

British Geological Survey



Mineral Reconnaissance Programme

Exploration for gold in the
Crediton Trough, Devon.
Part 2: detailed surveys

Department of Trade and Industry

MRP Report 134
Technical Report WF/94/13

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and D J Bland

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This report was prepared for the
Department of Trade and
Industry

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

Bibliographical reference

**Leake, R C, Cameron, D G,
Scrivener, R C, and Bland, D J.**
1994. Exploration for gold in
the Crediton Trough, Devon.
Part 2: detailed surveys. *British
Geological Survey Technical Report
WF/94/13 (BGS Mineral
Reconnaissance Programme Report
134).*

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This report relates to work carried out by the British Geological Survey on behalf of the Department of Trade and Industry. The information contained herein must not be published without reference to the Director, British Geological Survey.

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

Keyworth, Nottingham NG12 5GG

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SUMMARY

This report describes the results of geochemical sampling to trace the source of three groups of high-amplitude gold anomalies in panned drainage sediment within the outcrop of the Permian (New Red Sandstone) sedimentary rocks of the Crediton Trough. The sites for follow-up were chosen after appraisal of regional-scale survey data described in the previous report (Cameron et al., 1994). They comprised the Deckport and Solland areas at the western end of the Crediton Trough, and the Smallbrook area adjacent to the faulted southern margin of the Permian rocks some 20 km further east. This work consisted of more detailed drainage sampling and reconnaissance overburden sampling at all three sites, augmented by detailed overburden sampling and the mechanical excavation of a series of pits and trenches at Smallbrook. Microchemical mapping of gold grains from drainage sediment and from excavations in overburden aided the interpretation of the origin of the gold.

At Deckport, where the Bow Breccia (Early Permian) is in faulted contact with the Crackington Formation (Late Carboniferous), follow-up sampling indicated strongly that the major source of gold was the Bow Breccia. Telluride inclusions were more frequent in the gold grains from the southern part of the Permian outcrop, than in gold from most other sites in the Crediton Trough. This may indicate that the source is related to a nearby centre of igneous activity, the root of which may be marked by the lamprophyric dykes and vent agglomerate south and south-west of Hatherleigh.

The Solland area is immediately east of the trace of a component of the Sticklepath–Lustleigh Fault. Gold persists in drainage sediment towards the southern, faulted contact of the Bow Breccia with Bude Formation (Late Carboniferous) strata to the south. Overburden sampling across the trace of a fault to the east of Solland, parallel to the Sticklepath–Lustleigh Fault, indicated that the gold was not associated with this fault but occurred in alluvial terrace material derived from further south. However, the analysis of overburden samples indicated high values of uranium associated with this fault.

At Smallbrook, where the highest-amplitude drainage enrichments in gold had been found, further sampling showed a sharp cut-off for gold just north of the boundary fault with the Crackington Formation. The gold grains from the Small Brook differ from grains from other locations in the Crediton Trough in being finer grained, generally rounded, not enriched in palladium and with fewer and smaller inclusions. Gold was found physically and by analysis in panned overburden pit samples at several sites to the south-east of the Small Brook, particularly in the residual overburden derived from the Newton St Cyres Breccia (Late Permian), to a maximum of fourteen grains from one site. Trenching and pitting confirmed that the shallow overburden samples closely reflected the weathered bedrock beneath. Gold was found (12–35 ppb Au) in several unpanned <0.5 mm fraction samples, but no highly anomalous levels were detected. Microchemical mapping of a gold grain extracted from Newton St Cyres Breccia showed internal chemical characteristics and inclusions identical to grains from the alluvium of the Small Brook, and may indicate an igneous association. The horizontal and vertical distribution of gold in the overburden and weathered bedrock indicate that it is widely dispersed in the Newton St Cyres Breccia in the form of a fossil placer. The source of the gold is probably the older Permian sequence, within which a rich source of mineralisation may exist to the west of Smallbrook. Excavations in alluvium adjacent to the Small Brook indicate the widespread presence of gold (maximum 1180 ppb Au in panned material) from above 1.0 m.

Three grains of gold extracted from core from the faulted contact between Permian and Carboniferous rocks in the Upton Pyne Borehole, 5 km east of the Small Brook, were similar in chemistry, but not in shape, to grains from the Small Brook. This discovery reinforces the potential for gold mineralisation close to the contacts, both faulted and unconformable, of the Permian red-bed sequence in Devon.

Further work, including drilling, is recommended to determine the concentration of gold in the basal Permian rocks and to determine the potential and controls exerted by Permian igneous rocks on the mineralisation.

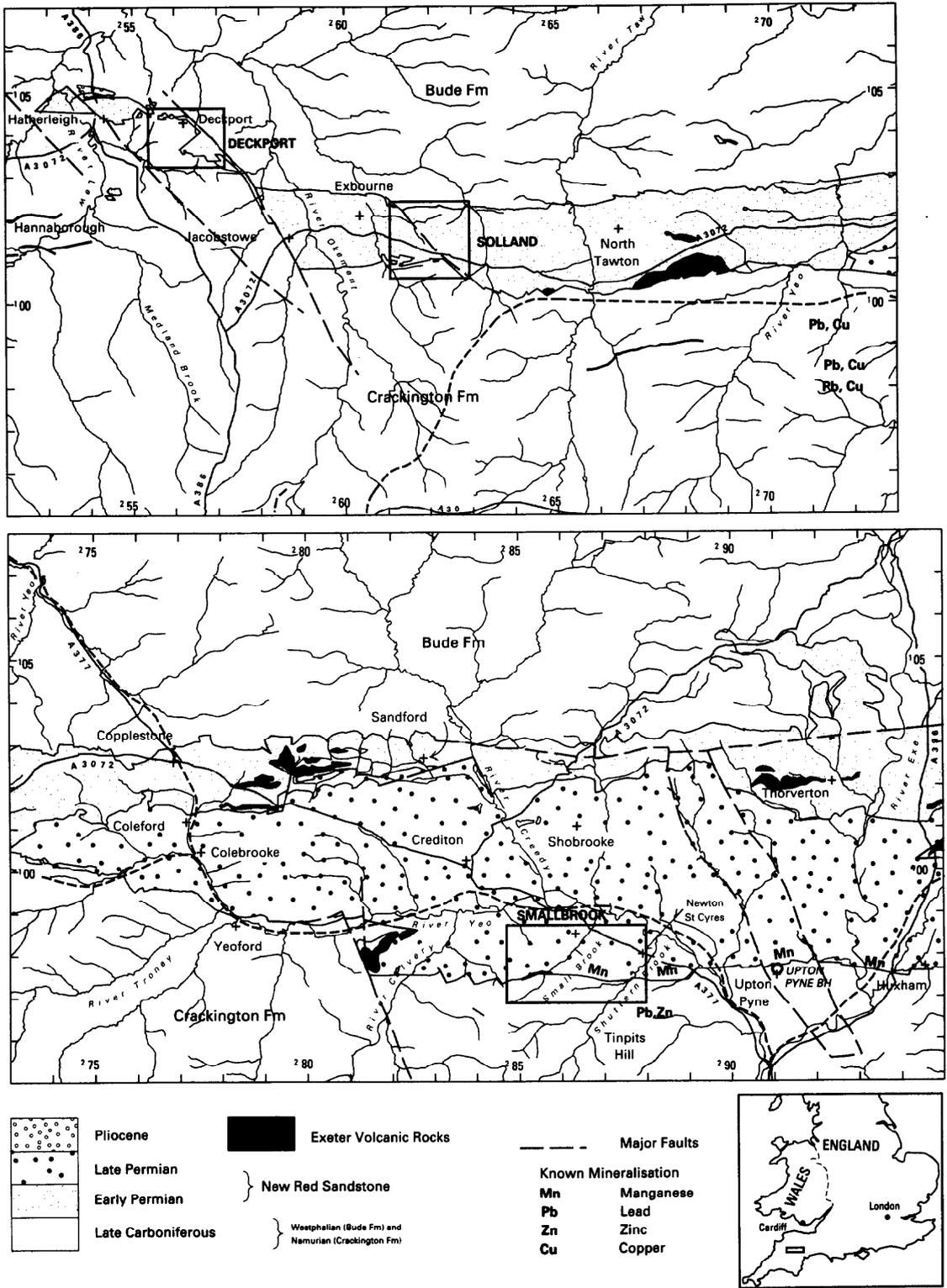


Figure 1 Simplified geological map of the Crediton Trough and location of the survey areas

INTRODUCTION

The Crediton Trough is an area of Permian (New Red Sandstone) breccias, sandstones and volcanic rocks downfaulted against Late Carboniferous shales and sandstones (the Culm Measures) in south-west England (Figure 1). Regional surveys described in Mineral Reconnaissance Programme Report 133 (Cameron et al., 1994) reported the presence of gold in drainage at a number of sites along the Permian outcrop, and three areas with the highest amplitude gold anomalies were chosen for further exploration work; Solland, Deckport and Smallbrook.

The follow-up work comprised closely spaced drainage sampling, overburden sampling using a hand auger along traverses, bulk overburden sampling at selected sites by manual pitting and, at Smallbrook, a programme of deep overburden or weathered rock sampling using a JCB backhoe excavator. In addition, core samples were examined from a borehole at Upton Pync, about 5 km to the east of Smallbrook, which intersected Permian strata and the underlying Carboniferous rocks. Since the borehole passed through an environment thought to be favourable to the occurrence of gold-bearing mineralisation, samples were crushed and heavy minerals separated in a search for gold grains.

Geochemical data collected during this project are held on a relational database and can be retrieved in a variety of formats for customers' own use: details are available from the Database Manager, Minerals Group, BGS Keyworth.

DETAILED DRAINAGE SURVEYS

The first stage of follow-up work comprised the collection of closely spaced samples of drainage sediment, to augment the samples collected during the regional survey. Only panned concentrate samples were obtained, as described previously (Cameron et al., 1994). Samples were examined mineralogically and gold grains recovered from samples where found. Subsequently, the samples were ground and a 60 g subsample was analysed for gold by acid digestion followed by solvent extraction and Atomic Absorption Spectrometry (AAS) at Analabs, Inchcape Testing Services (UK) Ltd, St Helens. An additional 12 g split was pelletised and analysed for Ca, Ti, V, Mn, Fe, Ni, Cu, Zn, As, Y, Zr, Nb, Mo, Ag, Sn, Sb, Ba, Ce, W, Pb, Bi and U by X-Ray Fluorescence Spectrometry (XRF) at the BGS Analytical Geochemistry Laboratories, Keyworth.

Extracted gold grains were weighed, then mounted on slides, sectioned and polished before microchemical mapping was carried out using the Cameca SX50 electron microprobe as described in Leake et al. (1991). Gold concentrations are derived from a combination of chemical analysis and grain weighing.

Deckport area

The gold contents of the closely-spaced panned concentrate samples collected in the Deckport area are shown on Figure 2. In this area, which is at the extreme western end of the Crediton Trough (Cameron et al., 1994), the Early Permian rocks comprise an outlier of the Bow Conglomerates (Edmonds et al., 1968), now termed the Bow Breccia (Edwards and Scrivener, in press). Typically, these rocks consist of fine and coarse red conglomerate and breccia with local interbeds of sandstone. The breccia clasts include subangular to rounded Culm sandstone, vein quartz, hornfels and lamprophyric and felsitic igneous rocks. The outcrop of these rocks comprises an irregular sheet resting on the deformed Late Carboniferous Crackington Formation, and a narrow north-west-trending area between two parallel faults, which in the north of the area turns to west-north-west. Gold was recovered from all sample sites downstream of the narrow Permian outcrop for a distance of about 800 m northwards (Figure 2). Gold is absent from the uppermost sample from this stream, collected very close to the western boundary of the Bow Breccia, which is a strong indication that these Permian rocks are the source of the gold.

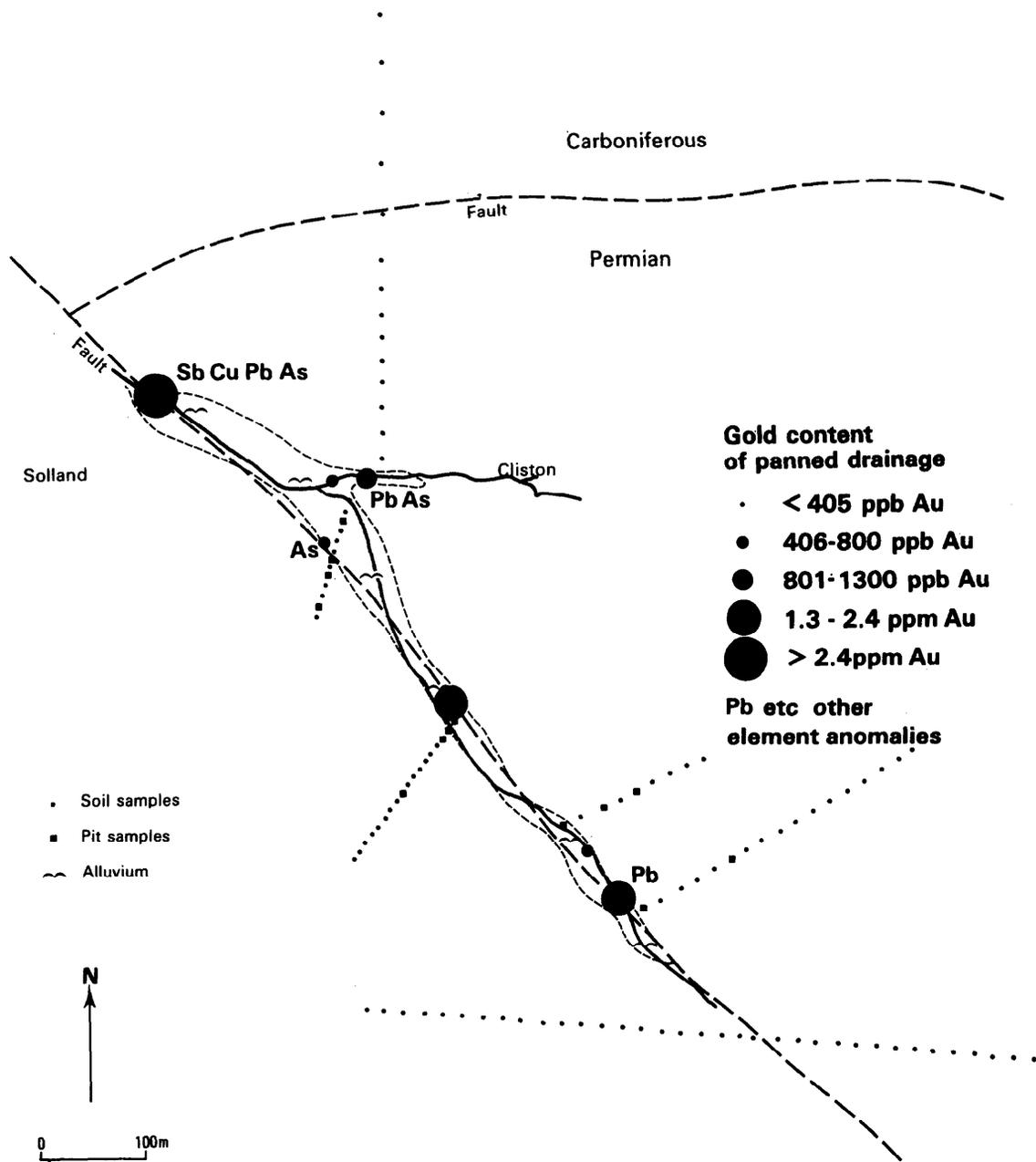


Figure 3 Gold content and base-metal anomalies in panned drainage sediment at Solland. See Figure 1 for location of area

However, the fact that gold contents do not decrease away from the Permian outcrop could indicate that another source, possibly a structure which the stream follows, may also exist. Such a structure is the most reasonable explanation of the base-metal anomalies which are also present in the samples. The cut-off of the base-metal anomalies is between the 6th and 7th sites from the north, below the cut-off for gold (Figure 2). The stream draining south from the Bow Breccia outcrop is also highly anomalous in gold. The presence of a smaller amount of gold in the other tributary draining from the Crackington Formation to the east suggests that another source of gold could exist unconnected with the outcrop of the Permian rocks. Nevertheless the drainage data clearly indicate that the outcrop of Permian rocks is the major source of the gold.

Microchemical mapping of sixteen gold grains from drainage samples north and south of the Permian outcrop showed that the internal chemical characteristics of most of the grains from each side of the Permian outcrop are broadly similar, with grain cores either with patches showing variable enrichment in palladium (maximum 2.9 % Pd) or essentially pure gold. Gold with a small amount of silver (0.7–4.3 % Ag) but no palladium is either intimately intergrown with the palladian gold or occurs as films penetrating through the grain. One grain contains films and patches with a much greater silver content (maximum 47.3 % Ag). Inclusions are often abundant and relatively coarse grained (up to 10 μm). They comprise palladium selenide, palladium selenotelluride, copper palladium selenide, copper selenide, tiemannite (HgSe), bismuth selenide and fischerite (Ag_3AuSe_2). There is a higher proportion of Pd, Ag and Te minerals in the grains from the south of the Permian outcrop than in grains from the north.

The relative abundance of tellurium-rich inclusions compared with most other sites in the Crediton Trough may indicate that the gold grains from the south of the area are derived from a centre of igneous activity (Afifi et al., 1988) which may control the temperature and intensity of the mineralising event. The manifestations of this igneous activity could have largely been eroded away leaving sub-volcanic dykes or a pipe at the present level of erosion. The area to the south and south-west of Hatherleigh is the locus of several lamprophyre dykes, and a vent agglomerate occurs at Hannaborough, 2 km south-west of Hatherleigh (Figure 1).

Solland area

The Solland area (Figure 3) is located towards the western end of the main outcrop of Permian rocks (Figure 1) forming the Crediton Trough (Cameron et al., 1994) and is underlain by Early Permian Bow Breccia. To the north, the Bow Breccia is in faulted contact with folded sandstone and shale of the Bude Formation of Late Carboniferous age. A short distance to the east, the ground is traversed by a component of the Sticklepath–Lustleigh Fault complex which trends north-west–south-east and has a right-lateral displacement of some 500 m.

The amount of gold in the drainage persists as the main stream is traced towards its source to the south-east of Solland (Cameron et al., 1994). All but one microchemical maps of eight gold grains show irregular patchy enrichment in palladium (range of maxima 0.7 % to 4.4 % Pd). Boundaries between palladium-rich and palladium-poor gold are generally diffuse and there is gradual variation within the palladium-rich patches. These patterns of palladium distribution are unlike the sharp variation in palladium seen in several gold grains from south Devon (Leake et al., 1991) and suggest that diffusion may have taken place. This in turn suggests that the grains were subjected to higher temperatures than the corresponding palladium-rich grains from south Devon. Most of the grains also contain thin films showing absence of palladium and very slight enrichment in silver (maximum 0.9 % Ag). Inclusions are conspicuous in most of the Solland grains and consist, in order of abundance, of palladium selenide, palladium selenotelluride, palladium telluride, mercury selenide, copper-palladium selenide and copper selenide. Two of the grains mapped at higher magnification ($\times 2000$) show in a striking way that the inclusions adhere to the surface of palladium-rich gold and are enclosed by the film of palladium-poor gold. This distribution of inclusions suggests that they were formed by reaction between a solution carrying gold together with Te, Se and other elements, and the palladian gold. The gold grains from this stream contain a relatively high proportion of tellurium-rich inclusions though not as high as in grains from the stream to the south of Deckport.

