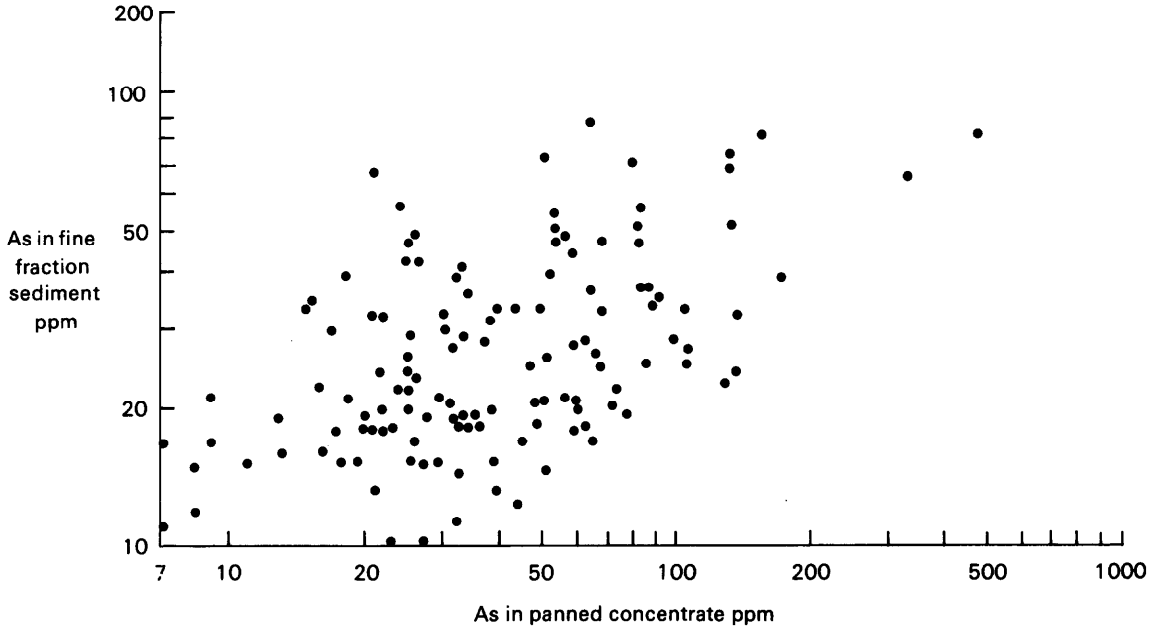


Figure 23 Comparison of As values in panned concentrate and 'fines' fraction

As_p shows the greatest positive correlation with Au (Figure 26), and is anomalous at about 70% of the sites with significant concentrations of Au. The Smallbrook and Becka Moor localities (Figures 24 and 25) are particularly enriched in As_p, both in absolute terms and in relation to other metallic elements. The highest As_p anomalies are found in the latter area, UDP 1007, 476 ppm [SS 5592 0317] and UDP 1147, 324 ppm [SS 5640 0312]. At UDP 1078 As_p 137 ppm [SS 5229 0347] the stream drains both Crackington Formation rocks and lamprophyric lavas.

In the Calverleigh area, an As_p anomaly at UDP 1184, 144 ppm [SS 9233 1457] was accompanied by Au in the pan. As_p is low in Hollacombe and around Thorverton and relatively depleted in relation to other elements at the gold-rich sites north-west of Hatherleigh, at Deckport and in the Exbourne–Solland area (Figure 24), as shown by the relative proportions of Cu_p-Zn_p-As_p in Figure 19. Between Honeychurch and Sampford Courtenay, (Figure 24) As_p anomalies cover a wider area than the Au anomaly. As_p anomalies occur to the east of the Au anomalies at Venn Lake (Figure 24) and just east of this area are two sites where only As_f is anomalous.

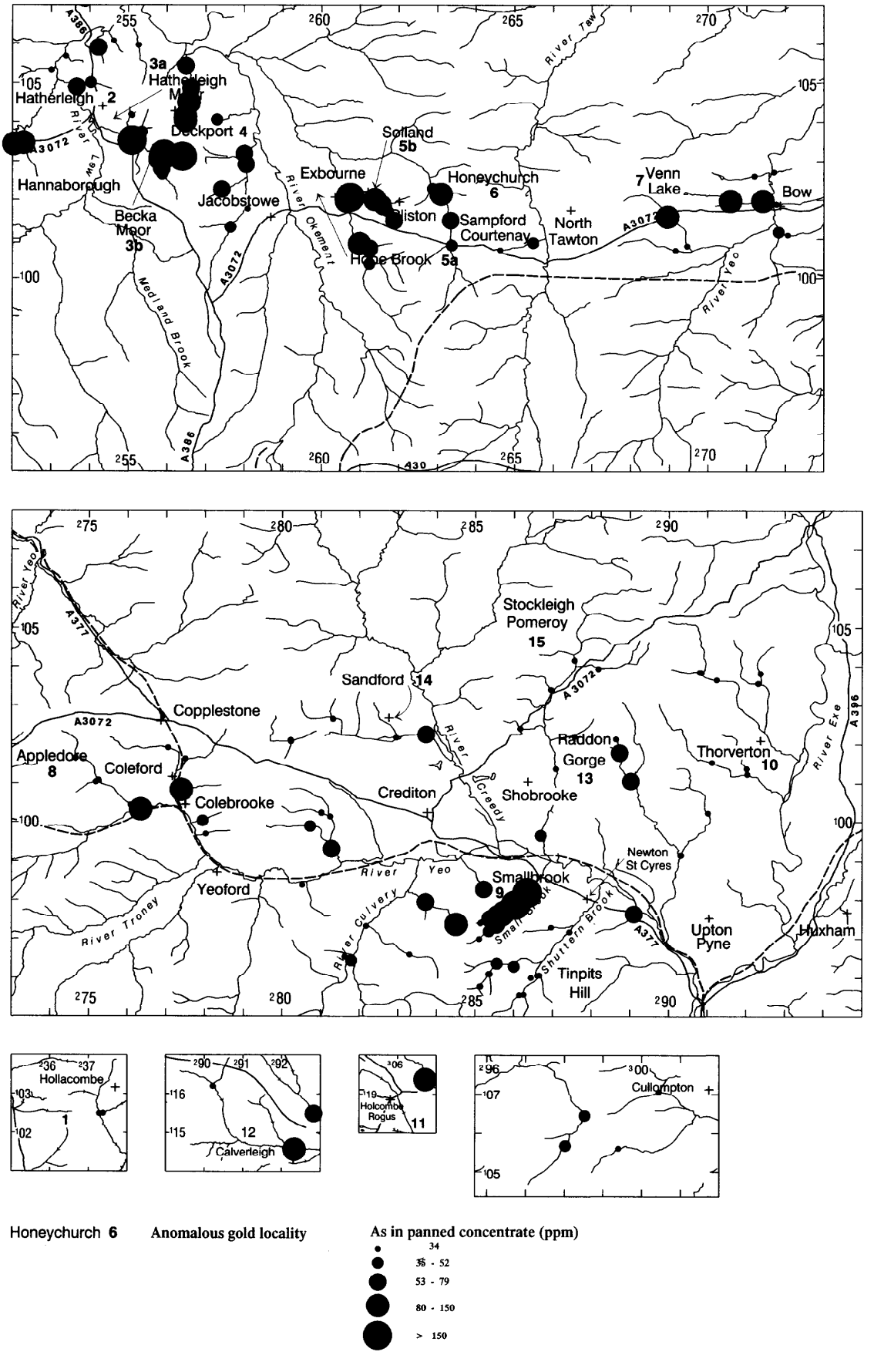
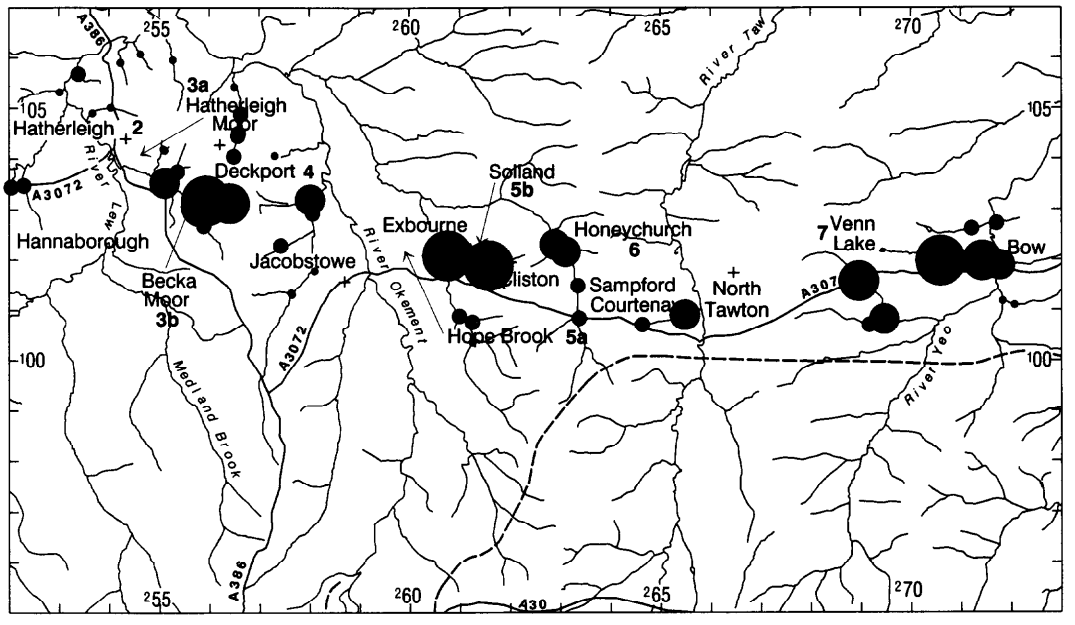
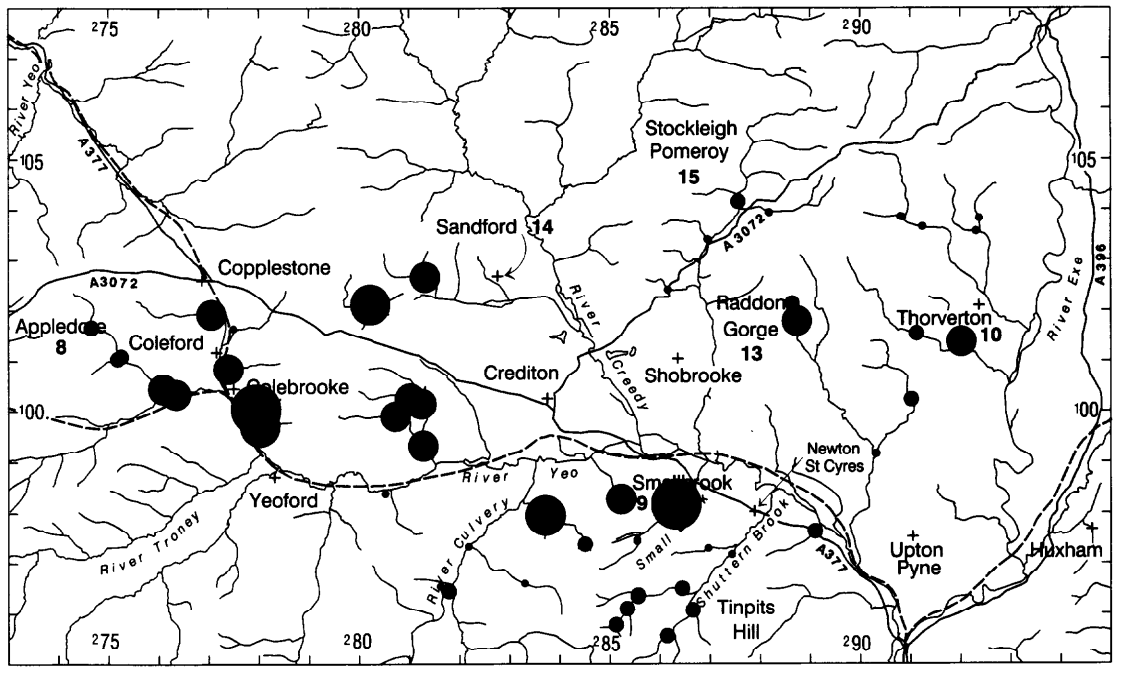
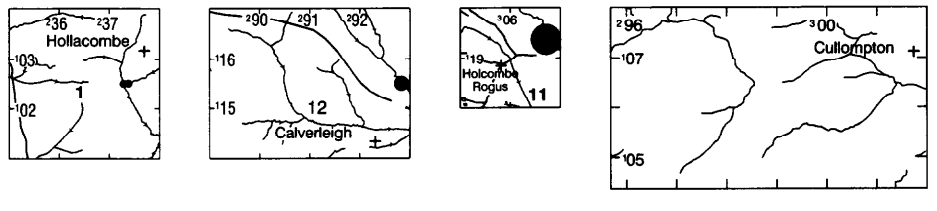


