British Geological Survey

Mineral Reconnaissance Programme

Assessment of the potential for gold mineralisation in the Southern Uplands of Scotland using multiple geological, geophysical and geochemical datasets

Department of Trade and Industry

MRP Report 141

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BRITISH GEOLOGICAL SURVEY

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SUMMARY

Geological, geophysical and geochemical datasets for the Southern Uplands of Scotland have been combined and evaluated to enable selection of areas potentially favourable for the occurrence of gold mineralisation. Datasets utilised comprise 1) residual polar aeromagnetic anomalies, 2) residual Bouguer gravity anomalies, 3) lineations derived from images of the aeromagnetic and gravity data, 4) the distribution of igneous rocks and agglomeratic volcanic vents, 5) mapped fault vectors, 6) significant deviations from the regional strike of the Lower Palaeozoic rocks, 7) the distribution of arsenic, antimony, bismuth, copper, lead, silver and nickel in minus 150μm stream sediment samples and 8) the locations of known gold occurrences in rock and alluvium. Three primary target areas, together with 19 smaller secondary target areas, were identified covering a range of different combinations of geological, geophysical and geochemical features. Particular attention was paid to 1) areas where widespread strike deviations were possible indications of anomalous relative tensional stress fields which could favour mineralisation, 2) intersections and foci of geophysical lineations and 3) small groups of arsenic and antimony anomalies which could indicate centres of minor intrusive igneous activity.

Reconnaissance drainage and rock samples were collected at the three primary target areas and, on a smaller scale, at eight secondary target areas. In one of the primary target areas, south-east of Moffat, widespread gold was found in drainage in the Glengap Burn, a tributary of the Wamphray Water. A level of 2.23 ppm gold was recorded in a sample of brecciated and altered red greywacke siltstone from the stream. Gold was also found in drainage samples from adjacent catchments. Electron microprobe characterisation of gold grains from this area showed several to be rich in palladium and therefore similar to grains found in association with the contact between Permian red beds and underlying Lower Palaeozoic rocks in the Thornhill area, to the north of Dumfries. In another of the primary target areas, gold was found in drainage on two sides of Stob Law to the south of Peebles. The small number of rock samples from this area contained up to 59 ppb gold and 1719 ppm arsenic. In the third primary target area, Laurieston Forest, west of Castle Douglas, minor amounts of gold were found in drainage, probably derived from a north-west-trending structure and in veined greywacke (65 ppb gold). The drainage data from this areas also provided evidence for the occurrence beneath drift of a centre of hydrothermal activity with which some gold may be associated. Significant amounts of alluvial gold were also found in three of the secondary target areas, Hawkshaw Burn and Auchencat Burn, to the north of Moffat, and Hopes Water, south of Haddington. Lesser amounts of gold were found in two other secondary target areas, Little Clyde Forest, north-west of Beattock and Glencotho, west of Tweedsmuir.

The results of the test sampling of targets identified by interpretation of the multiple datasets are sufficiently promising in the Glengap Burn, Stob Law area, Hawkshaw Burn, Auchencat Burn and Hopes Water to merit follow-up investigations to define and assess the source of alluvial and bedrock gold. Such findings indicate that the approach used in this study to the identification of promising targets for gold mineralisation within one geological terrane is valid and merits further testing and development.

INTRODUCTION

Alluvial gold is widespread in the Southern Uplands of Scotland and in situ mineralisation has been found at several locations, though not as yet in economic amounts. In the last few years new data have become available for the area which allow remodelling of the potential controls for mineralisation. Recent and continuing BGS remapping of the Southern Uplands has improved the understanding of local and regional geology and structural evolution of the area. In addition the results of the BGS regional geochemical survey of the complete Southern Uplands belt have been published (British Geological Survey, 1993) and interpreted in terms of new geological thinking (Stone et al., 1995). Microchemical characterisation of the alluvial gold (Leake et al., 1993) from several sites in the region has revealed that at least four different types can be recognised which are probably derived from different phases and varieties of mineralisation (Leake and Chapman, 1996). In addition, techniques of evaluation and interpretation of regional geophysical data have been developed which allow the identification of lineations within the data. Most of these lineations are thought to reflect lithological and structural features some of which are likely to have controlled igneous activity and possibly mineralisation. The analysis of multiple datasets has been used for the development of metallogenic/economic models and exploration criteria for gold deposits in several parts of Western Europe, including the Southern Uplands of Scotland, in the BGS-led European Commission funded MIDAS project (Gunn and Plant, 1995).

The first objective of the MRP work was to extend the analysis of multiple datasets with the combination of more comprehensive geological, geochemical and geophysical data, and to recognise within the Southern Uplands belt areas which exhibit geological, geochemical and geophysical features which could indicate a site favourable for the development of gold-bearing mineralisation. A second objective of the work was to test by field sampling whether any evidence exists for the occurrence of gold mineralisation in the favourable areas recognised. This phase of the work commenced but was not completed before the termination of the Mineral Reconnaissance Programme (MRP) so that several of the areas identified as having potential were not visited. In addition, the sampling carried in several of the areas visited was insufficient to give an adequate assessment of their mineral potential. However, sufficient sampling was done and evidence of mineralisation obtained to demonstrate the potential value of the approach adopted.

HISTORY OF EXPLORATION

The Southern Uplands of Scotland has had a long history of extraction of alluvial gold dating back to the sixteenth century. There are documents which record that 113 ounces of gold from the Leadhills area (Figure 1) was used to augment the Scottish Crown Jewels between 1537 and 1541 and that over a period of 30 days in 1579, 128 ounces of gold were sent to the Scottish mint. Similarly, during the same period significant amounts of gold were extracted from Glengaber Burn, a tributary of the Megget Water near St Mary's Loch (Figure 1). In more recent times there has been substantial exploration for bedrock gold mineralisation as part of the MRP and also on a larger scale by exploration companies.

MRP exploration in Galloway (Leake et al., 1981) led to the discovery of two phases of gold-bearing mineralisation at Glenhead (Figure 1) in the aureole to the south of the Loch Doon granite. These comprised an earlier, disseminated pyrrhotite-arsenopyrite-pyrite mineralisation containing minor gold (up to 0.16 ppm) and later quartz vein mineralisation carrying arsenopyrite and native gold (assaying up to 8.8 ppm Au in 300 g samples). During the same period systematic sampling of stream

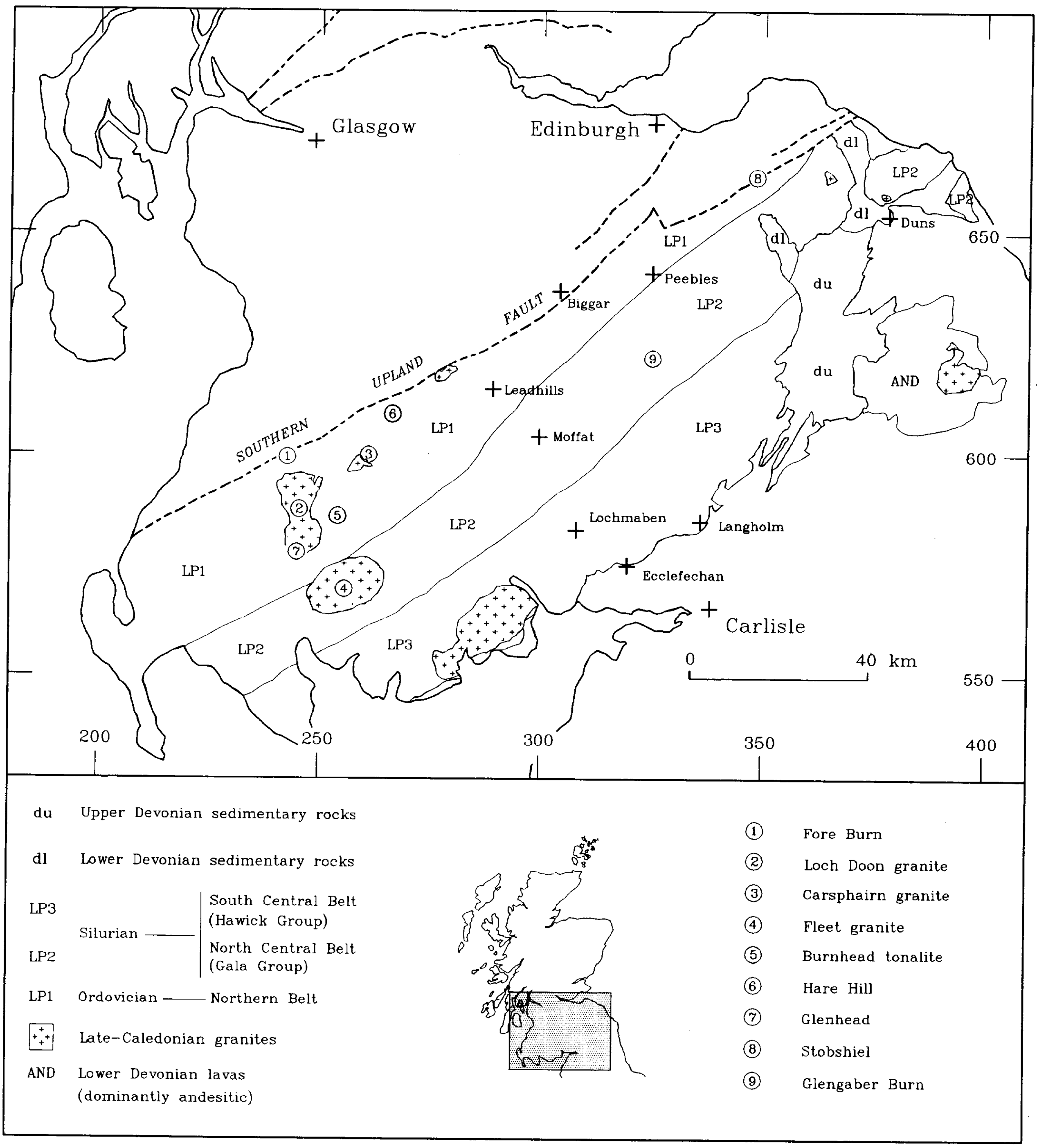

Figure 1 Regional geology and location map of the Southern Uplands.

sediment for gold was carried out over the Loch Doon and Carsphairn granites and their surroundings (Dawson et al., 1977). This work showed that gold was widely distributed in the region and locally conspicuous. Concentrations of gold in stream sediment were found north of the Fleet granite around Maggot Hill, around Moorbrock Hill on the margin of the Carsphairn granite and adjacent to the Burnhead intrusion. Subsequent work by BP Minerals located gold mineralisation in several areas in the Southern Uplands, including the Hare Hill intrusion (Boast et al., 1990), Stobshiel, and Moorbrock Hill. Reconnaissance drainage exploration was also carried out in the area between Moffat and Biggar (Dawson et al., 1979), including the Glengaber Burn area. In this project, gold grains were observed in 48 out of 182 panned stream sediment samples, over a large part of the area.

Gold was also found in association with arsenopyrite, pyrite, chalcopyrite and minor tennantite, tetrahedrite and cobaltite in intrusion breccia associated with the dioritic Fore Burn igneous complex, intrusive into early Devonian volcanic and sedimentary rocks just to the north of the Southern Uplands Fault (Allen et al., 1982). Subsequently, RTZ carried out further exploration in the area (Charley et al., 1989) and located gold mineralisation erratically in association with arsenopyrite-bearing quartz-carbonate veins and quartz chalcopyrite veins. Minor amounts of gold were found by chemical analysis to be associated with Fe-As-Sb-Pb-Zn-Cu-Hg mineralisation in breccia veins near the old Glendinning antimony mine to the north-west of Langholm (Gallagher et al., 1983).

Concentrations of alluvial gold were also discovered in the Duns area at the north-eastern end of the Southern Uplands belt as a result of BGS regional geochemical surveys in 1983 which were followed-up by the MRP (Shaw et al., 1995). In this area gold grains were observed in panned concentrates at about 40% of sites draining the Lower Palaeozoic succession. Most of the gold-rich sites were close to the Priestlaw and Cockburn Law intrusions. Subsequent overburden and rock sampling close to the drainage anomalies located gold anomalies in soil and weathered rock to maxima of 250 ppb and 98 ppb respectively. Analysis of rock samples also revealed 536 ppb Au in a barite-cemented breccia, and clay-rich fracture zones within abandoned copper workings yielded up to 1330 ppb Au.

THE MULTIVARIATE DATASETS

Multivariate statistical analysis of geophysical datasets has been frequently used to provide the spatial lithostratigraphic signature of discrete formations across an area and consequently an approximation to the regional geological map (Lanne, 1986; Eberle, 1993). Geophysical data are often associated with other spatial data to enhance multivariate clusters and lithofacies recognition. Cluster analysis, factor analysis and linear discriminant analysis techniques can all be used to produce maps of population clusters which reflect lithology. Probability criteria can also be used to improve the reliability of cluster assignment.

Many of these methods assume a normal distribution of the multivariate parameters across the region and require the observed parameters to be related to the surface geology. A general restriction is that all multivariate data are referenced on the same grid and are complete across the region. Theoretically this prevents inclusion of relevant vector or point data which do not form a continuous function. For the Southern Uplands the method adopted was that of multivariate display which recognises the significance of digital geological, geochemical and geophysical vector data and utilises these data together with gridded spatial data. This provides a more realistic geological model with the option of including subsurface property distributions. The utilisation of incomplete data is also an advantage in many regions. In the Southern Uplands the regional geophysical gravity and magnetic datasets have been integrated with regional geochemical data, selected tectonic data derived from the original 1:50

000 scale mapping, derived tectonic data from images of the geophysical data and mineral occurrence data.

The following BGS datasets were used:

1. Residual Polar aeromagnetic anomaly at 2 km above observation level
2. Residual Bouguer gravity anomaly at 5 km above observation level
3. Lineations derived from images of the gravity data
4. Lineations derived from images of the aeromagnetic data
5. The distribution of igneous rocks on the 1:625 000 geological map
6. Fault vectors taken from the 1:250 000 geological maps
7. Strike deviations from regional trend and inflexions taken from 1:50 000 geological maps
8. Location of agglomeratic volcanic vents taken from 1:50 000 geological maps
9. Distribution of arsenic, antimony, bismuth, nickel, copper, lead and silver in stream sediments
10. Location of gold-bearing mineralisation in bedrock

Geophysical data

A great deal of structural information is contained within the regional geophysical data. Much of this is only visible within the gradient information of the fields and is best displayed using the shaded-relief technique. Greyscale shaded-relief images from a variety of sun azimuths and inclinations provide a valuable source of tectonic data. Colour shaded-relief images provide both the gradient and amplitude information of the field. Lineations picked from shaded-relief images have provided the main structural dataset for analysis. Images of gravity and magnetic data from north, west and south illuminations have been analysed for structures and the lineations identified have been digitised. Figures 2 and 3 show the gravity and magnetic data illuminated as greyscale shaded-relief images (displayed using the BGS Colmap package).

Figure 4 shows the distribution of lineations picked from images of the regional aeromagnetic data. These show a modal azimuth close to 85°, reflecting the importance of east-west-trending quartz dolerite dykes. The distribution of all gravity lineations picked from images shows a similar pattern (Figure 5) with a modal azimuth close to 90°. However there are also secondary maxima in azimuth in the aeromagnetic lineations at about 40°, 50°, 110° and 130° respectively (Figure 6) and secondary maxima at about 25°, 50°, 60°, 70°, 130°, 160° and 170° respectively in the gravity lineations (Figure 7).

In the Southern Uplands, as for many regions, much of the amplitude and frequency content of the regional geophysical fields is derived not from the surface exposures but from the deeper geology. The effects of the near-surface geology can be enhanced by the use of a regional-residual separation. This has been done by derivation of a regional field for the aeromagnetic and gravity data by analytical continuation of the observed fields upwards to 2 km and 5 km respectively above observation level. The aeromagnetic data were also reduced to the pole assuming induced magnetisation. The residual polar magnetic anomaly was considered to better indicate the location of near surface intermediate stock-like intrusions and the residual gravity anomaly a better map of the more acid intrusive suite.

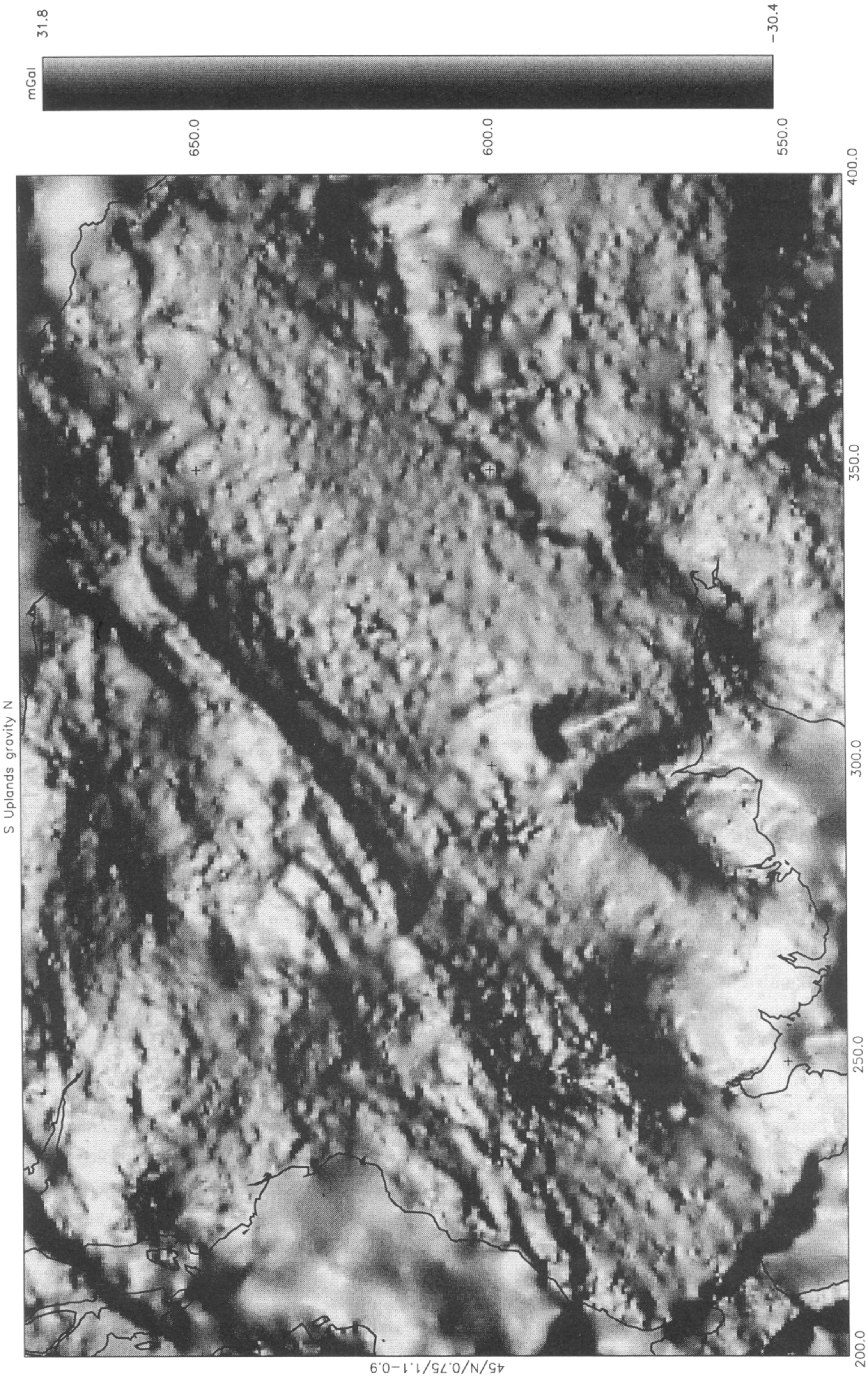

Figure 2 Southern Uplands: greyscale shaded relief image of regional Bouguer gravity data, with illumination from the north at an inclination of 45°

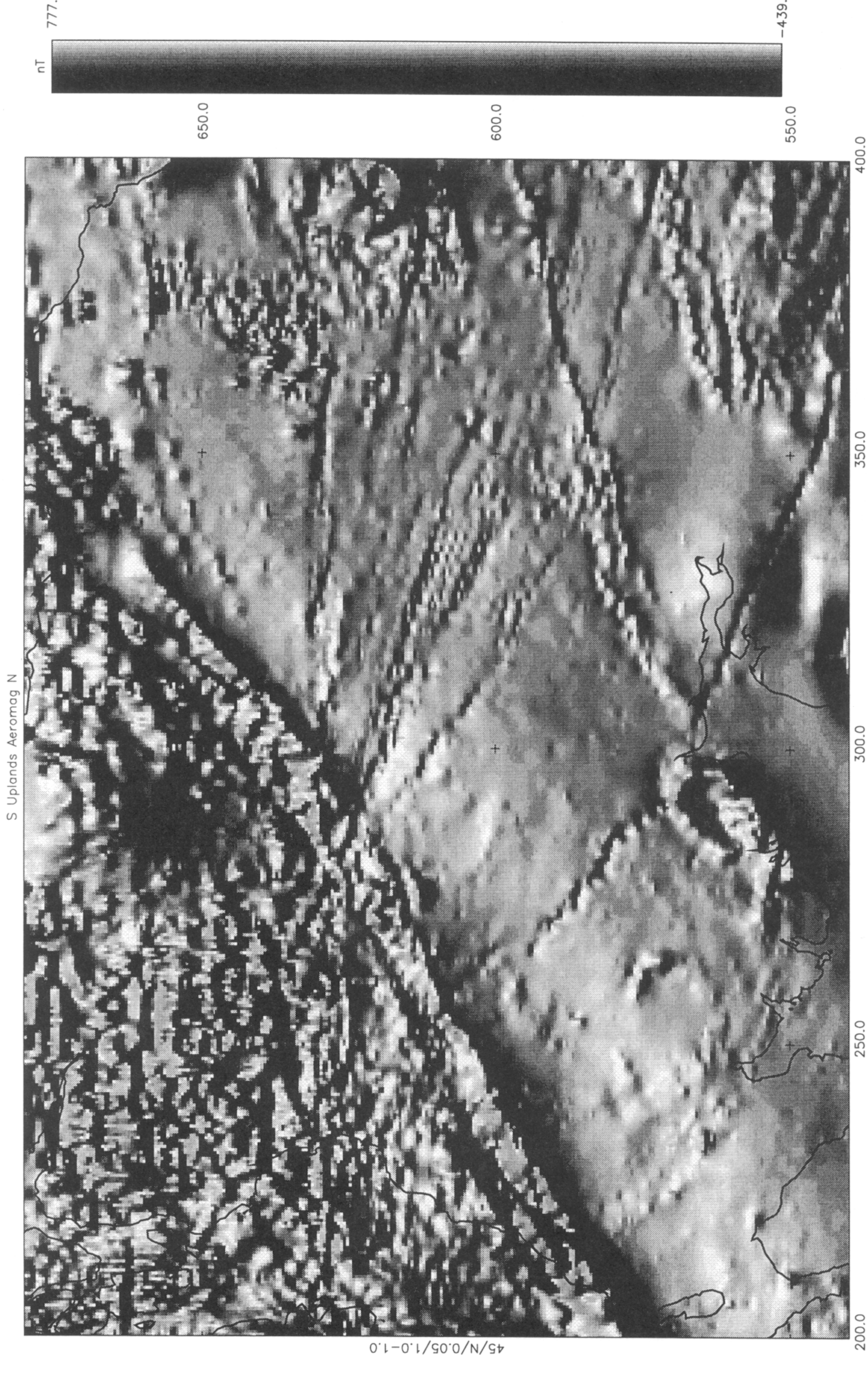

Figure 3 Southern Uplands: greyscale shaded relief image of regional aeromagnetic data, with illumination from the north at an inclination of 45°

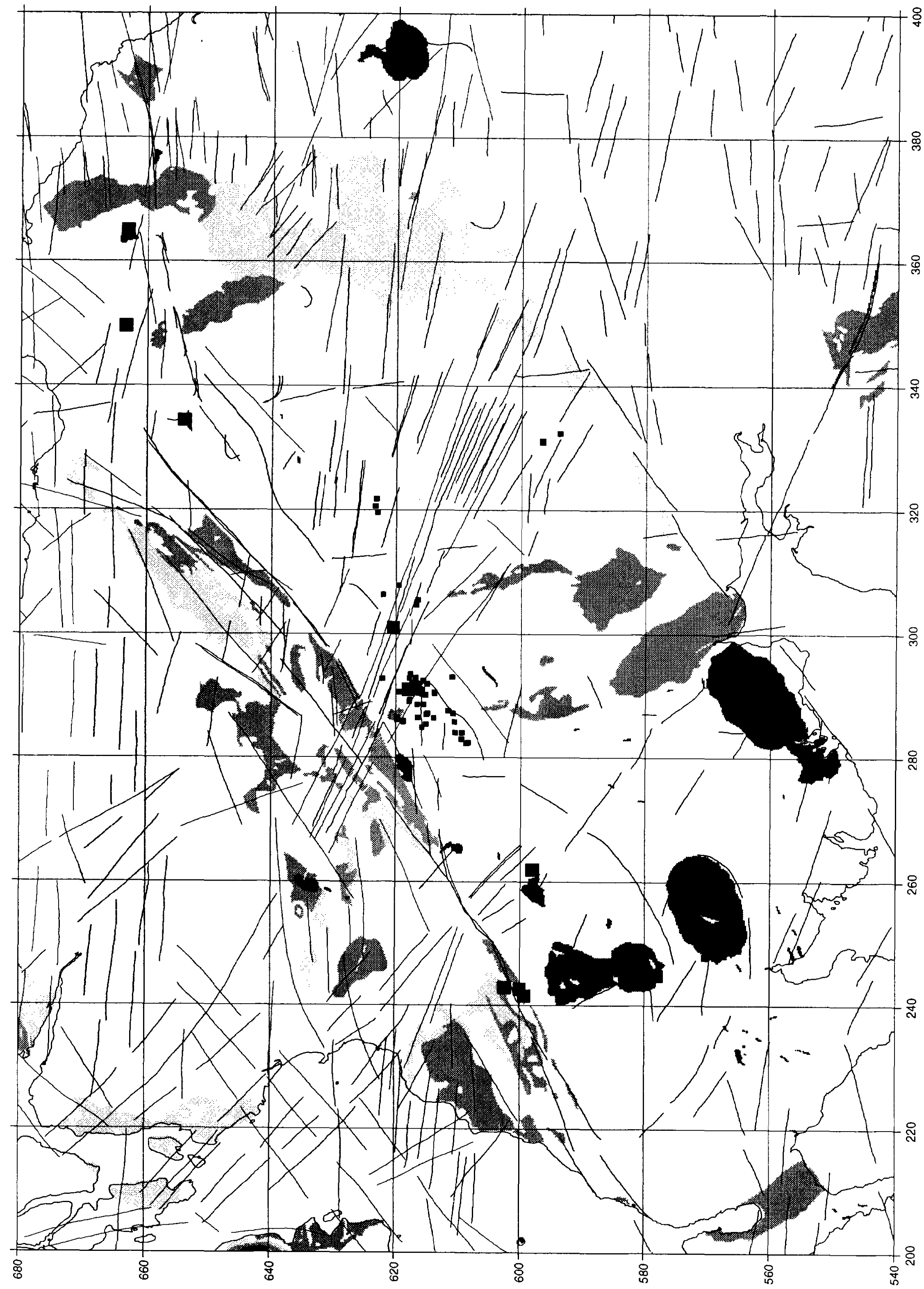

Figure 4 Southern Uplands: lineations derived from images of aeromagnetic data. Outcrops of granite (dark grey), Permian and Lower Old Red Sandstone sediments (medium grey), Upper Old Red Sandstone sediments (light grey) and locations of gold in bedrock (large and medium squares) and of analysed alluvial gold grains (small squares) also shown.