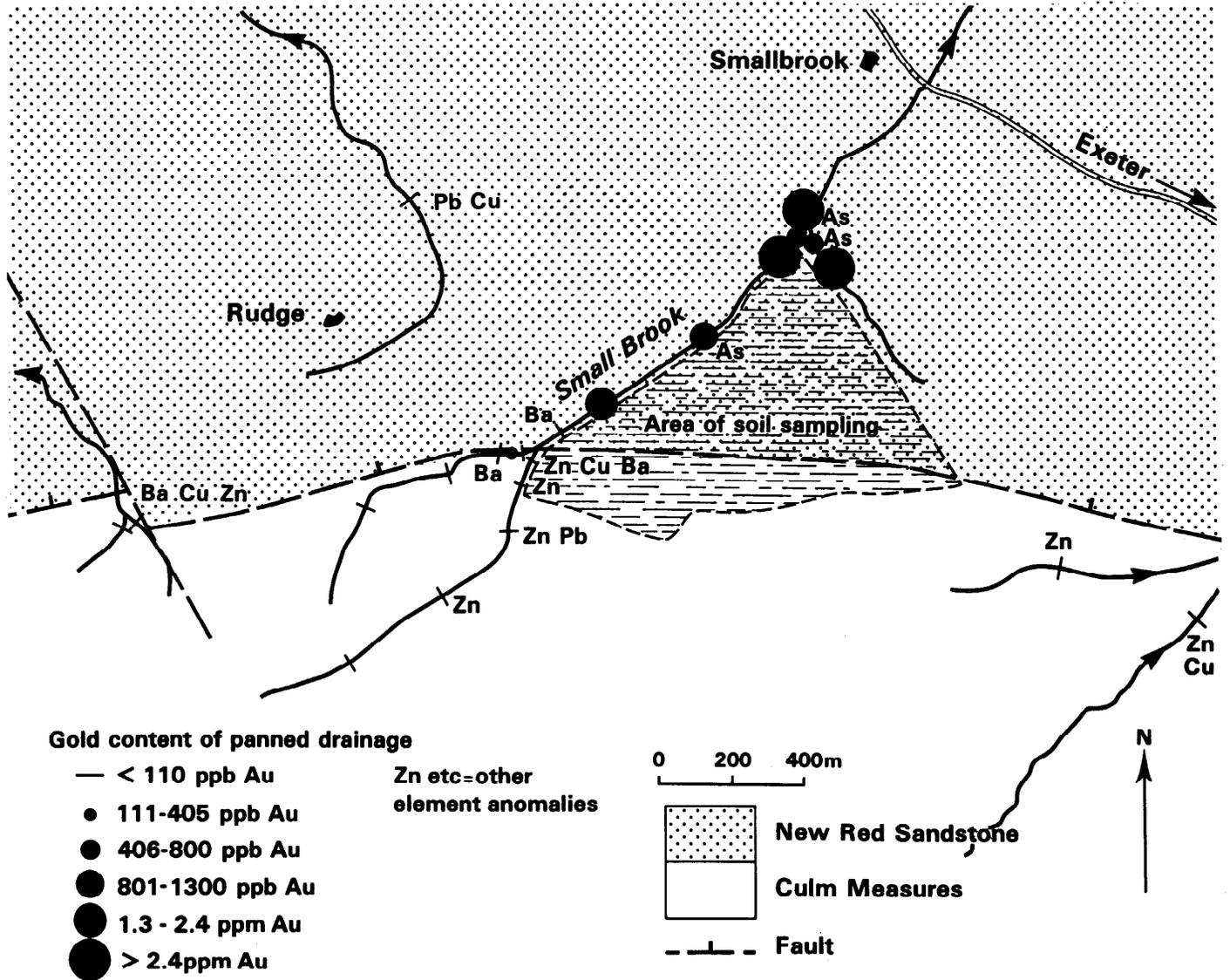


Figure 4 Gold content and base-metal anomalies in panned drainage sediment, and area of soil sampling at Smallbrook. See Figure 1 for location of area

Smallbrook area

The Smallbrook area (Figure 4) is traversed from west to east by the faulted southern boundary of the Crediton Trough. To the north are undeformed red beds of Late Permian age, the Newton St. Cyres Breccia, and to the south, strongly folded shales and sandstones of the Late Carboniferous Crackington Formation. In the vicinity of the Small Brook, a small outcrop of reddish-brown, clay-rich fine sand has been mapped adjacent to the boundary fault beneath the Newton St. Cyres Breccia. Manganese extraction was carried out in the south of the survey area, along part of the contact between the red beds and the Culm measures (Figure 1).

The distribution of gold in drainage concentrate samples from the Smallbrook area is shown in Figure 4. Gold is confined to the catchment of the Small Brook and shows a distinct cut-off in the upper part of that stream. Enrichment in As is associated with some of the auriferous samples. In contrast, base-metals and Ba are enriched in several of the samples from the upper part of Small Brook and in adjacent streams. Soil samples were collected from a grid on either side of the cut-off of gold in drainage, as shown in Figure 17.

The gold grains from the drainage samples at this locality are rounded and relatively fine grained compared with other localities in the Crediton Trough. Microchemical maps of polished mounts of 17 gold grains from several of the anomalous sites in the Small Brook have been produced. Compositionally, the grains differ from gold grains from other localities in the Crediton Trough in the absence of enrichment in palladium. All grains consist of a core essentially of pure gold within which, in most grains, there are films and patches showing slight enrichment in silver to a maximum of 2.5 % Ag. In two grains the content of silver in patches is greater (maximum 11.5 % Ag). Two other grains show silver enrichment in a distinct rim (maximum 3.2 % Ag) rather than as films and patches within the body of the grain. Inclusions are present in 12 of the mapped grains, but they are noticeably less abundant and smaller in size (maximum 1 μm) than in grains from other localities in the Crediton Trough. Palladium telluride is the commonest inclusion and there are isolated grains with inclusions of tiemannite (HgSe), a copper selenide of unknown composition and palladium and other selenides. The inclusion assemblage is similar to that found in grains from Deckport, and thus also suggests some relationship of the source to igneous activity.

OVERBURDEN SAMPLING

Three methods of overburden sampling were carried out during the follow-up surveys.

(1) Orthodox soil or shallow overburden samples were obtained by hand auger from depths of above 1 m in all three areas. The soil samples were dried and sieved, then a 12 g subsample of the -80 mesh fraction analysed by XRF for Ti, Mn, Fe, Ni, Cu, Zn, Rb, As, Sn, Pb and U at BGS Analytical Geochemistry Laboratories. These samples, by virtue of their small size are unsuitable for the assessment of gold distribution in overburden, but the element concentrations determined provide geochemical maps of the areas to assist in the interpretation of the of the local geology, and to establish whether pathfinder-element anomalies exist.

(2) At certain sites, pits were dug by hand to depths between 0.7 and 1 m and a bucket full of material from the base of hole, including the coarse fragments, was sieved and the -2 mm mesh fraction panned down to constant volume of about 100 ml to establish whether visible gold was present. Subsequently, the panned samples were mineralogically examined for gold and other grains, followed by subsampling and milling to provide 50 g samples for gold analysis at Analabs Inchcape Testing Services by AAS and 12 g subsamples for Ti, Fe, Ni, Cu, Zn, Y, Zr, Sn, Sb, Ba, Ce, W and Pb by XRF at the BGS Analytical Geochemistry Laboratories. At Deckport and Solland, Ca, Mn, V, Nb, Mo, Ag, Bi and U were analysed in addition to the elements listed above.

(3) Deep trenching and pitting using a JCB Sitemaster 125 backhoe excavator were carried out in the Smallbrook area, with samples collected at various depths in each excavation, including the bases. Large bulk samples of between 10 and 40 kg were collected, a few being subsampled and panned. Concentrates were then mineralogically examined and any gold grains removed.

Most of the bulk samples were sieved and the -0.5 mm fraction further subsampled for gold analysis at Analabs Inchcape Testing Services by AAS and other elements, Ti, Mn, Fe, Cu, Zn, As, Sn, Ba, Zr, Bi, Pb and U by XRF at BGS Analytical Geochemistry Laboratories.

Extracted gold grains were weighed, then mounted on slides, sectioned and polished, before microchemical mapping was carried out using the Cameca SX50 electron microprobe as described in Leake et al. (1991). Gold concentrations are derived from a combination of chemical analysis and grain weighing.

Deckport area

One line was sampled across the outcrop of the Permian rocks in the Deckport area comprising 27 soil auger sampling sites, three of which were also the site of pits (Figure 5). In addition, five shallow overburden and panned samples were taken from near the base of a sunken track running approximately east-west (Figure 5). Maps showing the distribution of Ti, Mn, Fe, As and Rb in the soil samples are shown in Figures 6 to 10.

The results suggest that the Carboniferous rocks are richer in Ti (Figure 6) than the Permian rocks. Of particular interest is the higher Ti contents of the soils from the western part of the line, as this may reflect differences in the nature of the Permian sediments. This part of the outcrop is potentially the source of the gold, rich in telluride inclusions, which was recovered from the drainage to the south of the Permian outcrop. These rocks could represent the basal part of the sequence, which is possibly the most prospective in this area.

Mn concentrations in the overburden samples are low (Figure 7), except in the region just to the north of Deckport Farm where they reach a maximum of 7060 ppm. Since there is no corresponding enrichment in the concentrate sample from the same site (1719 in Table 1), it is probable that the Mn is derived from the weathering of carbonate which may be controlled by the faulting in this area. Fe contents are significantly lower in samples derived from the Permian rocks than in those derived from the Carboniferous rocks to the north-east (Figure 8). The sample from the western end of the line is distinctly richer in Fe (10.9 %) than all the other samples and also shows a higher level of Ni. This could reflect a small amount of basic volcanic material in the rock, perhaps as fragments in the basal breccias. As levels are lowest over the Carboniferous rocks and highest at the western end of the line (Figure 9) where they reach a maximum of 135 ppm. The sharp drop in the As levels as the line is traced to the east (Figure 9) coincides with the decrease in Ti levels which probably marks a change in the nature of the underlying Permian strata. A marked change in Rb contents of soil samples is also evident at the same point (Figure 10).

Table 1 Analyses of panned pit samples from Deckport

<i>Sample</i>	<i>1702</i>	<i>1704</i>	<i>1707</i>	<i>1715</i>	<i>1716</i>	<i>1717</i>	<i>1718</i>	<i>1719</i>
Ti %	0.90	0.47	0.40	0.45	0.43	0.63	0.37	0.45
Mn ppm	1050	540	1680	670	400	450	280	450
Fe %	8.26	5.48	5.17	4.08	3.31	3.51	3.23	3.09
As ppm	85	85	19	71	58	46	59	60
Zr ppm	689	294	272	380	352	673	284	343
Nb ppm	28	17	10	14	15	22	14	18
Sn ppm	240	141	6	33	16	47	14	16
Ce ppm	239	113	61	90	119	153	108	119

Shading in table shows sample derived from Carboniferous rocks

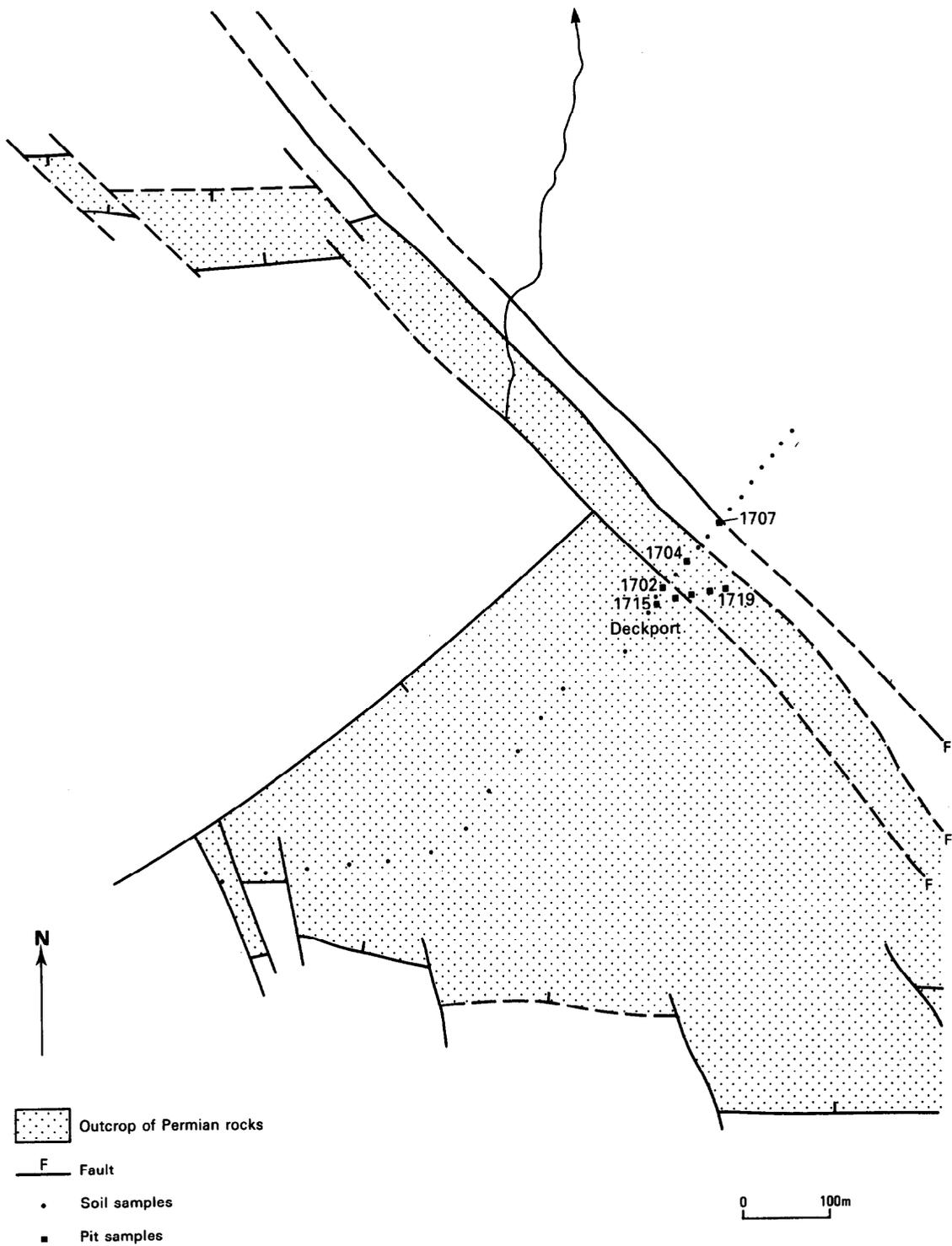


Figure 5 Geology and location of soil and panned pit sampling at Deckport.
See Figure 1 for location of area