Figure 24 Distribution of As in panned concentrate







Honeychurch **6** **Anomalous gold locality**

As in 'fines' fraction (ppm)

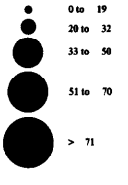


Figure 25 Distribution of As in 'fines' fraction

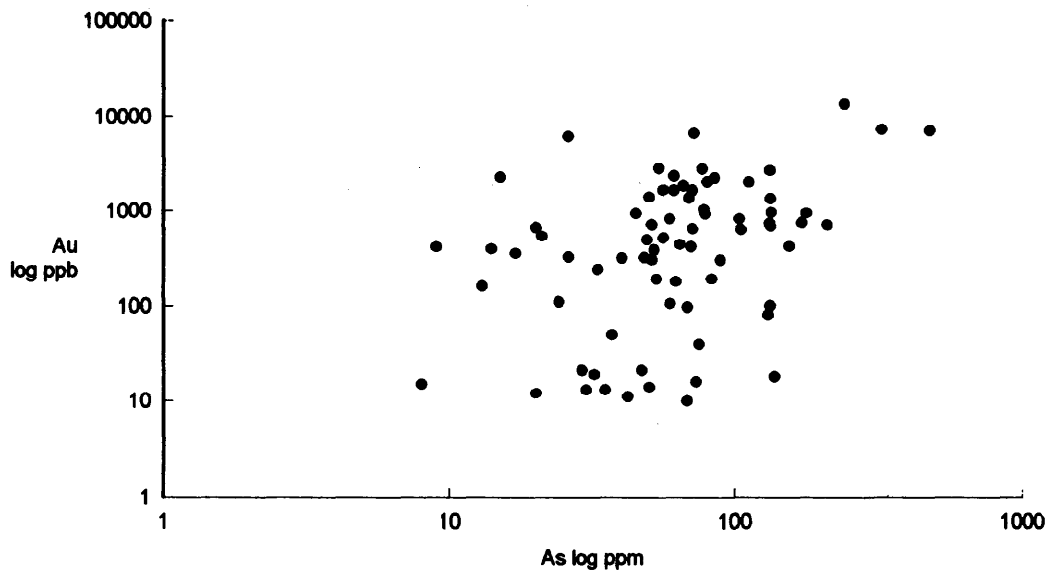


Figure 26 Plot of Au with As values in panned concentrate

Rubidium

Rubidium was determined only in the 'fines' samples and is generally most enriched in samples derived from the central part of the Crediton Trough, in the vicinity of Bow (Figure 27). Lowest levels are found in the breccias and volcanic rocks of the Thorverton area and in the samples from the western Trough. This probably reflects primary geochemical differences within the New Red Sandstone.

Yttrium

Y_p follows Ce_p closely in its distribution, but is less abundant, suggesting that the main rare-earth mineral is monazite, accompanied perhaps by some xenotime. Y_p also correlates with Ti_p to a lesser extent. Enrichments in Y_p occur particularly at two localities in the western half of the Crediton Trough, Solland and Deckport (Figure 28), both of which are also enriched in Au. The reason for this local enrichment of monazite is not clear. General upgrading of heavy minerals, both by stream processes and by panning, accounts for some, but not all, of this enrichment. The monazite-rich samples are also relatively enriched in zircon and cassiterite but there are several other samples from nearby parts of the Crediton Trough which are as enriched in Zr and Sn but not at all in the rare earths. This suggests that monazite enrichment may be associated with a restricted part of the earlier New Red Sandstone sequence, the outcrop of which may be discontinuous. An alternative and less likely explanation is that there are discrete, possibly igneous, sources of monazite within the Crediton Trough.

Zirconium

There is general enrichment in zirconium in samples derived from the New Red Sandstone compared with those derived from the Carboniferous rocks (Figure 29), as there is less detrital zircon in the predominantly shaley Carboniferous strata (Ault and others, 1990; Haslam, 1990). Concentrations within the Permian outcrop are lowest in the Thorverton area, in the east of the Crediton Trough. The three highest Zr_p contents reflect sites where heavy minerals have been concentrated more than usual by the panning process, associated with high levels of Sn_p and Au_p at Solland, Smallbrook and Appledore, in the centre of the Trough.