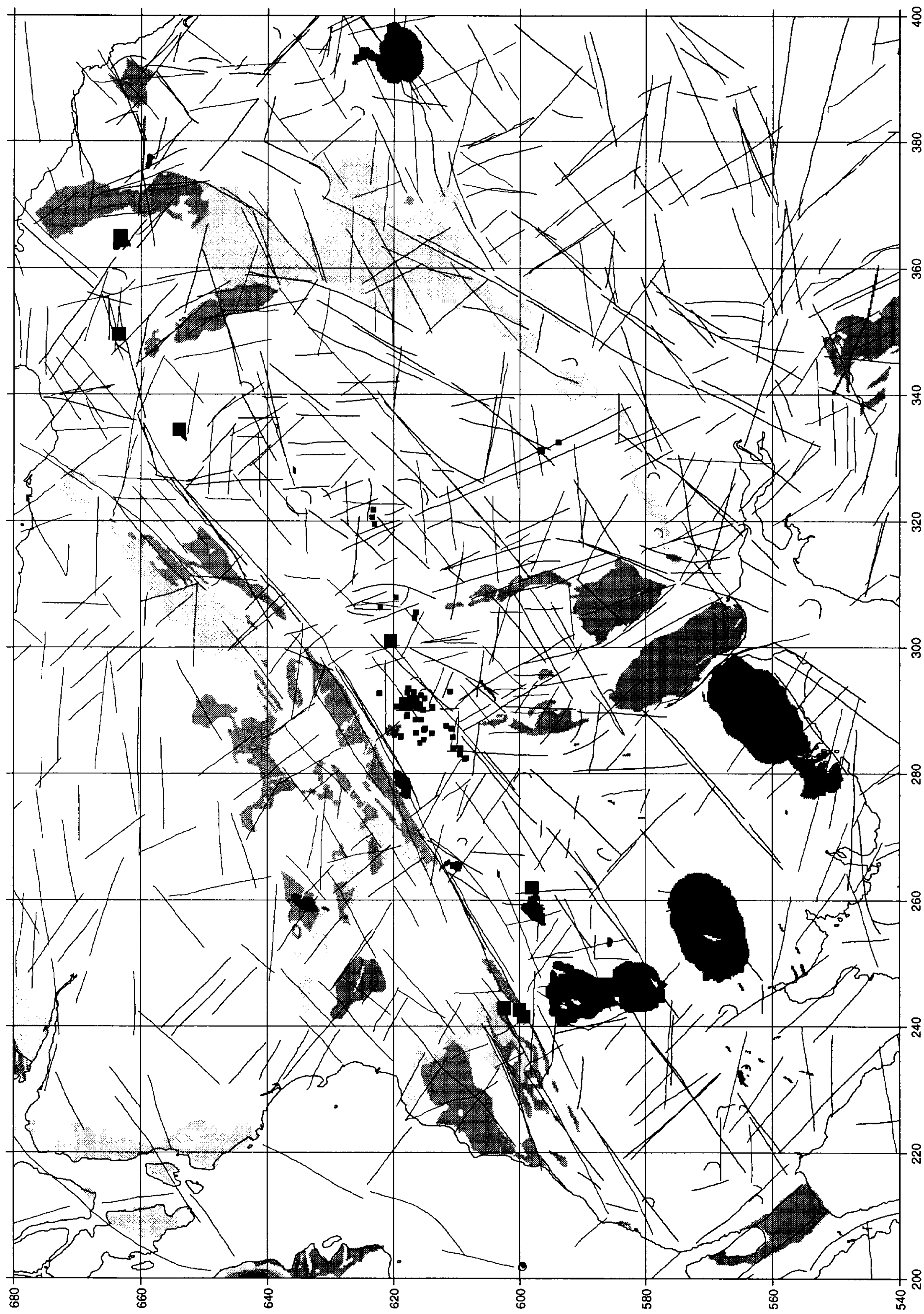

Figure 5 Southern Uplands: lineations derived from images of gravity data. Other features as Figure 4.

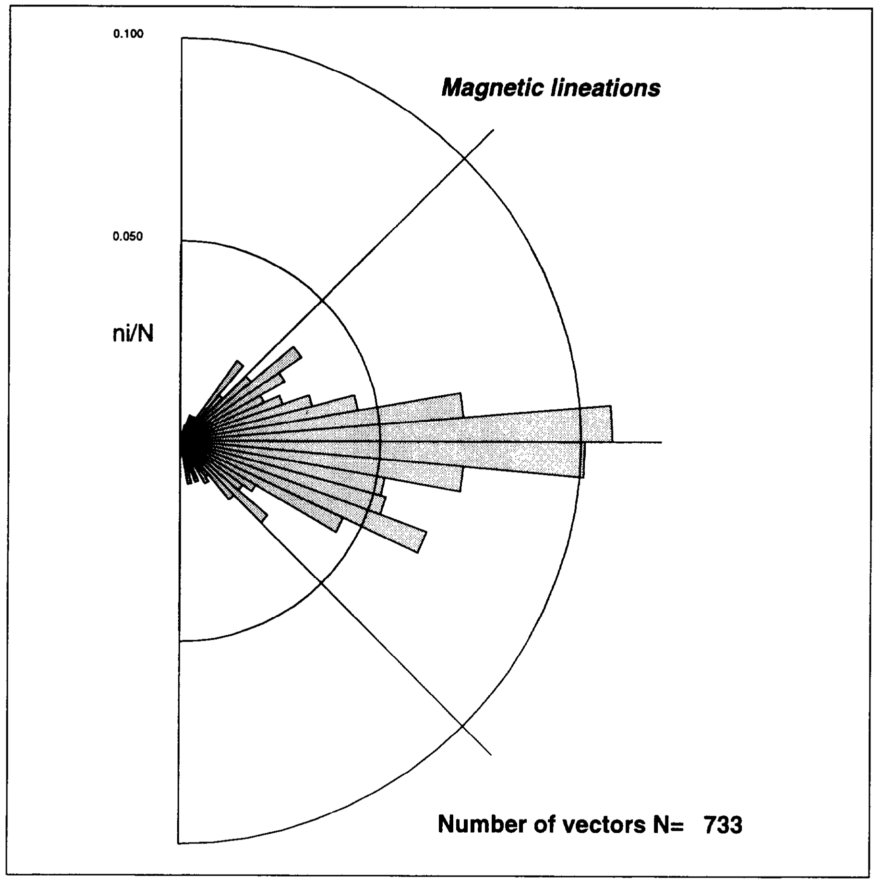

Figure 6 Southern Uplands: azimuthal frequency plot of lineations derived from images of regional aeromagnetic data

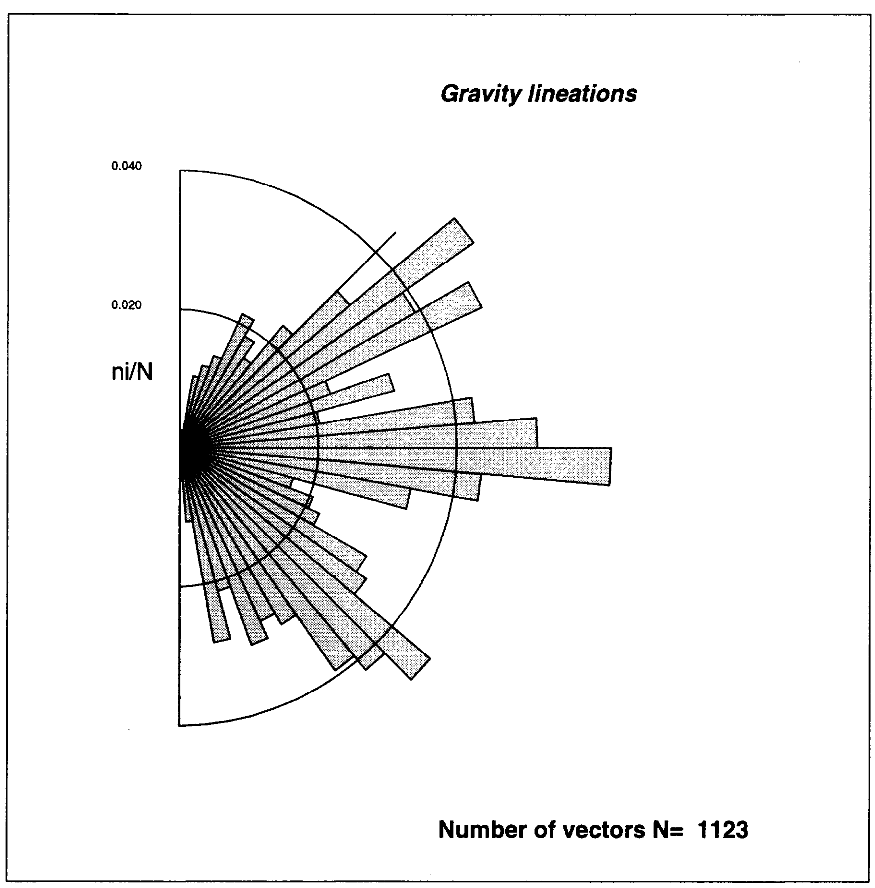

Figure 7 Southern Uplands: azimuthal frequency plot of the lineations derived from images of the regional gravity data

The main positive features of the residual aeromagnetic anomaly (A2) and the negative features of the residual gravity anomaly (G5) are shown in Figure 8 in relation to the distribution of anomalous concentrations of arsenic in stream sediment.

Geological data

Digital geological data provide additional parameters for the analysis. The BGS 1:625 000 lithostratigraphy-based geological map of the UK is available in digital form as a pixel-based map. Pixel integer codes in the range 001-115 reflect the mapped lithofacies as shown on the map. This permits discrete occurrences of particular facies to be displayed with any of the other multivariate data. Pixel size for the Southern Uplands analysis was 400 m. The digital 1:250 000 series geological map for the UK is currently in preparation and fault vectors taken from these maps provide a useful regional tectonic pattern for the analysis. Digital geology at 1:625 000 scale has been used to identify the main igneous lithologies. In addition, a supplementary database of volcanic necks and vents has been incorporated to support the regional tectonic model.

An important aspect of the siting of mineralisation in many areas is the intersection of regional shear sets. These provide zones of anomalous stress for fluid flow and deposit accumulation. Much of the Southern Uplands is not covered by recent geological mapping, although the early geological reference masters contain much detailed structural data. The geological maps were inspected for zones of marked strike deviation interpreted from strike and dip measurements and these locations were digitised. These data are thought likely to be reliable whatever the age of the geological mapping and have been extracted for most of the region except for areas in the south around Lochmaben and Ecclefechan (Figure 1). Individual deviant strikes have been neglected but groups of measurements where the strike swings round to north, or north-west or west have been plotted. Deviations from the regional strike can have a variety of causes, but in general they represent areas where the regional compressional and transpressional stress fields have been modified. Sources of strike deviations can represent fold noses, fault discontinuities, centres of minor igneous activity, roofs above buried igneous bodies, irregularities in the stress field due to the influence of deep crustal features and other crustal discontinuities. All modifications of the regional stress which may have resulted in local areas of relative tension favourable for the location of structurally controlled mineralisation need to be considered in a regional exploration model.

Figure 9 shows the locations of geological features comprising deviant strikes, volcanic vents, the mapped fault pattern from the BGS 1:250 000 series geological maps and the locations of igneous rocks from the BGS 1: 625 000 series geological map.

Geochemical data

Use was made of data from the regional drainage geochemical survey of the region (British Geological Survey, 1993) to provide indications of lithofacies and mineralisation. Maps showing the distribution of the elements As, Sb, Bi, Cu, Pb, Ag and Ni in minus 100 mesh BSI fraction (<150 μm) stream-sediment samples were used. The data were plotted in class-interval form, with up to 19 classes defined arithmetically and shown as spots of increasing diameter. No attempt was made to analyse the data statistically as only broad patterns of variation in element concentration were being considered.

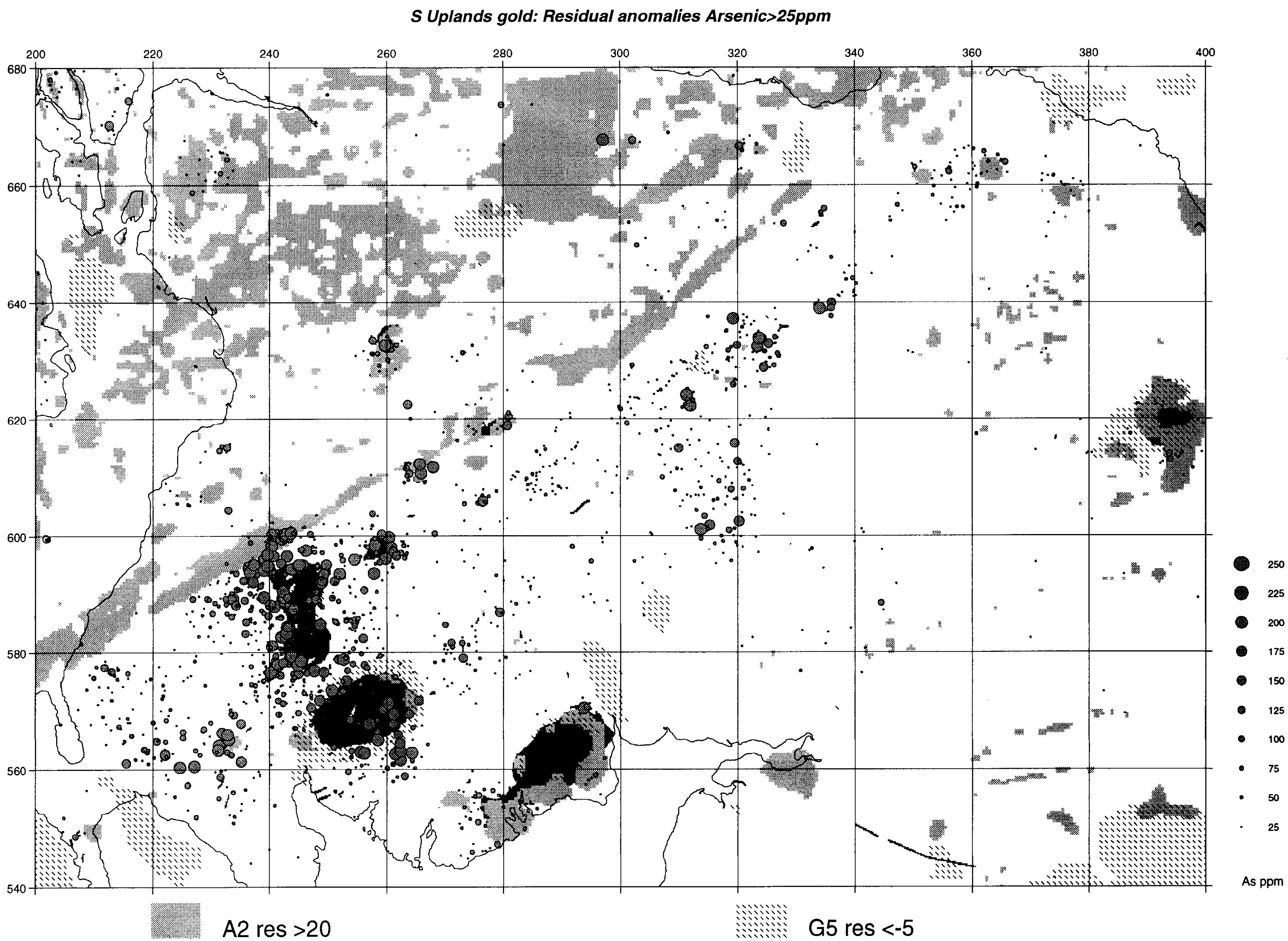

Figure 8 Distribution of arsenic (As) in stream sediment samples in relation to residual gravity (G5) and magnetic (A2) anomalies. G5 is the zone where the residual gravity is less than -5 mGal; A2 is the zone where the residual aeromagnetic anomaly is greater than 20 nT. Anomalous zones G5 and A2 are shown on the colour plates 13 to 18 as blue and red stipple respectively.

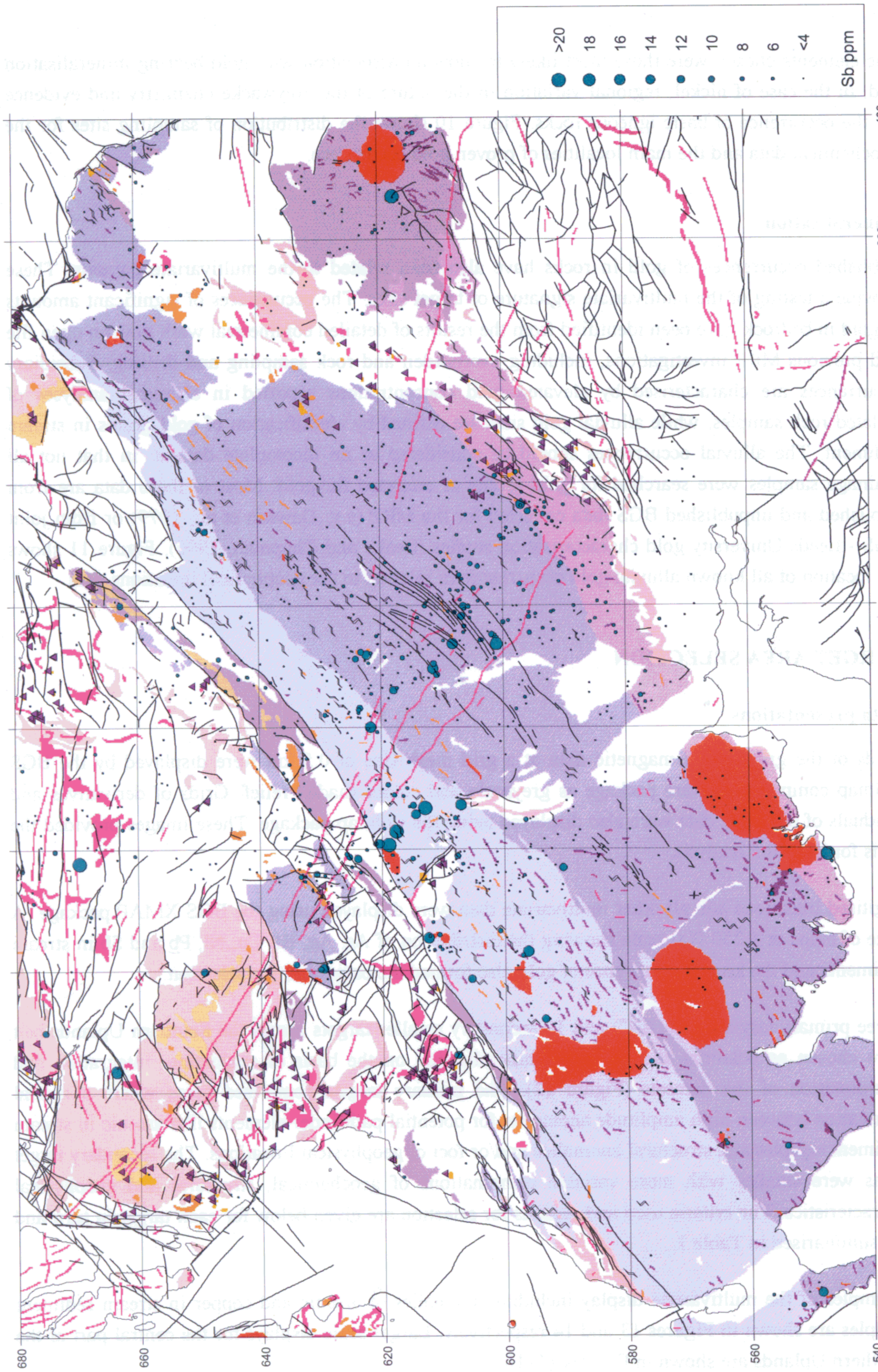

Figure 9 Distribution of antimony (Sb) in stream sediment samples in relation to faults (solid lines), volcanic vents (triangles) and deviant strike trends (sigmoidal symbol). Tone fields from the 1:625000 geological map.

The elements chosen were those most likely to show an association with gold-bearing mineralisation and, in the case of nickel, regional variation in the nature of the greywacke chemistry and evidence for the occurrence of basic igneous rocks. Figure 10 shows the distribution of sampling sites for the geochemical data and the main localities of proven gold occurrence.

Mineralisation

Published occurrences of gold in rocks have also been related to the multivariate datasets. These provide a testing of the multivariate signature of target sites. The occurrences of significant amounts of gold in bedrock have been identified from the results of detailed commercial work now on open file and previous MRP investigations, including overburden and rock sampling and drilling. Subsidiary occurrences are characterised by elevated gold concentrations reported in chemical analyses of isolated rock samples, while alluvial gold sites are defined by identification of gold grains in stream sediment. The alluvial occurrences should be considered as an incomplete dataset, in that not all drainage samples were searched for gold grains or analysed for gold. Most of these data are from published and unpublished BGS data collected for the MRP (e.g. Dawson et al., 1979) or from joint BGS - Leeds University gold characterisation studies (Leake and Chapman, 1996). Figure 11 shows the location of all known alluvial gold occurrences in relation to the geophysical lineations data.

TARGET AREA SELECTION

Data presentations

Grids of the gravity and magnetic data at a grid mesh size of 0.5 km were displayed by the BGS Colmap computer software package as greyscale and colour-shaded relief. Grids of derivatives and residuals of the same data were also displayed using the Colmap package. These images provided the basis for lineation analysis.

Digitised lineations and all other multivariate data were displayed using the BGS XMAP package. A suite of maps at 1:250 000 scale showing the distribution of As, Ag, Bi, Cu, Ni, Pb and Sb in stream sediments and the known occurrence of gold also formed the basis of target selection.

Three primary target areas (A-C) and 19 secondary smaller targets across the Southern Uplands belt were chosen as potential sites for gold mineralisation on the basis of evaluation, integration and interpretation of the datasets (Figure 12). The primary targets comprised areas where a spatial correlation between high amplitude anomalies for potential pathfinder elements like arsenic in stream sediment samples and structural anomalies and/or foci of geophysical lineations. The secondary target areas were smaller with more variable combinations of geochemical, structural and geophysical characteristics. The criteria used and reasons for selection are given below for each target in turn and are summarised in Table 1.

Examples of the multivariate display including anomalies of arsenic and copper in stream sediment samples are shown in Figures 13 and 14 respectively. Larger scale displays for the central part of the Southern Uplands are shown in Figures 15–18.