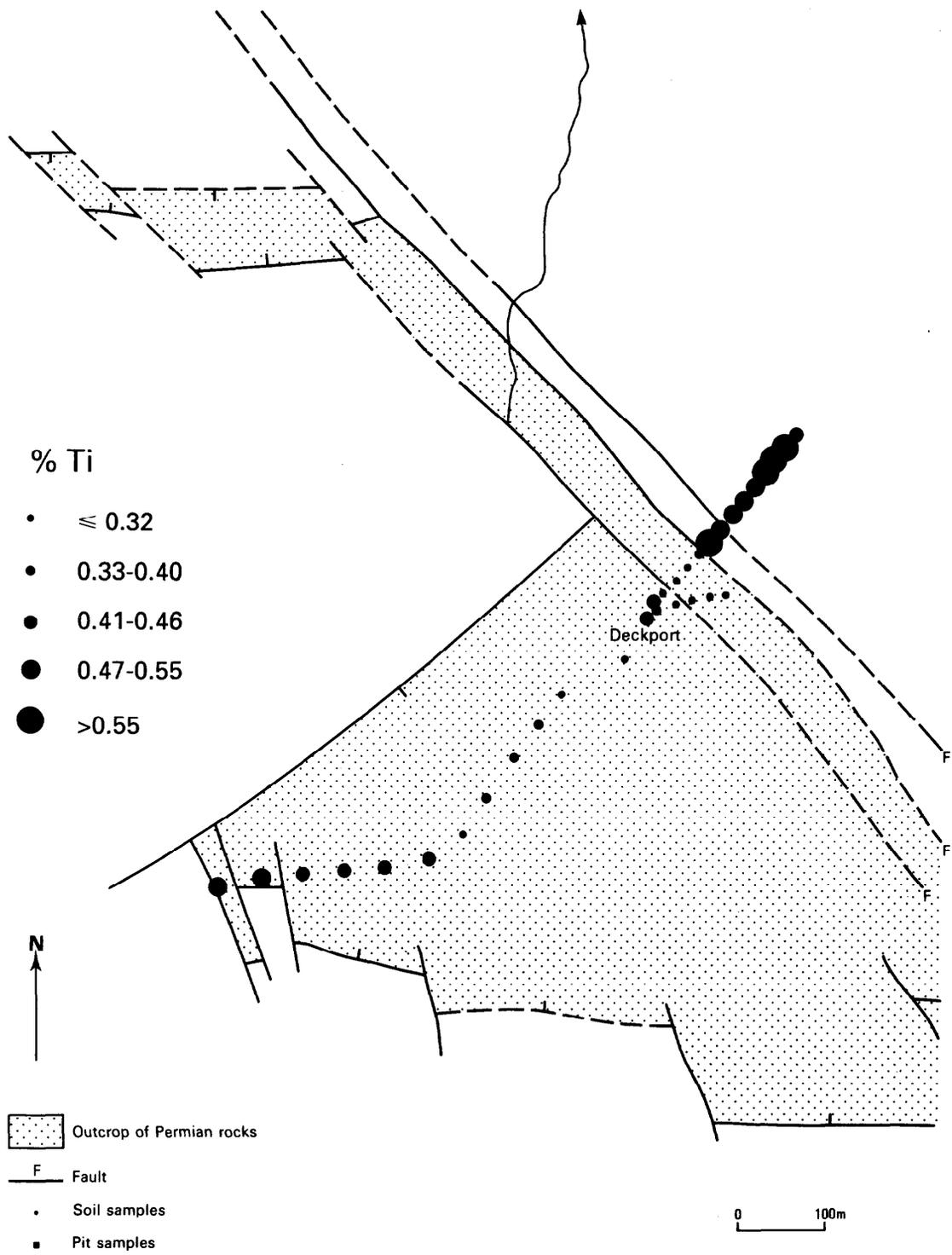


Figure 6 Ti in soil samples at Deckport

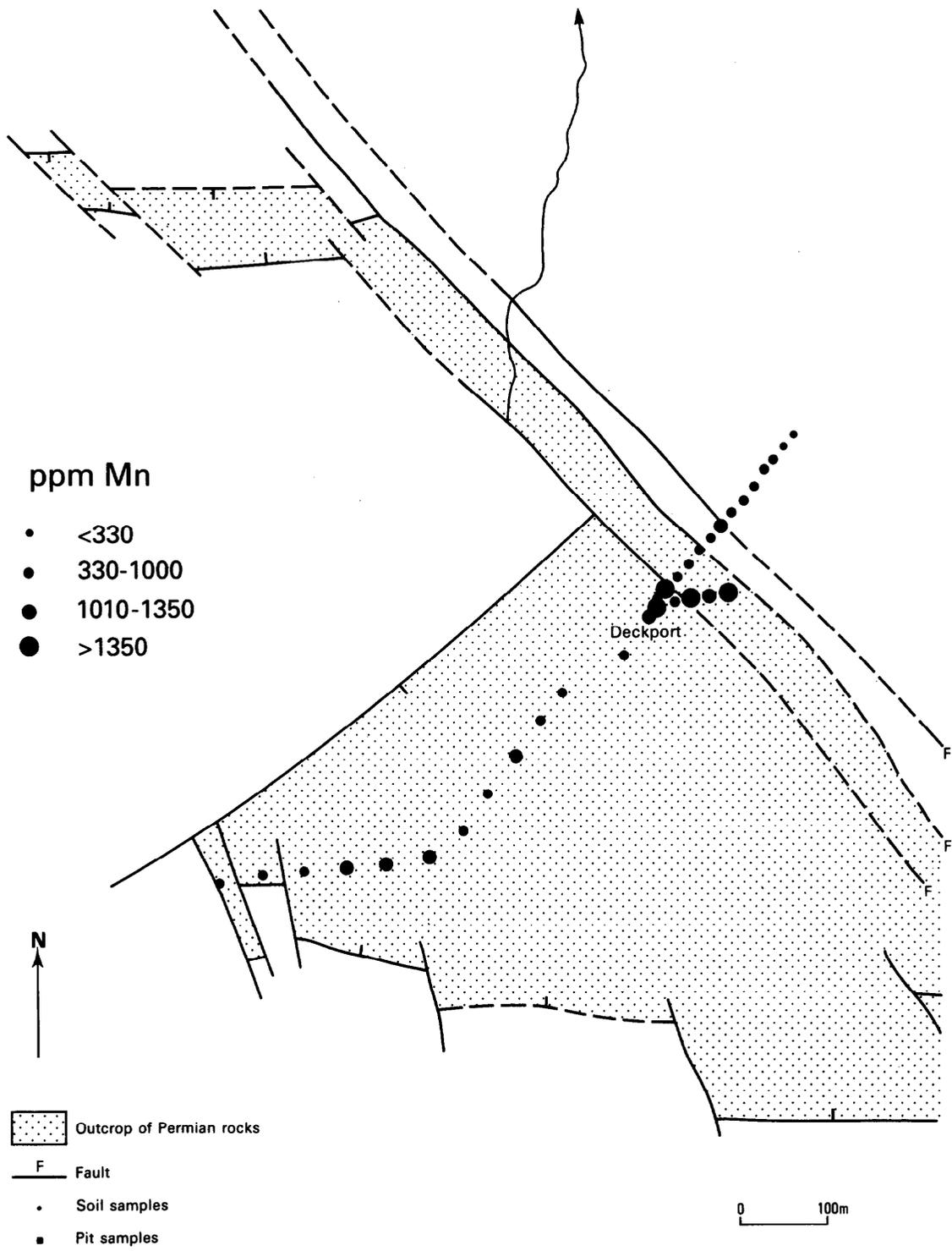


Figure 7 Mn in soil samples at Deckport

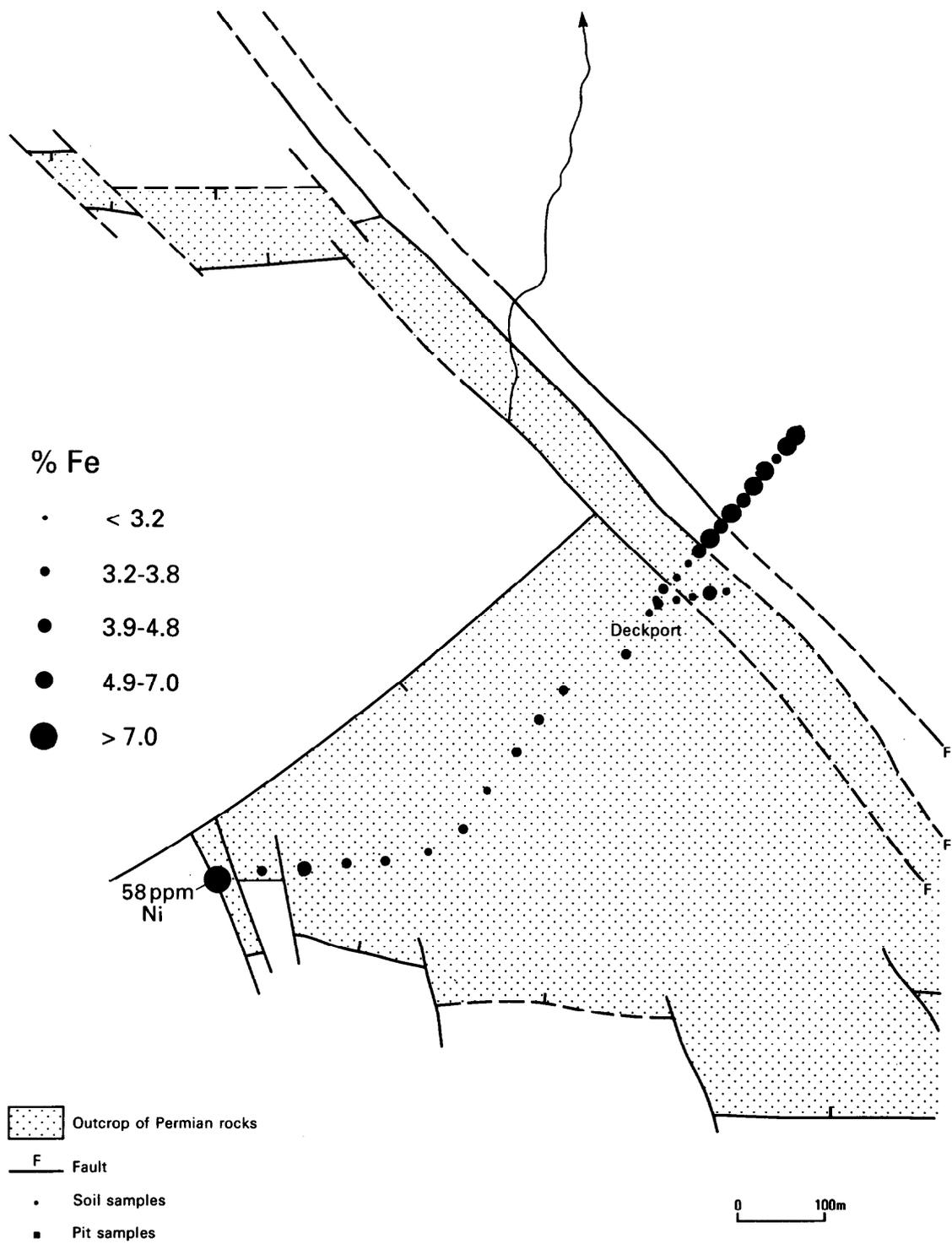


Figure 8 Fe in soil samples at Deckport and sample with highest level of Ni

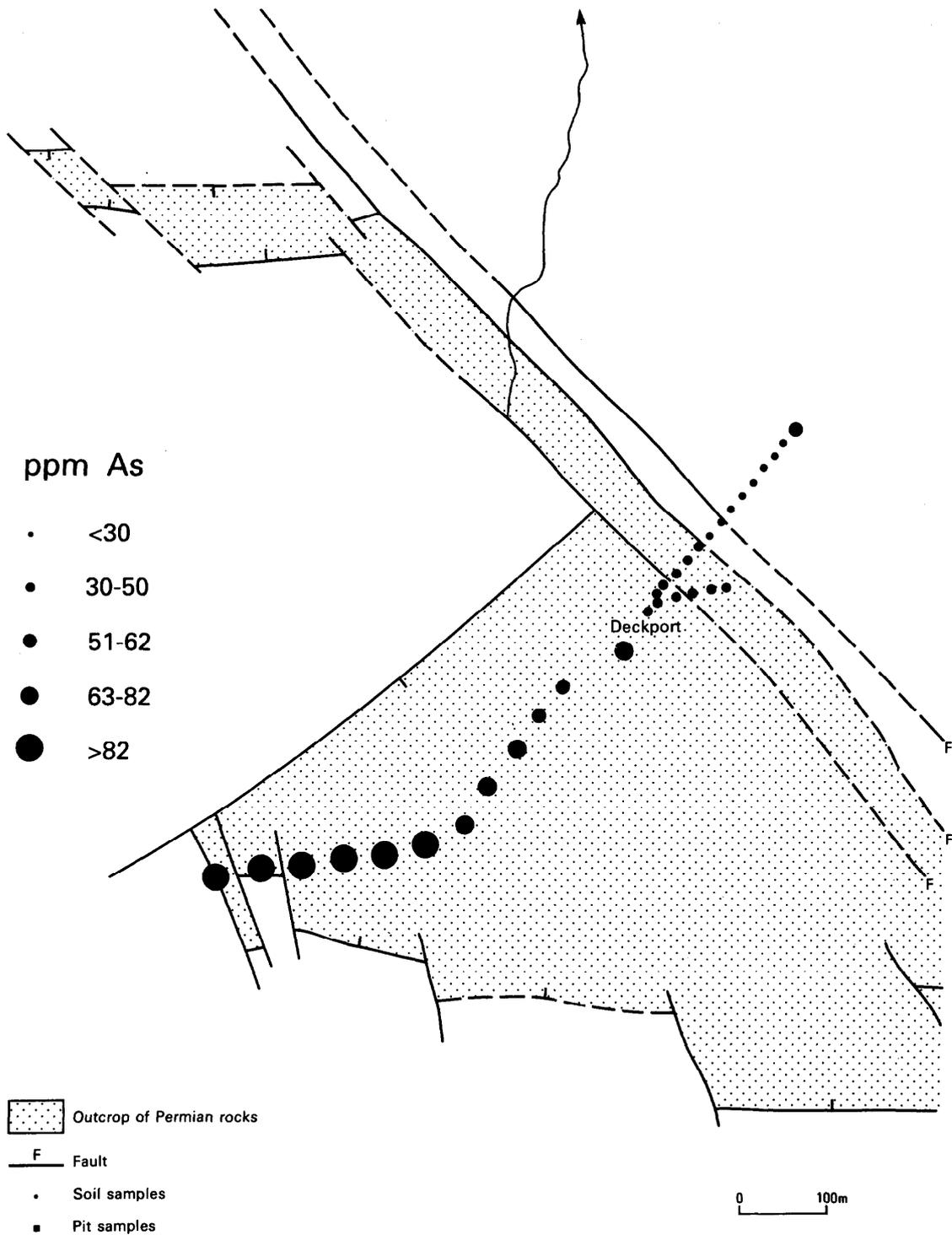


Figure 9 As in soil samples at Deckport

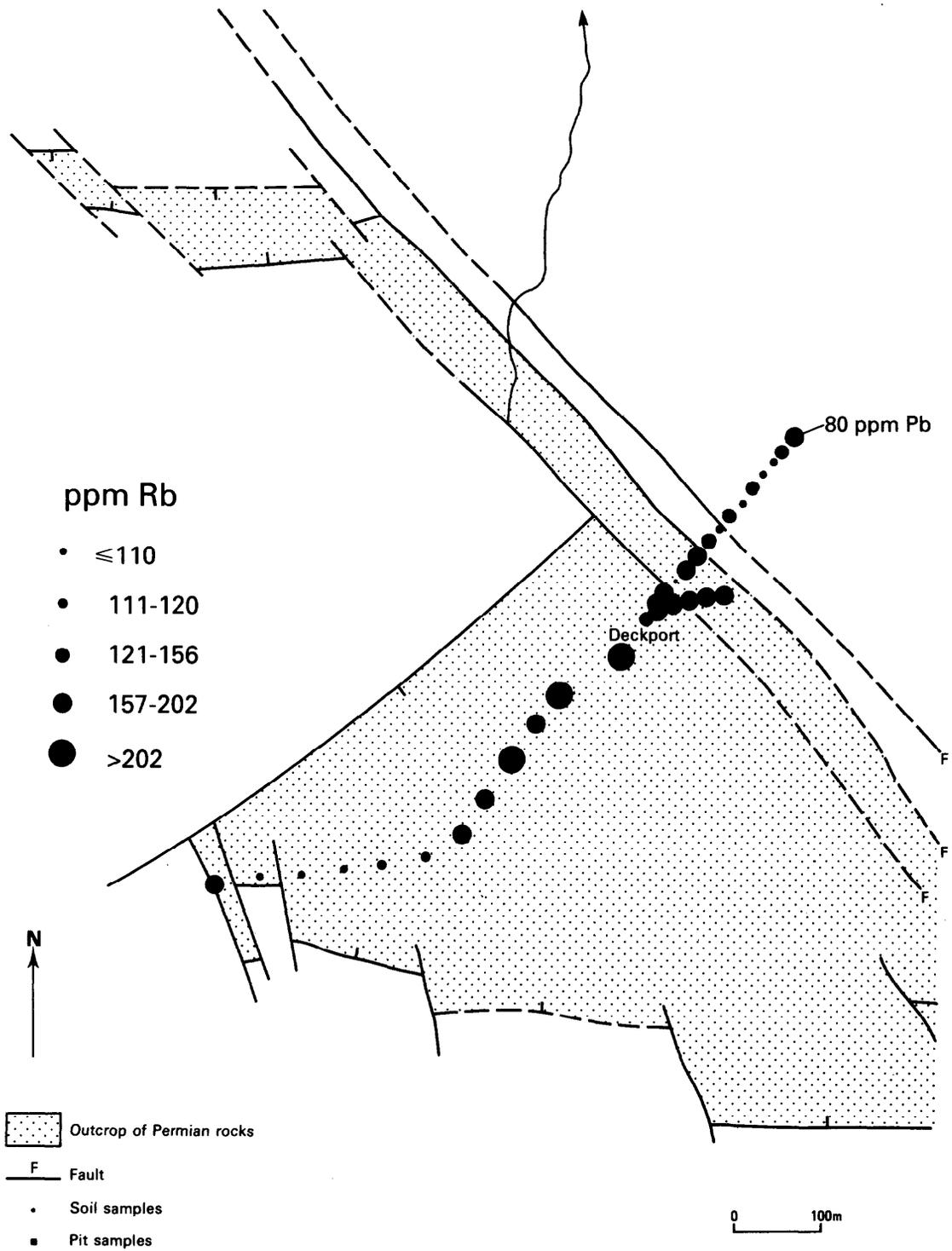


Figure 10 Rb in soil samples at Deckport

Gold was not detected visually or by analysis in any of the panned overburden samples but there are insufficient samples to test adequately whether it is present in association with the north-west-trending sector of the Permian outcrop in the north-east of the area (Figure 5). Furthermore, no panned samples were taken from the western part of the line which, on the basis of the interpretation of the shallow overburden results, is possibly the more favourable for mineralisation controlled by the Permian unconformity. The analyses of the panned pit samples are shown in Table 1. Concentrations of most elements are comparable to those in the panned drainage samples from the stream draining to the north. However, concentrations of tin and cerium are markedly higher in the first gold-bearing drainage sample to the north. This could indicate considerable upgrading of heavy minerals in the stream relative to the overburden or heavy mineral-rich horizons within the Permian sequence that have not been encountered in the overburden sampling.

Solland area

Soil lines were sampled with a hand auger. Four lines were oriented perpendicular to the trace of the fault followed by the stream, one line was oriented east-west and also crossed the trace of the fault and the other line was orientated north-south to cross the boundary between the Permian and Carboniferous rocks (Figure 11). Pits were dug at 13 sites, mostly close to the presumed trace of the fault (Figure 11).

As in the Deckport area, soils derived from the Carboniferous rocks are richer in Ti than those derived from the Permian rocks (Figure 12). In addition, the distribution of Ti over the Permian rocks suggests that a distinct central unit can be recognised which is low in Ti (Figure 12). The concentrations of Ti over this unit are very similar to those over the majority of the Permian rocks at Deckport (Figure 6). Mn is markedly lower in soils derived from the Carboniferous rocks than in those derived from the Permian rocks (Figure 13). In addition, the soils derived from alluvium following the stream are also low in Mn (Figure 13). Over the Permian rocks the variation in Mn content in soils is more irregular and levels (maximum 2880 ppm) do not reach as high as in the Deckport area. The concentration of Fe over the central unit within the Permian sequence around Solland is low (Figure 14). The locations of the one sample with high Ni and the two showing low-amplitude enrichments in Cu are also shown in Figure 14.

Concentrations of As in soil (Figure 15) distinguish the central unit within the Permian as being relatively enriched in the element. However, within this zone maximum levels (65 ppm As) are lower than in the Deckport area (135 ppm As). Similarly the soil samples indicate that the central unit within the Permian sequence is enriched in Rb compared with the rocks on either side. (Figure 16). Two samples close to the presumed trace of the fault are considerably enriched in U (Figure 16) above the background level of 0–4 ppm U. These samples are the only ones in the entire Crediton Trough soil dataset to show such levels of enrichment in U. Their coincidence with low-amplitude U anomalies in the fine-fraction drainage samples from the area (Cameron et al., 1994) suggest that the north-west-trending fault is mineralised.

Heavy mineral concentrates were obtained by panning material from pits at 13 sites as shown in Figure 11. Most of the sites sampled were close to the presumed trace of the north-west-trending fault. A gold grain was recovered from the sample from locality 1574, but the concentration of other elements strongly suggests that the material sampled is alluvium. No gold was found, either physically or by analysis, in the other pit samples. A selection of analyses of the panned pit samples is shown in Table 2.

The gold-bearing sample, collected from a pit in the bank of the stream, is characterised by much lower concentrations of Mn and Fe, and higher levels of Zr and very much higher levels of Sn (Table 2). It is markedly different from the adjacent sample, and therefore likely to be largely, if not entirely, derived from alluvium. The other pit samples within the mapped outcrop of alluvium are all somewhat enriched in Sn, but to a lesser extent. In other respects, these samples resemble chemically those collected away from the valley which suggests that the alluvium is either thin or stratified. The lack of gold in all but alluvial samples, together with the gradual increase in gold abundance in drainage samples upstream to the south-east, suggest that the source of the gold could be in rocks further to the south, perhaps adjacent to the southern contact of the Permian rocks.

Table 2 Analyses of panned pit samples from Solland

<i>Sample</i>	<i>1562</i>	<i>1565</i>	<i>1567</i>	<i>1571</i>	<i>1574</i>	<i>1575</i>	<i>1576</i>	<i>1583</i>	<i>1592</i>	<i>1594</i>	<i>1596</i>	<i>1605</i>	<i>1610</i>
Ti %	0.52	0.50	0.57	0.51	0.50	0.57	0.65	0.60	0.65	0.53	0.60	0.59	0.59
Mn ppm	870	580	580	1010	180	1630	1820	1880	720	1130	990	1310	1310
Fe %	6.86	4.77	7.56	15.02	2.16	14.41	19.18	15.58	6.79	11.24	12.10	12.54	16.15
As ppm	210	134	138	71	54	57	79	53	87	167	140	38	41
Zr ppm	356	359	365	274	801	536	433	466	452	336	414	635	352
Nb ppm	19	16	19	26	16	17	19	18	21	20	22	18	20
Sn ppm	23	14	70	315	761	24	27	21	92	17	19	22	13
Ce ppm	135	124	119	86	107	93	97	99	103	118	118	89	98

Shading in table shows sample containing gold grain

Samples of overburden were also obtained from a 3 m deep temporary excavation at Clifton, sieved and panned. Gold was not detected in any of the panned fractions of these samples. Concentrations of Ti, Zr, Nb, and Ce were higher (maxima 2.54 %, 1180 ppm, 63 ppm and 478 ppm respectively) in these samples than in the panned non-alluvial samples in Table 2. The close association of Ti with Nb suggests that rutile is the main Ti-rich phase present and high levels do not indicate the presence of mafic igneous rocks. Sn levels are enhanced (maximum 200 ppm), which probably reflects the widespread presence of detrital cassiterite in some of the Permian rocks.

Smallbrook

Soil samples

Soil samples from a depth of around 0.8 m were taken using hand augers on a grid to the south and east of the Small Brook, augmented by two intersecting lines to the west of the head of the stream (Figure 17). This sampling was intended to establish the presence of pathfinder-element anomalies and to provide a geochemical map of the area, characterising the local geology.

The distribution of Ti in these soil samples (Figure 18) generally delineates a sharp contact which, at the east and west edges of the area, coincides generally with the mapped trace of the east-west boundary fault between Carboniferous rocks and the Late Permian Newton St Cyres Breccia to the north. The source of the Ti-rich samples in the lensoid area to the north of the fault trace was originally also thought to be in Carboniferous rocks, but the subsequent deep excavations in the area revealed that a further unit of Permian sedimentary breccia existed to the south of the Newton St Cyres Breccia. None of the soil samples contains sufficient Ti (maximum 0.67 %) to suggest the presence of basic igneous rock within the area sampled.

The distribution of Mn in the soil samples (Figure 19) indicates that the Permian rocks are significantly richer in the element than the Carboniferous rocks to the south, although there are scattered local enrichments in the latter. The areas with the highest levels of Mn in soil (maximum 0.86 % Mn) occur within the lensoid unit of Permian rocks immediately north of the boundary fault in the centre of the area. There are sufficient samples containing in excess of 0.4 % Mn to suggest that significant amounts of Mn-bearing mineralisation occurs in the area, and this is the area of the old workings for manganese. Though the Mn is present as oxide in the weathered rock within reach of the excavations, the original form of the element is probably Mn-bearing carbonate impregnating the sedimentary breccias. The area to the north of the wood is marked by low levels of Mn in soil and, on the basis of the excavations and stream exposures, reflects the local presence of a unit of sands and clays within the Permian sequence.