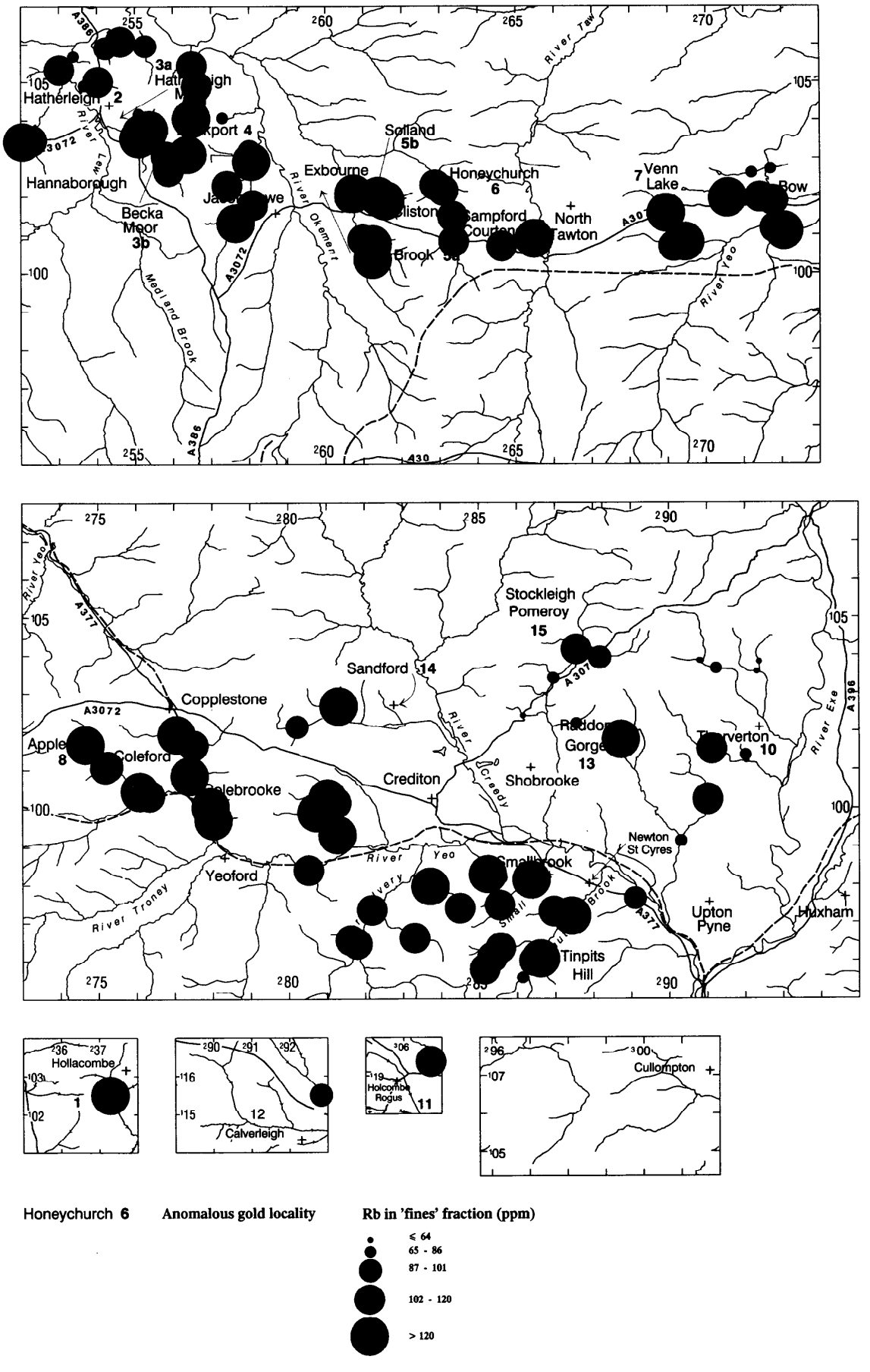


Figure 27 Distribution of Rb in 'fines' fraction

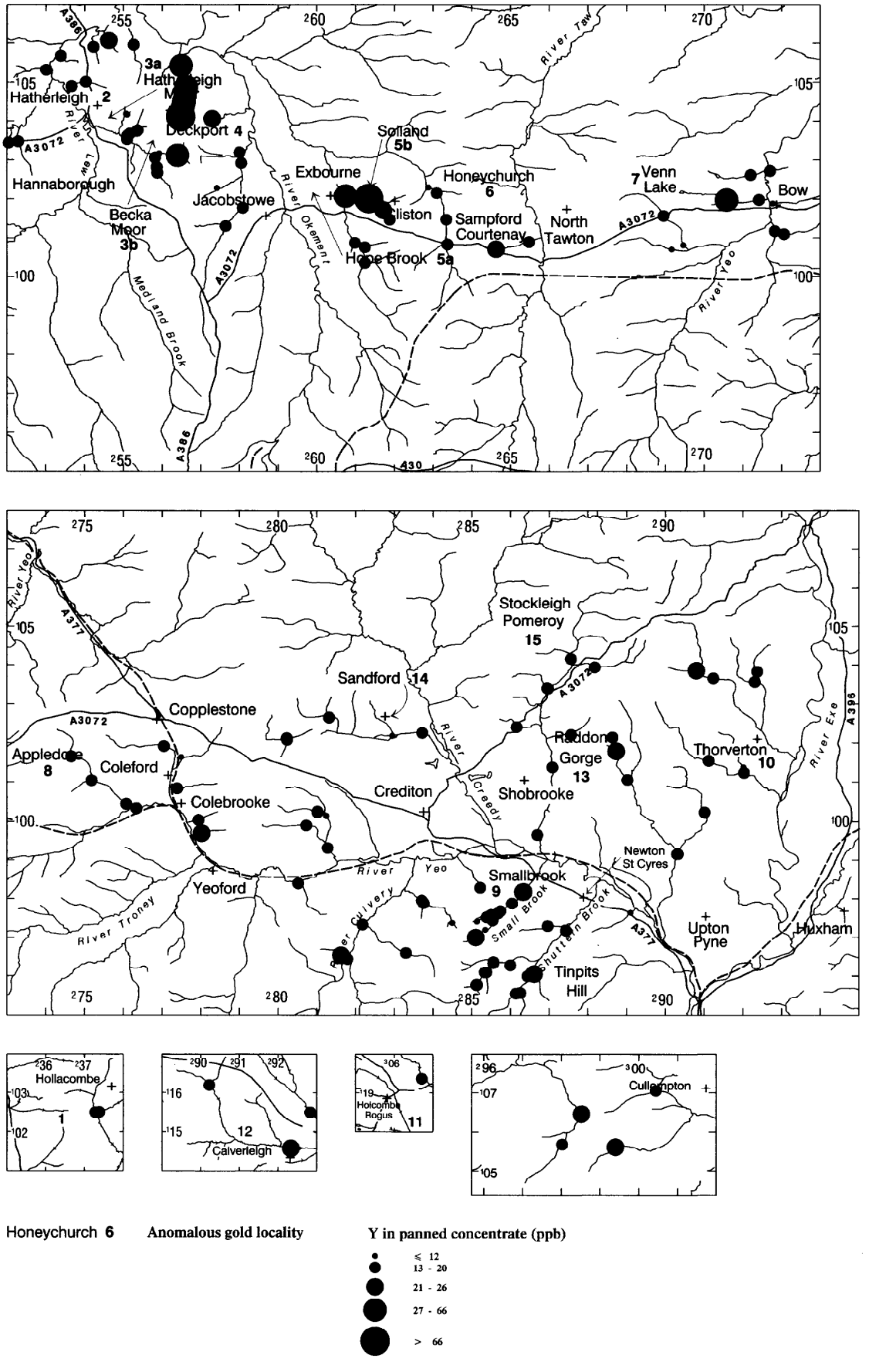


Figure 28 Distribution of Y in panned concentrate

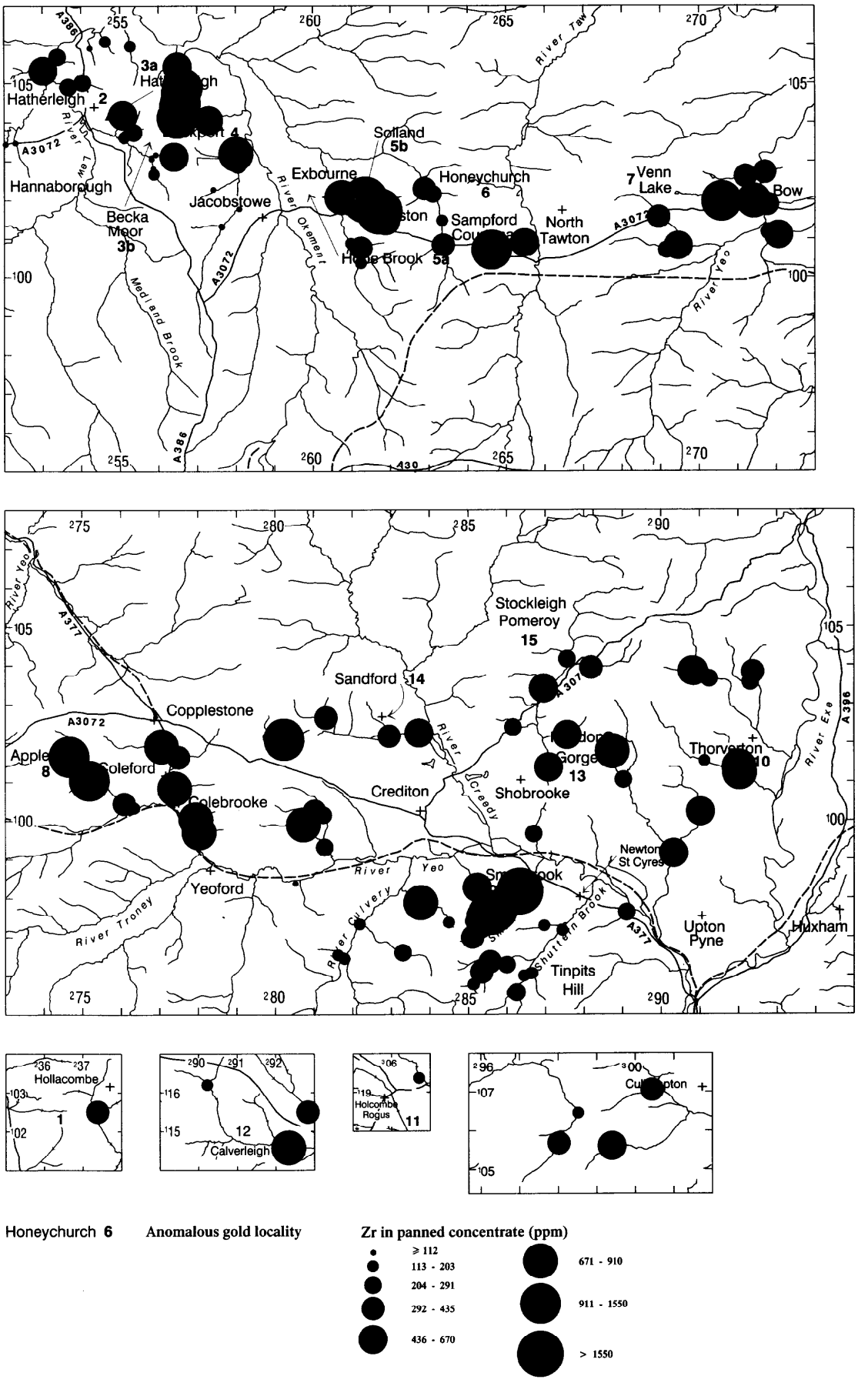
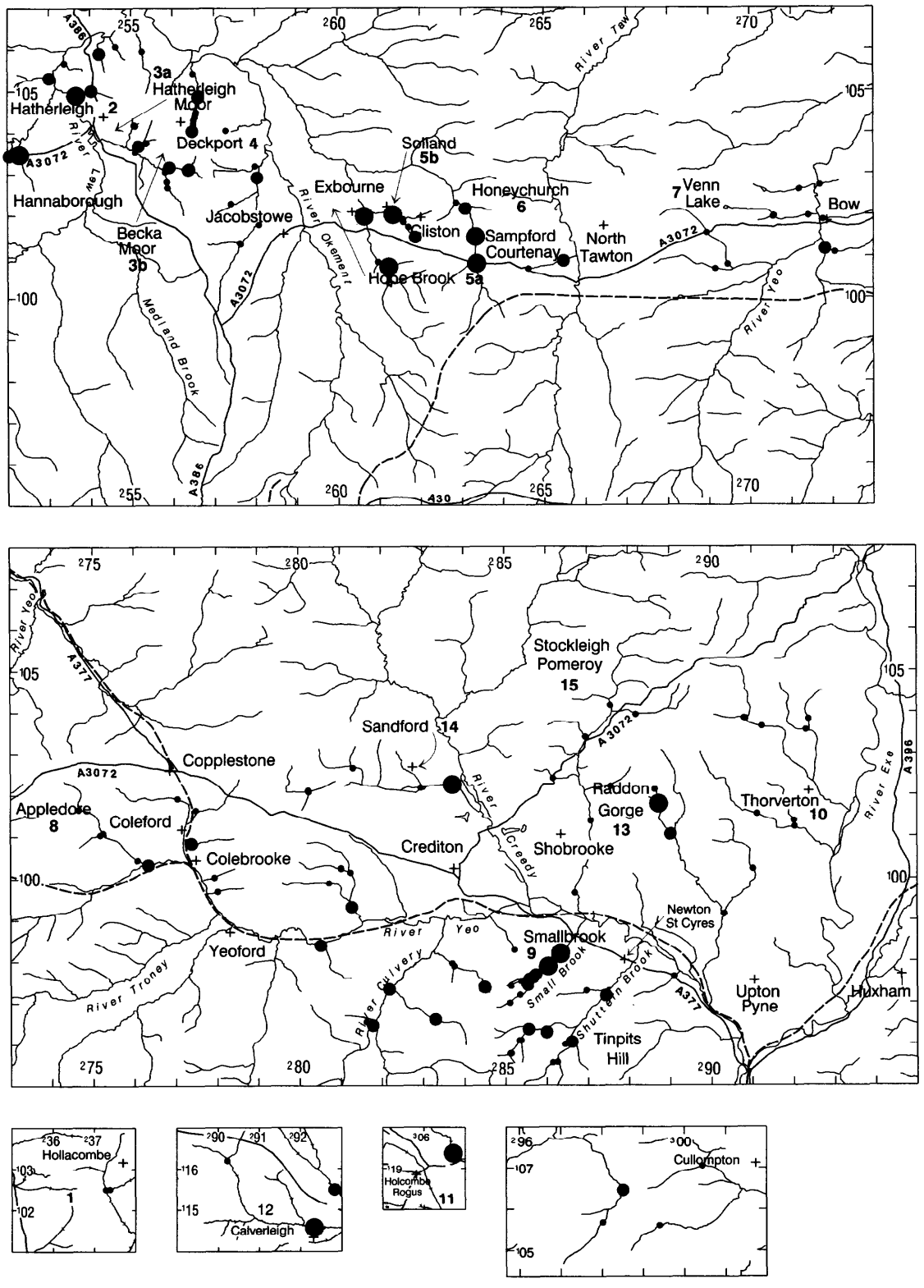


Figure 29 Distribution of Zr in panned concentrate



Honeychurch **6** **Anomalous gold locality**

Mo in panned concentrate (ppm)

- ≤ 7
- 8 - 13
- > 13

Figure 30 Distribution of Mo in panned concentrate

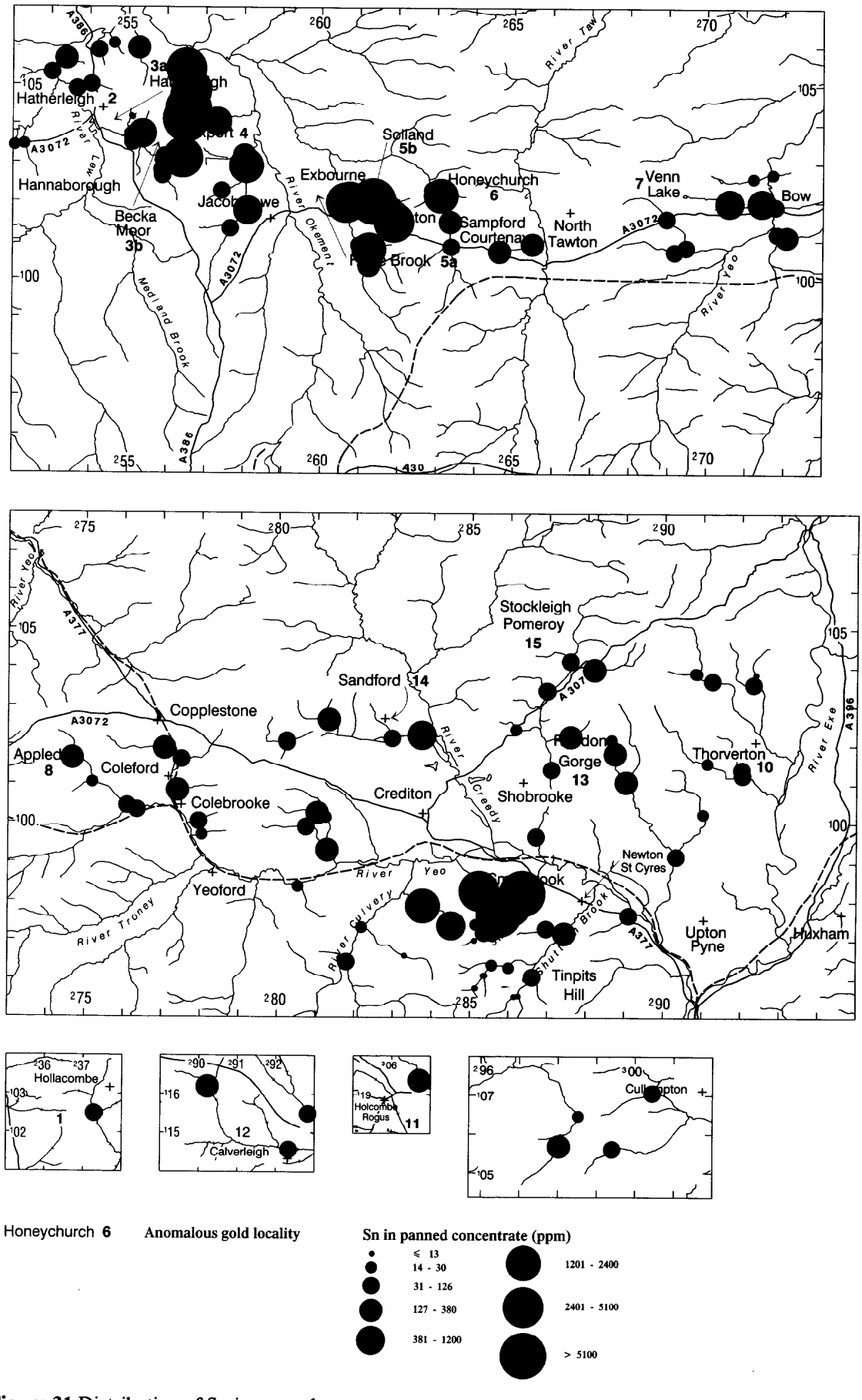


Figure 31 Distribution of Sn in panned concentrate

Niobium

Nb_p closely follows Ti_p and Ce_p in its distribution and is not shown here. The positive correlation between Nb_p and Ti_p,and the relative abundance of niobium relative to Ti suggest that the Nb is accommodated in rutile.

Molybdenum

Low-amplitude Mo_p anomalies are scattered throughout the area (Figure 30). They are particularly evident around Solland and the stream to the east (locality 5). The isolated sample from the Holcombe Rogus area in the north-east is molybdenum-rich, especially in relation to iron, UDP 1167, 23 ppm, [ST 0671 1937]. Mo_f levels are substantially lower than those in the concentrates and no anomalies are apparent, so this distribution is not shown.

Tin

Tin is generally enriched in samples derived from the New Red Sandstone rocks. Low contents (< 14 ppm Sn) are only associated with samples derived entirely from the Carboniferous rocks. The drainage data do not support the conclusion of the rock sampling that tin enrichment is only associated with the later Permian sequence within the Crediton Trough. Particular enrichment in tin is associated with three broad areas (Figure 31), all of which are also anomalous in Au, Smallbrook, Solland and Deckport. A plot of Au against tin concentrations is given in Figure 32, though this does not include samples containing the highest tin contents as these are outside the calibration limits of the analytical method used (>1.1 %).