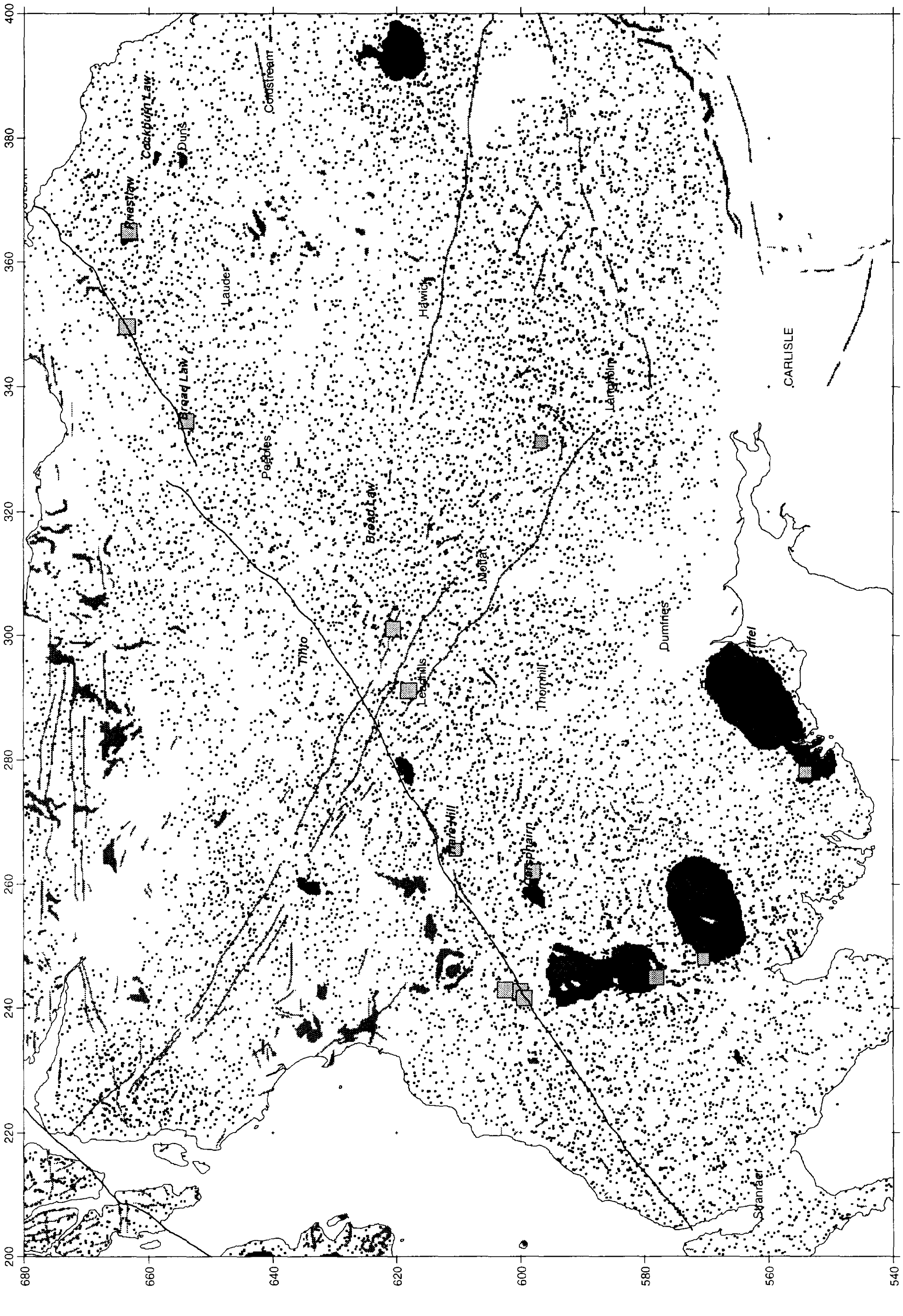

Figure 10 Regional geochemistry drainage sampling coverage and bedrock gold occurrences (filled squares, subsidiary type smaller size)

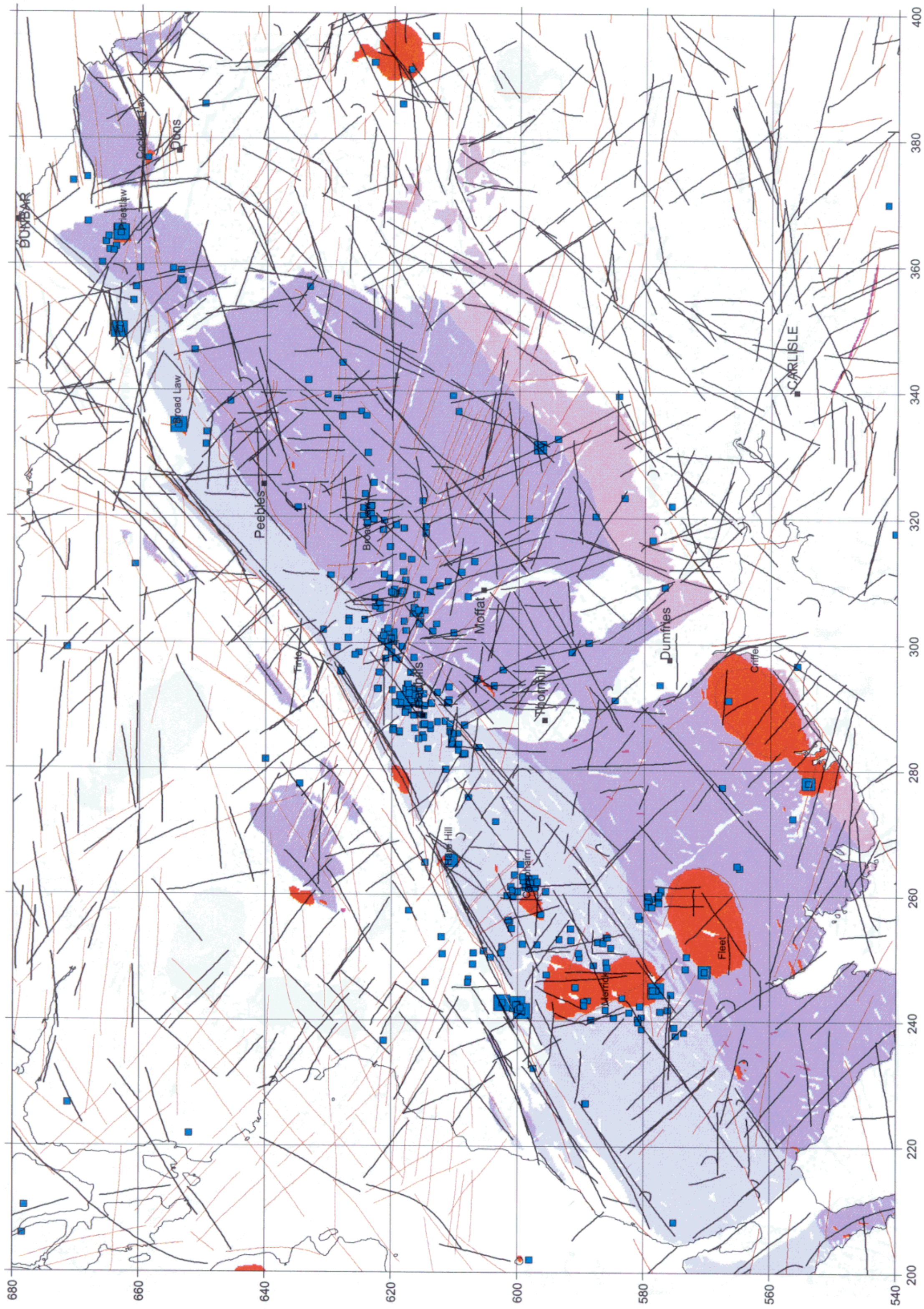

Figure 11 Principal geophysical lineation trends (black gravity, red aeromagnetic) and locations of gold (Au) in drainage pan concentrate samples (small squares) and in bedrock (large squares).

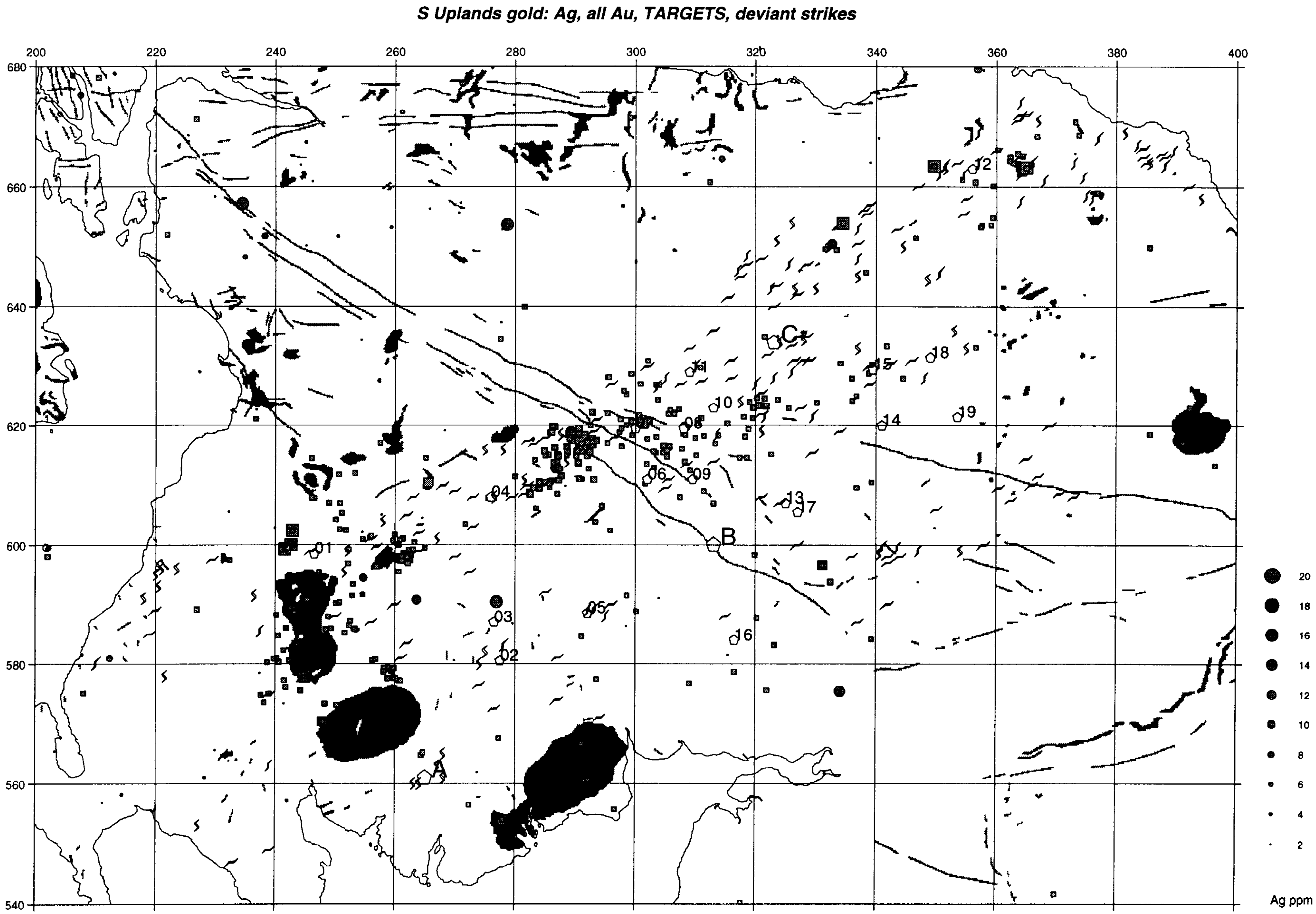

Figure 12 Deviant strike trends (sigmoidal symbol), gold (Au) in drainage pan concentrate samples (small squares), in bedrock (large squares), location of target areas and distribution of silver (Ag) in drainage samples

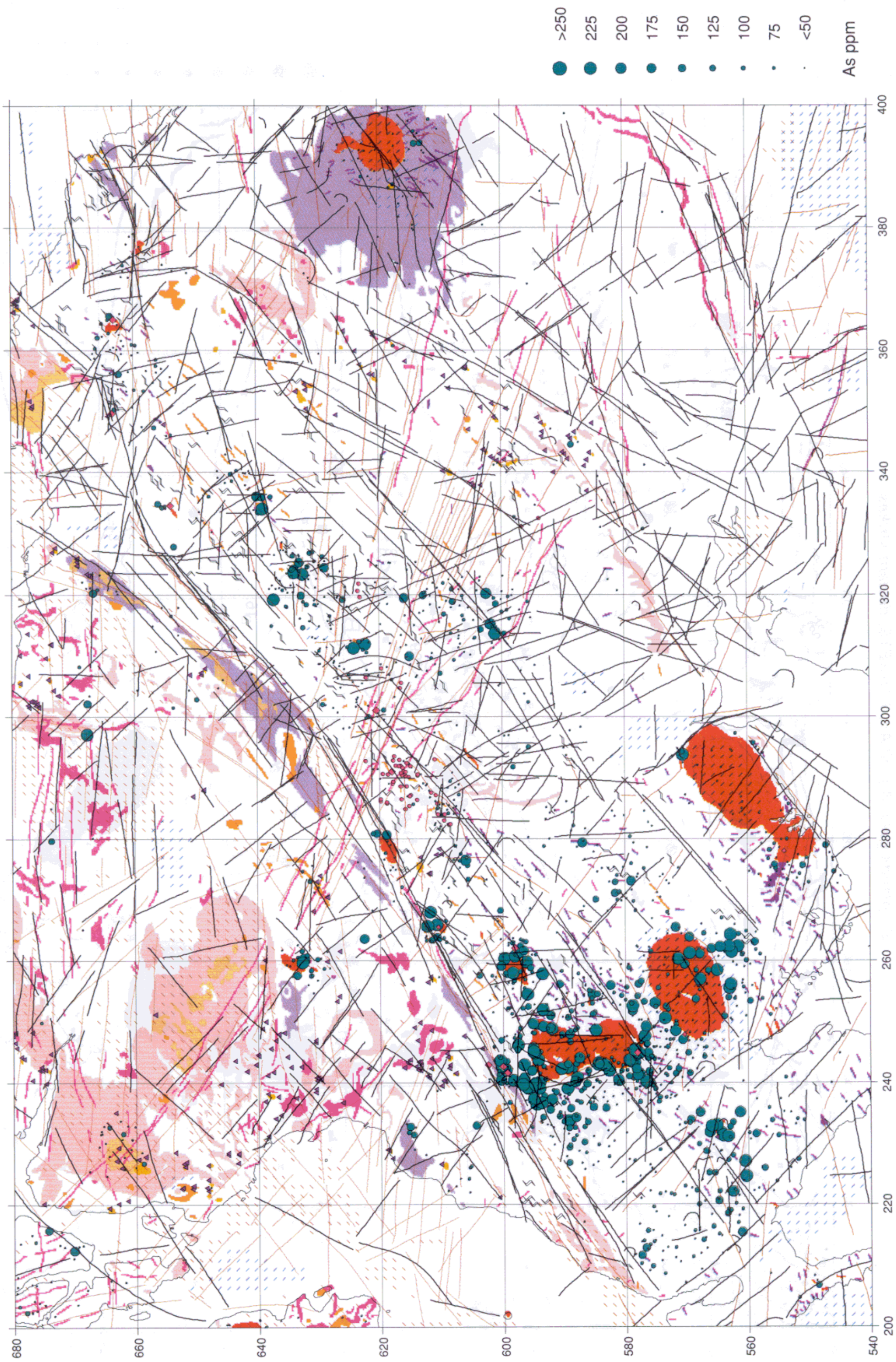

Figure 13 Principal geophysical lineation trends and anomalies in relation to distribution of arsenic (As > 25ppm) in drainage samples for the whole Southern Uplands. Tone field regions are igneous geology from 1:65000 geological map.

Figure 14 Principal geophysical lineation trends and anomalies in relation to distribution of copper (Cu > 40ppm) in drainage samples for the whole Southern Uplands. Tone field regions are igneous geology from 1:625000 geological map.

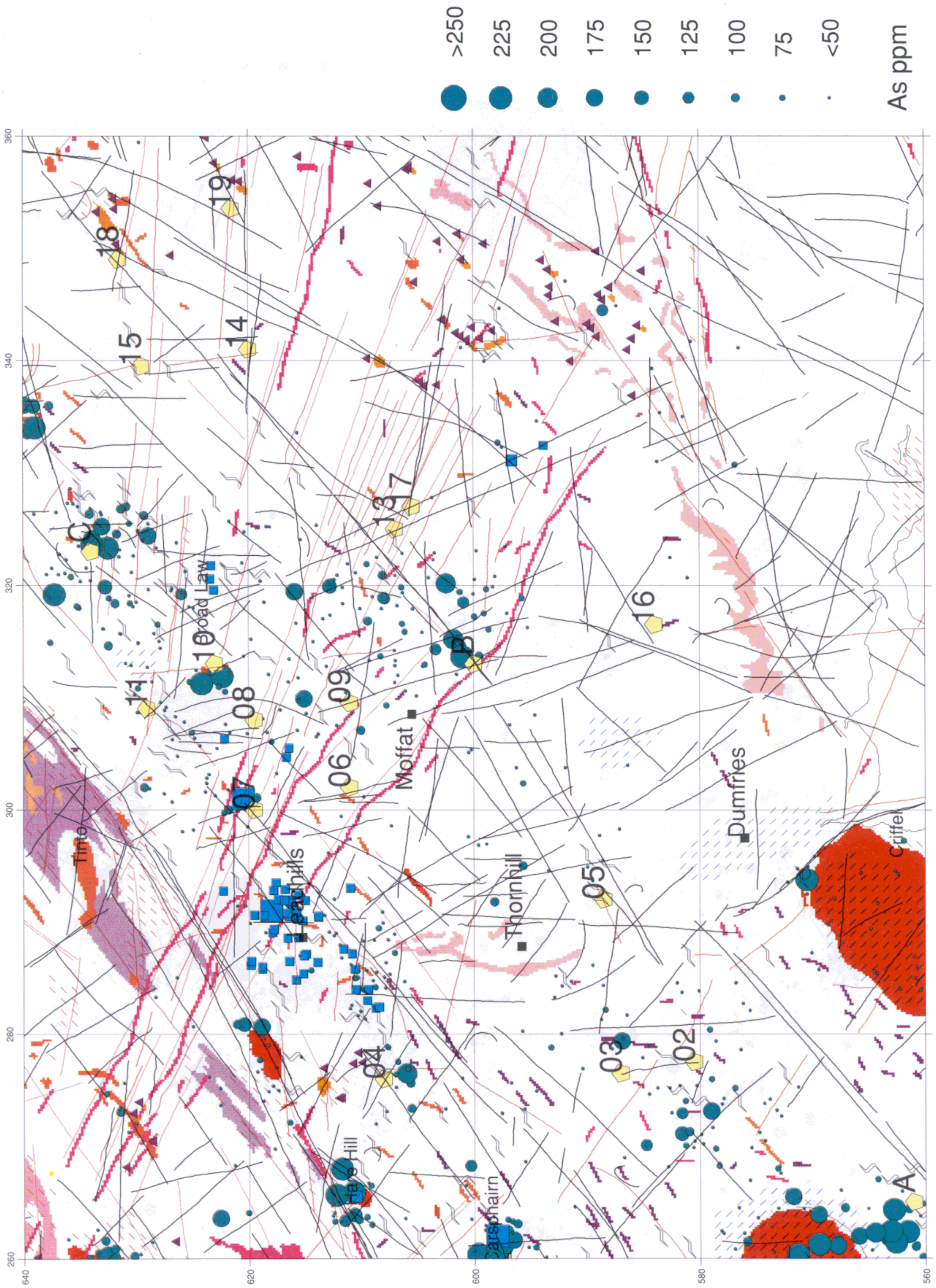

Figure 15 Principal geophysical lineation trends and anomalies, distribution of arsenic (As > 25 ppm) in drainage samples, locations of gold in bedrock (large squares) and of analysed alluvial gold grains and target areas (primary A–C, secondary 02–11, 13–19) in the Central Southern Uplands. Tone field regions are igneous geology from 1:625000 geological map.

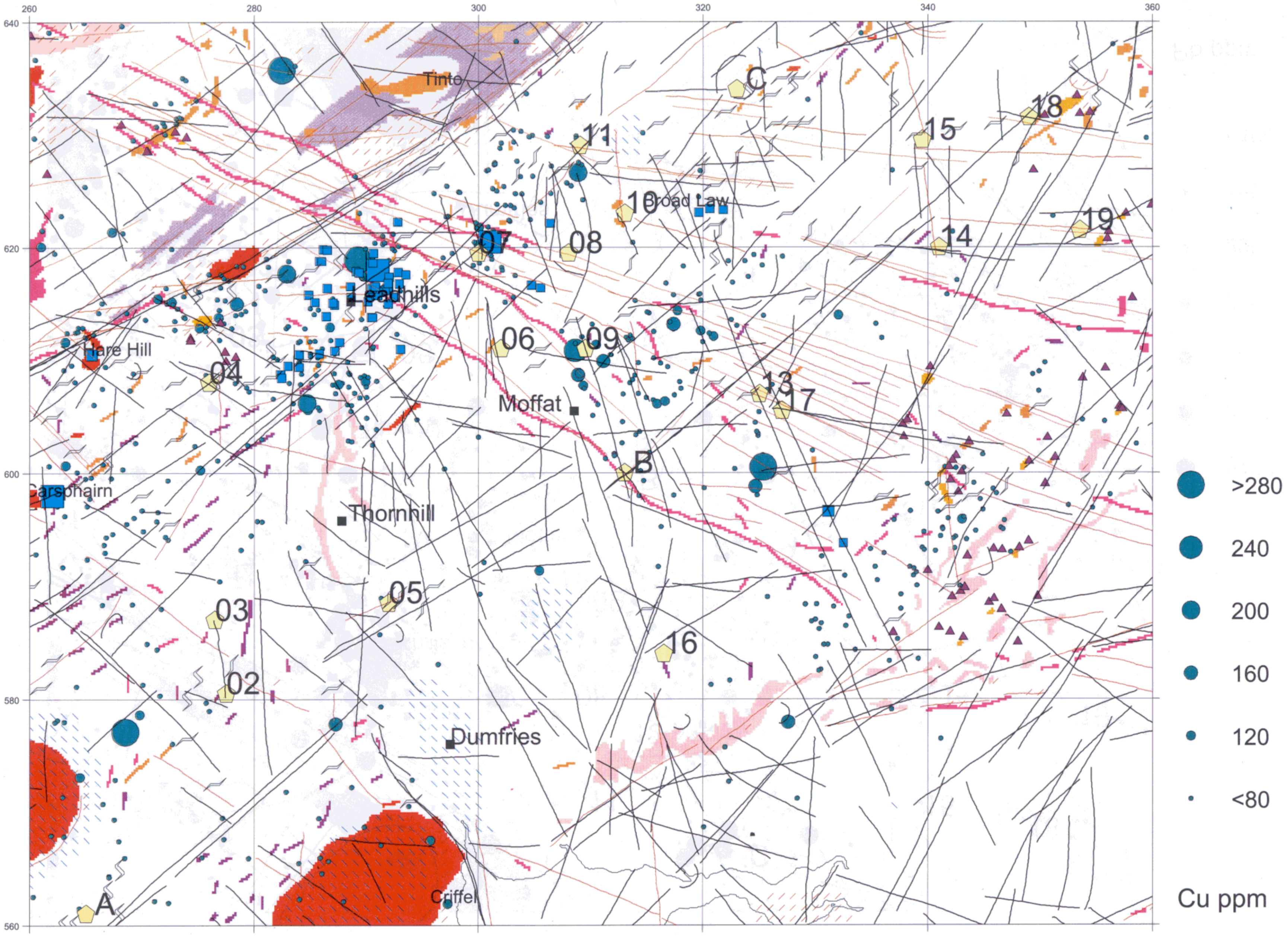

Figure 16 Principal geophysical lineation trends and anomalies and distribution of copper (Cu >40ppm) in drainage samples in the Central Southern Uplands. Other features as Figure 15.

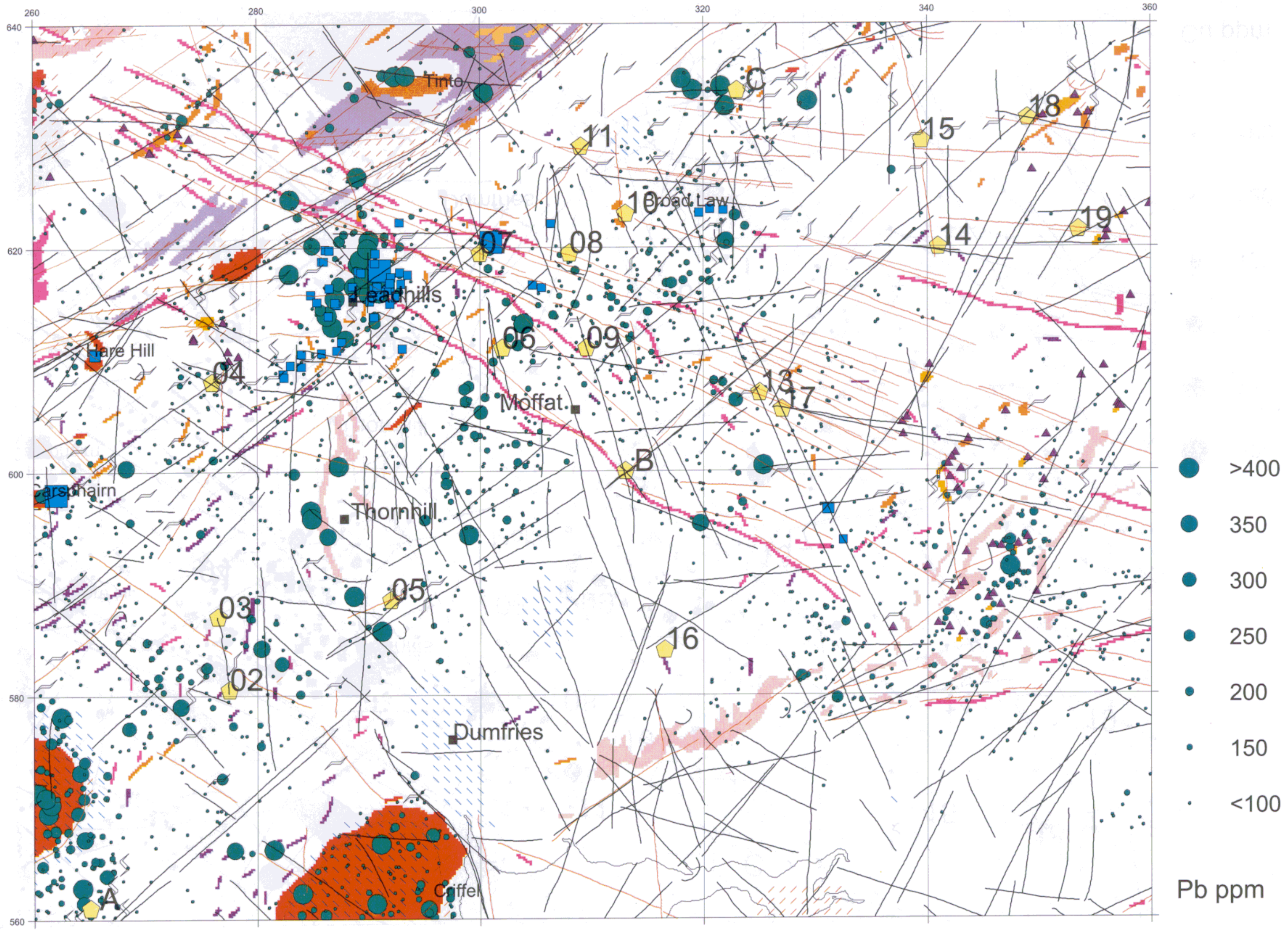

Figure 17 Principal geophysical lineation trends and anomalies, distribution of lead (Pb > 50 ppm) in drainage samples in the Central Southern Uplands. Other features as Figure 15.