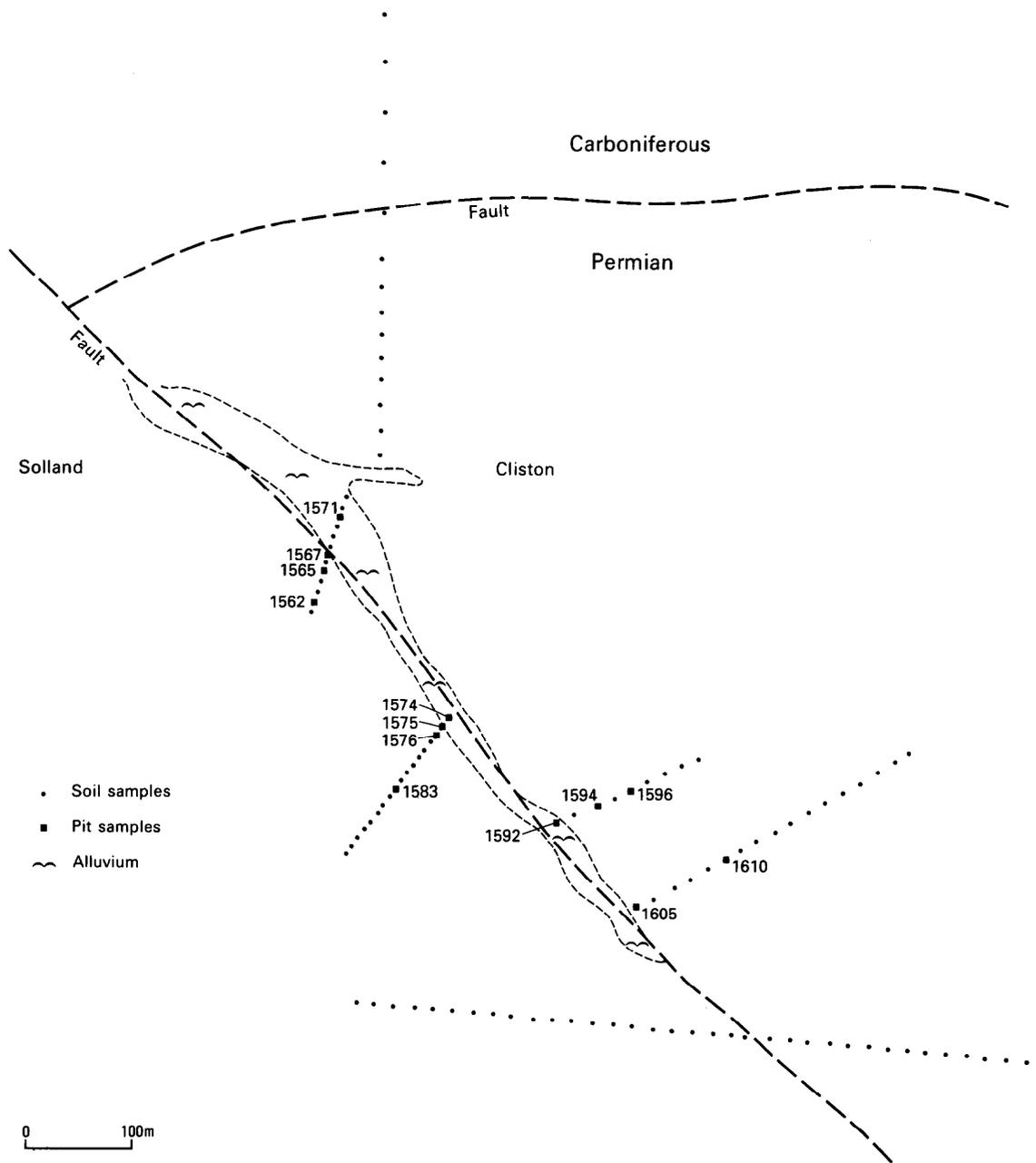


Figure 11 Location of soil and pit sampling at Solland.
See Figure 1 for location of area

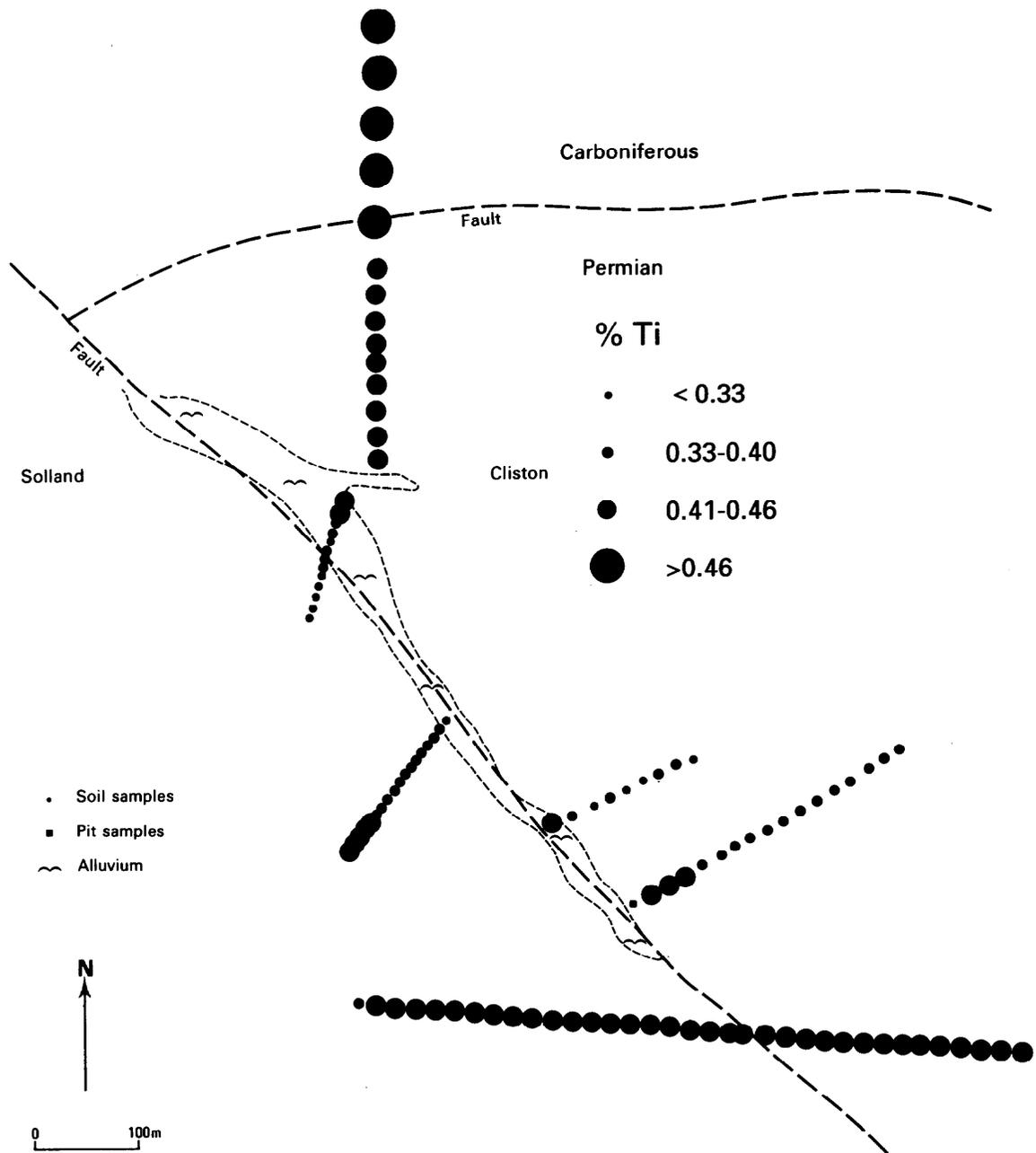


Figure 12 Ti in soil samples at Solland

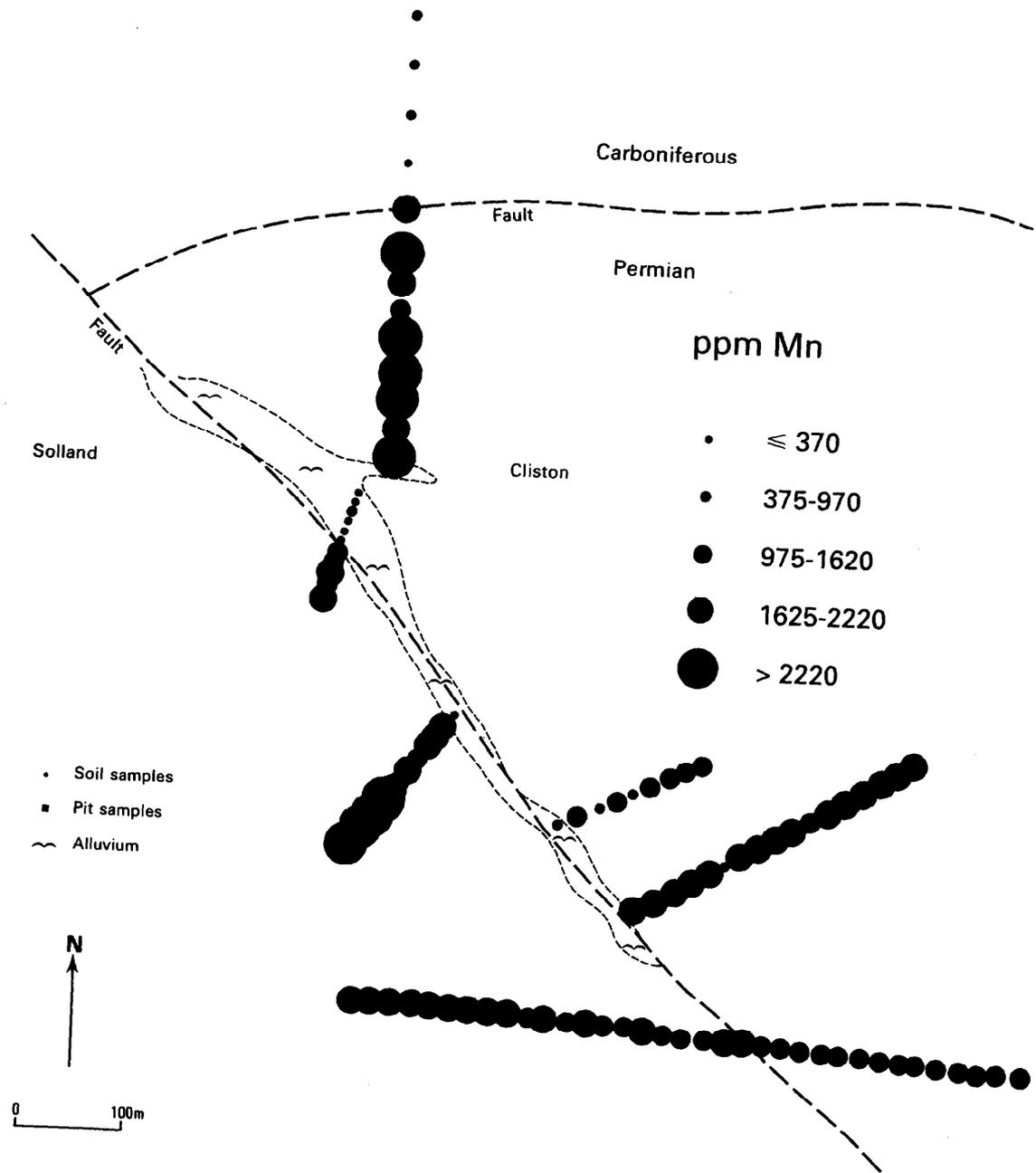


Figure 13 Mn in soil samples at Solland

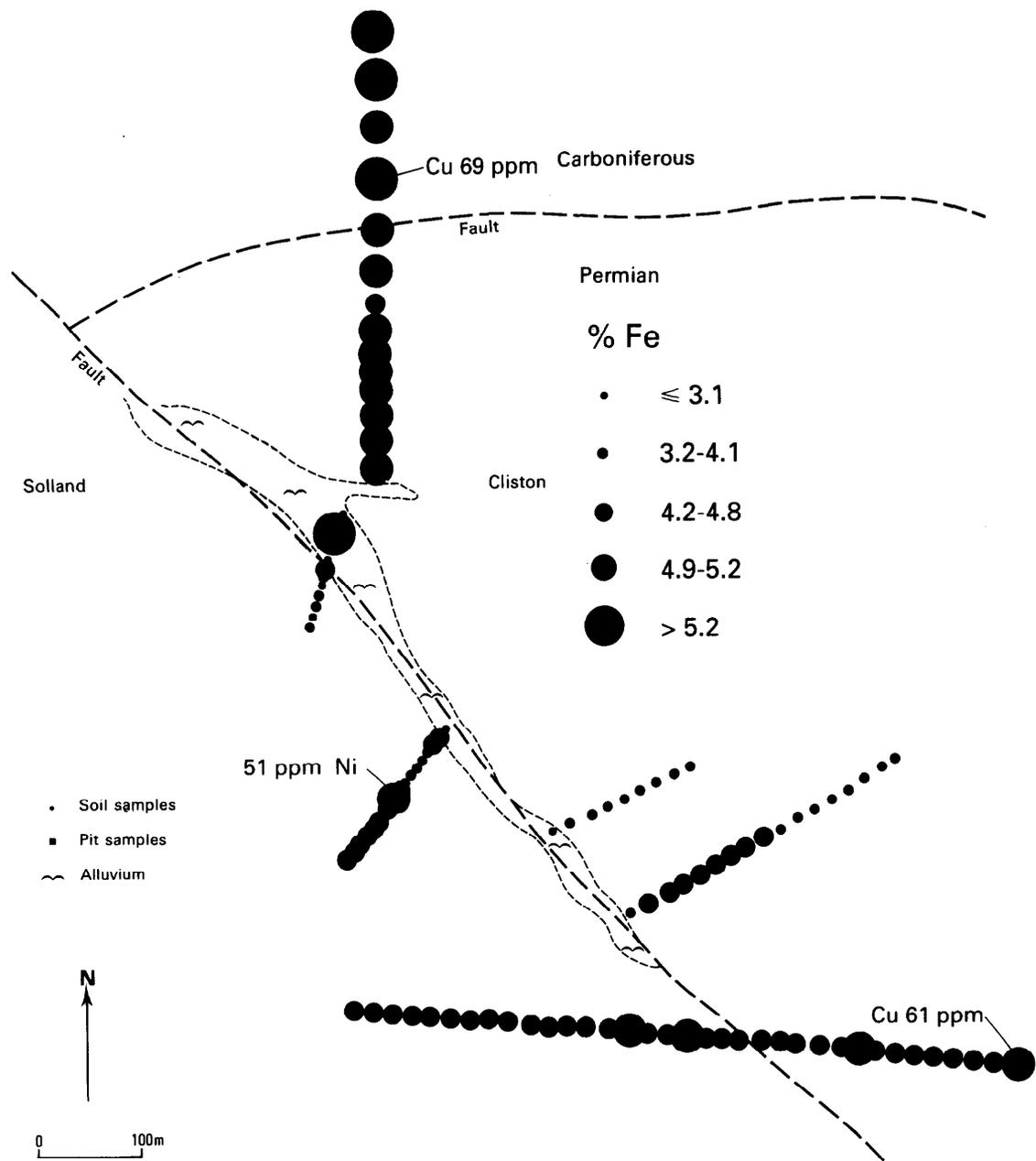


Figure 14 Fe in soil samples at Solland and samples with highest levels of Ni and Cu