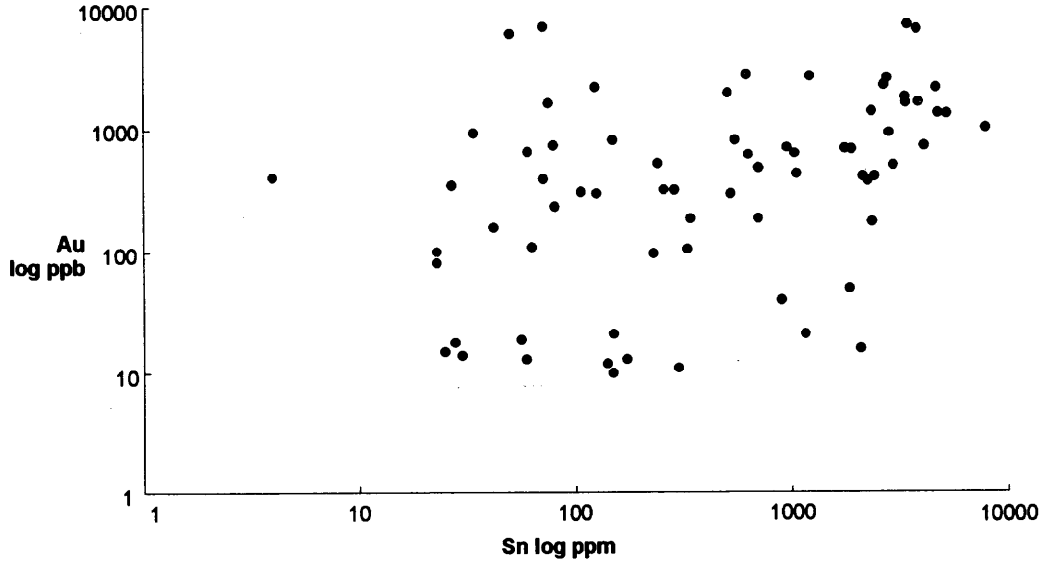


Figure 32 Plot of Au with Sn values in panned concentrate

The proportion of samples with anomalous tin and gold to those with only tin to those with only gold is roughly 5:1:1, partly reflecting the greater number of samples taken from the three gold localities with high tin, Deckport, Solland and the Small Brook. Sn_p anomalies without corresponding Au_p anomalies are mostly near to sites where both elements are anomalous. In contrast, the tin contents are low in gold-rich samples from Hollacombe, north-west of Hatherleigh, Thorverton, Calverleigh and Holcombe Rogus.

Some of the partial correlation between Sn_p and Au_p (Figure 32) is a consequence of the occurrence of both elements as detrital heavy mineral grains, upgraded together by natural stream action and by the panning process. It is also possible that both elements could be enriched in particular palaeoplacer horizons within the New Red Sandstone sequence. An alternative explanation of the association may be that gold was preferentially deposited hydrothermally in porous basal conglomeratic sediments which were already enriched in detrital cassiterite. The low-tin gold anomalies could be derived from mineralisation in rocks above or below this possible palaeoplacer horizon.

Antimony

Sb_p anomalies are of low-amplitude and of two main types, mostly associated with streams draining the Permian outcrop. Clusters of Sb_p anomalies appear to be associated with both gold and tin-rich samples from Deckport, Solland and Smallbrook (Figure 33). At Solland samples with anomalous Sb_p are also enriched in Pb_p, while those at Smallbrook are associated with As_p.

In addition, there are several low-amplitude anomalies in the Shuttern Brook, Thorverton and Calverleigh areas not associated with high Au_p or Sn_p levels, e.g. UDP 1130, Sb_p 20 ppm, Sn_p 312 ppm, Au_p one grain reported [SS 8873 0179]. However, this sample also contains 450 ppm Pb_p and the antimony may be due to contaminants. In contrast, the antimony in the Shuttern Brook samples may relate to known Pb-Zn mineralisation in the vicinity.

Barium

There are few Ba_p anomalies (Figure 34), and those that are present are located in the west of the area and at Smallbrook. At Smallbrook the anomalies are isolated and probably relate to discrete structures at or near the southern contact of the Permian rocks. The highest amplitude anomaly, UDP 1153, 1.7 % [SS 5510 0416], from Hatherleigh Moor is also likely to be derived from structures at the faulted contact of the Crackington Formation and the outlier of New Red Sandstone rocks. Further east a smaller amplitude anomaly may be related to the major north-north-west-trending Sticklepath Fault system.

Little variation is seen in Ba_f samples and there is no correlation with corresponding Ba_p levels. Maximum values occur in the northern contact zone of the Crediton Trough to the north-west of Crediton and to a lesser extent in the zone of Rb enrichment in the centre of the Trough. This distribution is not shown here.

Cerium

The pattern of distribution of Ce_p anomalies (Figure 35) is very similar to that of Y_p, described above, and is due to detrital dispersion of monazite and possibly xenotime. Sites near Smallbrook and Sandford, and the single site at Holcombe Rogus are more enriched in Ce_p than Y_p. Except for these sites and those near Cullompton, most of the eastern area is low in Ce_p.

Tungsten

Low-amplitude W_p anomalies (Figure 36) are found only at Solland and Deckport, associated with anomalous Au . As these samples are also rich in tin it is possible that they are derived from some palaeoplacer within the New Red Sandstone sequence that is derived from erosion of pre-existing mineralised rocks. The much lower ratio of tungsten to tin in the samples from Smallbrook compared to those from Deckport may reflect differences in the source material of the local sediments.

Lead

Scattered high Pb_p levels are found mainly over the Permian outcrop close to the anomalous gold localities near Hatherleigh, Deckport, Solland and Smallbrook, as well as near Venn Lake, Cullompton, Calverleigh and Holcombe Rogus (Figure 38). Lead in both sample types shows a sharp increase in