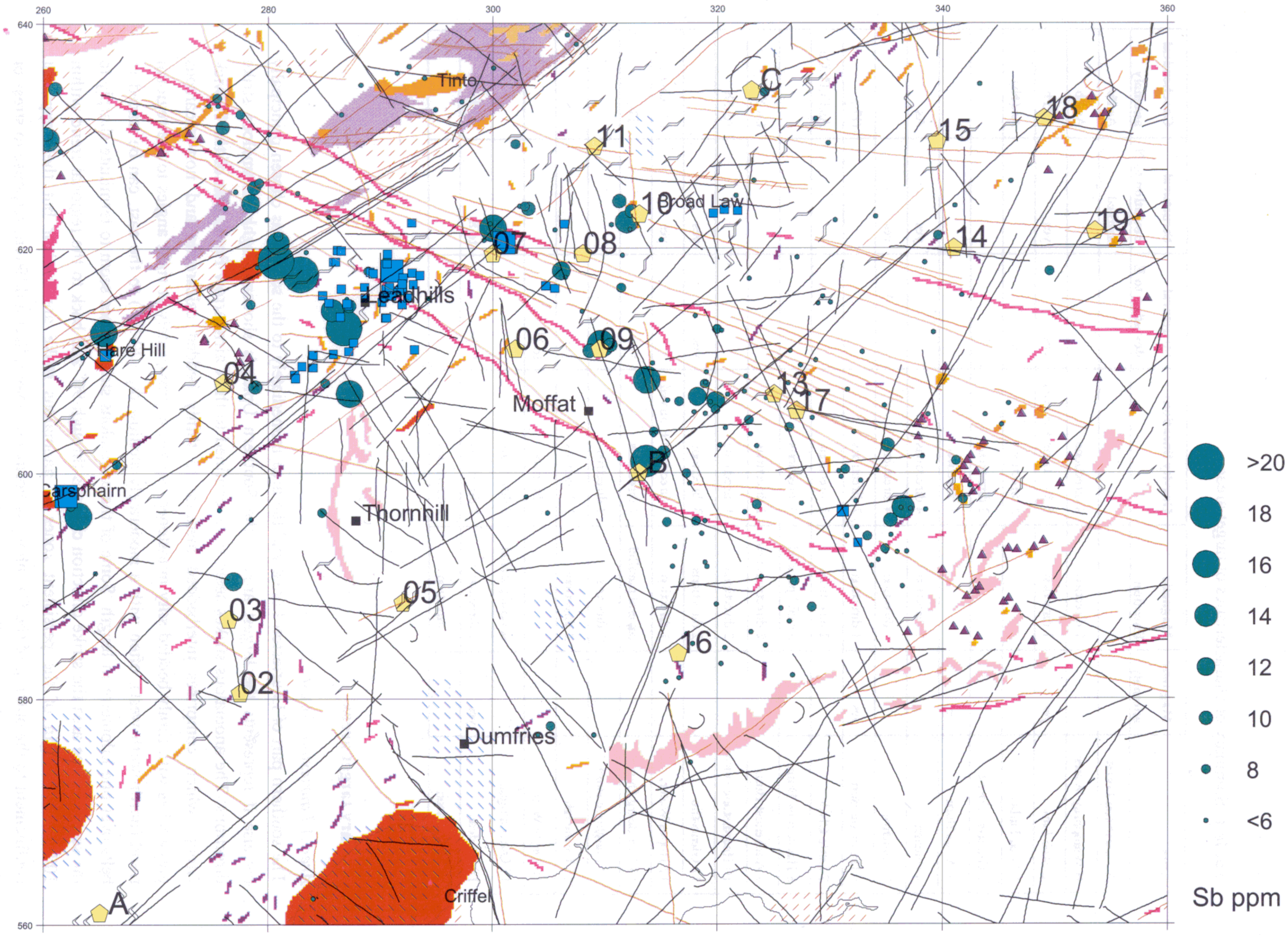

Figure 18 Principal geophysical lineaton trends and anomalies, distribution of antimony (Sb > 2 ppm) in drainage samples in the Central Southern Uplands. Other features as Figure 15.

Table 1 Summary of characteristics of target areas

Area	Magnetic anomaly	Magnetic lineation	Gravity lineations	Structural deviation to E	Structural deviation to N	Geochemical anomaly
A Laurieston Forest					marked	As,Pb
B Wamphray Water		2 directions	4 directions			As,Sb
C Stob Law	yes	1 direction	5 directions + curved	yes	yes	As,Pb
1 Loch Finlas			5 directions	yes		As,(Ni)
2 Glaisters Forest			2 directions			
3 Walls Burn	yes		1 direction			
4 Euchan		1 direction	4 directions		yes	As
5 Clauchrie		1 direction	4 directions		yes	
6 Harthope Burn.	yes	1 direction	2 directions			(Pb)
7 Little Clyde		2 directions	3 directions			As,Bi,Pb,Cu
8 Hawkshaw Burn		several parallel	4 directions			
9 Auchencat Burn		2 directions near	2 directions			Cu,Sb
10 Hearthstane Burn		2 directions	1 directions			As,Sb
11 Glencotho		2 directions	3 directions	yes	yes	
12 Hopes Water		1 direction	3 directions + curved		yes	(As,Cu)
13 Glendearg Burn		several parallel	2 directions	yes		(Pb)
14 Langhope Burn		1 direction	2 direction			
15 Fastheugh		2 directions	2 directions	yes		
16 Dryfe Water			2 directions	to N		
17 Quickningair		several parallel	3 directions			
18 Lindean	yes	1 direction	2 directions	to W	to S	(Cu)
19 Hassendean		1 direction	2 directions			

Primary target areas

Area A Laurieston Forest

The southern part of Laurieston Forest and the area immediately to the south was chosen principally because it represents the largest area in the Southern Uplands showing highly anomalous strike directions. The anomalous strikes seem to be confined to the Cairnharrow Formation of the Hawick Group, which comprises interbedded medium to thinly bedded calcareous and non-calcareous greywackes with thinly bedded silty mudstones. Strikes approximately at right angles to the regional trend (north-north-west), often with a moderately shallow dip (20-35°) to the east, can be traced in belts over one kilometre in length. Some of the anomalous strike zones seem to terminate sharply to the south. In one area the strike direction changes through 90° and back to the regional trend within 100 m. The origin of the persistent zones of anomalous strike are unclear but their apparent confinement to the outcrop of the Cairnharrow Formation may reflect a different response to stress of this unit compared with the adjacent units. The north-western part of the area is also marked by a group of high-amplitude As anomalies. These anomalies seem sufficiently separate from those associated with the nearby south-eastern part of the Fleet granite to suggest a separate centre of activity, perhaps associated with a centre of minor intrusive activity. Slightly further east there is also a group of Pb anomalies. The geological environment could be similar to that found marginal to the Loch Doon granite in the headwaters of the Glenhead Burn, where minor intrusions show enrichment in As and Au (Leake et al., 1981). In addition, gold had been observed and confirmed by chemical analysis (1.05 ppm Au) in a panned concentrate from the Kennick Burn near Lochenbreck Bridge at [6442 6480] during the MRP reconnaissance of the Fleet granite and its environs. Subsequent sampling in the same river revealed gold by analysis in the panned concentrate samples and also gold in the glacial drift in the same area. The area is not crossed by geophysical lineations, but lies just to the north-west of prominent north-east lineations seen in the gravity data.

Area B Wamphray Water

This area is characterised by the convergence of several linear features. These comprise: 1) a strong strike-parallel gravity lineation and a near-parallel magnetic lineation, 2) a series of west-north-west-trending magnetic lineations and a parallel gravity lineation. 3) two short north-north-west-trending gravity lineations and two longer near-parallel lineations, 4) an east-trending magnetic lineation which terminates at the edge of the area and 5) a short north-south gravity lineation. In addition, there are a few high amplitude As and Sb anomalies in drainage sediment. Although there is no evidence of deviation of regional strike, the arcuate outcrop of the major Tertiary dyke cutting the area could indicate shear. The dyke could have made use of pre-existing lines of weakness which reflect the stress field of a previous tectonic regime.

Area C Stob Law

This area is characterised by intersecting near east-west magnetic lineations, a parallel gravity lineation and a north-south gravity lineation. There are also two curved gravity lineations which could signify a centre of igneous activity. At the southern margin of the area there are also north-north-west and north-west gravity lineations together with a near strike-parallel lineation and a small residual magnetic anomaly. There is also evidence of significant deviations of strike from the regional, with east-west trends and west-north-west trends, although the number of measurements shown on the geological map (Sheet 24E Peebles) in the area is relatively low. Geochemically the area is marked by a group of high-amplitude As anomalies, and further west by a small group of high-amplitude Pb anomalies.

Secondary target areas

Area 1 Loch Finlas

This area is situated just to the north of the northern contact of the Loch Doon granite. It comprises a marked focus of several gravity lineations with five different trends. The local strike is east in the centre of the area in contrast to further north and south where it follows the regional trend. The area is also roughly on an east-west line joining the known occurrences of gold mineralisation at Fore Burn and Moorbrock Hill. The area to the south is marked by some As anomalies but this applies to most of the margin of the Loch Doon granite and its envelope. The area is part of a zone immediately north of the granite which shows enrichment in Ni greater than along strike in the same greywacke unit.

Area 2 Glaisters Forest

This represents the southern termination of a north-south gravity lineation and a west-north-west gravity lineation. The area is also on the western projection of small magnetic anomalies and is close to areas with north-west and north-trending strikes. Immediately to the west is a small group of As anomalies and a broader area showing variable enrichment in Pb.

Area 3 Walls Burn

This represents the coincidence of the northern termination of the north-trending gravity lineation and a small magnetic anomaly. No geochemical anomalies are associated with the area and there is no evidence from the geological map (Sheet 9W, New Galloway) of deviations in the strike from the regional direction.

Area 4 Euchan

In this area a north-south magnetic lineation intersects a strike-parallel gravity lineation and north-west and west-north-west-trending gravity lineations. The area also lies between the westward projection of a persistent set of gravity lineations trending just north of west and the mineralised locality of Hare Hill, further to the west. There are also several anomalous strike trends to east-west and west-north-west in the area, though the rapid variation of strike direction suggests a series of flexures rather than a large segment with anomalous strike. The area is also marked by a high-amplitude As anomaly and a few low-amplitude anomalies and two nearby samples showing some enrichment in Sb.

Area 5 Clauchrie

This area lies between the outcrops of the Permian Thornhill and Dumfries basins, and the geological mapping indicates that rocks are widely reddened. This indicates that Permian strata originally covered the area and that chemical reaction took place due to the penetration of oxidising solutions circulating from the Permian into the underlying greywackes. Previous work (Leake and Cameron, 1996; Leake et al., in press) has indicated that this type of environment is favourable to the occurrence of gold mineralisation. The area is intersected by north-west and north-trending faults, together with north-trending gravity lineations. There are also gravity lineations trending just north of west, north-west and along the regional strike in the same area. The area is also intersected by an east-north-east-trending magnetic lineation. Isolated north strikes have been recorded in the area, suggesting the possibility of local flexures. The area is not marked by any geochemical anomalies in drainage samples.

Area 6 Harthope Burn

This area is marked by three near-parallel north-south gravity lineations intersected by a north-west-trending magnetic lineation and a break in a west-north-west-trending gravity lineation. In addition there is a localised magnetic anomaly in the centre of the area. No anomalies are evident from the drainage geochemistry except for slight enrichment in Pb.

Area 7 Little Clyde Forest

This area lies to the south of a region in which gold was located in bedrock by BP Minerals. It is situated at the southern termination of a north-south gravity lineation and intersected by a north-west-trending magnetic lineation and a strike-parallel gravity lineation. Just to the south is an east-west magnetic lineation and the north termination of a north-east-trending gravity lineation. Some drainage samples from the area show enrichment in As, Bi, Pb and Cu.

Area 8 Upper Hawkshaw Burn

This area is marked by a focus of terminations of gravity lineations oriented along strike, near north, west-north-west and north-north-west, together with several west-north-west-trending magnetic lineations which probably reflect Tertiary dykes. No geochemical anomalies are associated with this area and no deviant strikes have been recorded.

Area 9 Auchencat Burn

This area is crossed by the same north-north-west-trending gravity lineation as area B. This feature is intersected by a west-north-west-trending gravity lineation. To the north and south are west-north-west and north-west-trending magnetic lineations respectively. The area is marked by Sb and Cu drainage anomalies. Malachite and minor chalcopyrite are recorded from an old mine trial in the south bank of the river at [30897 61104] (Dawson et al., 1979).

Area 10 Hearthstane Burn

This area is marked by the termination of north-south and west-north-west magnetic lineations and a north-north-west gravity lineation. There are also As and Sb anomalies in the area.

Area 11 Glencotho

This area is possibly a transfer zone. To the south-west there are a series of roughly north-trending gravity lineations which terminate along a strike-parallel line. To the north-east is a strike-parallel gravity lineation and further to the north-east is the southern end of a further north-trending gravity lineation. This pattern can be explained by the transfer of tensional north-south faulting along a reactivated strike fault for a few kilometres, which reappears as tensional faulting with the same trend extending further north. The area is also marked by a north-west-trending gravity lineation, by near west and west-north-west-trending magnetic lineations and by the interruption of a very prominent strike-parallel magnetic lineation. Both east and north deviant strikes are present in the area. The area is also close to the negative gravity anomaly which has been interpreted as due to a buried (Tweedsmuir) batholith, and lies on the westward projection of near east-west-trending magnetic anomalies. The area is not marked by any geochemical anomalies.

Area 12 Hopes Water

This area is characterised by arcuate gravity lineations and by the intersection of gravity lineations trending north-north-west, north-north-east and near east. It also lies just west of the termination of a prominent magnetic lineation trending just north of west. North-deviant strikes have also been recorded in the area which lies between the known gold occurrences of Stobshiel and Priestlaw. Low-amplitude As anomalies and a slight enrichment in Cu characterise the drainage samples from the area.

Area 13 Glendearg Burn

This area in the Eskdalemuir Forest is marked by the termination of gravity linears trending along strike and in an easterly direction. It also lies within the main swarm of west-north-west-trending magnetic lineations which probably reflect the main concentration of Tertiary dykes. A deviation of strike to east is also recorded in the area. Geochemically the area is marked by a Pb anomaly at the western edge of the area.

Area 14 Langhope Burn

This area is marked by the intersection of near east-trending gravity lineations with a north-trending gravity lineation and a magnetic lineation in the same direction. No drainage geochemical anomalies are evident in the area.

Area 15 Fastheugh

This area, to the south of the Yarrow Water, is marked by a focus of linear features comprising east-trending and near north-trending magnetic lineations and gravity lineations trending north and north-west. In addition, there are deviations of strike to the east. No drainage anomalies are present in the area.

Areas 16–19

These areas, which could not be visited due to funding limitations, are located at the intersections of north-north-west-trending gravity lineations and east-south-east-trending magnetic (plus gravity) lineations. In addition, areas 18 and 19 are close to mapped manifestations of volcanic activity.

TEST SAMPLING

Drainage samples

As an initial stage in the testing of the identified areas for direct evidence of gold mineralisation, drainage sampling was carried out in the three primary target areas. In addition, more limited sampling was carried out in as many of the secondary targets as possible within the time and resources available. Drainage sampling was carried out at up to four sites in a total of 8 out of the 19 secondary target areas identified. At most sites a panned sample was obtained together with a minus 100 mesh (150μm) suspended solid fraction sample (fine fraction). The latter sample was collected by agitating a half pan of stream sediment so as to produce a suspension and then rapidly filtering it through the 100 mesh sieve to remove coarse organic matter. The sample, equivalent to the float sample (Leake and Smith, 1975) is effectively a minus 75μm fraction and is used so that any relatively coarse gold grains, up to 150μm in diameter, are not included in the sample. Gold grains of this size are sampled adequately by panning but would give a large and potentially non reproducible anomaly in the sieved sediment fraction sample. Thus anomalies in the "fine fraction" sample signify more clearly the presence of fine-grained gold. This sample type is not the same as the conventional minus 100 mesh stream sediment used in the Geochemical Survey Programme but has been used in previous MRP surveys for gold (Leake et al., 1992; Cameron et al., 1994). The location of drainage sampling sites is given in grid reference form in Appendix 1.

Observable gold grains were physically extracted from the panned sample. Gold was also determined chemically in samples that had not been subjected to laboratory separation procedures and also in the residua of the samples from which grains had been extracted. The concentrates were ground in a P5 mixer mill and gold determined, after digestion in aqua regia and extraction into MIBK, by graphite furnace Atomic Absorption Spectrometry at Acme Analytical Laboratories, Vancouver, Canada. No other elements were determined in these samples. Extracted gold grains were mounted in resin, ground and polished for electron microprobe grain characterisation.

In addition, the fine fraction samples were analysed for *B*, *Na*, *Mg*, *Al*, *P*, *K*, *Ca*, *Ti*, *V*, *Cr*, *Mn*, *Fe*, *Co*, *Ni*, Cu, Zn, Ga, As, Se, *Sr*, Mo, Ag, Cd, Sb, Te, *Ba*, *La*, *W*, Tl, Pb, Bi, *Th* and *U* by ICP-ES after aqua regia digestion and for Hg by cold vapour atomic absorption spectrometry after oxidising acid attack at Acme Analytical Laboratories, Vancouver, Canada. For the elements shown in italics the chemical attack resulted in only partial extraction from a number of minerals. The results of these analyses are given in Tables 2, 3, 4 and 6; the elements showing little variation of interest have been omitted. Cumulative frequency plots for elements which are potential pathfinders for gold mineralisation are shown in Figures 19 and 20. Maps are plotted with a dot radius proportional to concentration.

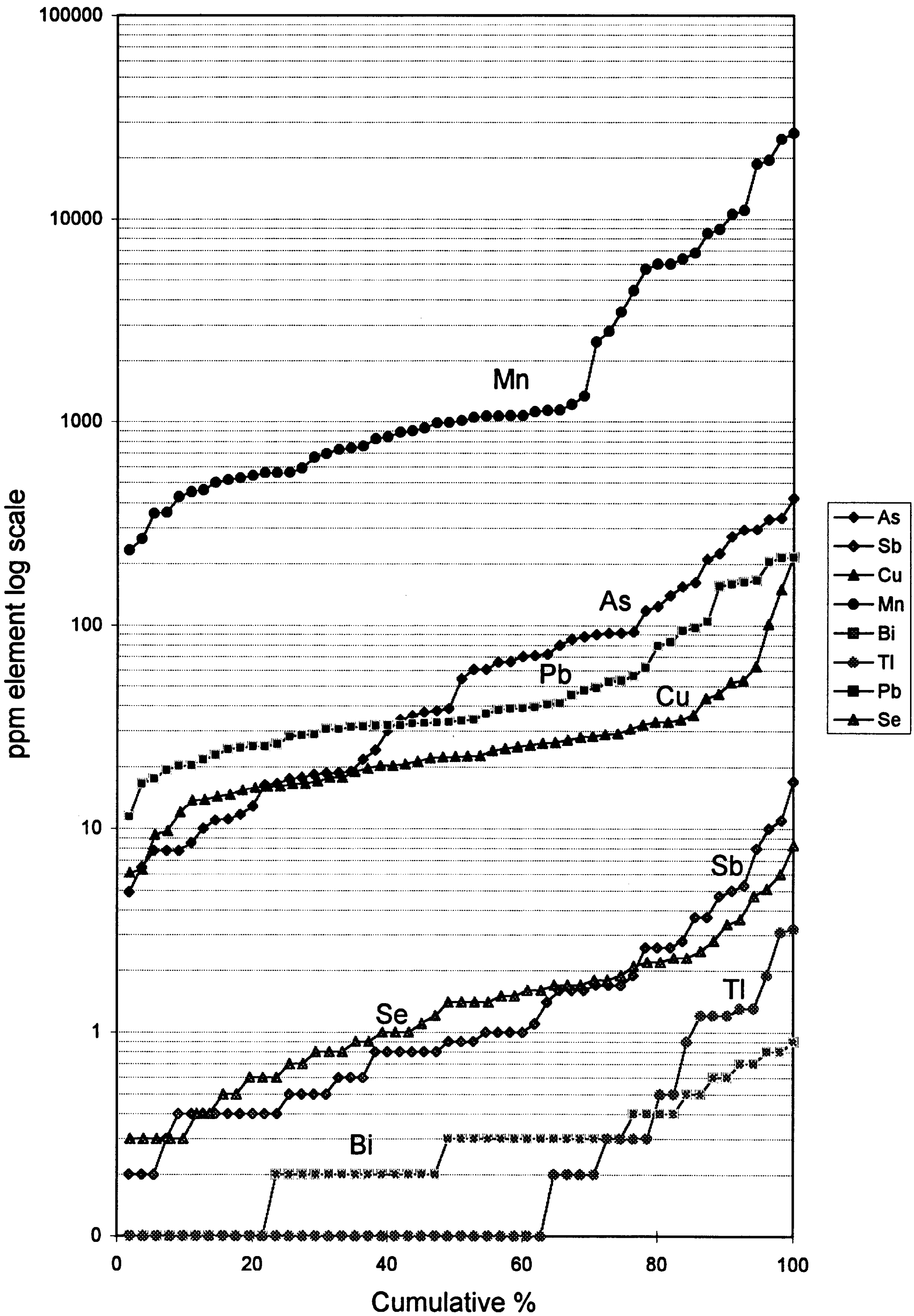

Figure 19 Cumulative frequency plots of potential pathfinder elements in suspended fine fraction drainage samples

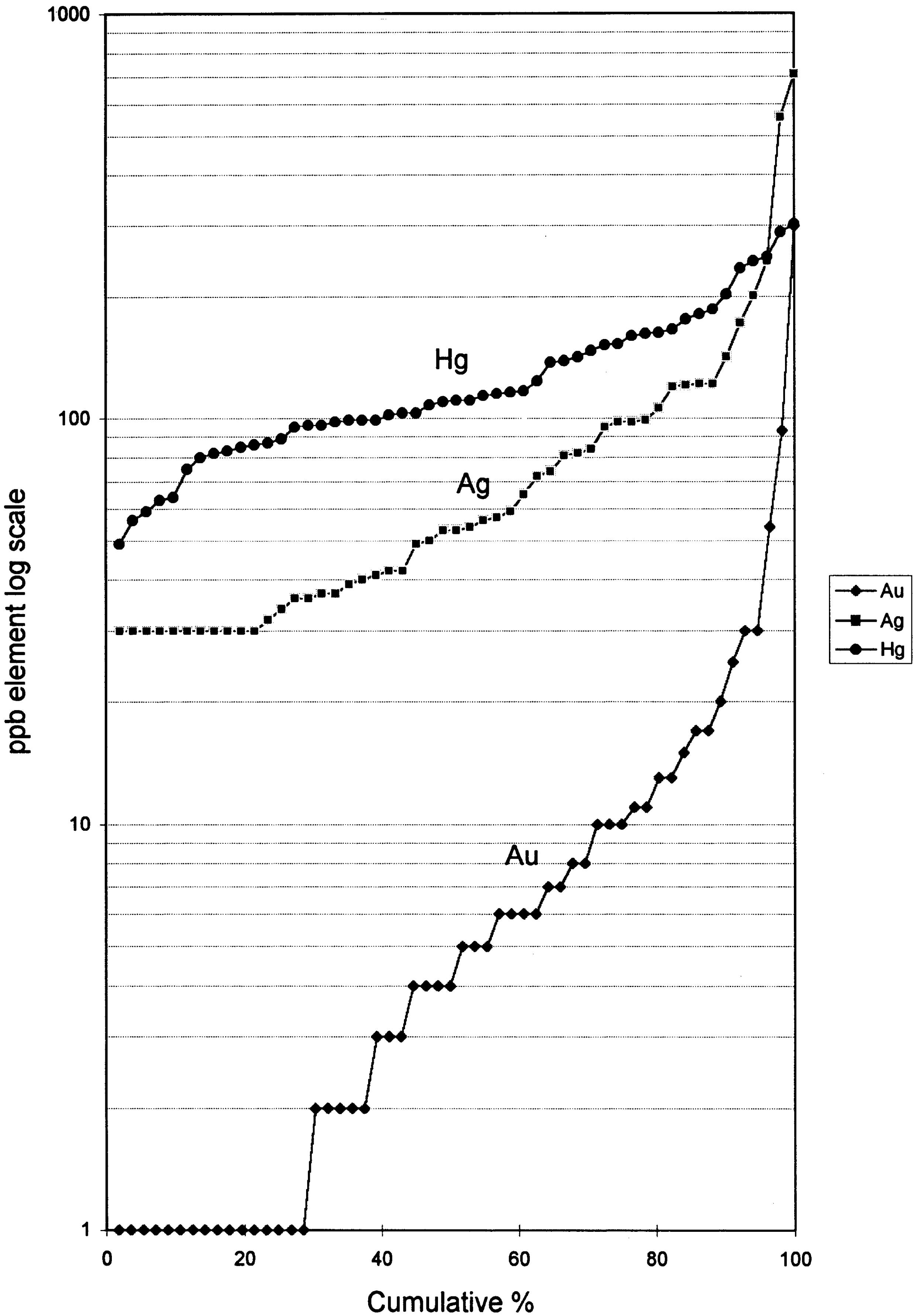

Figure 20 Cumulative frequency plots of gold (Au), silver (Ag) and mercury (Hg) in suspended fine fraction drainage samples