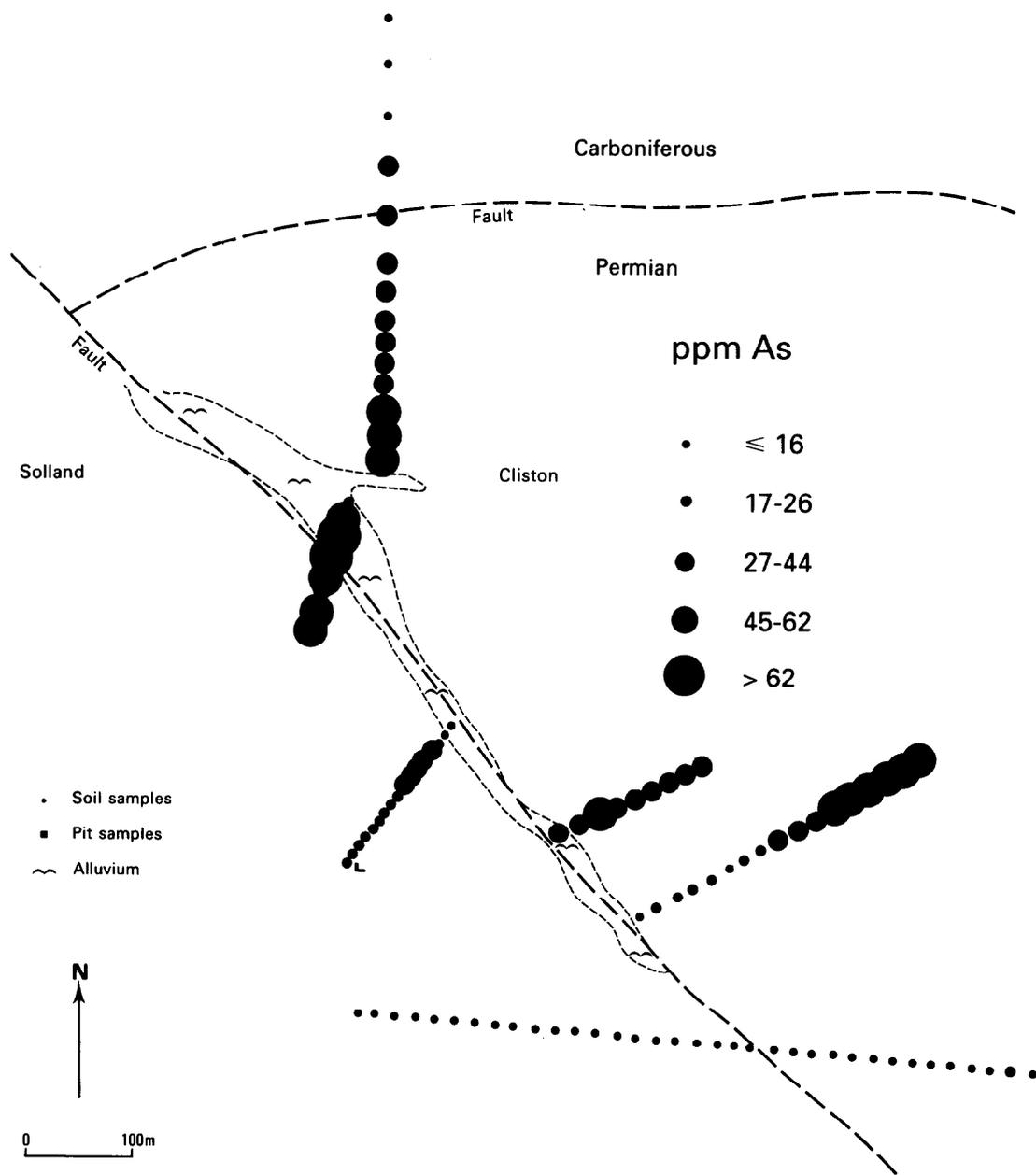


Figure 15 As in soil samples at Solland

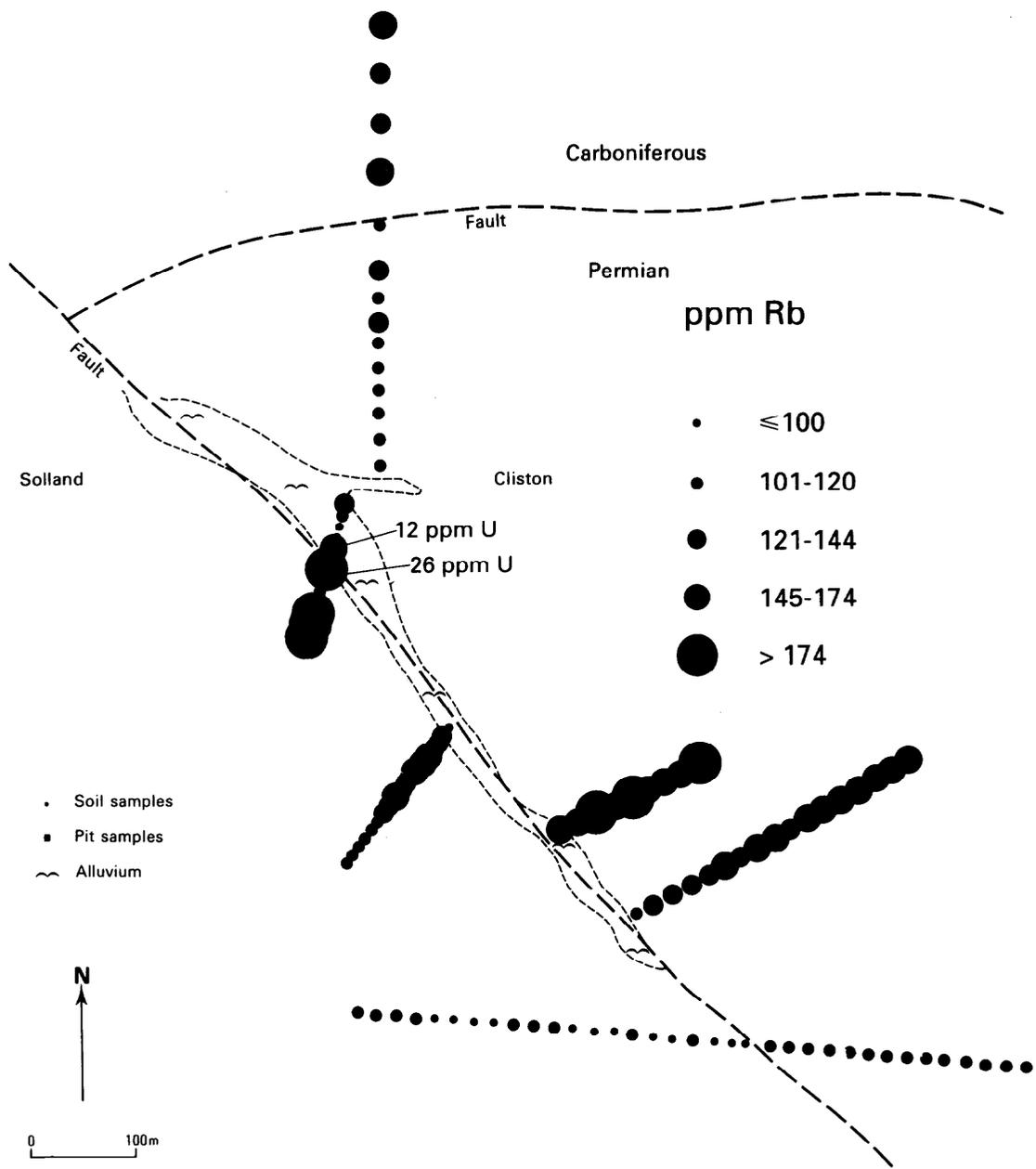


Figure 16 Rb in soil samples at Solland

The distribution of Fe in the soil samples (Figure 20) indicates that the Carboniferous rocks are richer in iron than the Permian sequence, though the lensoid unit to the north of the boundary fault in the centre of the area also shows relative enrichment in Fe. The concentrations of Fe in soil samples (maximum 8.2 %) are insufficient to suggest the presence of significant amounts of Fe-rich mineralisation, either as hematite or the oxidation products of iron sulphide. The distribution of Ni in soil samples (Figure 21) indicates that the Carboniferous rocks and the lensoid unit of Permian breccia to the north of the boundary fault in the centre of the area are richer in the element than the Newton St Cyres Breccia and the unit consisting of clays and sands to the north of the wood. The absence of correlation between Ni and Ti in the soils containing the greatest Ni contents (maximum 96 ppm) indicates that none of the Ni-rich samples reflect basic magmatic rocks.

Low amplitude Cu anomalies (maximum 198 ppm) are scattered within the southern part of the area, in soils thought to be derived from the Carboniferous rocks (Figure 22). A lower-amplitude enrichment is associated with three samples derived from the Newton St Cyres Breccia near to the stream (Figure 22). Samples containing the highest levels of Zn (maximum 284 ppm) occur mostly in the south of the area, over presumed Carboniferous rocks to the south of the boundary fault to the north of the wood (Figure 23). Lower levels of Zn are characteristic of the soils derived from the Newton St Cyres Breccia, though there are some zones within its outcrop showing slight enrichment in the element and one anomalous site (248 ppm) away from the stream.

The distribution of As in soils is potentially important as this element shows the greatest correlation with gold in the drainage samples from the Smallbrook area (Cameron et al., 1994). In soil samples derived from all the Permian rocks (except the sand and clay unit) As is considerably higher than in those derived from the Carboniferous rocks (Figure 24). The highest contents of As (maximum 128 ppm) occur within two lensoid zones largely over the Permian breccia to the south of the Newton St Cyres Breccia and in a less well defined zone adjacent to the Small Brook (Figure 24).

Panned pit samples

Au was detected by a combination of physical extraction of grains and chemical analysis in ten of the 84 panned samples collected from manually dug pits at sites along the soil grid lines, mainly in the west of the area (Figure 25). In two of these samples, Au was detected chemically at levels just above the detection limit of the method used (10 ppb) and so can be ignored. The other eight samples contain significant amounts of Au, to a maximum calculated content of 1.5 ppm Au (from a combination of chemical analysis and grain weighing). Fourteen grains of gold were extracted from this most anomalous sample. The location of the gold-bearing samples is shown in Figure 25. Five of the auriferous samples, including the two with the greatest Au contents, are derived from the Newton St Cyres Breccia. Au also occurs in two samples which appear to have been derived from the older breccia unit to the south of the Newton St Cyres Breccia. One sample derived probably from the Carboniferous rocks close to the contact with the Permian rocks also contains Au. The Au-rich samples tend to be relatively enriched in arsenic but there is no evidence of an association of Au with elevated base-metal contents. Levels of Sn are relatively high in the two most auriferous samples which suggests a possible general enrichment in heavy minerals such as would be present in a fossil placer.

There are some differences between the distribution of As in the panned pit samples (Figure 26) and the -80 mesh soil samples (Figure 24), with the As maxima in the former occurring slightly to the east of the As maxima in the latter and within a wider zone. Concentrations of As are generally higher in the panned samples but the ratios between the two sample types is quite variable. In the anomalous samples on line 8 (Figure 24) As levels are approximately equal in both sample types. In contrast, in the anomalous samples on lines 7 and 9, concentrations of As in panned pit samples are between 2 and 5 times higher than in the corresponding soil samples. The pit samples confirm the absence of As enrichment in association with the sand/clay unit within the Permian sequence.

The panned pit samples (Figure 27) indicate that Zr is most enriched in the Newton St Cyres Breccia (maximum 3900 ppm). The Zr contents of samples derived from the Permian clay/sand and boundary lensoid breccia units are much lower, and those probably derived from the Carboniferous rocks are lower still (Figure 27).

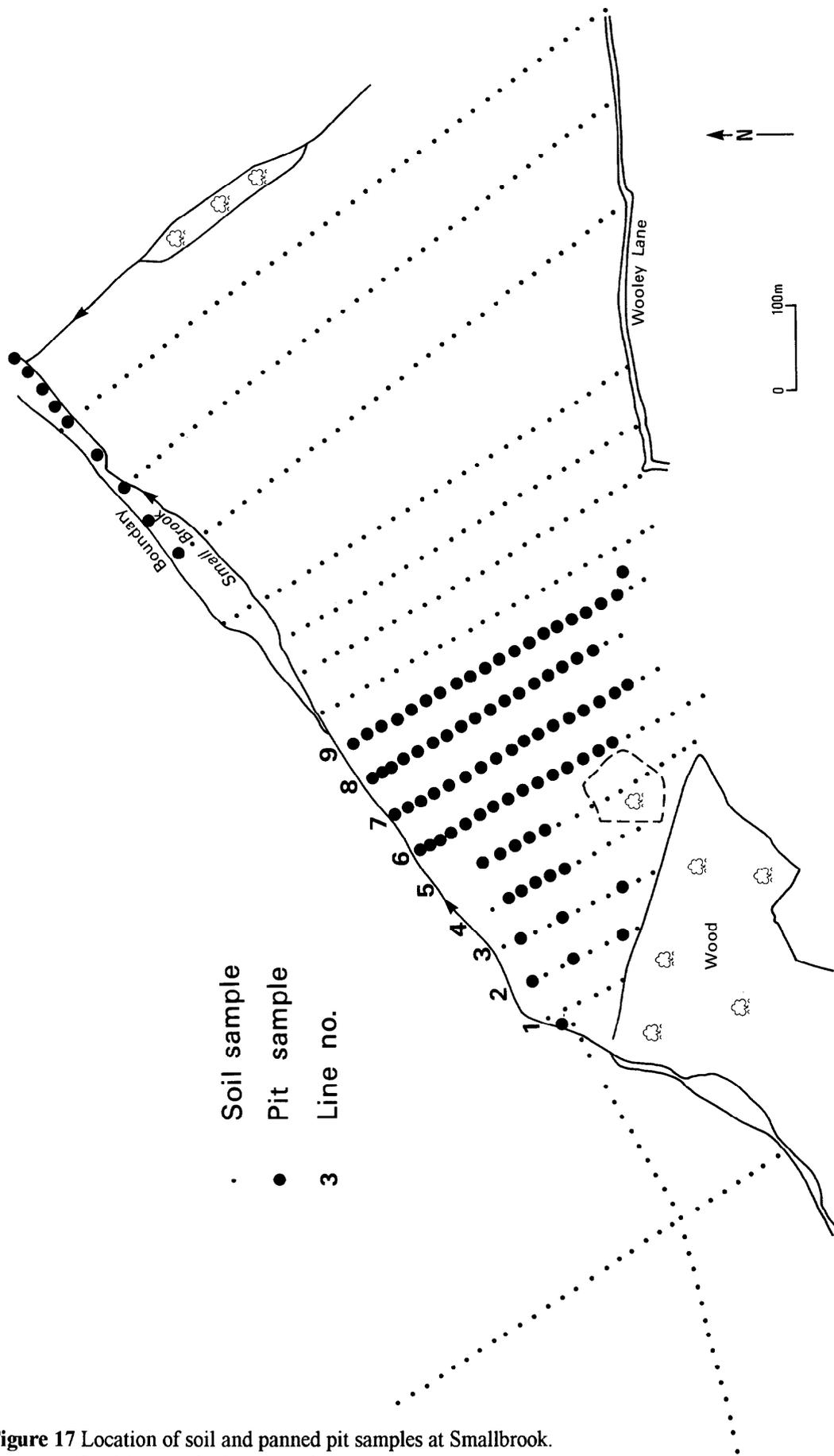


Figure 17 Location of soil and panned pit samples at Smallbrook.
 See Figure 1 for location of area