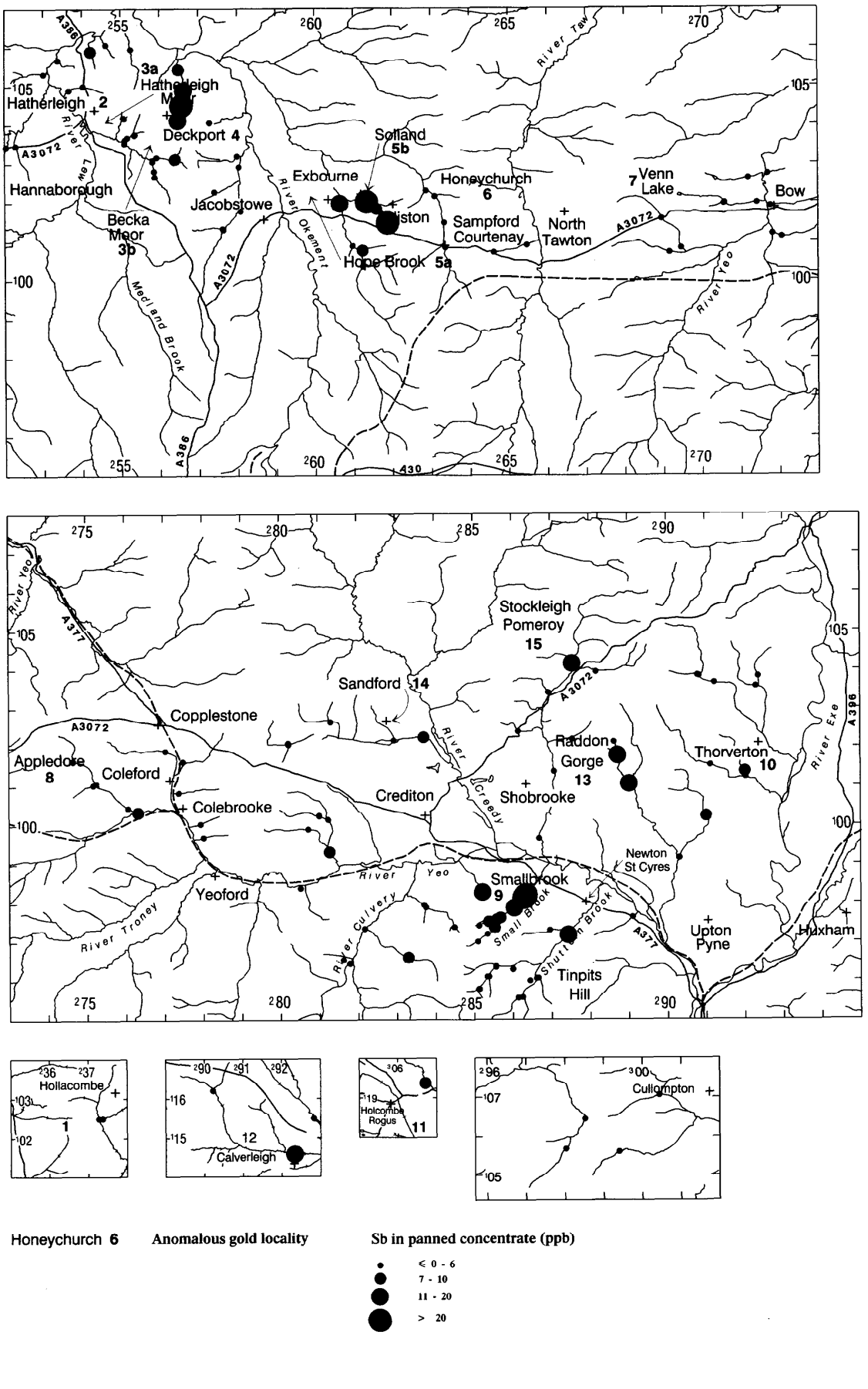


Figure 33 Distribution of Sb in panned concentrate

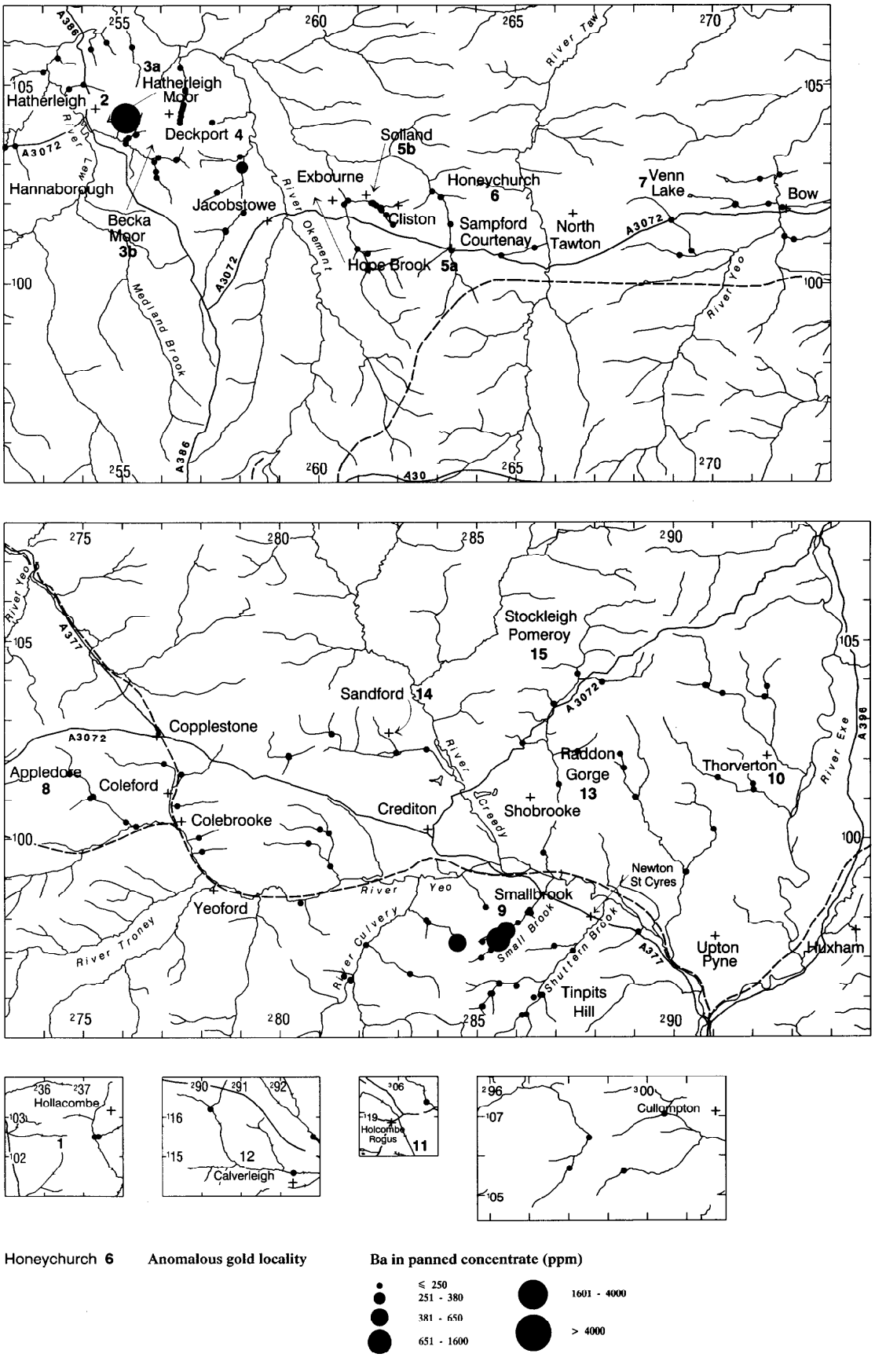
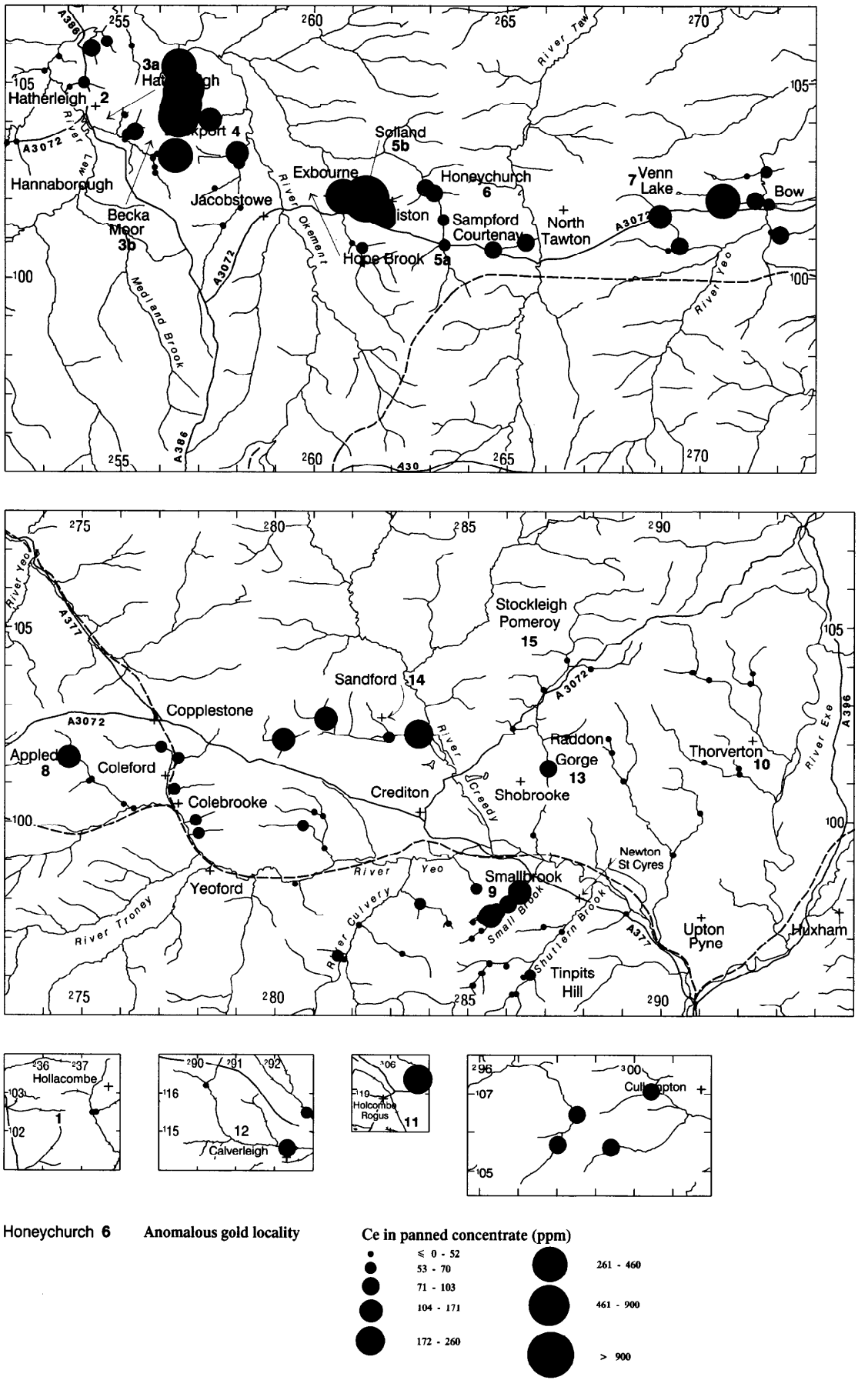


Figure 34 Distribution of Ba in panned concentrate



Honeychurch **6** **Anomalous gold locality**

Ce in panned concentrate (ppm)

⩽ 0 - 52	261 - 460
53 - 70	461 - 900
71 - 103	> 900
104 - 171	
172 - 260	

Figure 35 Distribution of Ce in panned concentrate

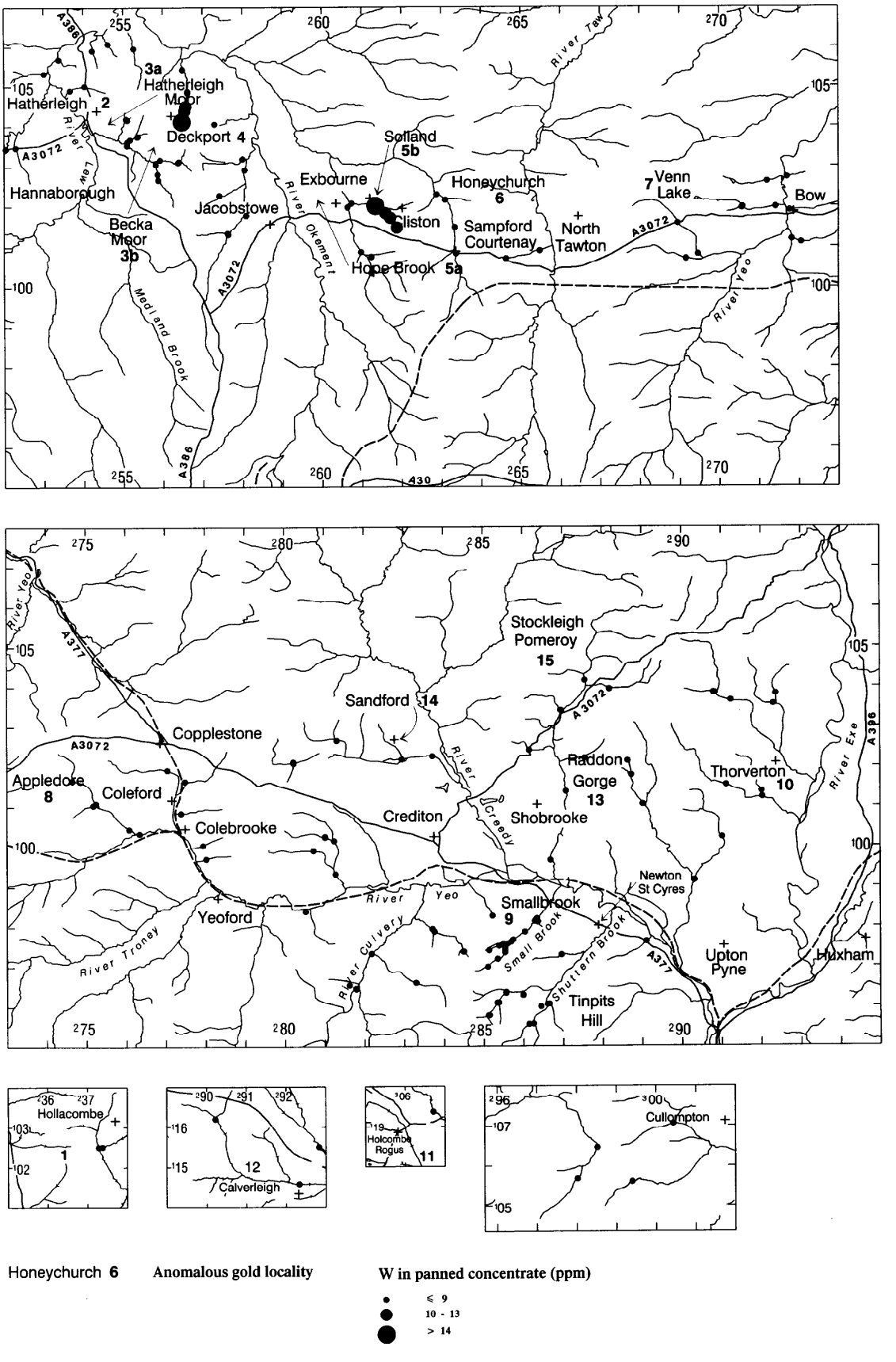


Figure 36 Distribution of W in panned concentrate

gradient in the cumulative frequency plots (Figures 4 and 5), but this is much more marked for Pb_p samples.

Lead is frequently present as a contaminant in panned concentrate samples from lowland areas of England with extensive farming, as in the Crediton Trough, and this is probably the source of some of the Pb_p anomalies. However, comparison of levels of lead in both sample types from individual sites, in conjunction with the contents of other elements, can help to distinguish natural anomalies from those due to contamination. Typical lead-rich contaminants like lead shot are relatively coarse-grained and stable and only appear as anomalies in the panned concentrates. Lead derived from mineralisation is usually in the form of secondary minerals which are often not mechanically resistant and can occur in both sample types.

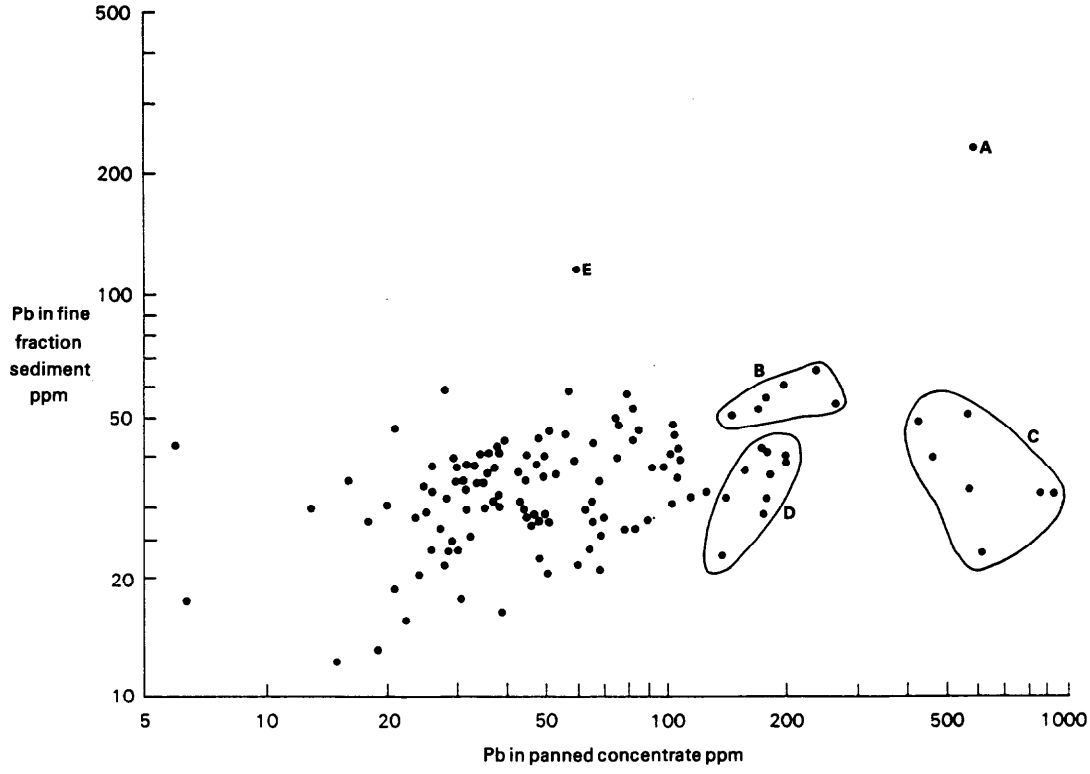


Figure 37 Comparison of Pb values in panned concentrate and 'fines' fraction

The plot of lead in the two samples types (Figure 37) shows a large degree of scatter. Five classes of point on this graph can be recognised. One sample UDFP 1076 [SX 8910 9764] (A on Figure 37), from east of Smallbrook, is highly enriched in lead (Pb_p 574 ppm, Pb_f 228 ppm) and reflects natural dispersion from the known mineralisation at Tinpits Hill. In contrast to Zn_p, samples derived from the Crackington Formation rocks west of the known mineralisation and south east of Hatherleigh do not show any Pb_p enrichment. A group of six samples (B on Figure 37) are less anomalous but show a similar ratio in lead content between the two sample types. Of these, two from the south-eastern part of the area clearly reflect mineralisation, being enriched also in Ba, Cu, Zn and As and Cu and Zn respectively. For the other samples in this group lead is the only anomalous element and its source is unclear.