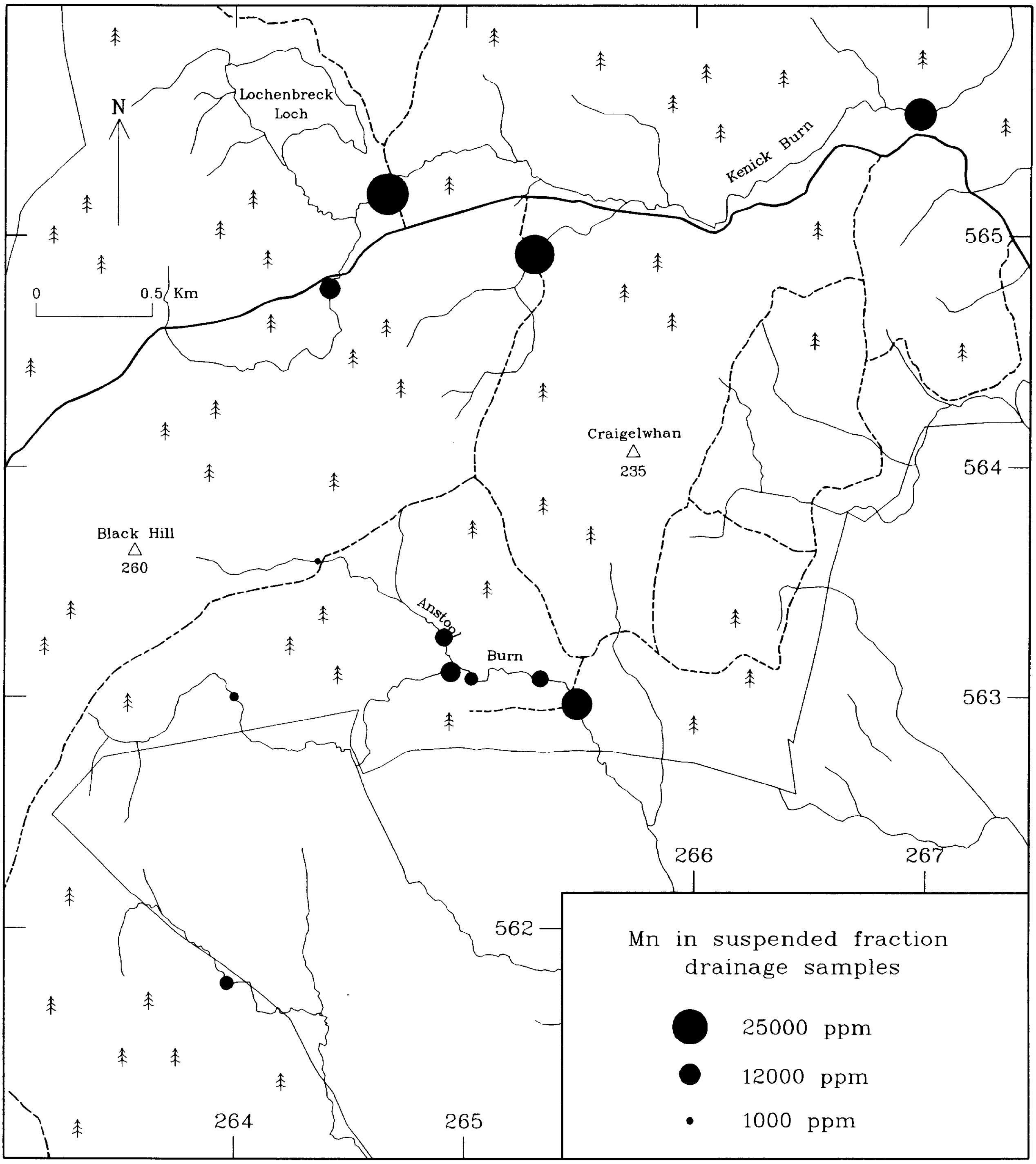

Figure 21 Distribution of manganese (Mn) in suspended fine fraction drainage samples from Laurieston Forest

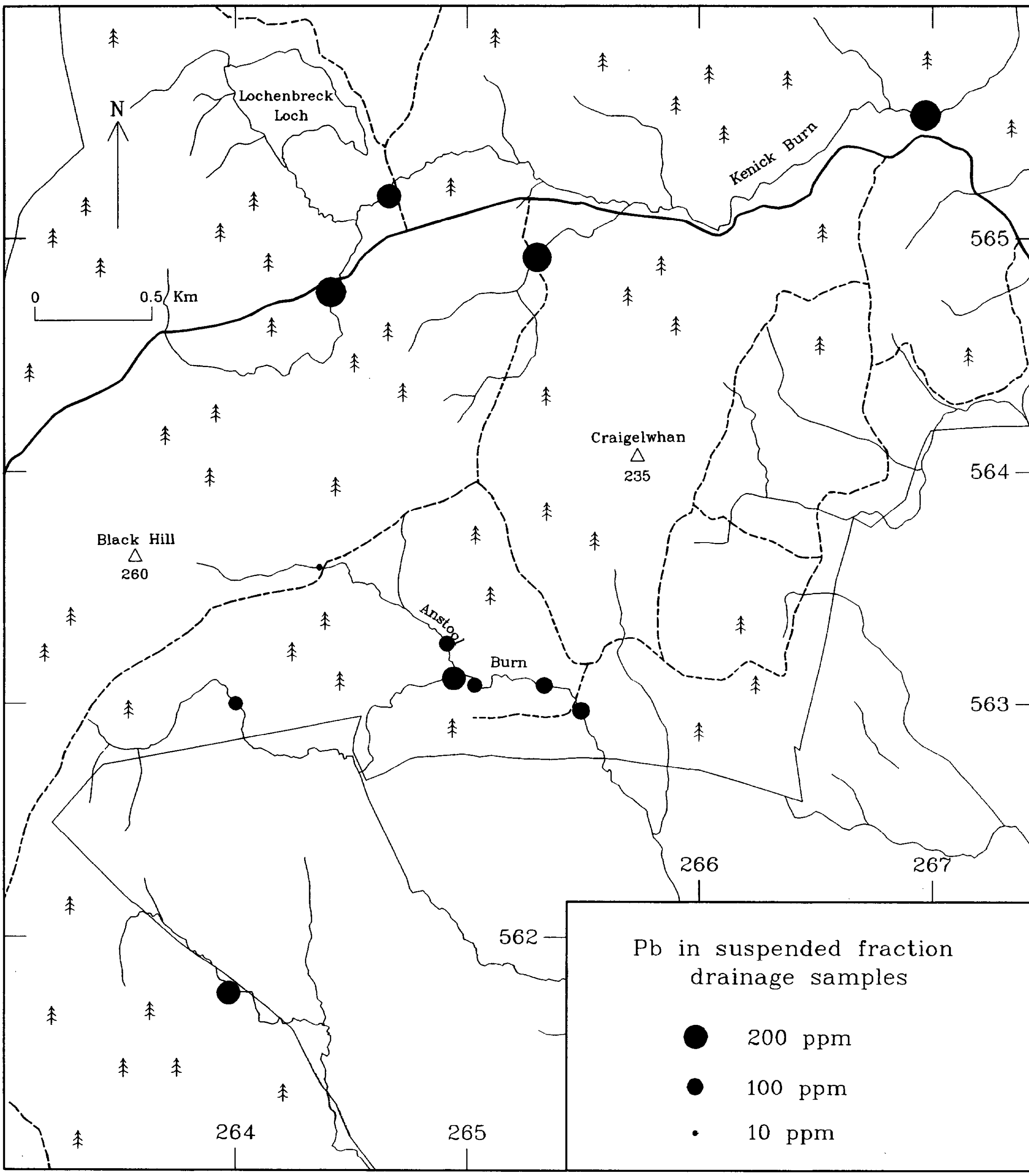

Figure 22 Distribution of lead (Pb) in suspended fine fraction drainage samples from Laurieston Forest

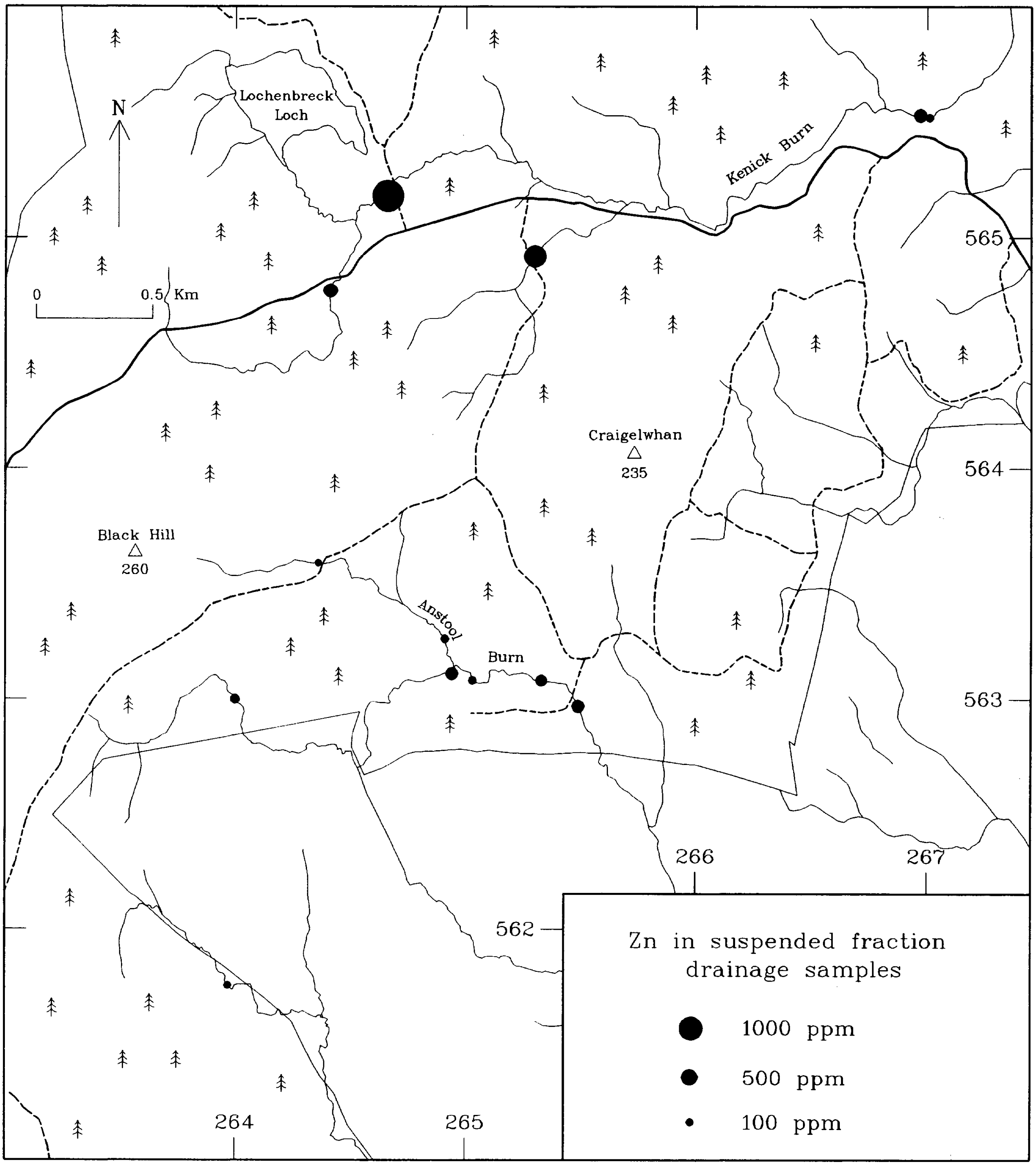

Figure 23 Distribution of zinc (Zn) in suspended fine fraction drainage samples from Laurieston Forest

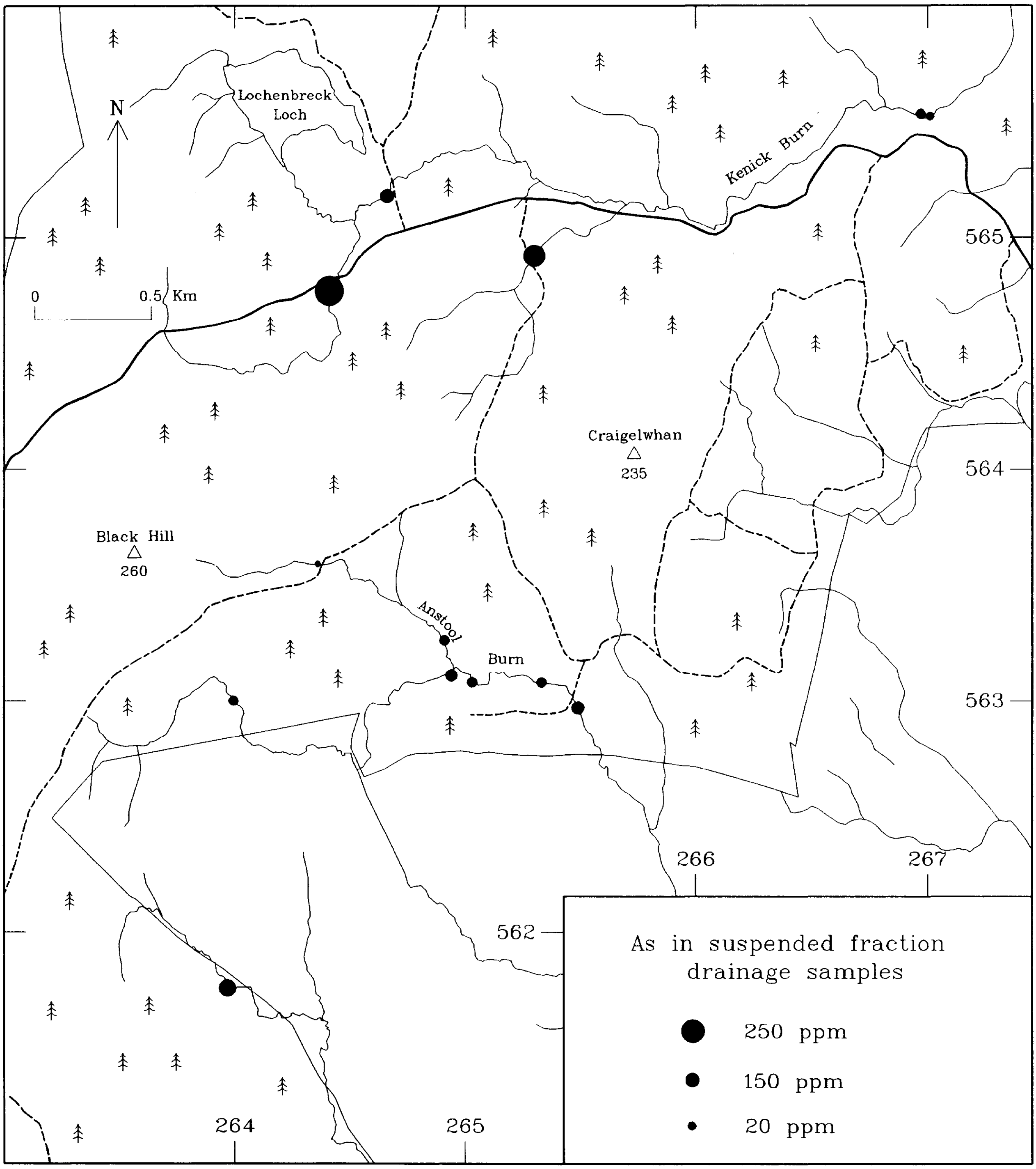

Figure 24 Distribution of arsenic (As) in suspended fine fraction drainage samples from Laurieston Forest

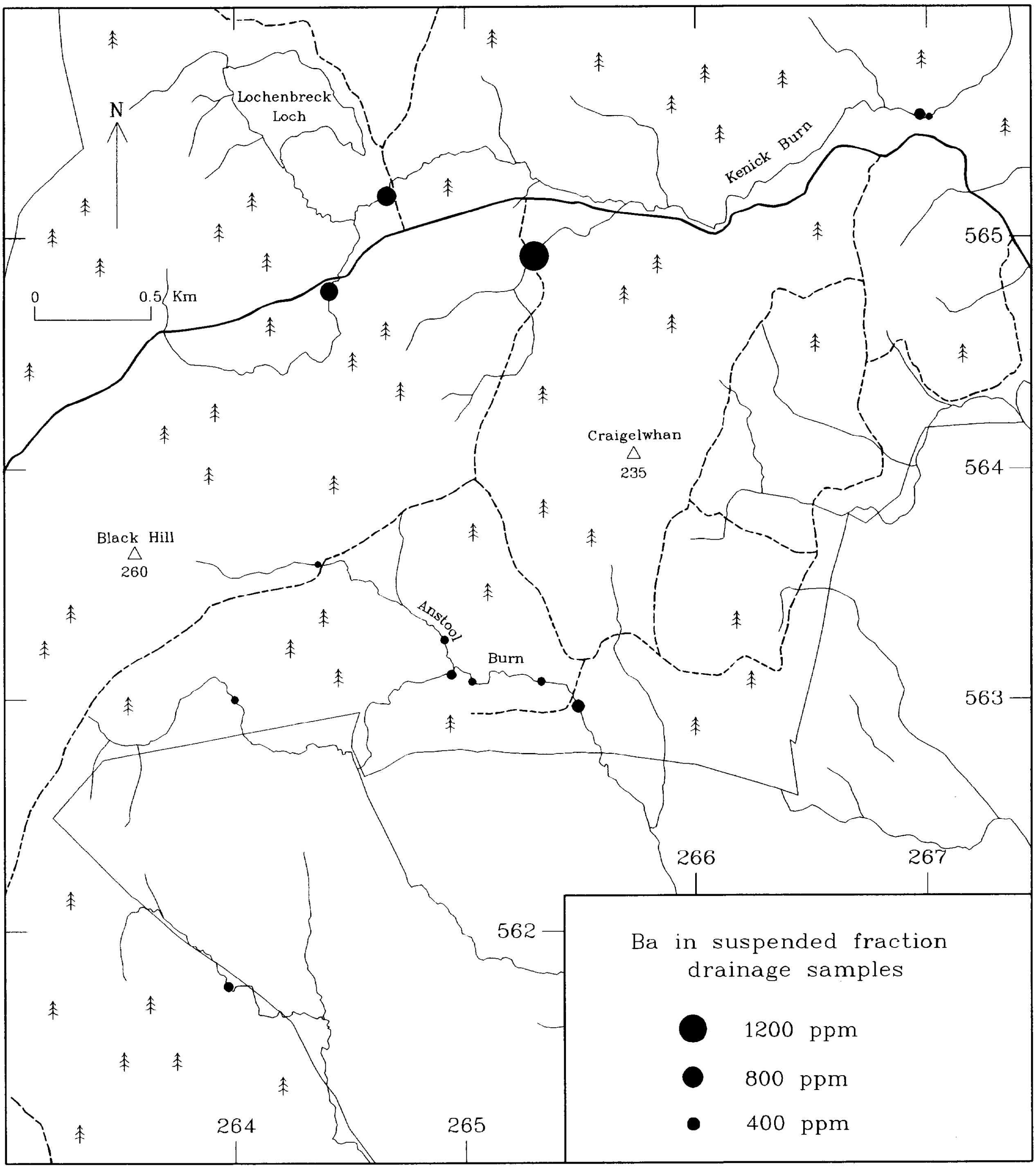

Figure 25 Distribution of barium (Ba) in suspended fine fraction drainage samples from Laurieston Forest

Primary target areas

Area A Laurieston Forest

No gold was found in three samples collected from sites a few metres of each other from the lower part of the the Kenick Burn, but a fine-fraction sample from the same area showed relative enrichment in Mn (Figure 21), Se, Hg and Pb (Figure 22) compared with samples collected from elsewhere in the area and from the Southern Uplands as a whole (Table 2). Further west in the headwaters of the stream, in the same area as the previous discovery of gold by panning, the fine fraction sediment samples show enrichment in Mn (Figure 21), Co, Zn (Figure 23), As (Figure 24), Cd, Ba (Figure 25), Tl and Pb (Figure 22). The area is one of relatively thick drift with no exposure, and some of the metal enrichment probably reflects environmental enhancement due to Mn oxide precipitation. However, the range of elements showing enrichment in the area suggests that mineralisation could be present, possibly associated with acid igneous rocks. One grain of gold was recovered from the lowest site in the Anstool Burn, at the southern edge of the forest and the same sample also contained 73 ppb Au by analysis. Quartz vein debris was conspicuous in the stream, which may be following a north-north-west-trending structure. The corresponding fine-fraction sample from this site shows enrichment in the same elements as found in the samples from the head of the Kennick Burn, but to a lesser extent. Upstream of this site the sample from the tributary draining from the west is the most enriched in Cu, As (Figure 24), Ag and Pb (Figure 22) and may also reflect mineralisation. Further to the west there are isolated low-amplitude Cu and As (Figure 24) anomalies.

Table 2 Chemical composition of fine fraction samples from Laurieston Forest (ICP analyses)

	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Mo	Ag	Cd	Sb	Te	Ba	Au	Aup	Hg	Tl	Pb	Bi
PSF 4	34	4431	3.48	22	28	22.3	141	60.8	2.2	0.9	99	1.15	0.5	0.3	114	17	1	203	0.2	53.5	0.3
PSF 5	37	19520	4.2	62	37	21.3	357.3	85.4	4.7	1.3	98	5.23	0.9	0.3	318	4		289	1.2	215.8	0.5
PSF 7	28	5980	2.86	28	29	16.1	144.6	90.3	0.8	0.6	41	1.5	0.6	0.2	145	1	3	80	0.5	82.7	0.2
PSF 8	46	8897	4.6	40	38	9.3	168	91.7	2.3	1.7	53	1.04	0.4	0.2	188	5		110	1.3	94.3	0.3
PSF 9	63	10633	5.7	83	74	63	340.8	123.9	1.9	1.6	201	2.22	1.6	0.3	239	5		186	0.5	158.5	0.8
PSF 10	61	886	3.82	15	46	9.7	104.6	17.8	0.3	0.5	95	0.16	0.8	0.3	81	1		49	0.1	11.4	0.1
PSF 11	36	18595	3.9	46	38	22.4	349.1	139.7	1.7	1.5	120	4.36	1.6	0.3	404	11	73	153	1.2	104.7	0.6
PSF 12	45	2797	4.03	27	45	53.5	195.6	79.7	0.6	0.5	122	0.76	1.1	0.2	137	2	4	63	0.9	79.3	0.4
PSF 13	42	6333	5.59	56	45	17.8	107.7	211.1	2.1	1.1	53	0.64	0.5	0.2	239	6	1	117	1.3	155.2	0.3
PSF 14	32	24676	6.14	16	36	20.6	746.7	293.9	1.4	1.6	82	9.75	1.4	0.4	1259	6	1	142	3.1	205	0.6
PSF 15	31	3489	2.53	22	37	13.7	103.1	66.1	0.3	0.5	172	0.73	0.6	0.2	134	10	1	59	0.3	45.3	0.2
PSF 16	34	11081	7.31	56	35	16.5	394.4	423	2.3	1.3	98	3.04	1.6	0.4	681	1	1	181	1.9	214.8	0.7
PSF 17	28	26529	4.87	64	41	14.3	1151	154.5	0.8	1	122	12.4	2.6	0.5	744	25	2	160	3.2	161.9	0.3
PSF 18	40	8477	4.21	36	38	15.4	281.3	87.7	1.4	0.8	56	2.6	0.4	0.3	180	1	2	176	0.3	96.9	0.4

Aup Concentration of gold in panned concentrate sample from same site

Fe in %, Ag, Au and Hg in ppb, other elements in ppm

Area B Wamphray Water

Drainage sampling was carried out in the upper parts of the Dryfe Water and the mid upper reaches of the Wamphray Water. Samples were obtained from the main rivers and several of their tributaries, though time was not sufficient to sample all the streams. Analyses of the fine fraction samples from the area are shown in Table 3; several of the elements in Table 2 have been omitted as they show little variation or enhancement.