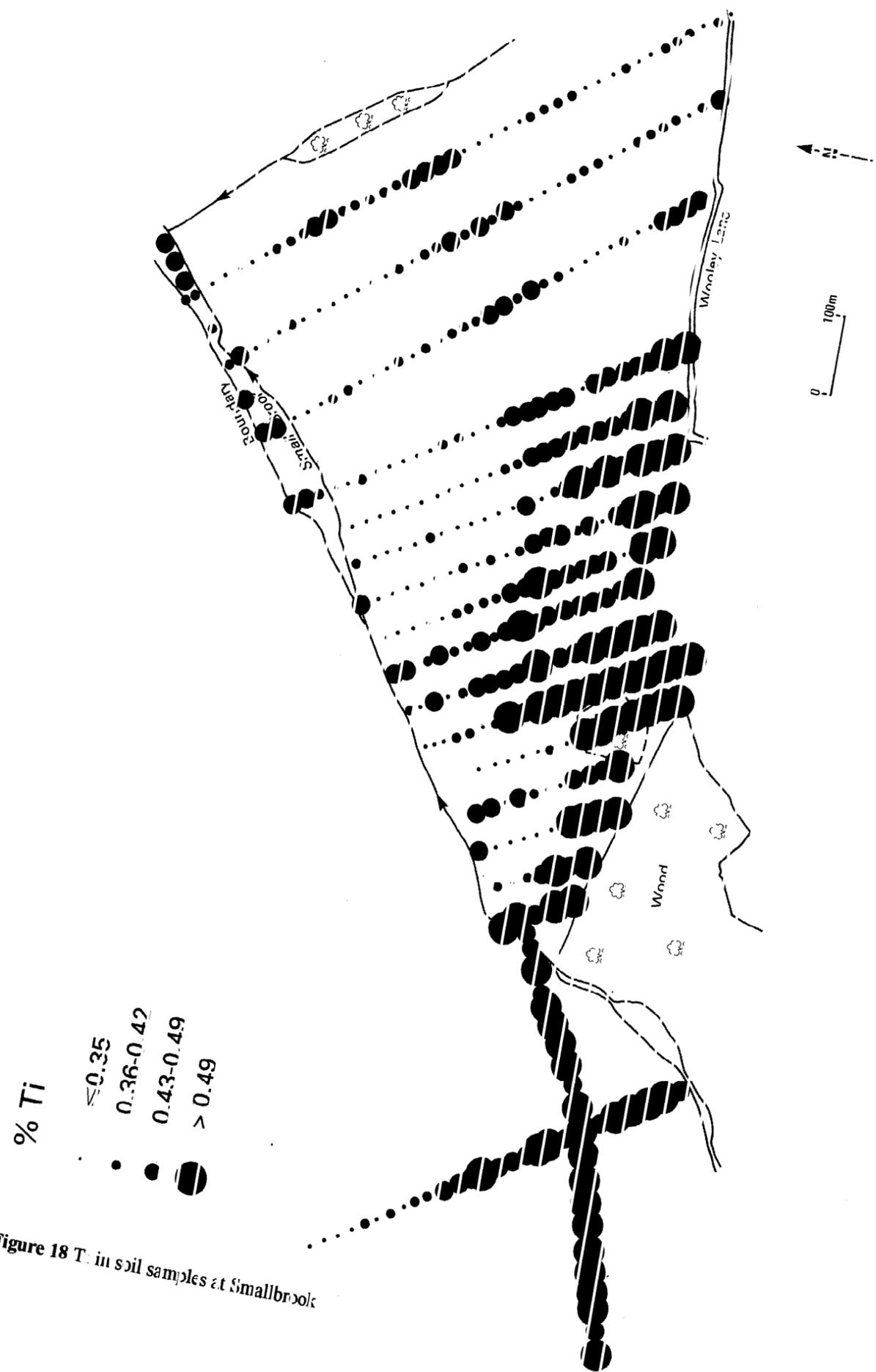


Figure 18 Ti in soil samples at Smallbrook



Figure 19 Mn in soil samples at Smallbrook



Figure 20 Fe in soil samples at Smallbrook



Figure 21 Ni in soil samples at Smallbrook

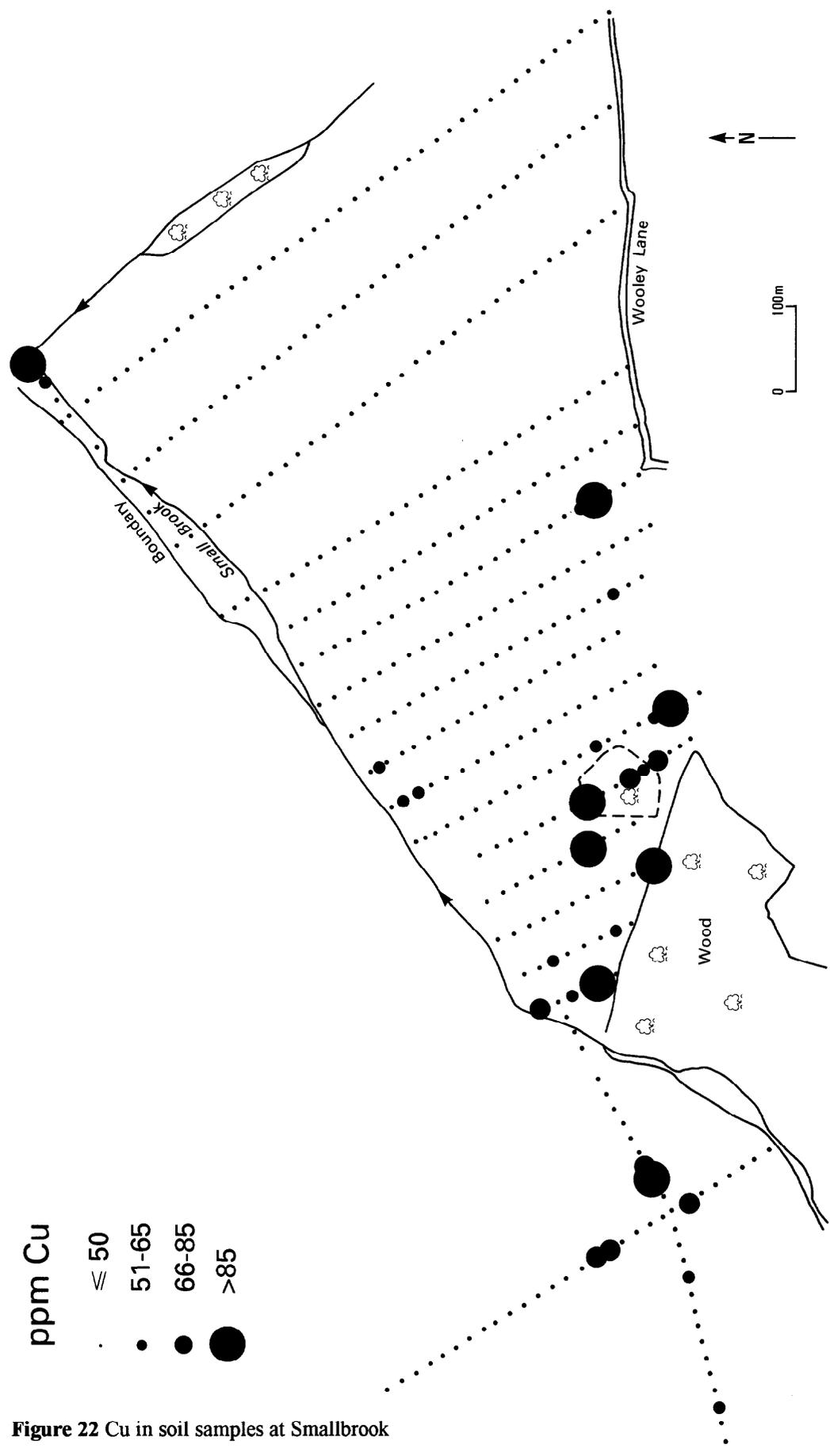


Figure 22 Cu in soil samples at Smallbrook



Figure 23 Zn in soil samples at Smallbrook

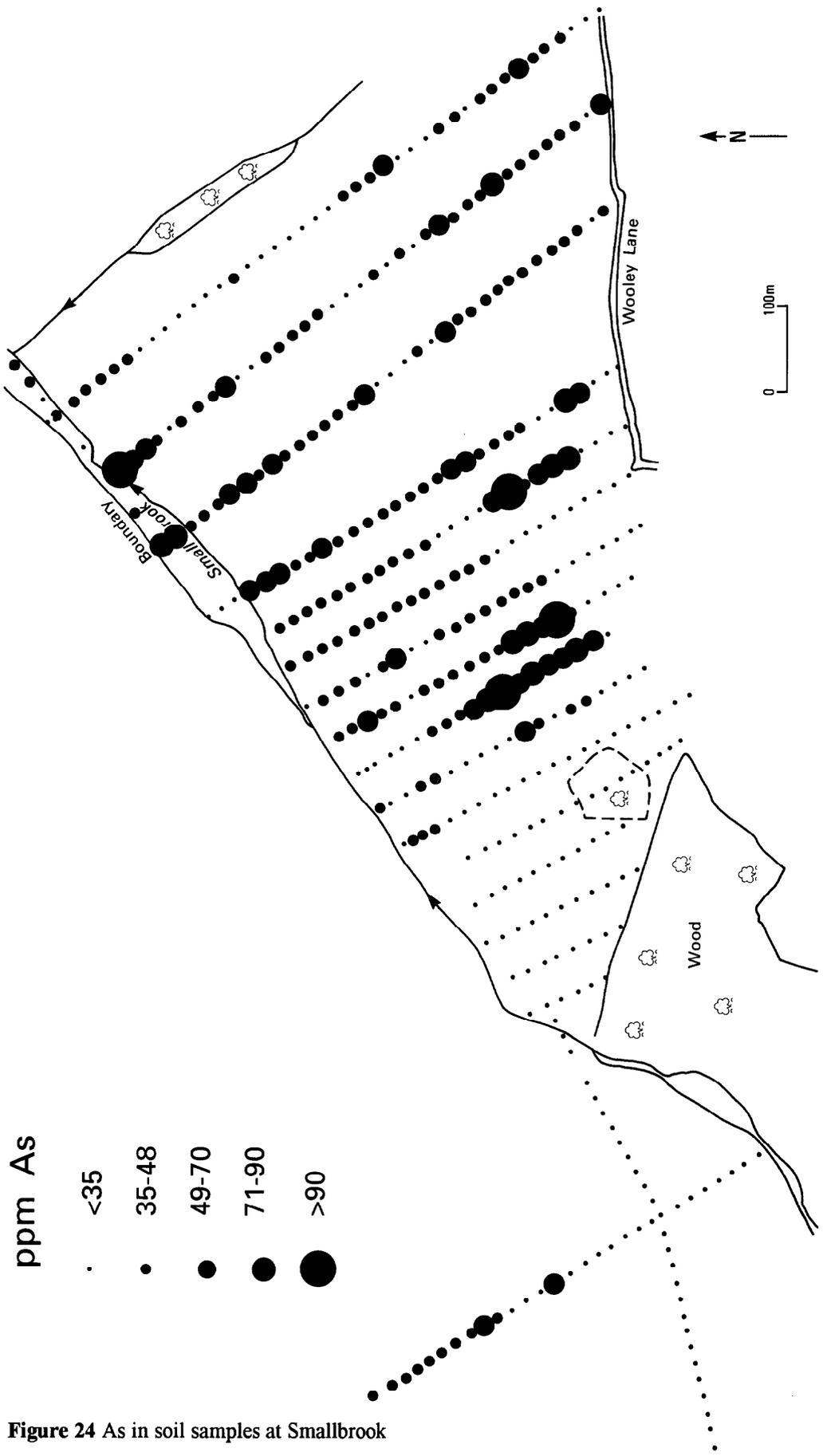


Figure 24 As in soil samples at Smallbrook

Most of the samples showing enrichment in Sn (maximum 116 ppm) are derived from the Newton St Cyres Breccia (Figure 28). Lower-amplitude Sn enrichment is also shown in samples derived from near the contact between the southern Permian lensoid breccia unit and the Carboniferous rocks to the south. The distribution of Sn in the Smallbrook soils shows, like the corresponding drainage samples (Cameron et al., 1994), significant positive correlation with Au. The much lower concentration of Sn in the panned overburden samples compared with the panned alluvial samples (maximum > 2 % Sn) indicates that considerable upgrading of heavy minerals has occurred in the alluvium relative to the residual overburden from which is largely derived.

Ba is sufficiently enriched in a few samples (maximum 9045 ppm Ba) to suggest the presence of a small amount of baryte. Three of the samples with the highest Ba contents (Figure 29) are located close to the presumed trace of the boundary fault between the Carboniferous and Permian strata. The anomaly in the middle of line 6 may reflect some baryte along the trace of the presumed north-south fault which forms the eastern boundary of the Permian clay/sand unit.

Ce is most enriched (maximum 228 ppm Ce) in samples derived from the Newton St Cyres Breccia (Figure 30). The Ce, accommodated mostly in monazite, does not show relative upgrading in the alluvial samples (maximum 2315 ppm Ce) to such an extent as the Sn. This may reflect the lower density of the mineral relative to cassiterite.

Samples with the highest levels of Fe, Cu, Zn and Pb are shown in Figure 31 and a concentration of these sites over the Carboniferous rocks in the south of the area is evident. Minor enrichment of Pb is present in two samples derived from the Newton St Cyres Breccia, one of which is the maximum Au anomaly and the sample also richest in Fe.

Table 3 Depths and element concentrations of soil and panned pit samples from profiled pit A

Depth m	Ti %	Mn ppm	Fe %	Ni ppm	Cu ppm	Zn ppm	As ppm	Pb ppm
0.2 (soil)	0.43	540	3.62	25	20	60	42	25
0.2 (pan)	0.18	–	3.69	–	15	36	49	23
0.45 (soil)	0.46	260	3.50	24	23	54	31	28
0.45 (pan)	0.20	–	3.19	–	14	35	37	21
0.6 (soil)	0.45	290	3.71	28	25	65	35	22
0.6 (pan)	0.17	–	3.62	–	16	39	46	27
0.7 (soil)	0.52	140	3.13	74	122	152	40	35
0.7 (pan)	0.23	–	5.67	–	21	58	54	41
0.8 (soil)	0.49	210	3.91	91	142	166	34	33
0.8 (pan)	0.31	–	13.77	–	50	92	114	83
0.9 (soil)	0.46	310	6.85	156	144	268	56	36
0.9 (pan)	0.33	–	15.60	–	52	125	120	89
1.0 (soil)	0.34	6060	12.13	362	107	295	121	48
1.0 (pan)	0.31	–	13.94	–	51	143	116	62

Note element not analysed: –

Panned pit samples in alluvium

Fourteen soil samples and nine panned basal soil pit samples were obtained from the area of alluvium to the north-west of the Small Brook, in addition at three of the pits, denoted A, B and C (Figure 17), both soil and panned concentrate samples were collected from various depths in the profile. Depths of

sampling and concentrations of selected elements for the two sample types in pit A are given in Table 3.

The variation of composition with depth in pit A shown by the two sample types is broadly the same. Above 0.7 m concentrations of all elements are consistent and relatively low. From 0.7 m to the base of the pit, concentrations of several elements in both sample types increase markedly. The greater concentration of Cu and Zn in the soil samples than in the concentrates indicates that these elements are present more in the fine fraction of the alluvium than in coarser detrital grains of metal-rich minerals. The marked increase in Mn in the soil samples at the 1.0 m depth could be the result of a precipitation barrier within the soil profile.

The variation of concentrations of Fe, Cu, Zn, Zr, As, Sn and Au in panned samples from the three profiled pits are shown in Figure 32. Heavy minerals, including gold, are concentrated at the 0.8–0.9 m level in pit A. There is also a general increase in concentrations of base-metals at the 0.8 m level. In contrast the concentration of Zr drops markedly from a peak at the 0.4–0.5 m level. Pit B shows a similar increase in base-metals and decrease in Zr towards the base but more irregular variation in Sn and Au levels. Pit C shows a general increase in most elements down the hole.

Gold was detected in 14 of the 23 samples from the panned alluvial samples to a maximum of 1180 ppb and a median value of 200 ppb. Gold is less frequent in samples obtained from less than 0.6 m depth than in samples from a greater depth.

Deep excavations

Subsequent to the collection and analysis of soil and panned shallow overburden and alluvial pit sampling, it was decided to collect deep overburden samples by trenching, using a backhoe excavator. This would allow collection of bulk samples for precious metal assessment and also, hopefully, reach bedrock and allow exposure and sampling of potential source rocks. The locations of these excavations are shown in Figure 33.

Pits 1 to 6 were excavated in the region of the largest-amplitude gold anomaly recorded during the manually dug pit sampling. Trench B was located in an attempt to intersect a north–south trending fault which was deduced from the soil geochemistry as separating the clay/sand unit from sedimentary breccias to the east and which appeared to carry at least baryte mineralisation. Trench C was located to intersect the contact between the Newton St Cyres Breccia and the lensoid unit to the south, which geochemically resembled the overburden derived from Carboniferous rocks, in an area with low-amplitude anomalies of gold from the manually dug pits. Originally this contact was thought to represent the trace of the unconformity between Permian rocks and Carboniferous rocks emerging from beneath them in the zone immediately to the north of the boundary fault. Trench E was to be excavated in the vicinity of the trace of the fault contact between Permian and Carboniferous rocks, but was constrained by the recent planting of tree seedlings in the area. The line of pits from which samples 2280 to 2306 were obtained (Figure 33) was oriented to cross the same boundary as Trench C and also a moderate amplitude gold anomaly recorded from the previous pit sampling.

The average composition of <0.5 mm fraction samples taken from various depths in the deep pits 1 to 6 are shown in Table 4, together with the corresponding compositions of soil and panned pit samples taken previously from the same sites. In all the holes there is little variation of chemistry with depth below 0.6 m depth, except in Mn content which, in some holes, tends to increase downwards. Furthermore there is little difference in chemistry between the holes, which all penetrate weathered Newton St Cyres Breccia. The agreement between the compositions of the deep overburden and soil samples, collected previously from the area, is close (Table 4). This gives support to the conclusion that soils away from the stream are mostly residual and that their gold content is derived from the weathered bedrock and is therefore essentially in situ. Au was detected by analysis in five of the samples from the deep pits in quantities between 15 and 23 ppb. However, the subsample of the < 0.5 mm fraction which was analysed for Au, corresponding to about 2 % of the total, represents a very poor sample for gold analysis. Despite sampling constraints, the lack of higher Au levels in these samples suggests that there is unlikely to be a rich source of Au in the rocks in the vicinity of these pits.