A further group of samples in which lead is highly anomalous in the pan but not in the corresponding 'fines' samples can be recognised (C in Figure 37). In five of the seven samples in this group the lead is probably present as a contaminant in view of the absence of other element anomalies that are likely to

reflect mineralisation. In the other two cases other evidence of mineralisation is present but the lead could still be a contaminant. These include the sample at Venn Lake, UDFP 1029 [SS 7141 0198], Pb_p 561 ppm, Pb_f 50 ppm, where the stream is also anomalous for Cu and Au upstream. There is a further group of sites where Pb_p anomalies are lower magnitude (D in Figure 37). Most of these probably reflect contamination but some, especially the group of anomalies to the north-west of Hatherleigh (Figure 38) could be natural in origin. Most of the anomalies around Solland and at Smallbrook are probably due to contamination, although the most anomalous Pb_p sample is also anomalous for Y_p, Ce_p, U_p, Nb_p, Sb_p, Zr_p W_p and Ti_p (UDP 1083 [SS 6134 0201]).

Pb_f enrichments are mainly in the Permian outcrop between Exbourne and Newton St. Cyres (Figure 39). The lowest values are in the area around Hatherleigh and in the Thorverton area. UDFP 1050 (E, Figure 37) is enriched in Pb_f (115 ppm) compared to Pb_p (60 ppm) and in view of its location on the edge of Crediton [SS 8124 0015] probably reflects contamination, possibly with organic-rich material which would not be retained on panning.

Bismuth

Low-amplitude Bi_p anomalies are confined to the south-eastern part of the area (Figure 40), the region underlain by the younger Permian rocks. Most of the anomalies occur in samples from the Small Brook. One occurs in Raddon Gorge and one near Crediton, also with high Fe. In these samples there is a good positive correlation between Bi and Fe contents, suggesting that Bi is present in the iron oxide fraction, which may be enriched in the younger breccias.

Uranium

The cumulative frequency plots of U_p and U_f (Figures 3 and 5) are rather similar in gradient, though in general that of U_p is the greater. This suggests dispersion as detrital grains as well as, more typically, in the finest sediment fraction. U_p (Figure 41) generally follows the distribution of cerium (Figure 35) closely, due to the appreciable uranium content of monazite. However, this association does not account for the slight enrichment in uranium in the two samples from south of Smallbrook.

The U_f anomalies are more likely to reflect uranium-bearing mineralisation in the area. Anomalies of this type occur locally in the Solland area and in the east of the area, to the south-south-west of Thorverton (Figure 42).

Mercury

Hg was not determined by analysis, but cinnabar grains were identified in the pan at 4 localities for the first time in this area (Figure 7). At three sites, Deckport, Solland and Sandford, north of Crediton, (all in Permian catchments) Au was also recorded. At Honeychurch, near Solland, no Au was recorded and the cinnabar was in a stream partly draining Bude Formation rocks cut by north-east-trending lineaments and a similarly trending, mapped, fault.

GOLD GRAIN ANALYSIS

Composition of gold grains

Microchemical maps of internal chemical compositional variation and quantitative spot analyses of composition have been obtained from 54 gold grains from 23 sites at 11 of the 17 gold localities in the Crediton Trough and surrounding area. The localities where gold grains have not been examined are 2, 3a, 6, 12, 13 and 14 (Figures 6 & 7). A total of 23 out of 54 grains contained detectable palladium, up to a maximum of 3.1 % Pd usually present as irregular patches intergrown with pure gold and gold showing slight enrichment in silver (maximum 9.3 % Ag, but generally 0.6–2.1 % Ag). This is