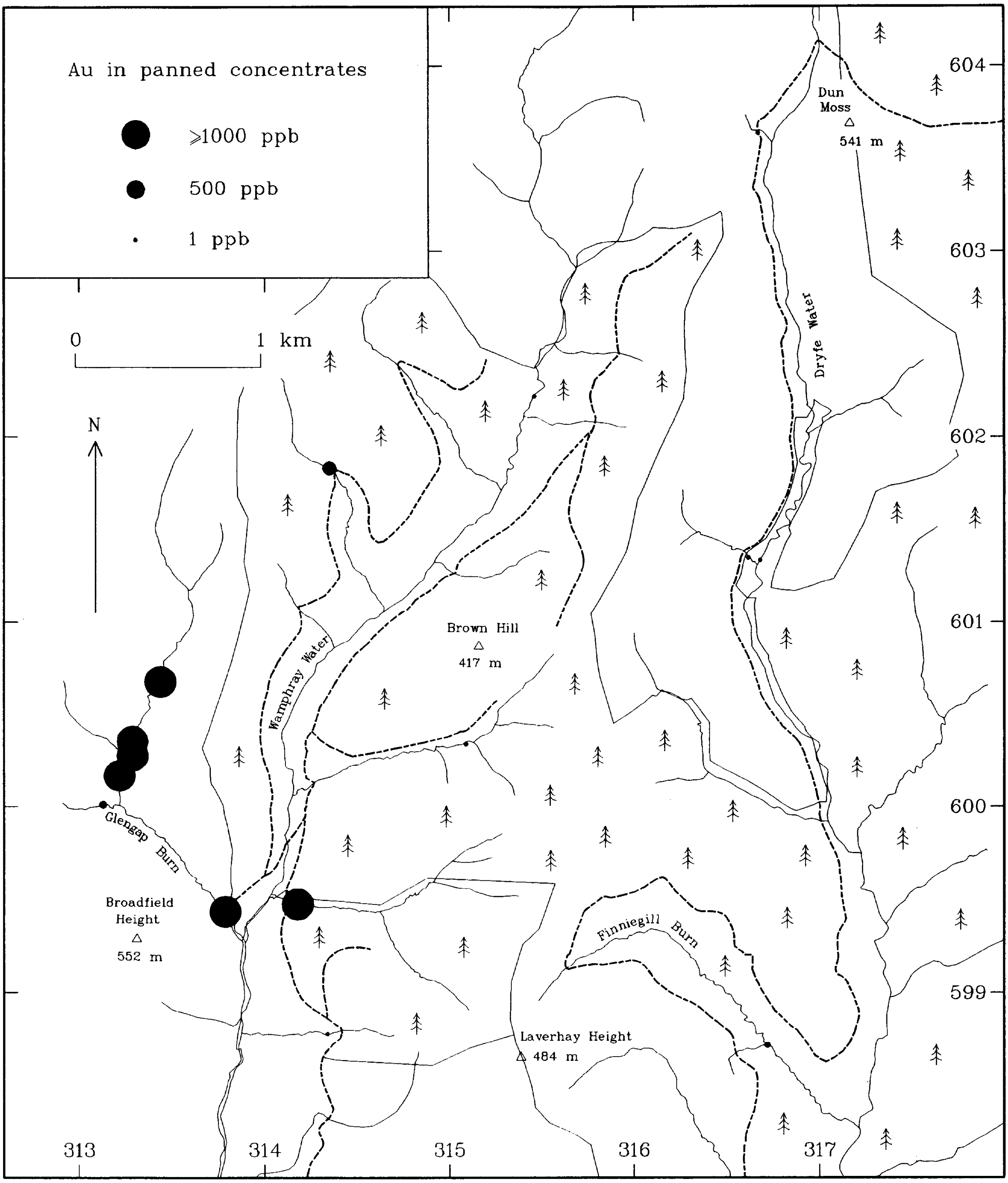

Figure 26 Distribution of gold (Au) in panned concentrates in the Wamphray Water area

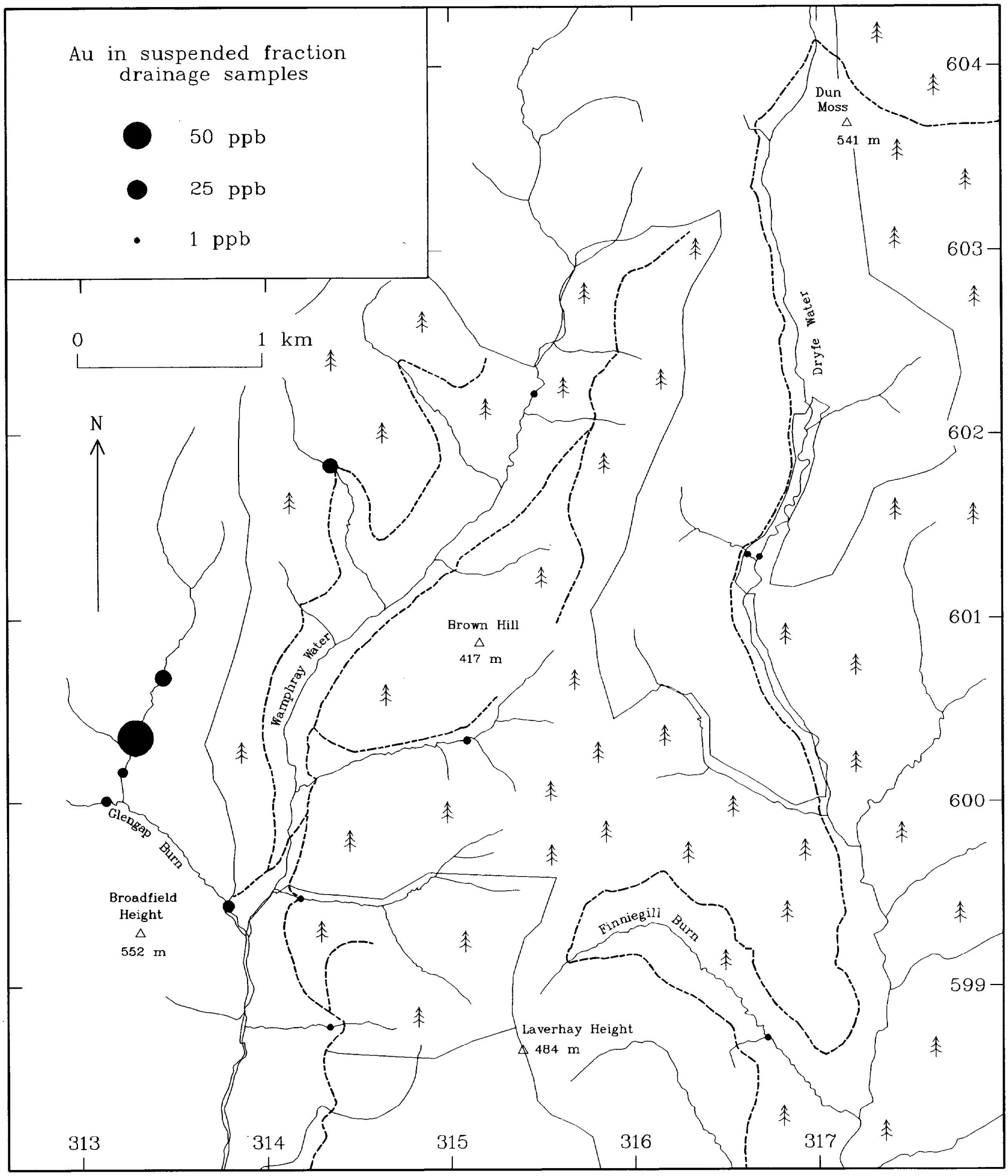

Figure 27 Distribution of gold (Au) in suspended fine fraction drainage samples in the Wamphray Water area

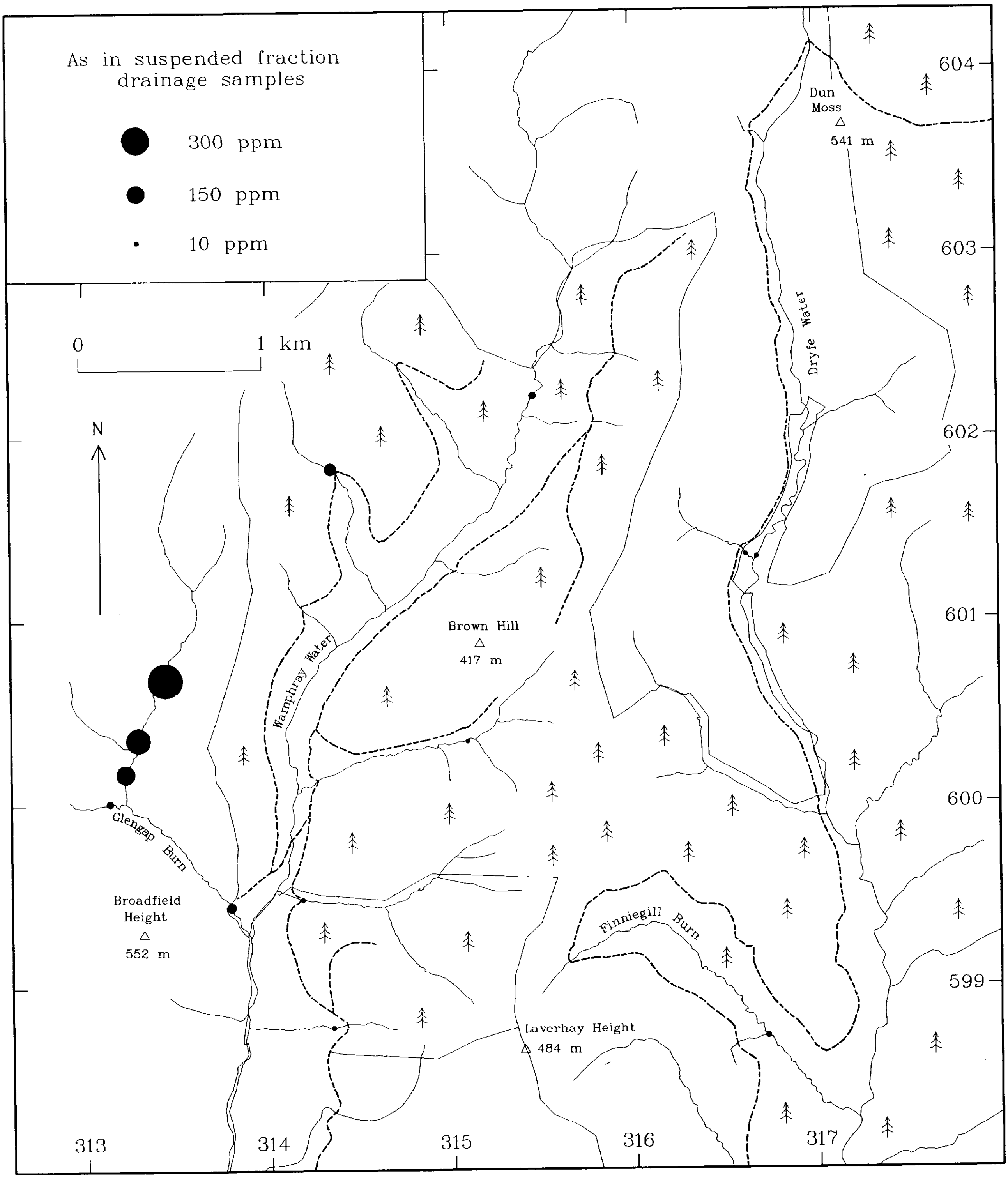

Figure 28 Distribution of arsenic (As) in suspended fine fraction drainage samples in the Wamphray Water area

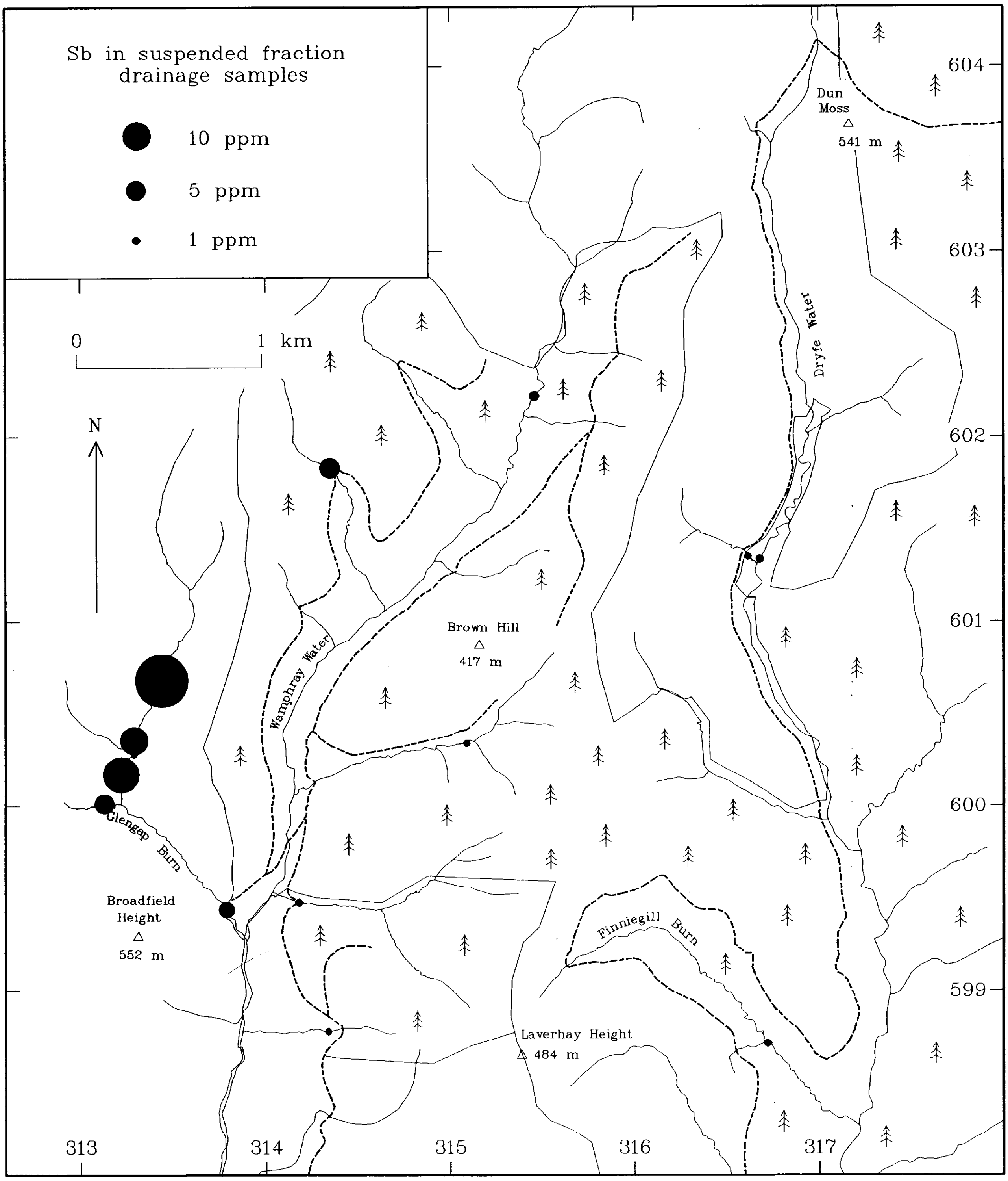

Figure 29 Distribution of antimony (Sb) in suspended fine fraction drainage samples in the Wamphray Water area

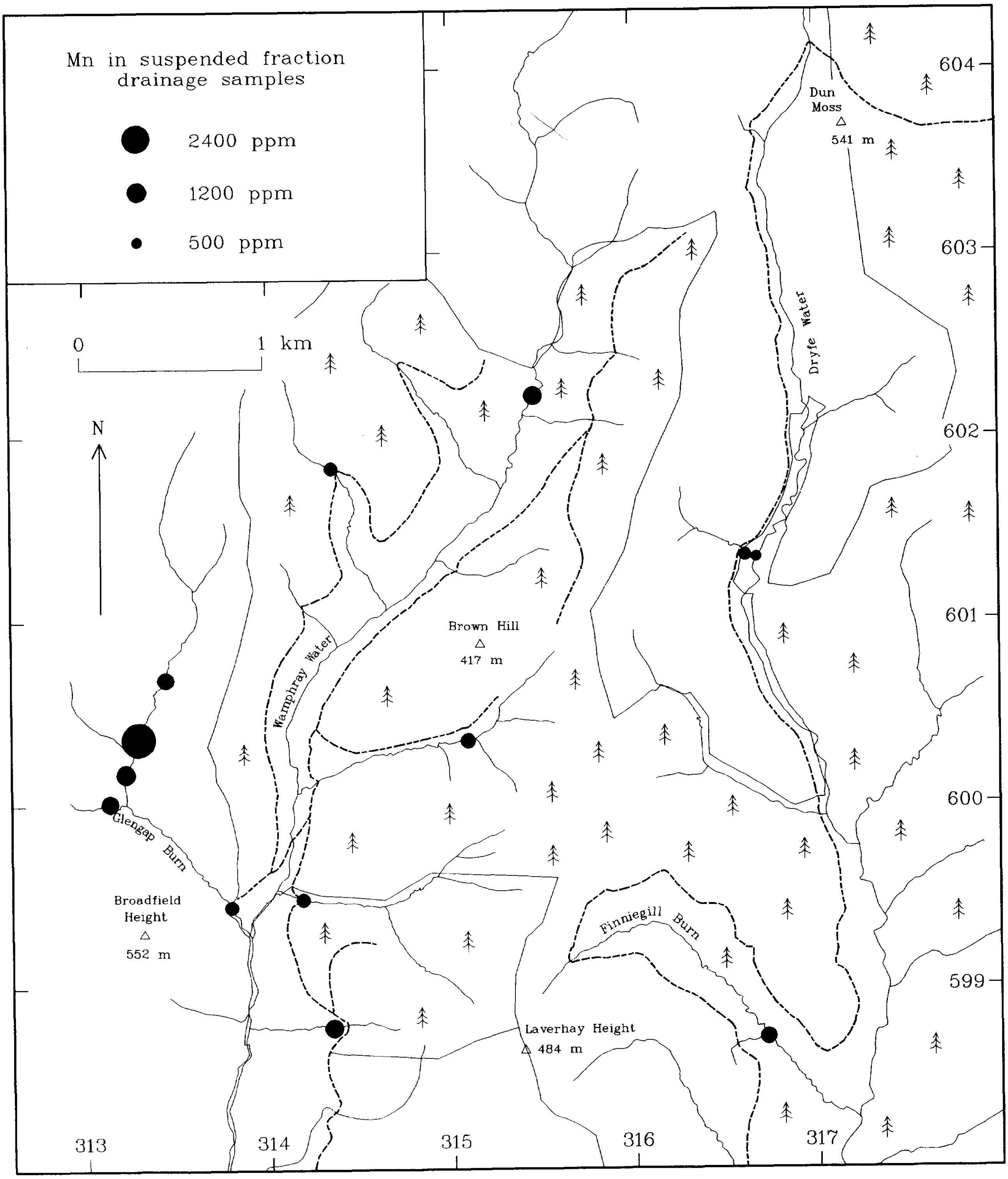

Figure 30 Distribution of manganese (Mn) in suspended fine fraction drainage samples in the Wamphray Water area

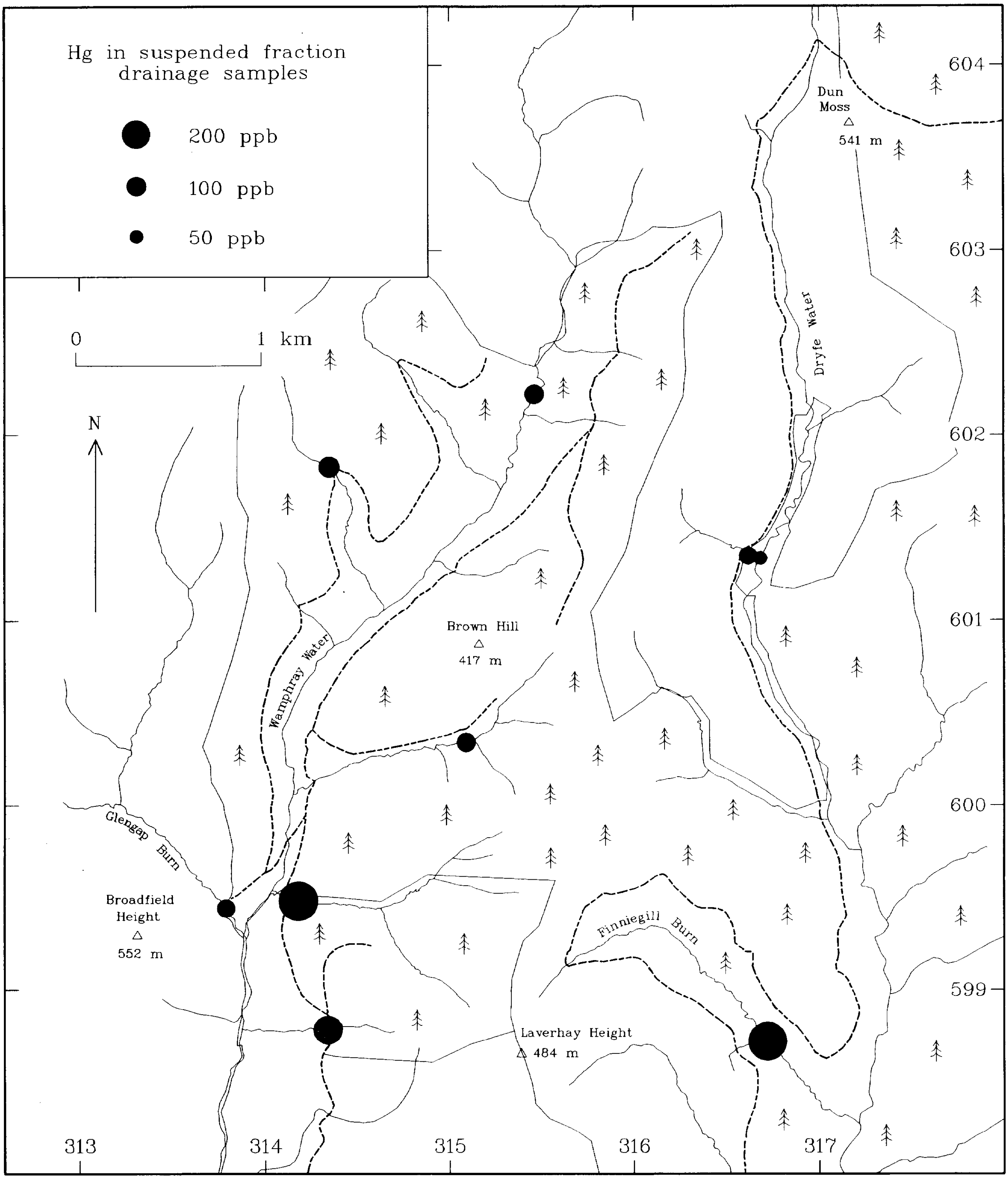

Figure 31 Distribution of mercury (Hg) in suspended fine fraction drainage samples in the Wamphray Water area

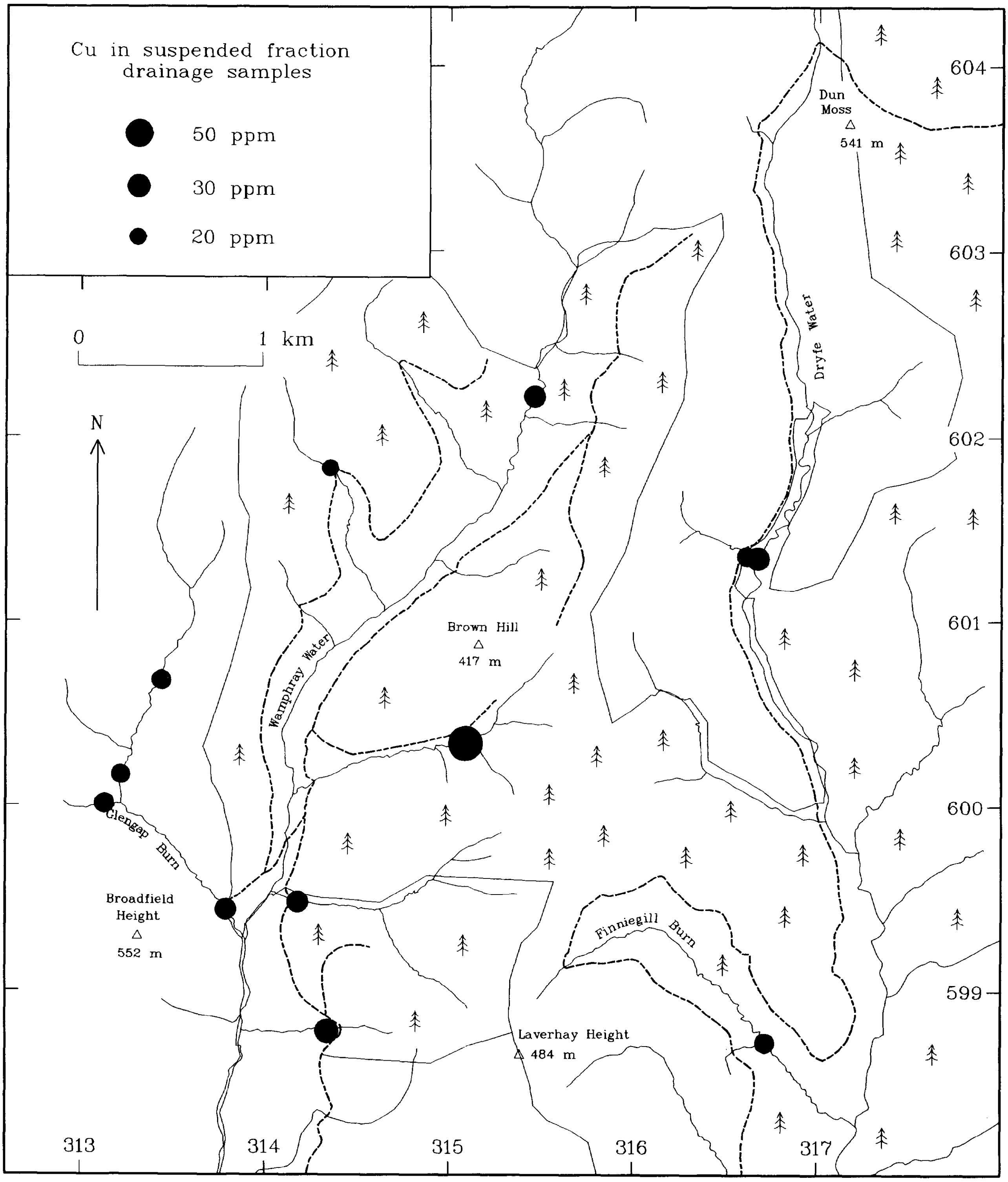

Figure 32 Distribution of copper (Cu) in suspended fine fraction drainage samples in the Wamphray Water area

None of the samples (PSF 47-55 in Table 3) shows the enrichment in Mn, Zn, Se, Mo, Ag, Ba and Pb found in samples from the Laurieston Forest area. However, Au was found by analysis in panned samples in significant amounts at three sites (Table 3) and also in a small amount at a further site. The greatest quantity of gold was obtained from the lower reaches of the Glengap Burn. Subsequently, further drainage sampling was carried out upstream of this site and a further five samples taken (PSF 60-64). The location of anomalous gold contents in the concentrate samples is shown in Figure 26. In this map the dot size is truncated at the 1 ppm level. The follow-up fine fraction samples were analysed for gold and a reduced list of elements (Table 3), but the complementary panned concentrates were analysed for the complete range of elements by the same method (Table 4). The gold-rich fine fraction samples (Figure 27) also show enrichment in As (Figure 28), Sb (Figure 29) and, to a small extent, Mn (Figure 30), and there is also a strong association between Au, As and Sb in the concentrate data (Table 4). Enrichment in Hg in the fine fraction samples (Figure 31) is present at the two sites away from Glengap Burn which also show enrichment in gold in the concentrate (Figure 26). Slight enrichment in Cu is evident in the sample from south of Brown Hill (Figure 32), though no gold enrichment is present in either sample type.