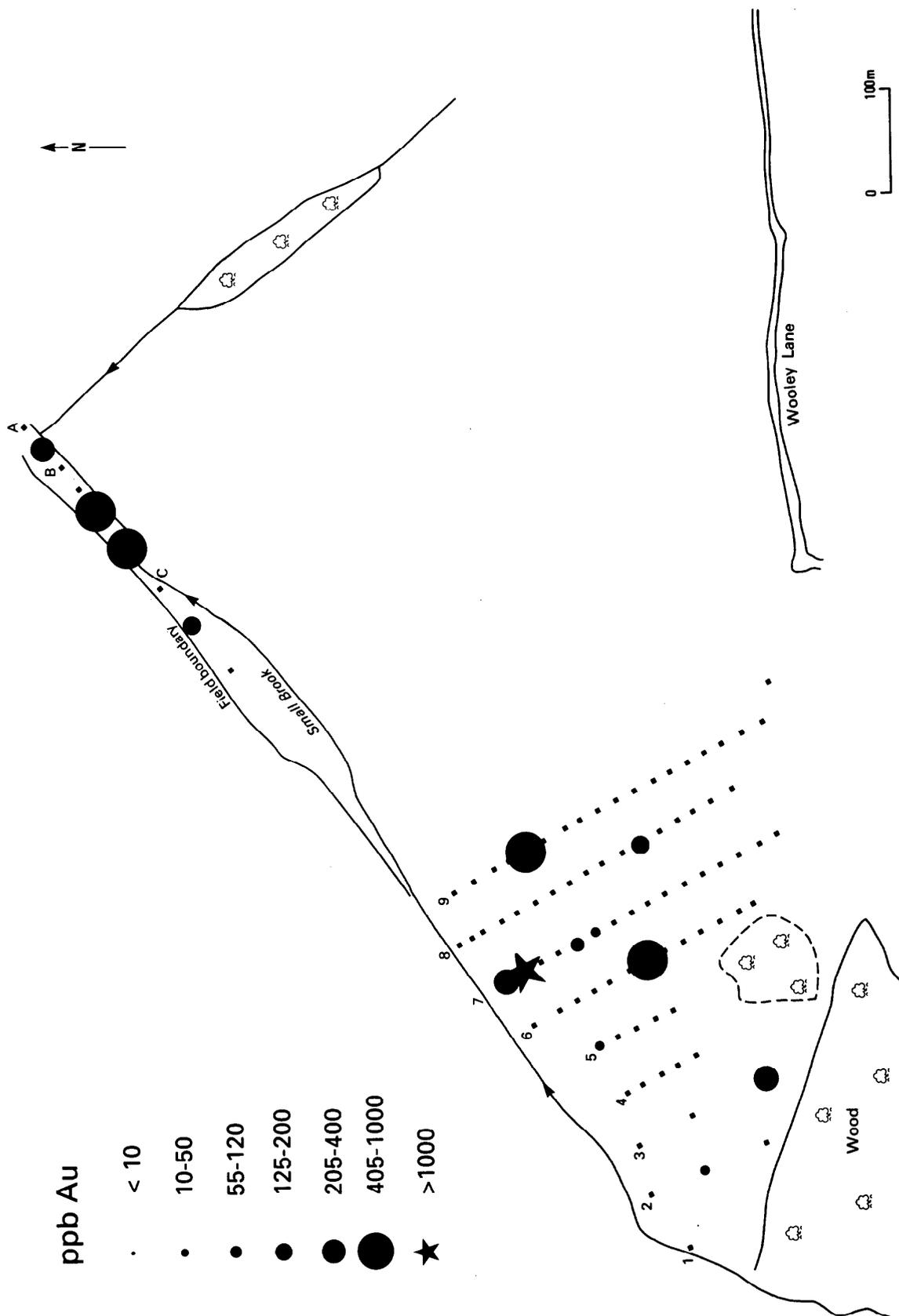


Figure 25 Gold in panned pit samples at Smallbrook

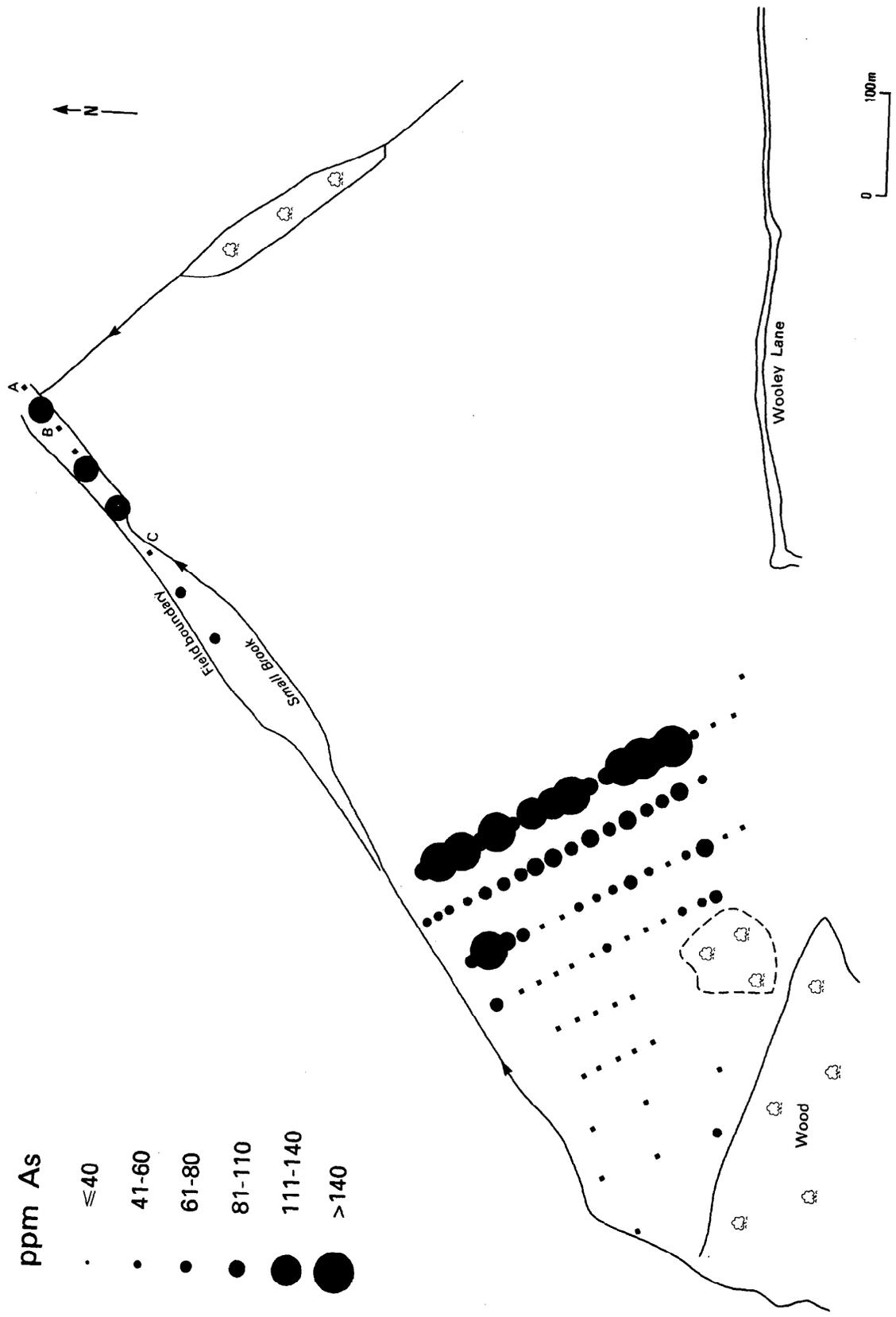


Figure 26 As in panned pit samples at Smallbrook

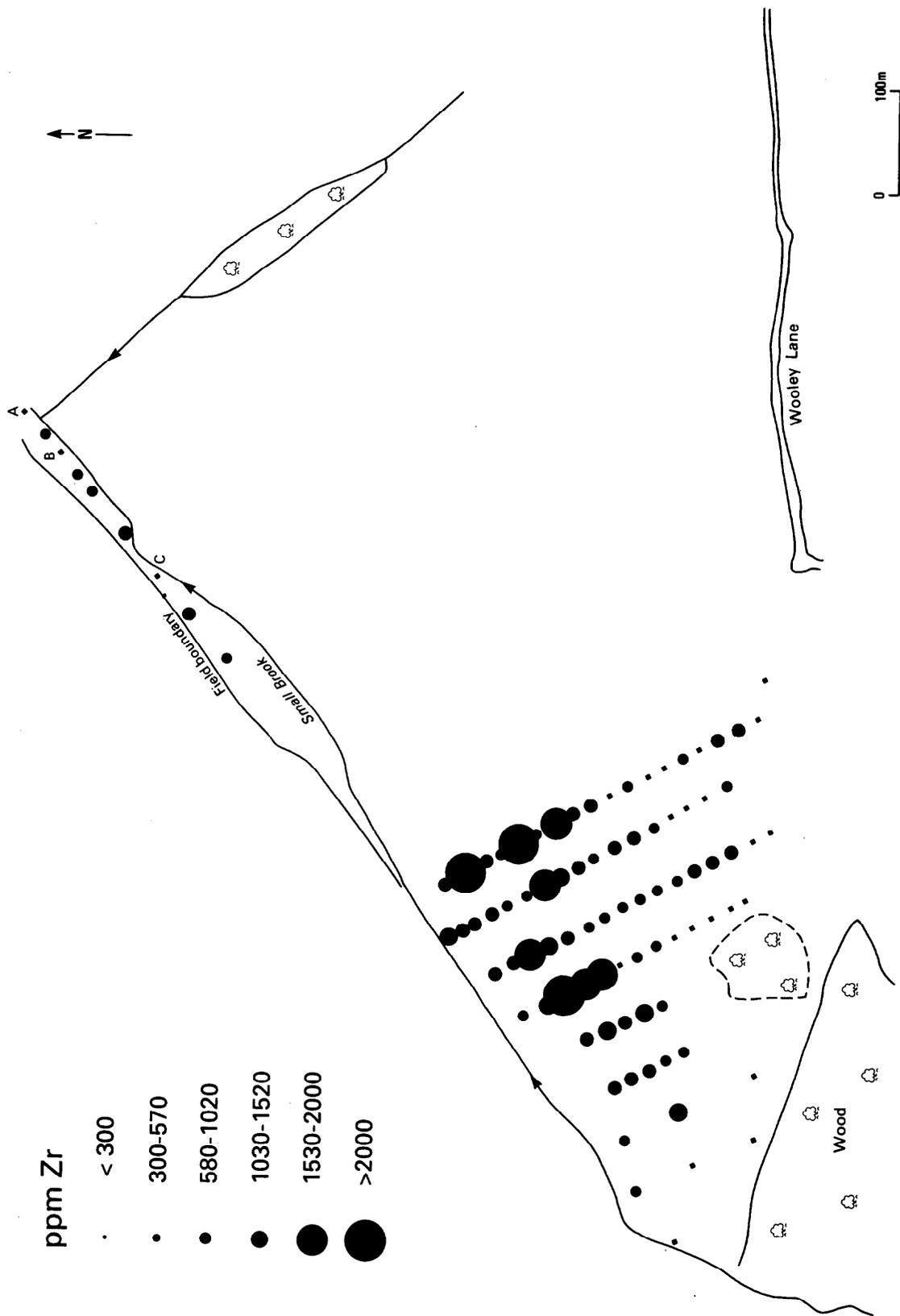


Figure 27 Zr in panned pit samples at Smallbrook

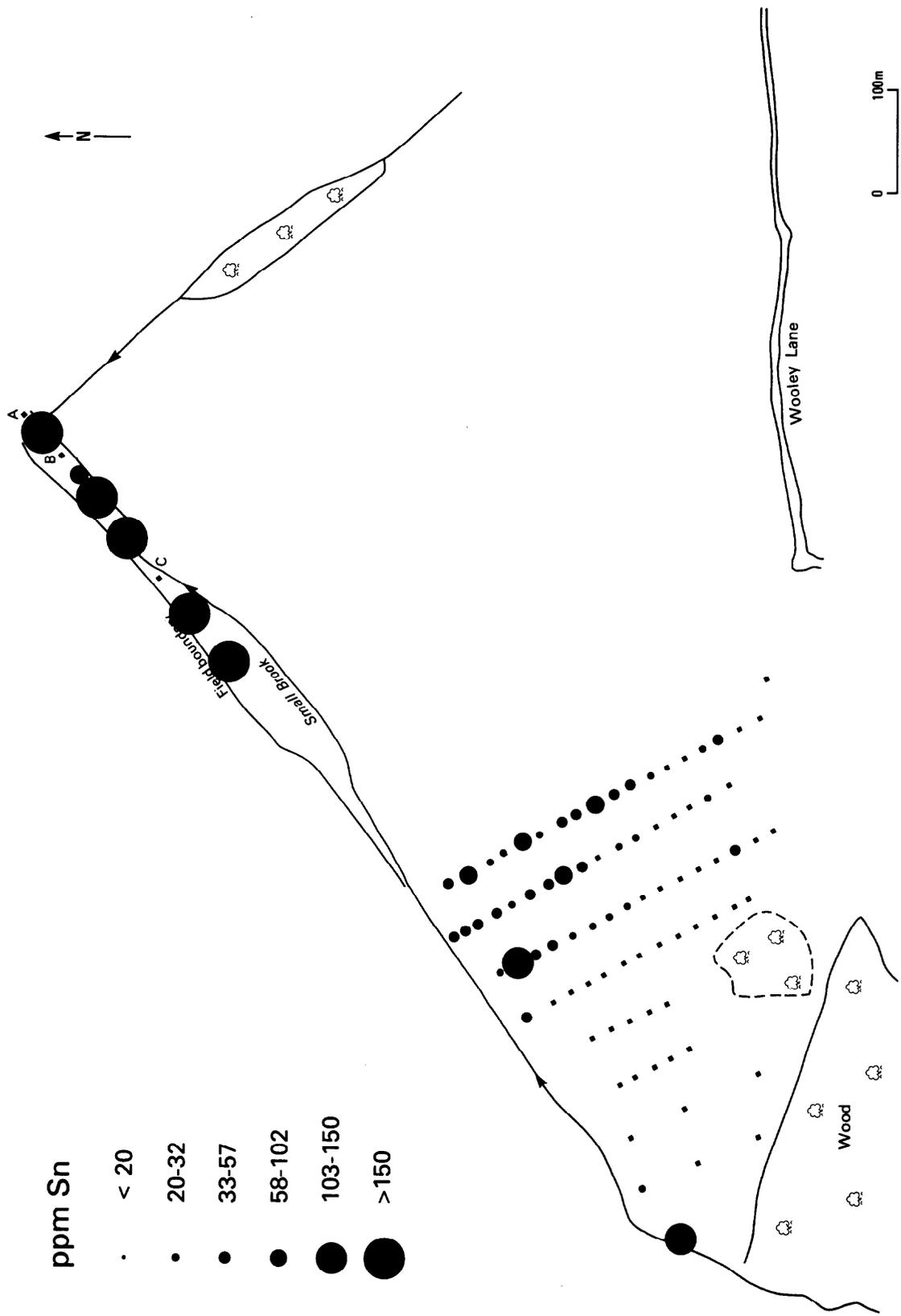


Figure 28 Sn in panned pit samples at Smallbrook

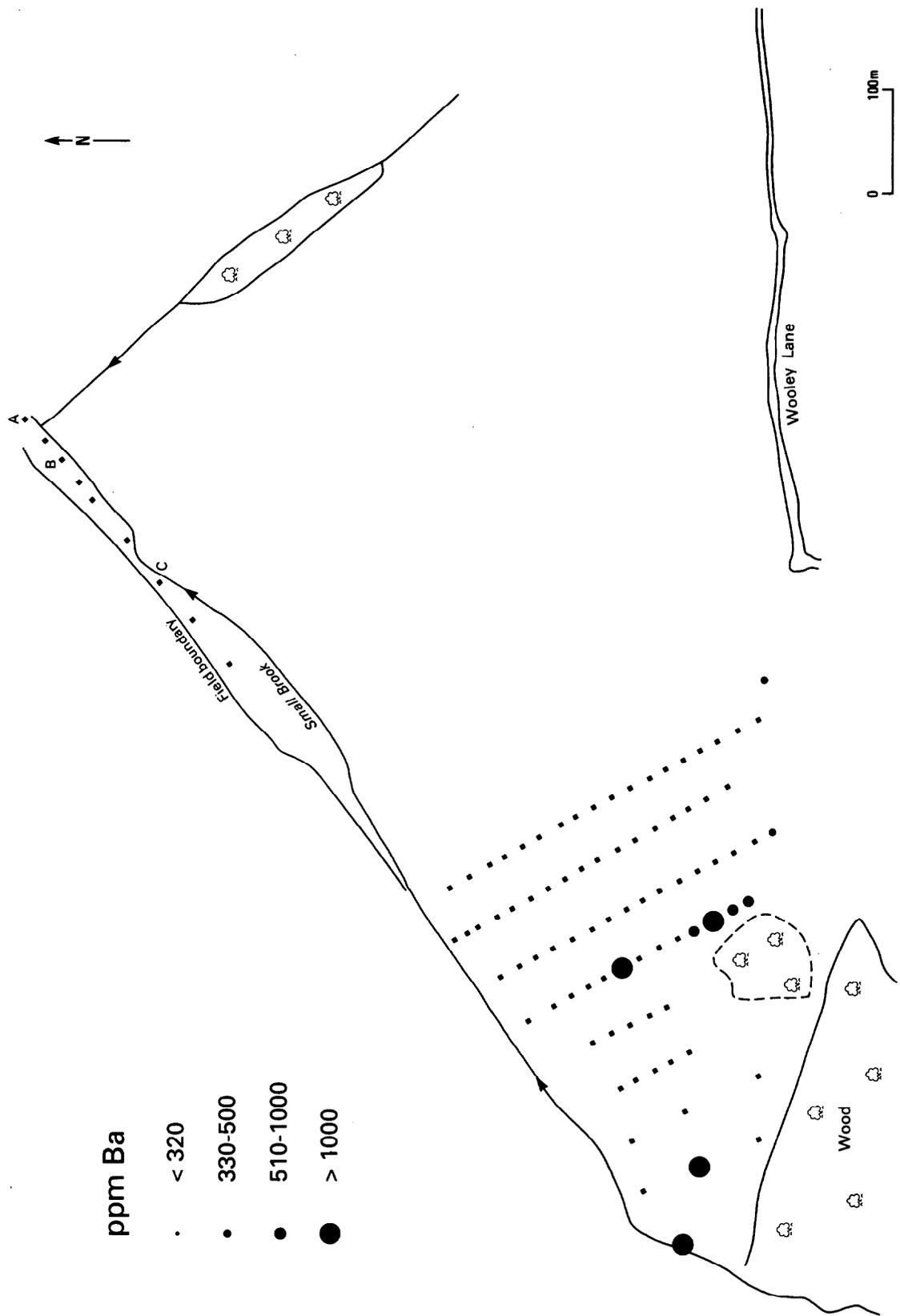


Figure 29 Ba in panned pit samples at Smallbrook

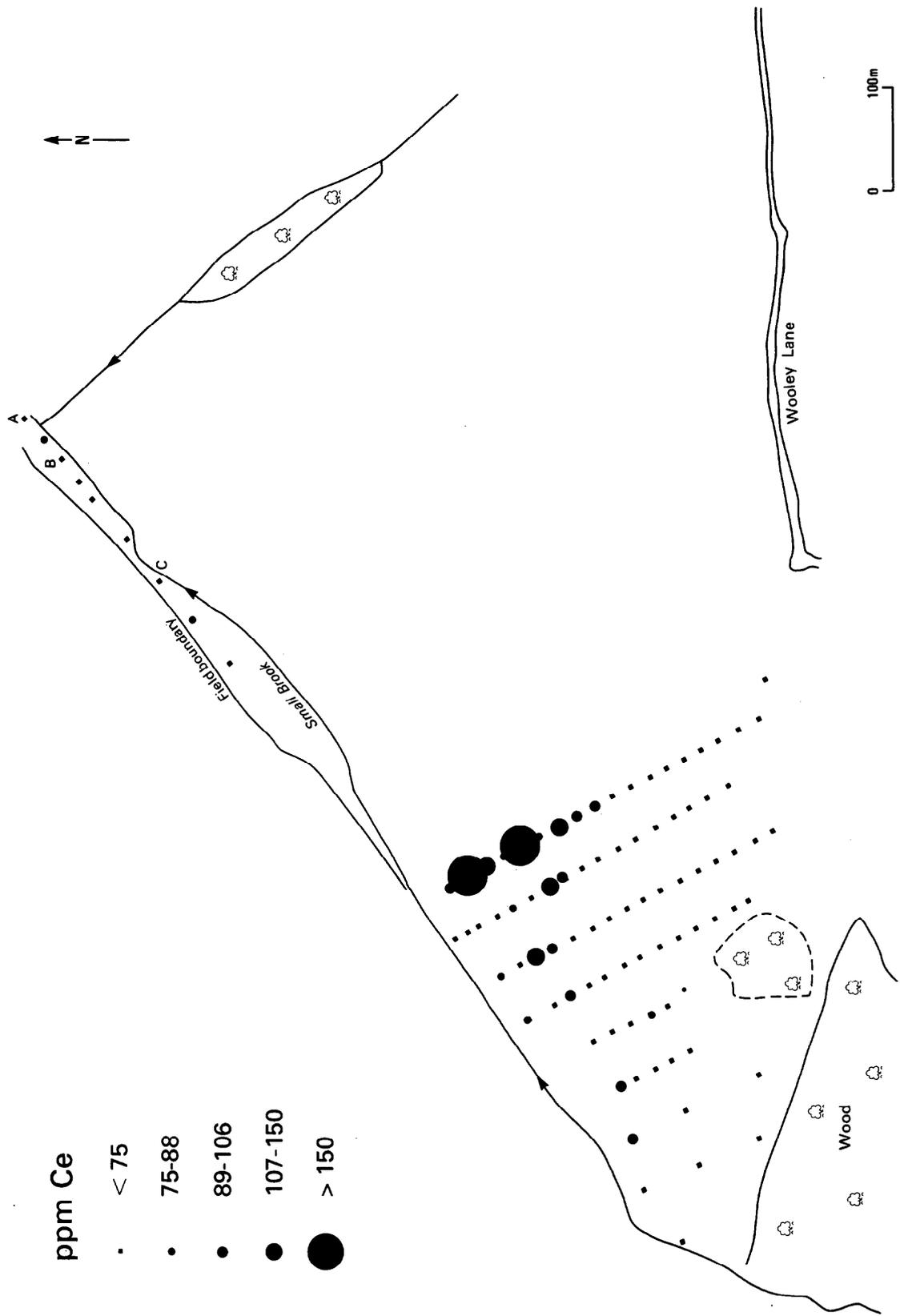


Figure 30 Ce in panned pit samples at Smallbrook

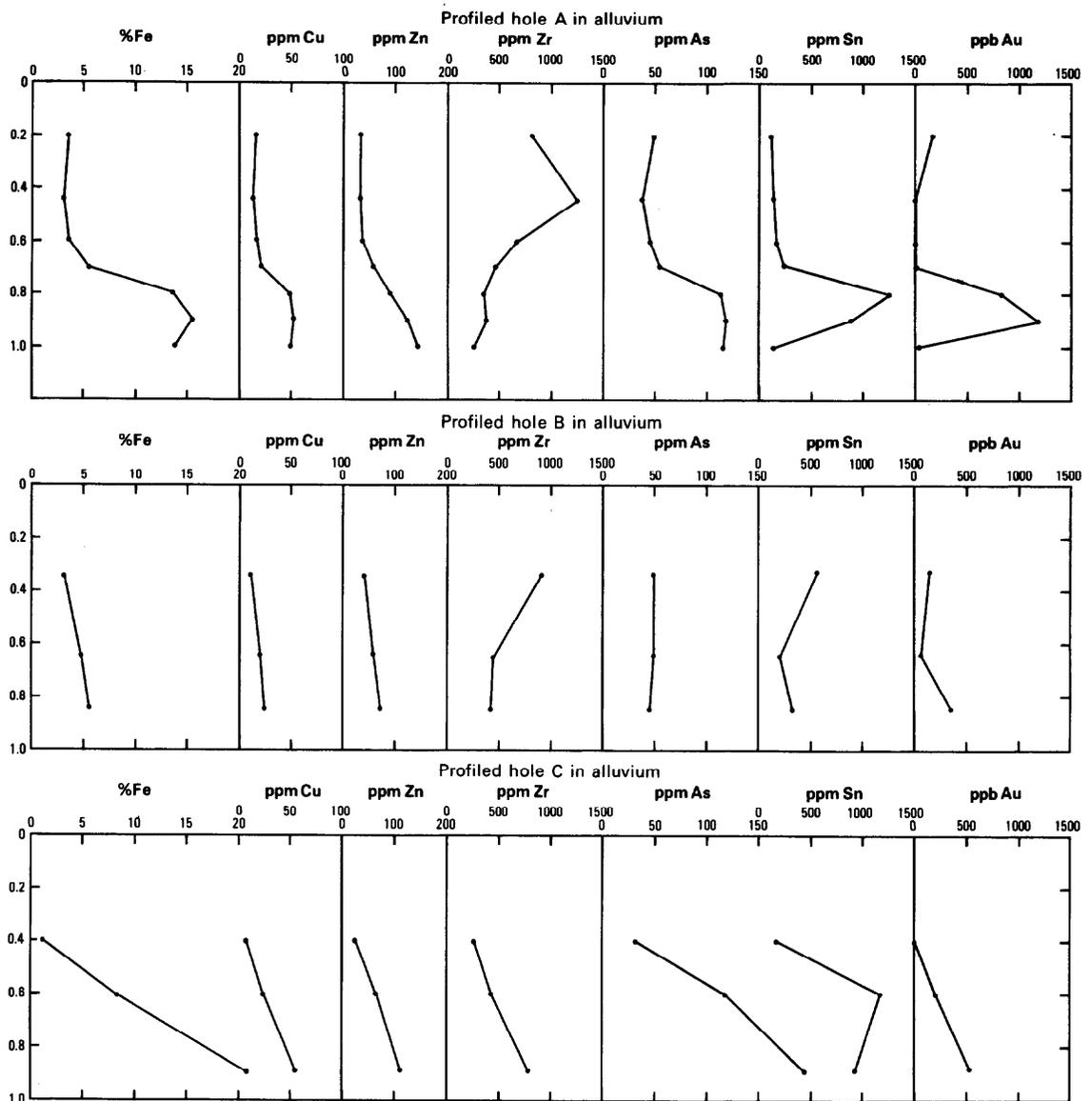


Figure 32 Variation in element concentrations with depth in panned pit samples of alluvium at Smallbrook

Table 4 Average element concentration of deep pits 1 to 6, and adjacent soil and panned pit samples

Deep pit	Depth m	Mn ppm	Fe %	Cu ppm	Zn ppm	As ppm	Zr ppm	Sn ppm	Pb ppm	Au ppb
1	1.4–2.0	1720	3.60	34	65	42	333	8	27	<10
2	0.6–2.0	1675	3.79	36	70	35	298	8	26	<10
soil	0.6–0.8	1430	5.45	51	61	29	–	–	30	–
pan. pit	0.8	–	20.50	68	104	141	599	116	91	1500
3	0.8–2.0	2145	3.94	39	82	40	280	11	26	<10–23
4	0.9–1.8	1380	3.76	31	65	42	287	10	26	<10–16
soil	0.9	510	4.68	39	98	43	–	–	25	–
pan. pit	0.9	–	7.62	27	58	93	1729	37	51	<10
5	0.8–2.5	1400	4.17	40	67	27	282	6	25	<10–20
6	1.8–2.9	1315	3.70	28	66	29	330	8	25	<10

Note element not analysed: –

It appears that Trench B did not intersect a faulted contact between the clay/sand unit and the more typical sedimentary breccias of the Permian sequence. The entire trench was in the clay/sand unit, which is marked by relatively lower levels of all elements (Table 5) than the Newton St Cyres Breccia (Table 4). The fault contact must be slightly further to the east of the east end of the trench. The nearest soil sample, the composition of which is also given in Table 5, is more typical of samples derived from the sedimentary breccias to the south of the Newton St Cyres Breccia. Gold was not detected analytically in any of the samples from Trench B.

Table 5 Average element concentration of samples from Trench B, and adjacent samples

Sample	Mn ppm	Fe %	Cu ppm	Zn ppm	As ppm	Zr ppm	Sn ppm	Pb ppm	Au ppm
average clay	957	3.51	29	46	9	203	2	23	<10
average sand	1083	1.30	16	28	10	181	1	17	<10
minimum	527	0.83	12	22	2	152	<1	9	<10
maximum	1440	5.08	55	97	18	248	6	40	<10
soil	860	4.58	29	69	16	–	–	22	–
pan	–	11.20	50	95	45	460	10	10	515

Note element not analysed: –

The compositions of samples from the base of excavations at intervals along Trench C are shown in Table 6. In this excavation, a contact occurs between material typical of the Newton St Cyres Breccia and sandy clay and sand chemically similar to the weathered rock taken from Trench B. The presence of this contact in Trench C suggests that the contact between the clay unit and the typical sedimentary breccias is not a simple north–south fault as was deduced from the overburden geochemical survey. The composition of the nearest soil sample taken from just to the east of the south end of the Trench (Table 6) is more typical of material derived from the sedimentary breccia and suggests that the clay

unit cannot extend far to the east of Trench C. Au was detected by analysis in two of the samples from Trench C, to a maximum of 21 ppb, (22.6 m, 4.4 m depth).

Table 6 Composition of basal samples along length of Trench C (from north to south)

Location	Depth m	Mn ppm	Fe %	Cu ppm	Zn ppm	As ppm	Zr ppm	Sn ppm	Pb ppm	Au ppb
0	4.2	534	6.15	58	72	24	221	3	28	12
9 m S	3.9	3517	3.67	42	79	33	329	9	24	<10
15 m S	4.0	2804	3.66	31	69	21	266	11	25	<10
18 m S	3.4	1588	3.74	42	61	37	220	3	24	<10
20.5 m S	3.0	256	1.54	17	26	26	149	1	6	<10
22.6 m S	4.7	426	1.95	14	27	10	186	<1	13	<10
27.4 m S	4.9	380	2.09	14	30	7	199	<1	12	<10
soil	1.0	800	4.20	24	72	17	–	–	25	–
pan	0.8	–	6.81	25	47	35	415	18	33	23

Note element not analysed: –

The short Trench E (6 m long), the position of which was constrained by the boundary of the area planted with tree seedlings, intersected sandy material geochemically similar to samples from Trench B. The contact between the Permian and Carboniferous rocks must therefore be slightly further to the south of the trench. A small subsample of sandy material from this trench was found by analysis to contain 32 ppb Au.