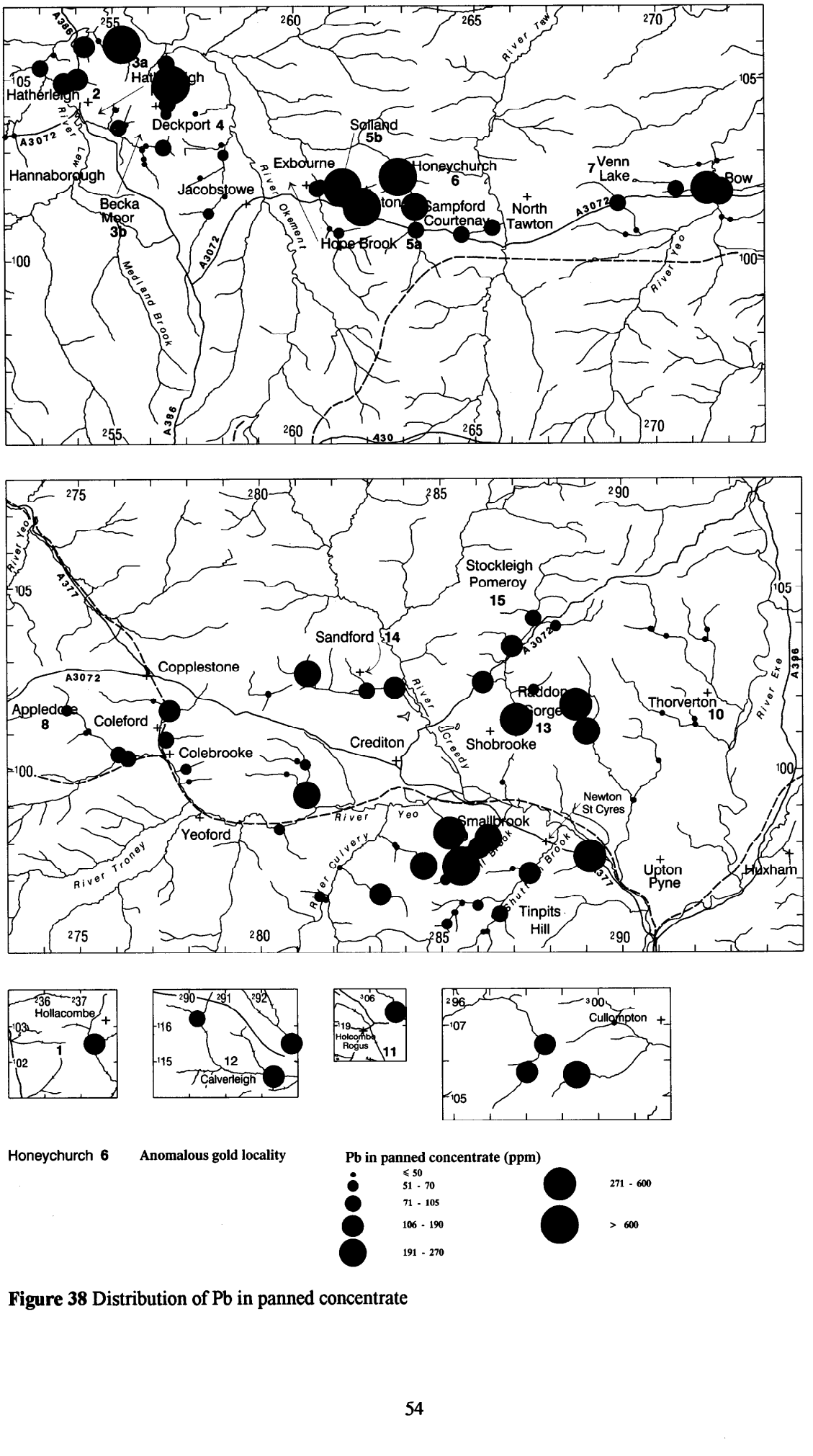


Figure 38 Distribution of Pb in panned concentrate

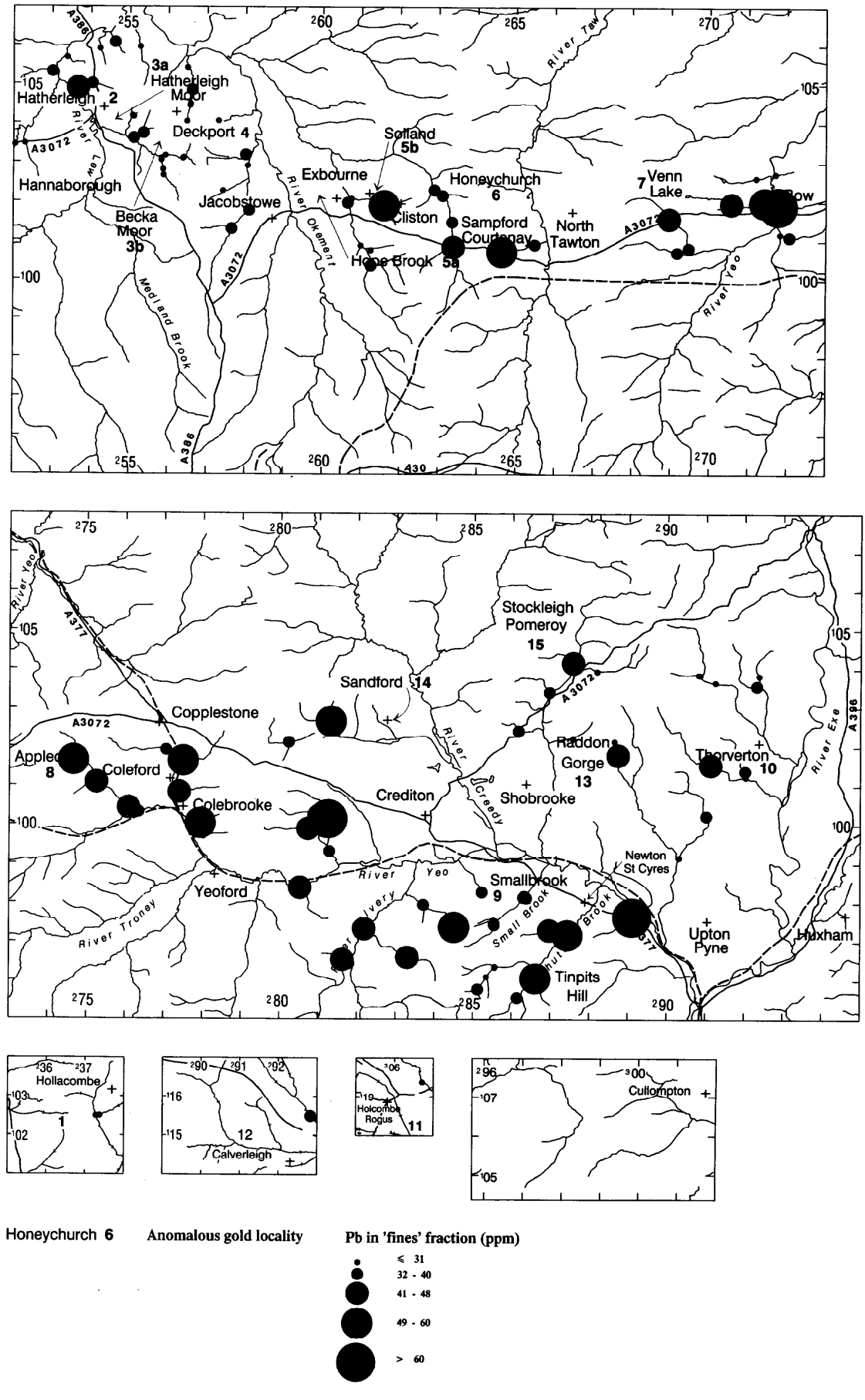


Figure 39 Distribution of Pb in 'fines' fraction

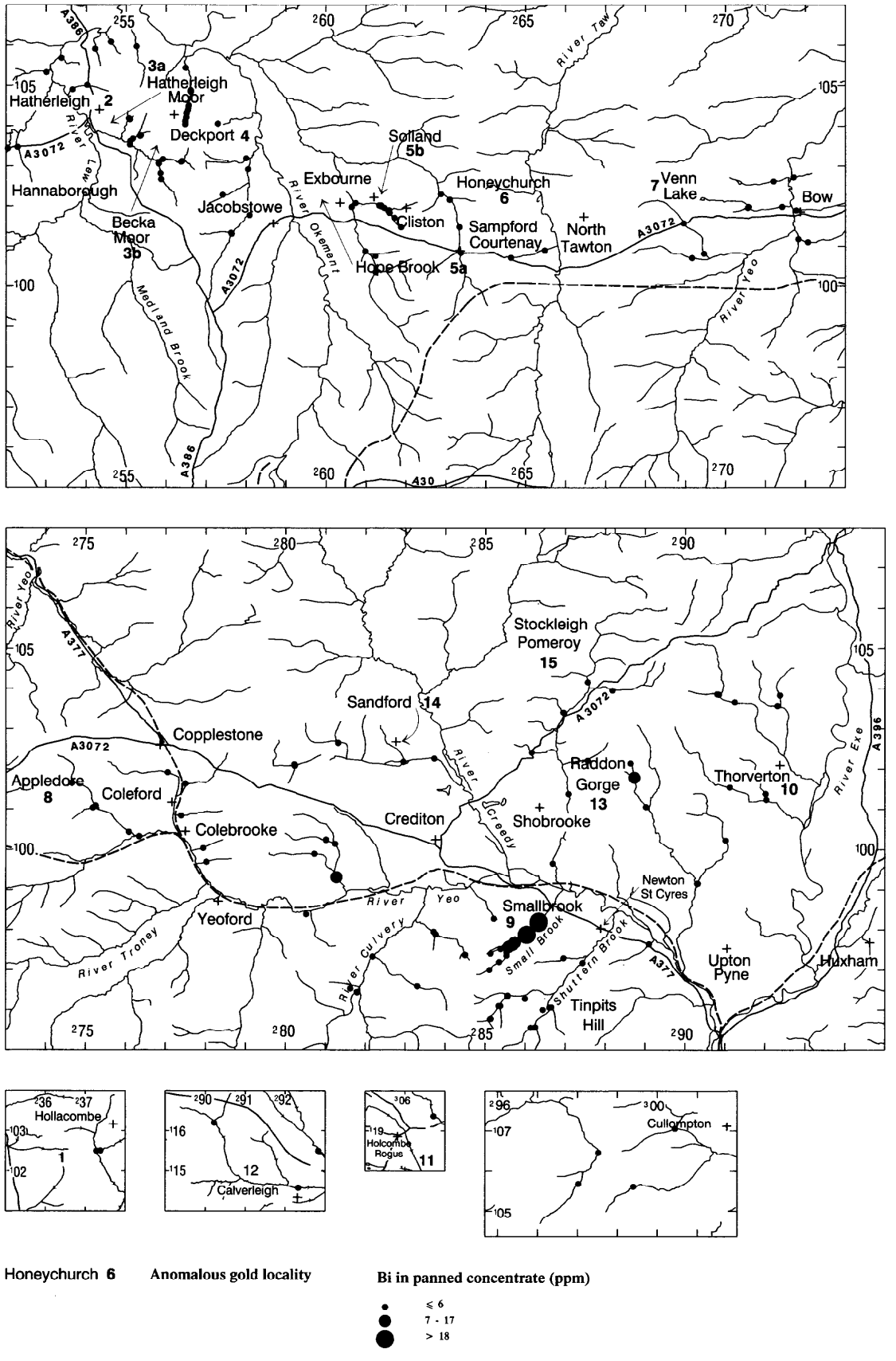
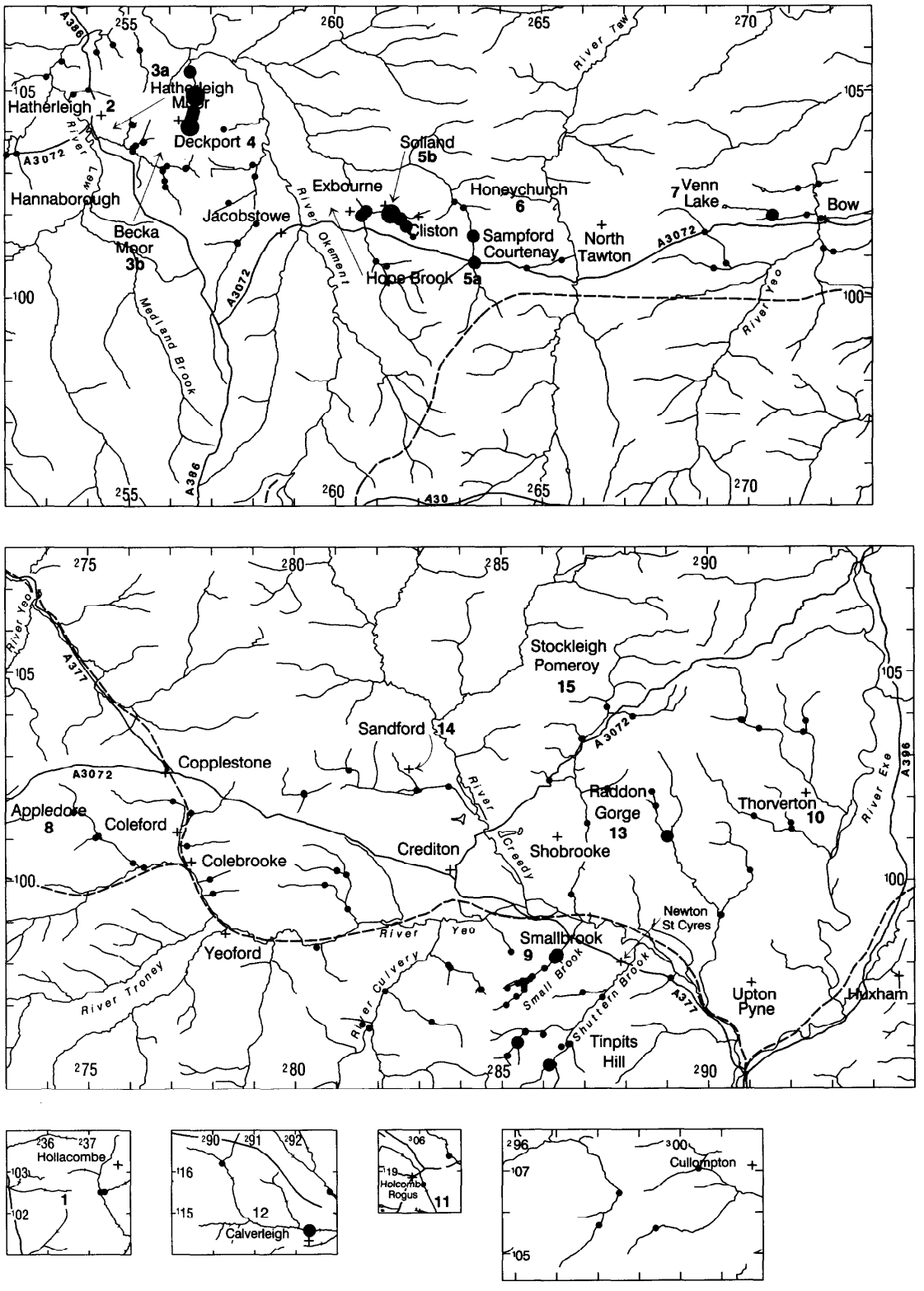


Figure 40 Distribution of Bi in panned concentrate



Honeychurch **6** Anomalous gold locality

U in panned concentrate (ppm)

- ≤ 6
- 7 - 14
- > 15

Figure 41 Distribution of U in panned concentrate

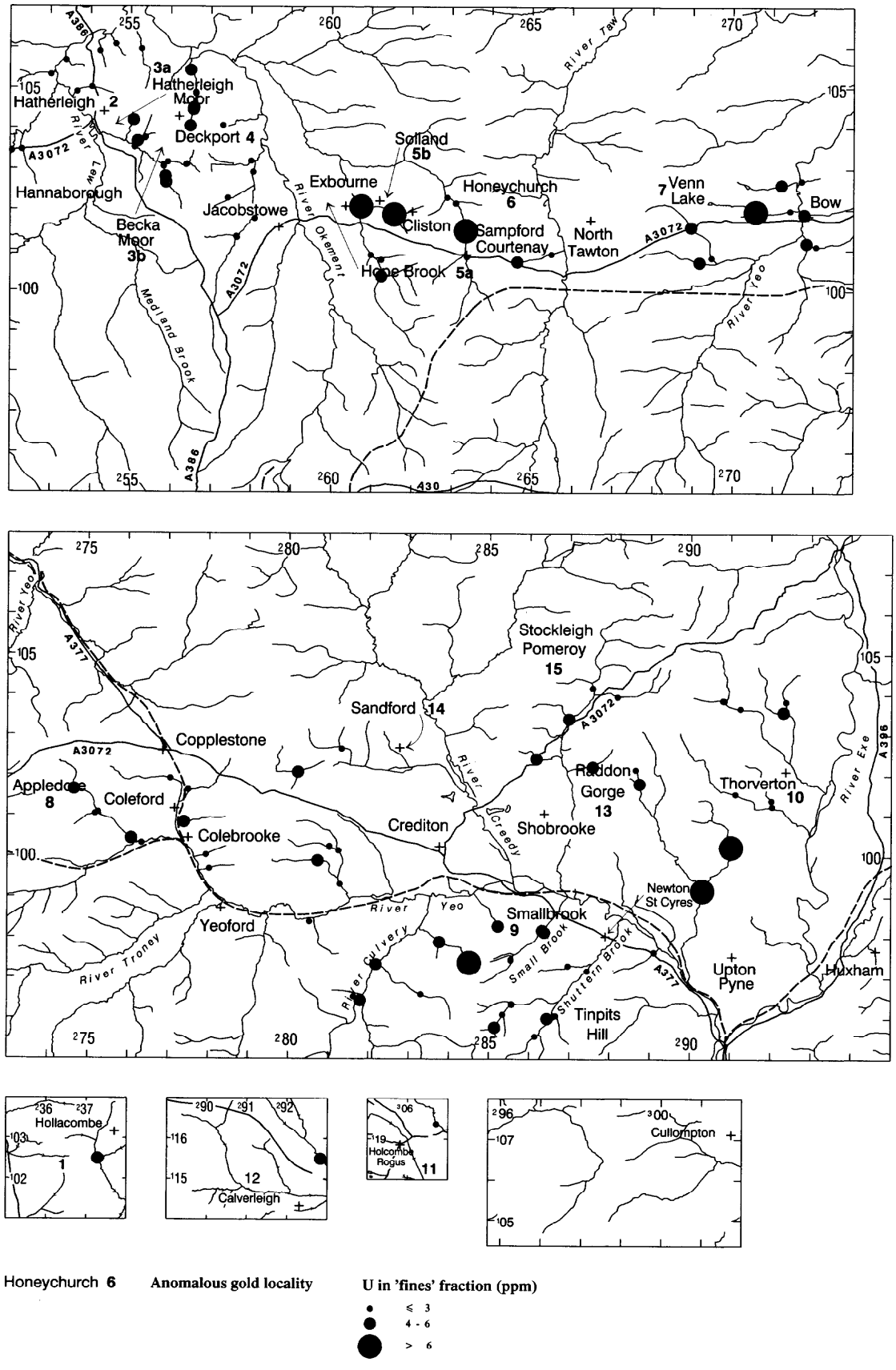


Figure 42 Distribution of U in 'fines' fraction

significantly less than the maximum Pd content of grains from South Devon (11.9% Pd). In 34 of the 54 grains, Ag-enriched gold occurs in anastomising films throughout the grains. In 3 grains more argentiferous gold (11.3–47.3 % Ag) occurs as films within pure gold and 3 further grains consist largely of argentiferous gold (3.5–5.6 % Ag).

Inclusions within gold grains

Inclusions have been located in 42 grains out of 54 examined from 21 sites covering 10 localities. The inclusions range in size from about 10 micrometres down to less than 1 micrometre. Most of the inclusions are less than 3 micrometres in longest dimension and several are at the limits of detection (< 0.5 micrometres). Quantitative determinations of the composition of inclusions have been made by using spot analyses, sometimes with the beam Kv reduced to lessen the volume from which X-rays are produced. In most cases total elimination of a component of X-rays from the gold grain matrix was impossible. Nevertheless, consistent ratios between elemental compositions were usually obtained where apparent gold contents derived from the matrix were less than 10 %.