Table 3 Chemical composition of fine fraction samples from Wamphray Water (ICP analyses)

	Mn	Fe	Ni	Cu	Zn	As	Se	Mo	Ag	Sb	Te	Ba	Au	Aup	Hg	Pb	Bi
PSF 47	1137	4.44	39	28.7	91	35.5	0.5	0.8	42	1.7	0.1	116	2	6	102	36.4	0.2
PSF 48	843	5.57	38	52.4	75.6	4.9	0.4	0.2	32	0.4	0.1	157	4	21	96	20.2	0.3
PSF 49	930	3.56	51	25.4	111.3	18.6	0.3	0.3	37	0.8	0.1	104	1	72	235	28.5	0.2
PSF 50	589	3.93	49	24.6	90	6.5	0.3	0.1	30	0.4	0.1	142	1	10	87	17.5	0.1
PSF 51	427	3.49	38	30.7	100.5	8.5	0.6	0.2	30	0.8	0.1	112	1	4	56	16.5	0.3
PSF 52	1122	3.74	56	33.1	102.5	11	0.4	0.2	36	0.5	0.1	130	1	1	166	31.3	0.3
PSF 53	755	3.52	45	29	81.9	10	1.1	0.3	30	0.8	0.1	145	1	2520	245	25	0.2
PSF 54	730	3.72	36	28.1	69.7	70.3	0.6	0.3	36	3.7	0.1	135	11	10860	89	24.7	0.2
PSF 55	697	3.3	34	20.3	63.1	92.6	1.4	0.5	37	5.3	0.1	108	17	351	111	30.5	0.3
PSF 60	1069	4.35		26	89	37				5			8	137		25	
PSF 61	1216	5.79		24	80	162				11			8	35000		32	
PSF 62	2478	5.91			101	225				8			54	984		28	
PSF 63	984	5.52		25	92	336				17			20	1490		32	
PSF 64													7	4370			

Aup = concentration of gold in panned concentrate sample from same site

Fe in %, Ag, Au and Hg in ppb, other elements in ppm

Table 4 Chemical composition of panned concentrates from Upper Glengap Burn (ICP analyses)

	Mn	Fe	Ni	Cu	Zn	As	Se	Mo	Ag	Sb	Te	Ba	Aus	Aup	Hg	Pb	Bi
PSP 60	1609	15.91	52	38.6	53.6	159.5	1.5	4.5	<30	38.8	1.7	226	8	137	150	32.4	0.6
PSP 61	456	24.25	62	62.6	39.1	678.1	2.8	5.4	<30	85.6	3.7	248	8	35000	1023	39.3	1.4
PSP 62	489	24.33	77	37.6	42.8	735.2	0.9	5.6	<30	112	1.5	222	54	984	590	49.4	0.4
PSP 63	387	16.48	82	45.3	68.7	815.5	0.4	2.1	79	84.5	0.5	171	20	1490	123	22.1	0.3
PSP 64	447	18.64	71	34.4	50.1	652	0.5	2.4	<30	88.6	0.7	253	7	4370	122	15.7	0.4

Aus = concentration of gold in fine fraction sample from same site

Fe in %, Ag, Au and Hg in ppb, other elements in ppm

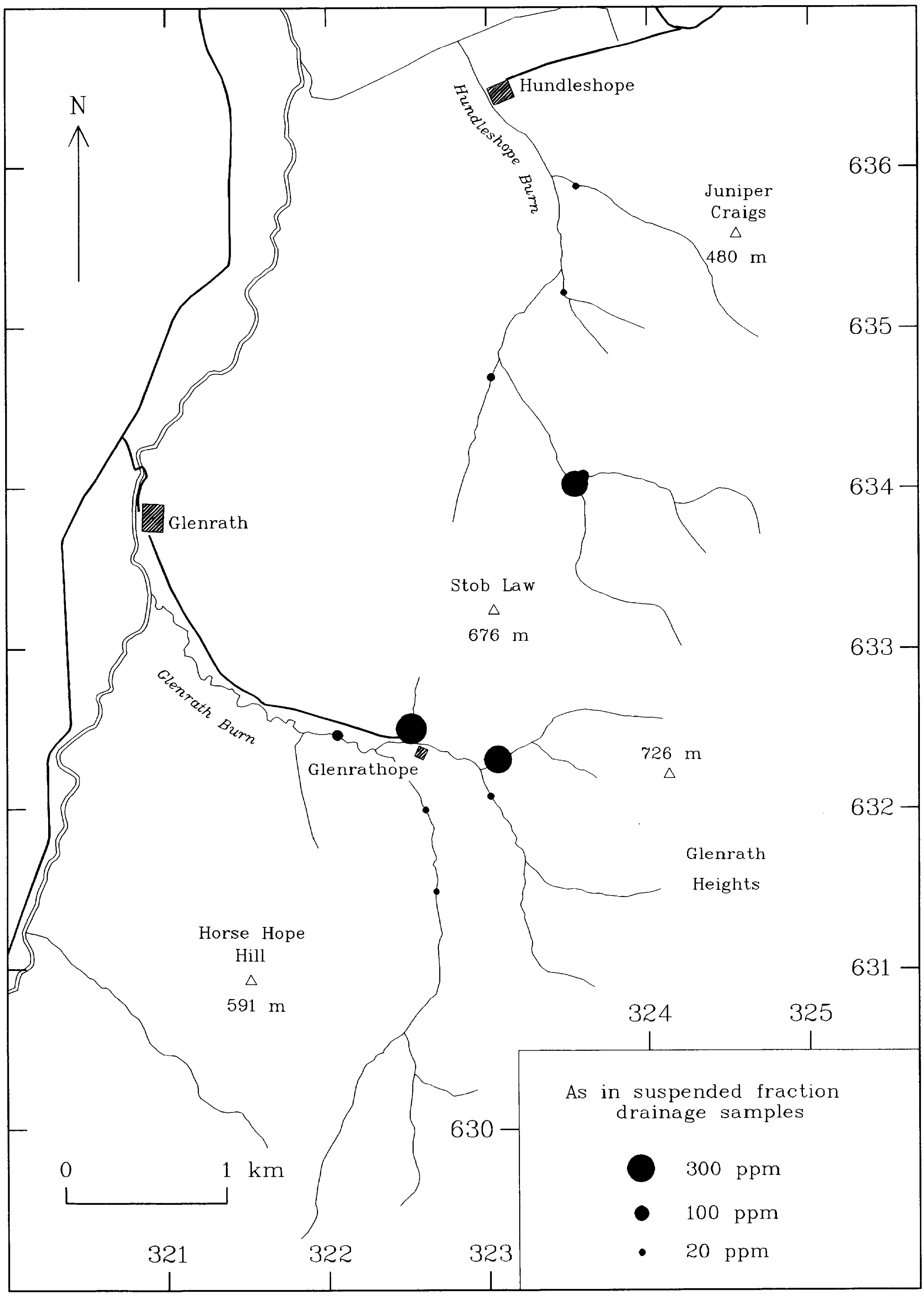

Figure 33 Distribution of arsenic (As) in suspended fine fraction drainage samples from the Stob Law area

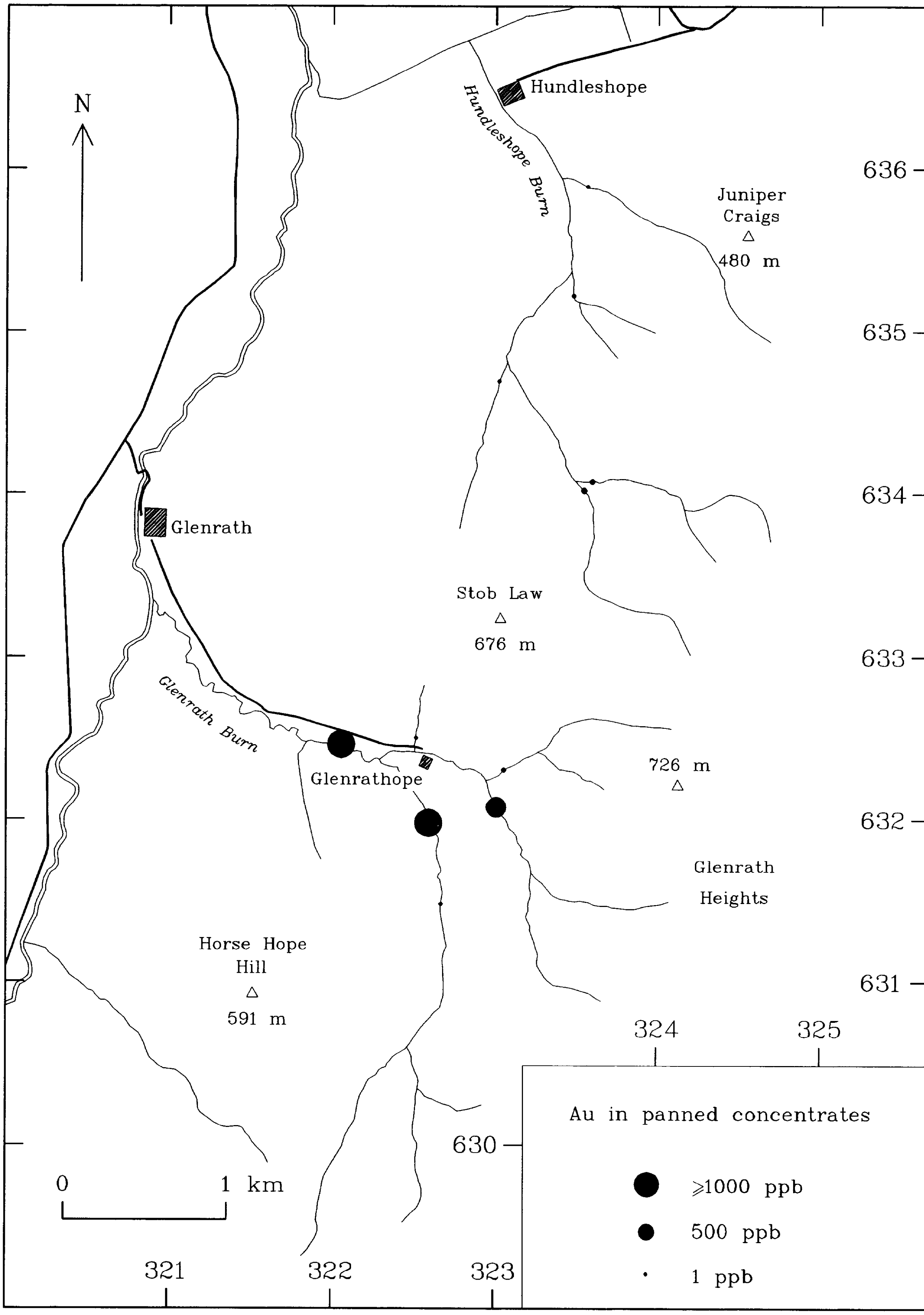

Figure 34 Distribution of gold (Au) in panned concentrates from the Stob Law area

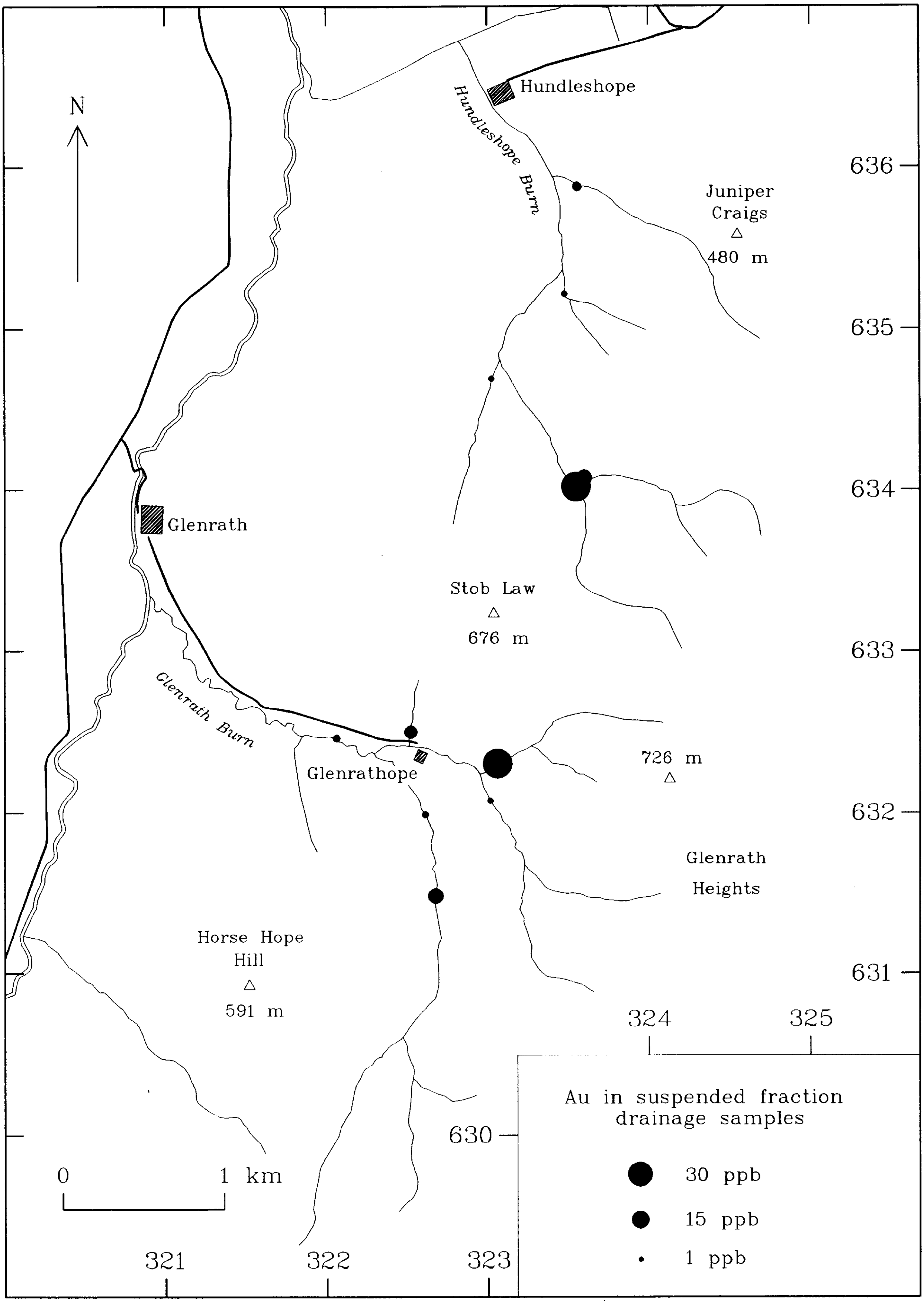

Figure 35 Distribution of gold (Au) in suspended fine fraction drainage samples from the Stob Law area

The concentrate data indicate some degree of association between Au and Fe, As, and Sb. The most auriferous sample also shows slight enrichment in Cu, Se, Te, Hg and Bi.

Area C Stob Law

Drainage sampling was carried out in Glenrathope and Hundleshope Burns and their tributaries. Analyses of the fine fraction sediment samples are given in Table 5.

There is little variation in Mn, Fe, Ni, Cu, Zn, Se, Ag, Sb, Te, Ba and Hg contents of the fine fraction samples. Enrichment in As is present in three samples (Figure 33), one of which shows considerable enrichment in Mo (Table 5). Enrichment in Pb is confined to the most northerly sample. Gold is enriched in three panned concentrate samples (Figure 34) but not in the corresponding fine fraction samples (Figure 35). The highest Au contents in fine fraction samples (Figure 35) are associated with only slight enrichment in Au in the concentrate samples, but they do correspond with the highest concentrations of As (Table 5).

Table 5 Chemical composition of fine fraction samples from Stob Law (ICP analyses)

	Mn	Fe	Ni	Cu	Zn	As	Se	Mo	Ag	Sb	Te	Ba	Au	Aup	Hg	Pb	Bi
PSF 34	665	3.2	59	27	77.8	91.6	1.7	0.5	54	2.6	0.3	74	13	83	86	31.8	0.3
PSF 35	517	2.85	45	20.3	75.4	272.6	1.5	0.4	84	1	0.1	64	30	102	98	41.3	0.8
PSF 36	542	3.14	50	22.1	67.5	38.6	1.6	0.3	34	0.4	0.1	66	1	16	75	21.6	0.2
PSF 37	357	2.51	43	16	97.6	18.7	1.8	0.2	30	2.8	0.1	57	1	29	99	47.8	0.1
PSF 38	561	3.84	60	27.8	126	295.5	1	0.7	65	0.9	0.1	61	30	48	85	49	0.9
PSF 39	450	1.98	39	13.8	96	30	0.9	0.4	42	0.4	0.1	59	1	694	103	34.1	0.3
PSF 40	529	2.48	55	17.8	182.2	16.6	1.8	0.3	30	0.4	0.1	123	2	45	99	39.3	0.2
PSF 41	461	2.52	59	16.6	197.9	11.1	1	0.2	30	1.7	0.1	173	13	10	163	24.3	0.1
PSF 42	233	2.15	36	18.9	80.5	331	1	12	121	1	0.1	67	10	7	115	33.7	0.7
PSF 43	560	2.84	47	22.6	179.1	21.7	1.7	0.4	72	0.8	0.1	85	5	4	116	166.1	0.1
PSF 44	500	2.82	51	19.6	104	72.3	0.3	0.5	39	1.9	0.1	83	3	11640	99	38.1	0.5

Aup = concentration of gold in panned concentrate sample from same site

Fe in %, Ag, Au and Hg in ppb, other elements in ppm

Secondary target areas

No drainage samples were obtained from target areas 1, 4, 6, 10, and 13 to 19. The analyses of fine fraction samples from the other areas are shown in Table 6. Only concentrate samples were obtained from areas 2 and 8.

Area 2 Glaisters Forest

There was no evidence of the presence of gold in panned concentrate samples taken from two sites in a stream draining the northern edge of this area.

Table 6 Chemical composition of fine fraction samples from secondary targets (ICP analyses)

	Target	Mn	Fe	Ni	Cu	Zn	As	Se	Mo	Ag	Sb	Te	Ba	Au	Aup	Hg	Pb	Bi
PSF 21	3	5981	2.89	47	6.1	205.2	16.3	0.8	0.3	30	0.2	0.1	172	4	1	103	22.8	0.1
PSF 22	3	5654	3.18	56	12	315.1	17.5	1.6	0.4	49	0.6	0.2	122	1	1	147	32.9	0.2
PSF 23	3	823	3.29	40	6.3	76.3	18.9	0.5	0.3	30	0.2	0.1	79	2		96	19.2	0.1
PSF 24	5	1014	2.91	33	14.6	113.3	11.7	2.8	0.6	40	0.4	0.2	199	3	1	162	38.8	0.2
PSF 25	7	1068	2.98	48	17	151.4	7.8	0.7	0.2	30	0.3	0.1	121	6	1	64	25.8	0.1
PSF 26	7	993	2.98	46	15.8	111.4	7.8	1.2	0.2	30	0.2	0.1	133	1	178	95	28.7	0.1
PSF 27	7	563	3.86	53	22.7	133.6	7.8	0.7	0.2	30	0.5	0.1	80	6	21	82	30.5	0.1
PSF 30	12	1072	3.02	70	34.1	142.6	18.3	1.5	0.5	59	0.4	0.1	137	93	721	108	38.7	0.2
PSF 31	12	354	2.75	50	33.1	94.8	37.6	2.5	1.3	74	0.9	0.1	133	2	24	124	33	0.3
PSF 32	12	1340	3.46	66	43.6	150	66.3	3.6	0.9	142	0.8	0.2	291	1	24	138	61.8	0.3
PSF 33	12	1049	5.37	63	26.3	112.3	60.5	1.4	1.1	57	1	0.1	198	7	35	111	32.7	0.2
PSF 45	11	1145	4.74	90	45.9	125.3	34	0.9	0.6	81	1.9	0.1	79	1	28	83	33.2	0.2
PSF 46	11	740	3.5	61	35.9	114.2	24.1	2.2	0.6	50	1.7	0.1	61	15	56	152	31.4	0.1
PSF 56	9	900	3.78	56	101.2	83.5	54.6	6	6.1	245	3.7	0.1	65	3	15	114	40.6	0.4
PSF 57	9	6804	7.59	48	217.2	57.9	118.4	5.1	15	555	4.7	0.1	100	4	8	302	20.3	0.4
PSF 58	9	264	5.38	23	149.8	21.7	71	8.3	20	711	10	0.3	35	10	18	251	56.4	0.3
PSF 59	9	1073	3.11	50	32.2	107.8	12.9	3.4	1	106	1	0.1	87	299	455	139	52.6	0.3

Aup = concentration of gold in panned concentrate sample from same site
Fe in %, Ag, Au and Hg in ppb, other elements in ppm

Area 3 Walls Burn

No indications of the presence of gold were evident from either fine fraction samples (Table 6) or panned concentrates taken from this area. The concentrations of metallic and pathfinder elements in the fine fraction samples from the area are relatively low (Table 6). Mn is enriched in two of the samples, as is Zn to a moderate degree, but as other elements do not show any relative enrichment it is likely that the elevation of Zn is due to the presence of Mn oxides of secondary origin.

Area 5 Clauchrie

The samples from the one site sampled in this area do not show evidence of enrichment in Au or any other element of potential interest.

Area 7 Little Clyde

A low-amplitude Au anomaly (178 ppb) is evident in one of the three concentrate samples taken from this area. The anomalous sample was taken from the top of Upper Moss Cleugh, directly south of Roger Law at [298620 617180]. Concentrations of metallic elements and potential gold pathfinders in the fine fraction samples from this area are relatively low (Table 6).

Area 8 Hawkshaw Burn

A total of 69 grains of gold were extracted from stream sediment in Hawkshaw Burn by Dr R Chapman at [3081 6201]. The results of the study of the chemistry of these grains is given in Leake and Chapman (1996).

Area 9 Auchencat Burn

Four drainage sites were sampled on the Auchencat Burn. One sample (PSF 57) was taken just downstream of the old mine trial. The suspended fraction sample from this site shows enrichment in Cu and several other metallic elements (Table 6). However, other sources of metals must exist as the sample from some 600 m further north-east (PSF 58) is also enriched in Cu and contains higher levels of Se, Mo, Ag, Sb and Pb than sample PSF 57. Gold is essentially absent in the suspended fraction samples from these two sites and also from the site further downstream (PSF 56) but it is present in both sample types (Table 6) from the site further upstream in Auchencat Burn (PSF 59). This suggests that the old copper mine and any extension of the mineralised zone to the north-east is not the source of the gold in drainage. This is also indicated by the absence of anomalous levels of Cu, As, Se, Mo, Ag and Sb in the gold-rich samples. However, gold is also present in the lower part of the Auchencat Burn as 19 gold grains have been extracted from the stream at a site between PSF 56 and 57 by Dr R Chapman.