The variation in composition of samples taken from the base of the line of pits 2280 to 2306 (Figure 33) is shown graphically in Figure 35. The analysed samples were taken from depths ranging from 2.4 m to 4.4 m and were all of weathered sedimentary breccia. A compositional break is apparent in several elements beyond 80 m from the northern end of the line (Figure 35) which corresponds to a change in the visual appearance of the breccia. To the north of this point the sample chemistry is similar to material from the deep pits, 1 to 6, which penetrated weathered, typical, Newton St Cyres Breccia. South of the same point, the samples contain less Sn, Zr and As and higher levels of Mn, Fe, Cu and Zn. Concentrations of Mn reach over 1.8 % Mn in the < 0.5 mm fraction, comparable to the maximum level found in the soil samples from the area. An isolated sample obtained from a point 110 metres south of the south end of the line is richer in Ti, Cu and Zn than other samples from the line and probably is derived from Carboniferous rocks. Au was detected by analysis in 6 of the samples from this line of pits (range 12–35 ppb).

In addition, one grain of gold was extracted physically from a sample from 3.9 m depth in one pit in the Newton St Cyres Breccia and a microchemical map obtained. This grain, obtained from material well within the weathered bedrock, is roughly spherical in shape and 130 µm in diameter. It consists predominantly of pure gold, within which there are films, patches and a partial rim of gold showing slight enrichment in silver. In addition it contains an inclusion of palladium telluride. These internal chemical characteristics are identical to grains extracted from alluvium in the Small Brook and clearly demonstrate that the gold in the alluvium is of local derivation, mostly from the Newton St Cyres Breccia. The predominance of inclusions of palladium telluride, together with smaller numbers of selenide inclusions in the Smallbrook gold, suggests that the source lies within the Permian sequence where fluids would be oxidising and possibly that it is connected with basic magmatism (Afifi et al., 1988).

Location of JCB excavations

- | B,C,E trenches
- 1-8 pits
- panned overburden

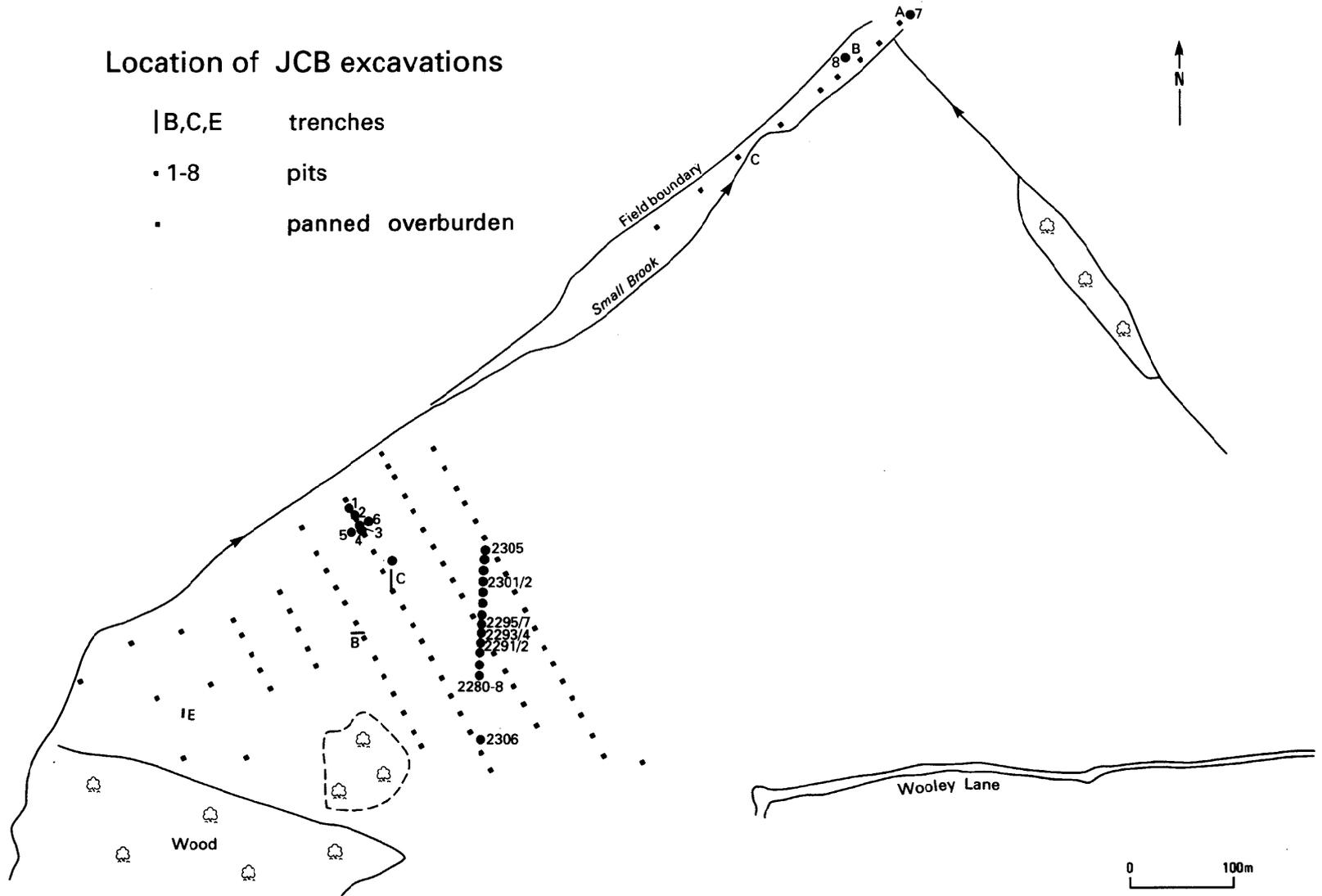


Figure 33 Location of deep excavations at Smallbrook

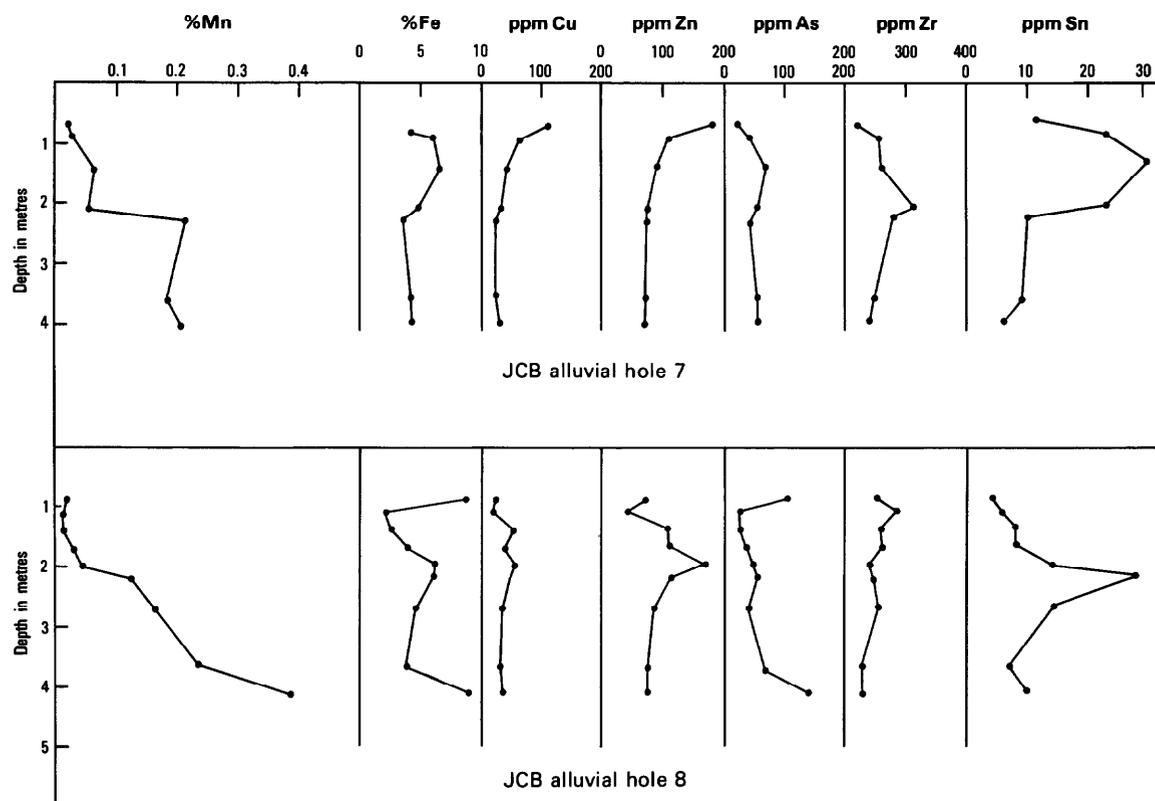


Figure 34 Variation in element concentrations with depth in deep excavations in alluvium at Smallbrook

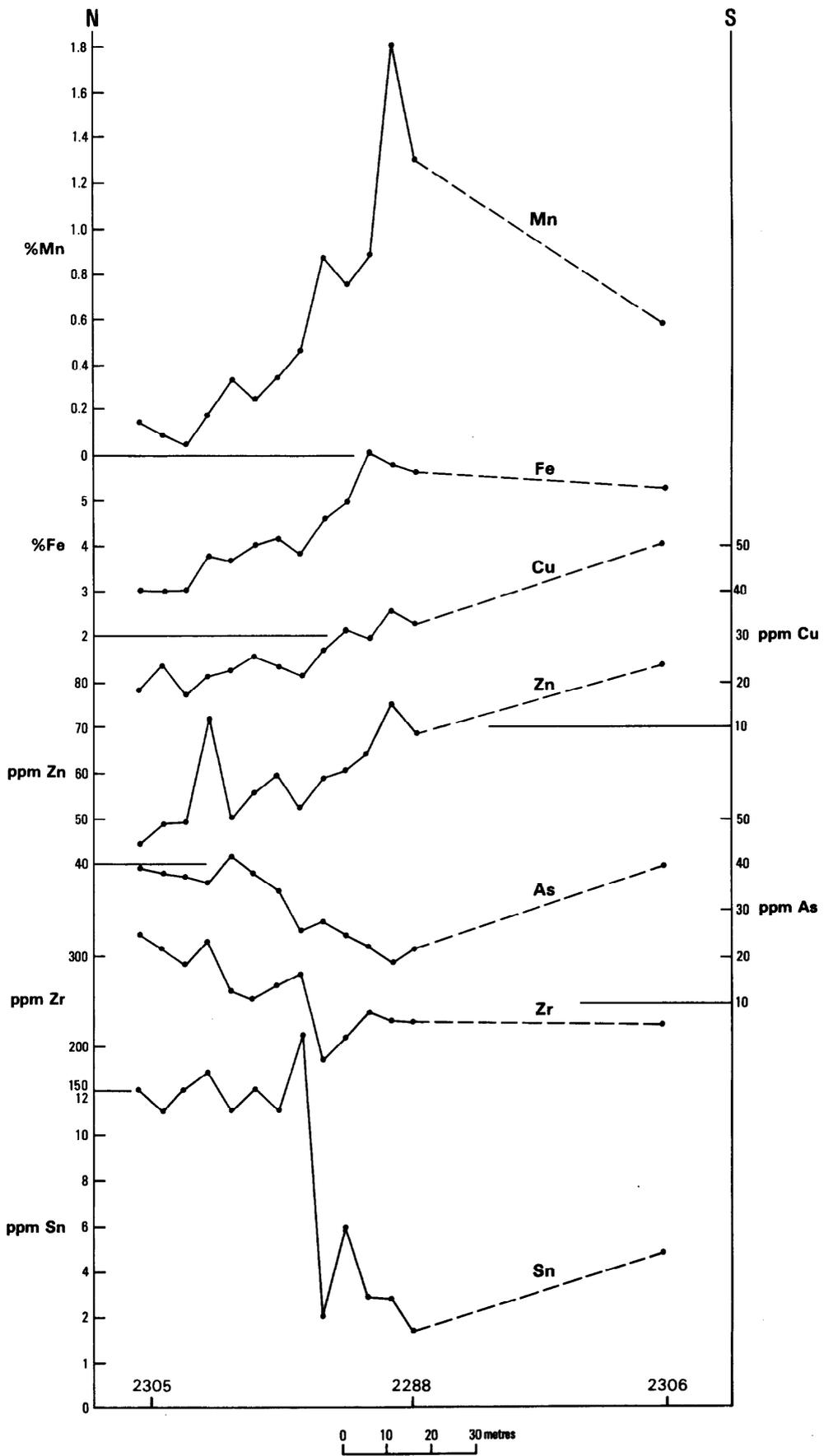


Figure 35 Variation in element concentration in basal samples from deep pit traverse at Smallbrook
 See Figure 33 for location of traverse

Two deep pits were excavated by backhoe in the alluvium of the north-east of the survey area, to depths of 4.0 m and 4.1 m respectively (Pits 7 and 8, Figure 33). Bulk samples were collected at various depths and subsamples panned, this showed gold was most abundant at depths of 0.7 and 0.9 m in Pit 7, where 3–4 grains were reported. Below this layer in Pit 7, and in the samples from Pit 8, only isolated grains were observed.

The variation in chemistry with depth in Pits 7 and 8 is shown in Figure 34. In Pit 7 there is a sharp break in composition between 2.1 and 2.3 m which probably reflects the change from alluvium into weathered bedrock. Base metals are concentrated at the top of the hole, at depths comparable to the maximum levels of these elements in the manually dug alluvial pits. Sn concentrations are elevated in the material above the 2.3 m level, probably reflecting material enriched in heavy minerals towards the base of the alluvium. Below the 2.1 m level, concentrations of most elements are relatively constant. In Pit 8 a compositional break is less clear but can be discerned for some elements between the 2.2 and 2.7 m levels, again probably reflecting a transition from alluvium into weathered bedrock. Mn, Fe and As levels are more variable in the lower part of Pit 8 than in the equivalent part of Pit 7, which could reflect some carbonate-rich veining in the bedrock.

THE UPTON PYNE BOREHOLE

In 1982 a hole was drilled across the southern boundary of the Crediton Trough at Upton Pyne [SX 9108 9773], some 5 km to the east of the Small Brook. The hole was drilled by the BGS in order to investigate the stratigraphy, structure and mineralisation of the area as part of the 1:10 000-scale primary geological survey of the Exeter district.

The borehole was sited close to the disused and flooded Pound Living Mine at Upton Pyne and proved 51.16 m of Newton St Cyres Breccia in faulted contact with reddened shale and sandstone of the Crackington Formation. Beneath 41 m depth are a series of carbonate-cemented hardgrounds, while below 46 m is a 2 m zone of pockets and stringers of manganese oxides. The breccia is fractured and disturbed.

Manganese ores were formerly worked from scattered small deposits (Figure 1) in Late Permian breccia and sandstone host rocks in the southern part of the Crediton Trough close to the boundary between the Carboniferous and the New Red Sandstone. It is known (Dewey and Bromehead, 1916) that the manganese minerals in this area form a cement in the sediment host, swelling out locally into pockets of ore. Although no examples of *in situ* mineralisation can be examined at the present day, material scattered around former workings and prospects confirm that the ores extracted were nodular replacements of the Permian breccia and sandstone host rocks by manganese oxide and carbonate minerals. Scrivener et al., (1985) considered that the ore-forming fluids were channelled along minor faults crossing the Permian-Carboniferous boundary fault.

Gold in the Upton Pyne Borehole.

Three gold grains were extracted from one of six samples of core taken from below 46 m depth in the hole. The gold was in a sample taken from 51.6 m depth, in the contact zone between the Permian and Carboniferous rocks. The grains, flat and relatively thin in shape, were separated from a sample of crushed core weighing about 600 g. Based on their estimated volumes, they would be equivalent to between 50 and 100 ppb Au in the sample. Chemical analyses of the surface of each of the grains was carried out by electron microprobe and showed concentrations of silver at 12.6 %, 7.6 % and 8.2 % respectively, but no palladium. In this respect they are similar to grains from the Smallbrook area.

CONCLUSIONS AND RECOMMENDATIONS

The Bow Breccia is thought to be the main source of gold in the Deckport, Solland and Cliston areas. The nature of the inclusions in the gold suggests that an association with igneous activity is also probable. Minor sources may occur in the Carboniferous rocks from which Permian strata have been

stripped by erosion. The north-west wrench faulting does not appear to control gold distribution, but it does control enrichments in uranium.

Fresh samples of the basal Bow Breccia in which the carbonate fraction is preserved should be investigated by drilling. A study of the alkaline basic igneous rocks to the south and south-east of Hatherleigh should be carried out to assess if this igneous activity exerted any control on the gold distribution.

Overburden samples indicate that gold is present widely, but diffusely, in the Late Permian Newton St Cyres Breccia in the Smallbrook area and that the amount of gold derived from other rocks in the area is subordinate to this source. The gold cut-off in the stream alluvium corresponds to the deduced boundary between the Newton St Cyres Breccia and a clay/sand unit. In the Smallbrook area the Newton St Cyres Breccia probably represents a fossil placer. Gold grains in the stream alluvium are derived from the erosion of a large volume of this rock which, due to relative concentration of heavy minerals, results in a large-amplitude, and extensive, drainage anomaly. The presence of gold in such a coarse-grained and poorly sorted rock as the Newton St Cyres Breccia, probably over an area of at least several hundred square metres, suggests the presence of a local and possibly rich source of gold in the rocks that were being eroded in the Late Permian. This source could have been either in the older Permian sequence or in the underlying Carboniferous rocks and may still be present. As in the other areas, telluride inclusions suggest an association with igneous activity.

In view of the high levels of gold found by analysis in samples of alkali basalt of Early Permian age from Thorverton Quarry (Cameron et al., 1994), areas where basaltic lavas are present close to the southern margin of the Trough should be investigated as possible remnants of the source of the gold in the Newton St Cyres Breccia. The nearest outcrops to Smallbrook, at Posbury and Uton, some 3 to 5 km to the west of the Small Brook, where basalt lavas of the Exeter Volcanic Rocks overlie New Red Sandstones, merit priority in investigation. This could involve lithogeochemical sampling and drilling to delineate the extent of the lavas. Wider attention should also be paid to the Permian sequence immediately north of the southern boundary fault, as previously unknown units of older Permian sediments may occur in this environment.

The gold found in the alluvial area of Smallbrook is apparently limited to the upper layers of this material, which appears to be less than 3 m thick. More extensive sampling and a detailed study of the bulk samples collected from the deep pits is required for a fuller assessment.

The manganese carbonate mineralisation which occurs in the Permian rocks close to the faulted boundary with Carboniferous rocks in both the Smallbrook and Upton Pyne areas should be investigated to examine any association with gold mineralisation.

Several moderate-amplitude gold anomalies occur in other parts of the Crediton Trough and Tiverton Basin (Cameron et al., 1994) and merit follow-up surveys in order to complete an assessment of the mineral potential of the Permian succession in this region.

ACKNOWLEDGEMENTS

The authors wish to thank the following landowners for their co-operation in the survey work; Mr G J Cleverdon, Hatherleigh, Mrs W N Oke, Deckport Farm, Mr J C Hawkins, Solland Farm, Mr J Hanks Clifton Farm, Ms L Bryant, Rudge Farm and Sir John Quicke & Partners, Home Farm, Newton St Cyres. They also thank G E Norton, R Thompson, C P Dickson, C Bendall, S Black, T Kennedy, A Ritchie, W J Chant and D Jordan for their assistance in sample collection and curation, and C Kelley and colleagues in the Exeter Office of BGS for logistical aid. Diagrams were prepared in the Drawing Office, BGS Keyworth, under the supervision of R J Parnaby.

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