At least fourteen different inclusion types were recognised and these are described in detail in Leake and Bland (in preparation). Over 40% of the inclusions are of palladium selenide with a composition close to $PdSe_2$, a new mineral. The second commonest inclusion is palladium telluride (probably merenskyite, $PdTe_2$). Tellurium-bearing minerals make up 27 % of the inclusions, the rest being almost pure selenides. Some 73 % of the inclusions are of palladium-bearing minerals. Lead and mercury only occur as single selenides, tiemannite and clausthalite respectively. In contrast, copper and bismuth occur both in single and complex selenides with palladium and with each other as metal alloys. Silver occurs only in complex selenides either with gold or with bismuth.

Inclusions occur in three ways within gold grains. Most of them occur in association with the Ag-enriched gold, occurring as thin films penetrating palladian gold or pure gold, or within grains consisting largely or entirely of argentiferous gold. In several grains, mapping at higher magnification reveals that many of the inclusions occur exactly at the interface between palladian gold and later non-palladian gold. Further details of the mode of occurrence of the inclusions is given in Leake and Bland (in preparation).

A clear correlation between the nature of the inclusions and the composition of the early gold is evident. In the vast majority of grains palladium-rich inclusions only occur in grains where the earlier gold is palladian. This observation indicates that palladium-rich inclusions are formed by reaction between later solutions which deposited non-palladian gold and the pre-existing gold. These solutions carried selenium, tellurium, silver, copper, bismuth, mercury and lead in different proportions in different parts of the area.

Both the overall chemistry of the gold grains and their associated inclusions vary from one locality to another within the Crediton Trough. Thus, palladian gold has not been found at Smallbrook or Thorverton, in the east of the area. The palladium content of a grain from Holcombe Rogus is appreciably higher (4.5–4.7 % Pd) than typical of grains from the Crediton Trough (average 2.2 % Pd) but similar to the palladium content of grains from many sites in south Devon.

Differences from one locality to another are more apparent in inclusion type, with tellurium-rich inclusions markedly concentrated at the western end of the Crediton Trough, particularly at Becka Moor. In addition Pb- and Bi-rich inclusions are far more abundant in grains from further north at Holcombe Rogus than in grains from the Crediton Trough itself.

Both the variation in overall grain chemistry and the variation in inclusion type could reflect zonation, on a regional scale, in the nature of the mineralising fluid but reflecting two different mineralising episodes. The cause of the variation in palladium content of the gold during the first mineralising event is uncertain. However, the occurrence of tellurides in association with gold is thought to indicate a magmatic component to the mineralising fluid (Afifi and others, 1988) and the restriction of such inclusions to a limited part of the Crediton Trough may indicate the location of the centre of the second phase of mineralising activity. Similarly, the relative abundance of Bi and Pb tellurides in the grains from Holcombe Rogus may indicate that fluids active in this area were lower temperature and more peripheral, with relative enrichment in Bi and Pb.

SATELLITE IMAGERY

Rationale behind Landsat TM interpretation

To provide a structural overview of the survey area, Landsat TM data were used to produce a rapid interpretation of the Crediton Trough and Tiverton Basin, based on geomorphology.

The aims were as follows:

1. To produce an interpretation of the TM imagery using topography and tonal features and to indicate possible geological explanations for these features.

2. To concentrate on those features which might provide new information and ideas related to the structural evolution of the area.

3. To consider how features detected in the TM data might relate to the known gold occurrences.

Landsat TM data from scene 203-025 had already been processed as part of routine UK coverage by the Remote Sensing Group of BGS. The data were acquired by Landsat on 30 October 1988; winter acquisition means that the sun angle is low and subtle topographic features are enhanced. Image processing was designed to further emphasise topographical information and consisted of geometric correction to the National Grid, edge-enhancement, contrast stretching and the writing of colour and black and white negatives using TM bands in the reflected infrared wavelength region. Both colour and black-and-white prints were produced from these negatives, to cover the survey area at 1:50,000 scale.

Results

Features mapped in the imagery include ridge-crests and scarps displaying a consistent, sinuous east-west pattern which may relate to the strike of more resistant beds. Straight incised valleys, stream sections, scarps and valley sides are mapped as lineaments (Table 4). As far as possible linear features of artificial origin were excluded from the interpretation by reference to OS base maps. A summary diagram of the results for the main Crediton Trough area is presented as Figure 43.

Lineaments

In the Crediton area and, less clearly defined, near Tiverton, east–west lineaments are broad, weakly defined features between similarly trending strong ridges. These are most common on the edges of the Trough. north–south lineaments, usually 1 km in length but occasionally up to 4 km, are more commonly found outside the Trough but those inside are widely spaced and cross-cut the major ridges. The most frequent lineaments have north-east and north-west trends, are usually closely spaced, and are rarely longer than 1 km. north-north-east and west-north-west lineaments are present both within and

outside the Crediton Trough and are most common in the Tiverton area. North-west lineaments lie parallel to the major Sticklepath fault zone and geological maps show many faults with similar trends. The lineaments occur in discrete sets, which suggests a geological explanation.

Table 4 Dominant lineament directions derived from Landsat TM image interpretation

	Trend	Description
1	**east–west**	parallel to strike of bedding, >1 km and relatively widely spaced
2	**north–south**	orthogonal to trend 1, >1 km and relatively widely spaced
3	**north-west**	parallel to strike of the Sticklepath Fault, <1 km and closely spaced
4	**north-east**	orthogonal to trend 3, <1 km and closely spaced
5	**north-north-east**	variable length and spacing
6	**west- north-west**	variable length and spacing

Ridges and Scarps

A distinctive set of sinuous east–west scarps and ridges occurs over the whole area. This may be an expression of more resistant sedimentary units, and represent dominant strike direction. Folds are seen in the coastal section near Bude, and landforms seen inland suggest that folding may occur throughout the Carboniferous and Permian strata.

At or near the boundaries of the two basins, longer east–west scarps and ridges are seen. In addition, a distinctive agricultural pattern occurs in the Crediton Trough, and there are near-circular scarps with dissected faces which occur in various of the breccia formations. These may relate to syn-depositional features, and do not occur in the Tiverton area.

Interpretation

The interpretation in Figure 43 mostly reflects the geology mapped in the recent 1:10,000 survey. For the late Carboniferous Bude and Crackington formations (Culm Measures) the lineaments reflect the dominant east–west fold axes, in places dissected by north-west–south-east and north–south faults. Within the Crediton Trough, in the ground underlain by Permian red beds, further east–west lineaments and scarps highlight the gently southward dip of the strata and the characteristic dip-and-scarp topography. Exceptions are the east-facing scarps to the west of Crediton in both Permian and Carboniferous strata; these may reflect the disturbance of a major north-north-west-trending fault complex which can be traced across the New Red Sandstone basin infill.

The prominent curved scarp shown to the west of Newton St. Cyres, near the Small Brook is problematic, possibly representing a feature such as a volcanic subcrop beneath Late Permian cover.

Correlation with gold anomalies

All gold anomalies lie on or near lineaments, usually the north-east-trending set. Some lie adjacent to the near-circular scarp features. It is suggested that if the lineaments represent fractures, then the north-east-trend may be more closely associated with mineralising pathways than other directions.

Further field work is required to determine the exact relationship between interpreted features and geology. A more detailed interpretation and map will be presented in Part 2 of this report.

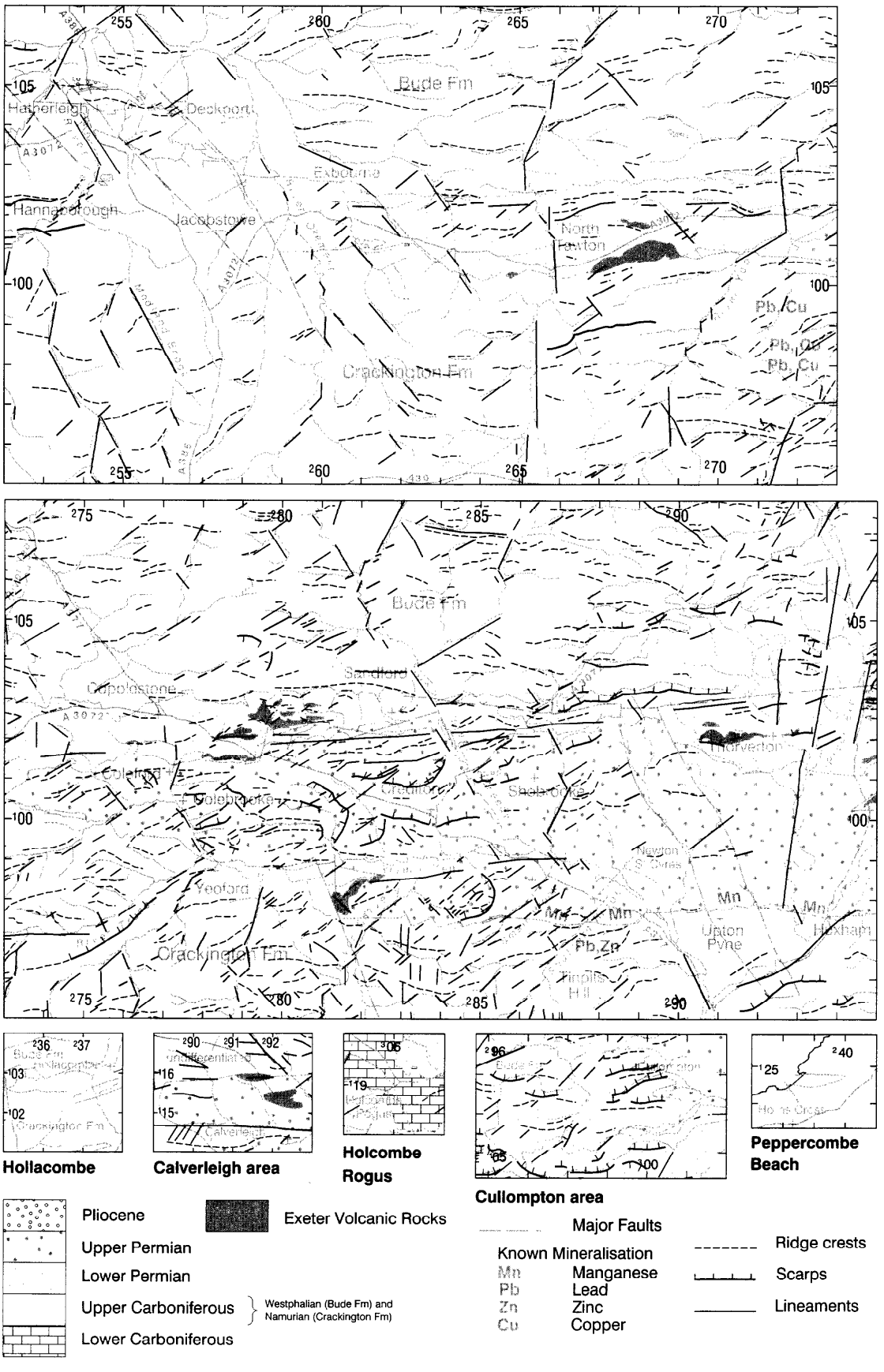


Figure 43 Distribution of dominant lineament, scarp and ridge crest directions derived from Landsat TM image interpretation

CONCLUSIONS

There are probably three main source environments of drainage gold anomalies. In the west of the area, where the outcrop of Permian rocks is discontinuous, there is clear evidence of an association of gold anomalies with the Permian sediments. Thus anomalies are derived from both sides of the outcrop of Permian rocks around Deckport. In this western area, gold could be derived from the basal unconformity of the local Permian sequence or from placer horizons within the basal sediments.

Gold is also present in sites in the Tiverton Basin and further north in the Permian outcrop near Wellington. Again gold may be derived from the unconformities between the Permian and the earlier Carboniferous strata, with the additional possibility of the more calcareous facies in this strata being a possible host.

Further east in the Crediton Trough there is evidence of an association of gold with the east–west boundary faults of the Crediton Trough. This is particularly evident for the high-amplitude anomaly near Honeychurch, on the northern boundary of the Permian rocks, and at Smallbrook at the corresponding southern boundary.

There are several gold occurrences well within the outcrop of Permian rocks in the Crediton Trough, at Venn Lake, Appledore and Thorverton. Gold at these sites could be derived from structures within the Permian sequence or from the basaltic lavas which magnetic evidence suggests underlie some of the eastern part of the Trough, including Thorverton (Cornwell and others, 1990).

Extensions to known base metal mineralisation were also seen, particularly along the contact of the Permian rocks with the Culm, where zinc and, to a lesser extent, lead anomalies are found in association with manganese. Two areas where this occurs are near Hatherleigh and south of Smallbrook, where further work is necessary to delineate the extent of the enrichments.

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