Area 11 Glencotho

One of two samples from south-east of Glencotho, from the Willow Wand Burn at [308850 629740], shows slight enrichment in gold in both suspended fraction and panned concentrate samples (Table 6) but is without significant enrichment in other elements that are indicative of mineralisation.

Area 12 Hopes Water

Gold is enriched in both sample types from one of the four sites sampled in this area at [354890 661700] but there are no other anomalies which may indicate the presence of mineralisation in the suspended fraction sample (Table 6). Slight enrichment in As is evident in two samples from further east.

GOLD GRAIN CHARACTERISATION

Physical separation of gold grains from drainage samples allows the gold grain characterisation procedures developed at BGS to be carried out. The extracted gold grains were mounted in resin, ground and polished to reveal a section through each grain. These grains were examined in detail microscopically to locate visible inclusions. Subsequently the composition of the grains and associated inclusions was determined using a Cambridge Instruments Microscan 5 electron microprobe fitted with a LINK systems energy dispersive analyser.

The results of the quantitative probe determinations of 13 gold grains extracted from the uppermost sample from Auchencat Burn and 14 grains from Glengap Burn are given in Table 7.

Interpretation of gold grain data

It is possible to deduce a great deal about the source of alluvial gold from the chemical characteristics of the grain and the nature of microscopic inclusions preserved within the gold. Ideally over 30 grains are needed to provide an adequate signature of a suite of gold grains and more are required if multiple populations are present. From neither site are there sufficient grains for adequate characterisation. Nevertheless, much useful information can be deduced.

Table 7 Quantitative electron microprobe composition of gold grains

Grain	Area	Part	Inclusion	Au%	Ag%	Pd%	Total
PSP59/1	9		$AgBiSe_2$	84.0	13.6	0	97.6
PSP59/2	9			80.4	18.5	0	98.9
PSP59/3	9			87.8	11.4	0	99.2
PSP59/4	9		FeS, $(Ni,Fe)_9S_8$,	94.8	3.7	0	98.5
PSP59/5	9			82.8	15.9	0	98.7
PSP59/6	9			76.4	21.4	0	97.8
PSP59/7	9			90.7	9.9	0	100.6
PSP59/8	9		FeS_2	89.4	10.4	0	99.8
PSP59/9	9			80.9	19.7	0	100.6
PSP59/10	9			82.3	19.6	0	101.9
PSP59/11	9			83	19.6	0	102.6
PSP59/12	9			91.1	11.1	0	102.2
PSP59/13	9			82.4	19.1	0	101.5
PSP64/A	B			101	0	0	101
PSP64/B	B	a	Sb_2As + Fe	97.6	0	3.6	101.2
PSP64/B	B	b		94.9	6	0	100.9
PSP64/C	B			102	0	0	102
PSP64/D	B	a		102	0	0	102
PSP64/D	B	b		96	0	6.4	100.4
PSP64/D	B	c		96.9	0	2.5	99.4
PSP64/E	B	a		100	0	0	100
PSP64/E	B	b		97.3	0	3.4	100.7
PSP64/1	B	a		99.8	0	1.3	101.1
PSP64/1	B	b		95	0	4.4	99.4
PSP64/2	B		$Ag_2Bi_3Se_5$	96.9	4.0	0	100.9
PSP64/3	B	core		99.3	0	2.1	96.7
PSP64/3	B	rim		84.7	5.9	0	98.4
PSP64/4	B			101	0	0	101
PSP64/5	B			102	0	0	102
PSP64/6	B			103	0	0	103
PSP64/7	B			102	0	0	102
PSP64/8	B	core		101	0	0	101
PSP64/8	B	rim		97	0	4.2	101.2
PSP64/9	B			102	0	0	102

The gold grains from Auchencat Burn are mostly relatively argentiferous. A further sample comprising 18 grains obtained from a site further down the river contains less argentiferous gold with mostly sulphide inclusions (R J Chapman pers. com., 1996). On the basis of comparisons with the BGS database on Southern Uplands gold, it is probable that two main types of gold area present in the stream. One of these is probably the predominant type of gold in the Central Southern Uplands with a silver content mostly below 10% and a predominance of base metal sulphide inclusions together with minor amounts of Sb and Se-rich inclusions (Leake and Chapman, 1996). The other probable type of gold present, with silver contents between 15 and 30%, is found in minor amounts in the Leadhills area and is characterised by Ni and Sb-rich inclusions. The absence of the diagnostic Ni and Sb-rich inclusions in the Auchencat Burn gold leaves some doubt which can only be resolved with the examination of more grains from the stream.

The gold from Glengap Burn appears all to be of the same type. Palladium was detected in 6 of the 14 grains studied and almost all the other grains are mostly pure gold. Palladium is relatively rare in gold in the amounts found but is characteristic of gold associated with the Permian red-bed environment in Britain. Thus palladian gold of this type is characteristic of South Devon (Leake et al., 1991) and the Crediton Trough (Cameron et al., 1994), and also of the Mauchline (Leake et al., in press) and Thornhill basins (Leake and Cameron, 1996) in Southern Scotland. Identification of the gold in Glengap Burn as of this type is important in establishing the nature of the source. The site is about 1.2 km from the nearest outcrop of Permian rocks, but much more of the Lower Palaeozoic rocks of the area would have been covered by Permian rocks previously. In the red-bed environment characterising the Permian basins in Scotland, gold mineralisation is considered to be formed within the underlying rocks where faulting and fracturing permitted downward percolation of the oxidising saline solutions circulating within the basin into the rocks beneath. The major chemical contrast between these oxidising solutions and the underlying rocks and their associated fluids would cause any gold present as a chloride complex to precipitate out. The presence of gold of this type at a site away from the present Permian outcrop supports this mineralisation model and suggests that oxidising ore solutions may have penetrated well into the Lower Palaeozoic rocks beneath. On this model significant mineralisation may be present where major fracturing and brecciation is present in the Lower Palaeozoic rocks concentrated close to the contact with the Permian rocks.

Rock Samples

Some rock sampling was carried out at the same time as the drainage sampling, particularly in the primary target areas but systematic sampling for the follow-up of alluvial gold occurrences was not undertaken. Samples were analysed for a range of elements by XRF at the BGS analytical laboratories at Keyworth and 30 g subsamples were analysed for Au by graphite furnace AA after aqua regia attack and MIBK extraction. The location of all rock samples is given as a grid reference in Appendix 2.

Primary target areas

Area A Laurieston Forest

The chemical analyses of rock samples from this area are shown in Table 8. Rock exposure is rare over much of the Laurieston Forest area. Roadside quarries, now much overgrown, provide the best exposures and many of the samples were obtained from these. However, exposure is lacking over a large part of the area and the only material available is rock fragments within drift.

Table 8 Chemical analyses of rock samples from Laurieston Forest area

Sample	Locality	Rock type	Au	MgO	K_2O	CaO	TiO_2	MnO	Fe_2O_3t	Cu	Zn	As	Zr	Ba	Pb
236	quarry	black shale breccia	18	1.4	3.46	<0.05	0.819	0.016	19.94	136	30	56	196	561	149
237	quarry	black shale	23	0.3	1	<0.05	0.214	0.005	2.11	48	6	20	31	314	70
238	quarry	black shale	3	0.6	1.78	<0.05	0.43	0.007	0.88	9	5	7	80	327	33
239	quarry	dark grey slate	6	0.7	1.73	<0.05	0.352	0.012	2.58	59	9	19	68	418	50
240	quarry	dark grey shale	2	6	3.1	6.76	0.625	0.591	4.58	11	39	15	171	463	11
241	quarry	b shale + qtz veining	6	0.5	0.64	<0.05	0.206	0.027	2.08	38	18	2	38	563	8
242	quarry	quartz vein breccia	1	0.2	0.25	<0.05	0.069	0.02	1.13	42	8	2	11	238	7
243	quarry	quartz vein	<1	0.3	0.13	<0.05	0.032	0.14	1.43	24	7	10	5	68	5
244	quarry	b shale + vein quartz	<1	0.1	0.07	<0.05	0.031	0.015	0.84	66	6	5	5	90	8
245	quarry	black shale	7	0.3	0.52	<0.05	0.062	0.029	1.32	10	9	2	10	445	<3
246	quarry	quartz vein breccia	2	0.6	0.63	<0.05	0.126	0.042	1.63	15	19	2	21	898	<3
247	quarry	greywacke	1	3	1.6	0.17	0.9	0.052	5.72	4	52	2	322	346	5
248	drift	brecciated greywacke	4	2.1	1.28	0.19	1.136	0.05	6.11	12	47	9	585	245	<3
249	drift	quartz vein in slate	12	2.6	0.9	0.19	0.425	0.074	4.77	15	34	5	157	167	3
250	roadside	greywacke	4	3.2	1.39	2.56	0.645	0.18	4.65	14	48	5	187	238	9
251	boulders	greywacke	5	2.5	1.38	0.11	0.66	0.057	4.52	9	38	2	316	251	17
252	boulders	vein quartz	4	1.6	0.53	1.01	0.273	0.13	2.89	3	22	2	115	119	10
253	boulders	greywacke	2	3.8	2.45	0.16	0.843	0.034	6.59	20	56	8	236	424	10
254	drift	porphyrite	22	1	2.75	0.6	0.872	0.072	4.53	24	52	93	334	402	7
255	drift	porphyrite	7	1	3	2.15	0.825	0.082	4.6	3	47	21	316	364	7
256	drift	porphyrite	7	1.4	2.67	2.4	0.819	0.089	4.63	35	76	2	338	3067	4
257	roadside	hornfelsed greywacke	1	3.1	1.49	0.18	1.061	0.065	6.46	12	46	9	476	339	13
258	drift	greywacke	19	3.2	2.52	0.15	0.87	0.042	6.25	17	54	87	282	478	11
259	quarry	greywacke	2	2.3	1.44	7.09	0.465	0.094	3.4	11	40	6	182	216	9
260	quarry	greywacke	2	2.2	1.3	0.75	0.843	0.06	5.08	16	36	2	318	265	3
261	quarry	brecciated greywacke	8	2.6	1.33	0.24	0.553	0.385	5.45	28	24	53	188	259	5
262	quarry	greywacke	13	2	1.72	3.76	0.526	0.081	3.42	9	169	65	296	223	55
263	quarry	greywacke	2	2.3	0.91	3.19	0.676	0.076	4.38	10	35	2	301	217	6
264	quarry	greywacke	2	1.5	1.1	0.17	0.731	0.062	4.38	18	29	2	279	206	3
265	roadside	greywacke	1	2.8	2.11	1.97	0.755	0.069	5.21	8	55	5	271	317	8
266	streamside	shale	4	3.7	2.64	0.16	0.967	0.044	6.74	19	76	8	246	478	13
267	outcrop	greywacke	5	3.3	1.67	0.97	0.676	0.086	5.85	12	65	2	224	287	13
268	stream	greywacke	3	2.6	1.32	2.24	0.591	0.091	4.32	11	42	2	311	200	7
269	stream	greywacke	2	2	0.48	0.8	0.301	0.066	2.43	4	12	2	178	92	9
270	roadside	greywacke	4	2	0.86	0.57	0.563	0.042	3.91	9	42	5	377	154	7
271	boulders	vein qtz in greywacke	4	3.3	1.15	1.15	0.613	0.066	4.16	5	28	6	201	181	<3
285	roadside	greywacke	3	6	1.1	5.79	0.417	0.199	4.09	20	23	2	168	177	7
290	quarry	greywacke	65	2.2	1.52	0.18	1.059	0.055	6.42	8	47	192	385	555	34
291	roadside	breccia	2	10.3	2.82	15.42	0.289	0.229	3.69	33	22	6	74	318	5
331	roadside	brecciated greywacke	2	5	1.5	3.07	0.545	0.121	5.63	13	48	2	155	242	3
332	quarry	greywacke		3.4	1.86	0.18	0.746	0.061	6.38	14	57	5	251	234	<3
333	quarry	greywacke+carb vein		3.6	2.34	16.13	0.497	0.166	4.4	19	53	2	117	306	10
334	quarry	greywacke+qtz & carb		1.6	0.74	10.68	0.294	0.1	2.32	14	22	2	126	99	3

MgO, K_2O, CaO, TiO_2, MnO and total Fe as Fe_2O_3 in %, Au in ppb, other elements in ppm, all samples prefix PSR. b=black.

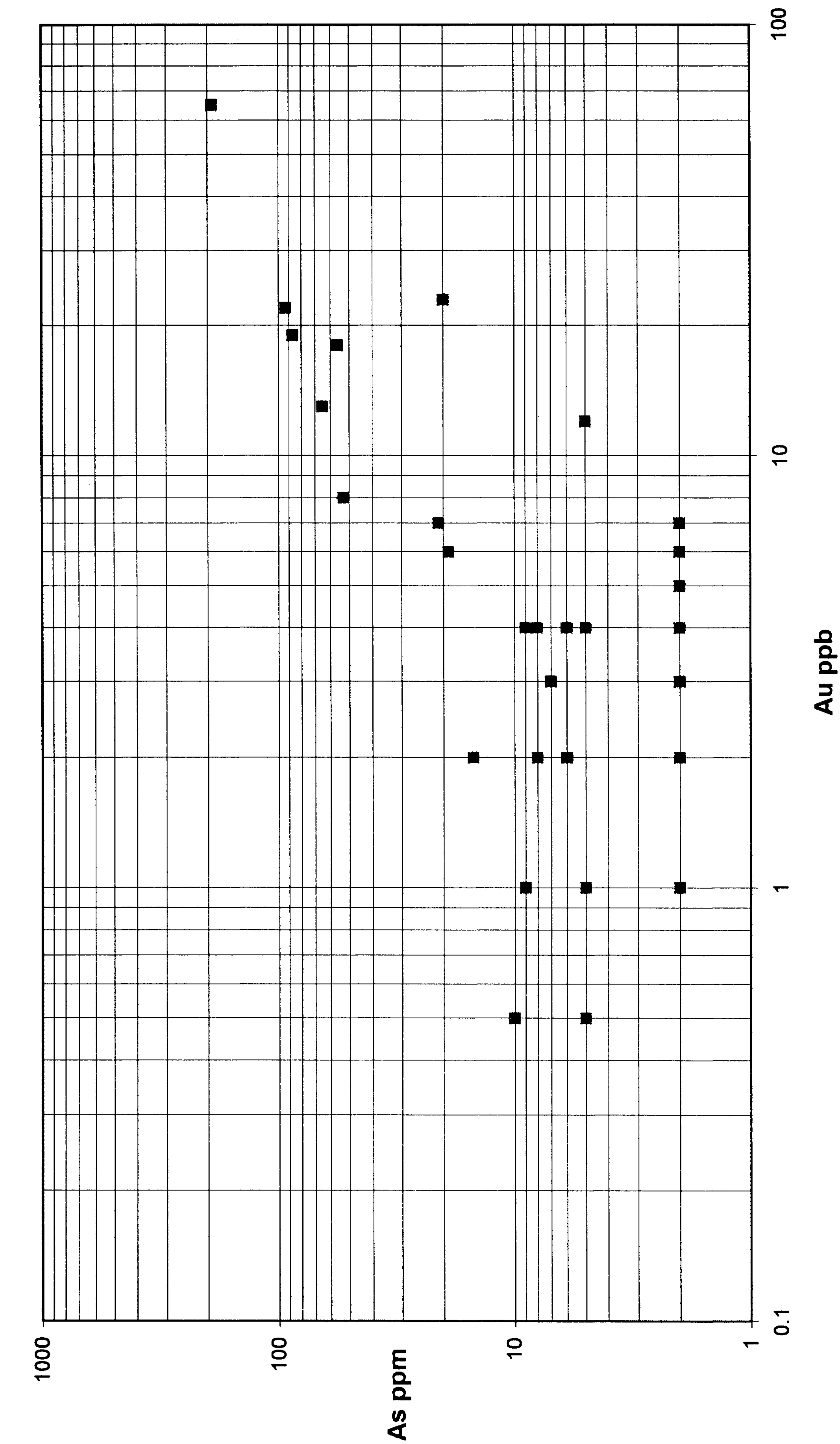

Figure 36 Gold (Au) vs arsenic (As) scatterplot for rock samples from the Laurieston Forest area

Gold shows only slight enrichment, to a maximum of 65 ppb, in the rock samples from this area. Some degree of positive correlation between Au and As is evident in the rock data (Figure 36) but not with the other elements determined. The maximum gold level was found in a greywacke sample showing no enrichment in other elements except As. On this basis it is probable that gold is associated with As-rich pyrite in this and possibly other samples showing slight enhancement. Samples containing vein carbonate were analysed, but there is no evidence of an association of gold or significant amounts of other metals with such veining. Massive multiphase quartz veining from south-east of Craigelwhan (Figure 21) were analysed (PSR 242, 3, 6) but no evidence of gold enrichment was found, though the surrounding black and grey shale (PSR 236–240) shows some enrichment in Cu, As and Pb (Table 8). Samples of smaller-scale quartz veining in greywacke (PSR 249, 252, 271) show no enhanced metal values. Potentially of interest are the samples of porphyrite (Table 8) as these show some enrichment in Au and As, and considerable enrichment in Ba in one sample. Disseminated pyrite is present in these rocks and the high Ba level suggests some form of hydrothermal alteration. These samples were taken from trackside drift in an area devoid of exposure to the north of Anstool Burn (Figure 21) and could indicate that a centre of minor igneous activity is present in the vicinity but has escaped notice because of the lack of exposure. Centres of minor igneous activity represent good targets for gold-bearing mineralisation.

Area B Wamphray Water

Rock sampling was confined to a traverse along the forest tracks, together with limited follow-up of the alluvial gold in the Glengap Burn (Figure 26). Exposure is variable on the higher ground but essentially limited to the track-side within much of the extensive area covered by forest. Chemical analyses of the rock samples are shown in Table 9. By far the most interesting sample is the rock (PSR 354) collected as float from the Glengap Burn, near to the site of the original discovery of alluvial gold. The rock is a reddened altered brecciated siltstone. It is highly enriched in gold (2.23 ppm Au) and As (789 ppm) but not in other metallic elements (Table 9). The relatively high Ca content suggests that carbonate is present. Carbonate veining or flooding could be the source of the gold, especially as the gold characterisation work indicates that the gold from higher up the Glengap Burn is of the Permian red-bed type, a mineralisation type with which carbonate gangue would be expected. The relatively high Fe content could indicate that Fe has been introduced into the sample, possibly originally as Fe-rich carbonate. A small amount of further rock sampling higher up the Glengap Burn failed to find similar levels of gold either in outcrop or float, though because of extensive snow cover, this work could not be done effectively and it was not possible to sample the occurrence of outcropping reddened greywackes in the northern part of the catchment mentioned by a local farmer. These samples (PSR 357-363) are not enriched in As or metallic elements but they contain relatively high levels of Ca (Table 9) which could reflect carbonate alteration.

Other samples from the area only show very slight enrichment in gold (Table 9) and no corresponding enrichment in As. Samples from around Cornal Burn (PSR 217–219), north of the area in Figure 26, show enrichment in several metallic elements (Table 9) but not Au. The anomalous samples probably reflect fracture-controlled base-metal dominant vein mineralisation.

Area C Stob Law

Eleven rock samples were collected from the Glenrath-Stob Law area, mostly from float and rock scree. Analyses of these samples are shown in Table 10. Three of the samples show enrichment in gold, though only of low amplitude. Two samples of vein quartz show the greatest enrichment in gold (Table 10). Elevated As levels are also present in these samples and also, in one case, enrichment in

Pb. Much larger samples would be required for analysis, to take account of possible nugget effects in vein material, in order to give a reliable indication of the level of gold associated with such veining.

Table 9 Chemical analyses of rock samples from Wamphray Water area

Sample	Locality	Rock type	Au	MgO	K_2O	CaO	TiO_2	MnO	Fe_2O_3	Cu	Zn	As	Zr	Mo	Ba	Pb
PSR217	trackside	quartz vein	5	1.2	1.71	0.7	0.597		4.72	4	14	8	222	2	225	10
PSR218	trackside	vein breccia	7	0.3	1.14	0.03	0.327		22.02	90	322	271	57	15	161	184
PSR219	trackside	silicified breccia	5	0.2	0.61	0.03	0.155		7.18	48	90	149	28	12	133	43
PSR231	trackside	brecciated chert	1	0.2	0.82	0.03	0.168		5.17	35	51	73	31	<1	162	8
PSR312	quarry	brown shale	4	2.9	4.13	0.03	0.984	0.057	9.18	19	107	<5	193		588	5
PSR313	quarry	vein quartz	3	1.5	0.86	0.03	0.356	0.03	3.61	11	40	<5	106		118	17
PSR314	quarry	greywacke	3	1.9	2.22	0.03	0.833	0.089	6.91	28	80	<5	256		301	8
PSR315	quarry	greywacke	3	2.8	1.69	0.03	0.885	0.062	6.01	8	66	<5	329		270	6
PSR316	trackside	vein qtz in greywacke	2	1.7	0.9	0.03	0.427	0.041	3.83	8	34	<5	138		153	6
PSR317	trackside	greywacke	4	3.3	1.76	0.06	0.828	0.048	6.6	15	63	<5	266		330	22
PSR318	trackside	greywacke	2	3.3	1.89	0.19	0.824	0.055	6.7	15	62	<5	237		314	10
PSR319	trackside	greywacke	2	1.7	0.88	0.03	0.409	0.022	3.69	94	33	<5	135		137	8
PSR320	trackside	grey/red shale	23	3.1	5.36	0.03	0.883	0.049	9.55	60	102	<5	165		765	15
PSR321	trackside	brecciated greywacke	2	2.1	1.42	0.03	0.623	0.112	6.62	5	70	<5	182		203	5
PSR322	trackside	greywacke	3	2.7	2.25	0.13	0.778	0.074	6.19	5	60	<5	229		341	4
PSR323	trackside	vein qtz in greywacke	4	2.8	0.99	0.03	0.338	0.171	5.12	20	45	6	55		146	9
PSR324	trackside	vein qtz in greywacke	10	1.5	0.64	0.03	0.247	0.053	2.84	8	23	<5	57		105	4
PSR325	trackside	oxidised greywacke	3	3.3	2.27	0.17	0.85	0.06	6.63	10	67	<5	233		302	5
PSR326	trackside	green greywacke	3	2.1	2.05	0.14	0.825	0.079	6.11	11	51	<5	263		247	11
PSR327	trackside	oxidised greywacke	2	1.5	2.6	0.12	0.842	0.046	5.55	10	50	<5	273		274	6
PSR328	trackside	oxidised greywacke	2	1.2	2.14	0.07	0.874	0.059	5.58	12	43	<5	350		240	11
PSR329	trackside	greywacke	4	0.2	0.54	0.03	0.253	0.065	4.73	16	30	19	66		85	17
PSR330	trackside	shale	6	5.4	3.95	0.11	1.012	0.04	9.18	3	83	10	169		362	10
PSR345	trackside	greywackw+qtz vein	0.5	1.6	0.65	0.09	0.298		2.84	4	25	5	87	2	109	3
PSR346	stream float	greywacke + Fe coating	21	2.9	0.9	0.35	0.796		5.9	6	60	5	395	3	158	6
PSR347	outcrop	red siltstone	2	4.1	4.06	0.17	0.928		7.64	4	72	6	191	2	690	9
PSR348	outcrop	greywacke+qtz vein	1	2.4	1.26	0.14	0.674		4.59	10	37	5	247	2	245	32
PSR349	stream side	greywacke+qtz vein	2	3.1	1.51	1.83	0.826		5.69	8	57	5	334	3	571	5
PSR350	stream side	qtz vein in greywacke	1	2.5	0.3	0.69	0.141		3.48	18	34	5	32	1	65	3
PSR351	stream side	dolerite dyke	0.5	2.6	3.26	5.06	0.785		7.19	52	64	5	215	5	623	12
PSR352	float	Vein quartz	1	3.4	1.79	0.21	0.589		4.65	4	52	5	193	2	192	11
PSR353	trackside	red greywacke	3	2.2	4.11	0.1	0.88		8.9	25	56	18	203	5	294	14
PSR354	float	brecciated siltstone	2230	3.7	0.97	4.79	0.269		9.21	30	109	789	53	4	86	9
PSR356	float	red greywacke	2													
PSR357	outcrop	greywacke	5	2.9	2.00	1.26	0.842		6.51	4	59	9	338	4	273	7
PSR358	stream side	greywacke	2	2.8	2.38	4.23	0.734		5.33	19	29	20	243	4	270	20
PSR359	stream side	pink greywacke	3	3.1	1.41	5.17	0.581		7.61	12	33	14	212	3	171	7
PSR360	float	greywacke+qtz vein	2	3.2	1.27	5.11	0.377		6.12	31	31	18	124	3	157	10
PSR361	stream side	red greywacke	2	3.4	2.13	6.11	0.602		9.32	11	46	28	155	3	248	15
PSR362	outcrop	altered greywacke	2	2.3	1.68	3.64	0.786		7.48	9	26	27	278	2	198	28
PSR363	stream side	brecciated greywacke	1	4.2	1.54	7.09	0.5		6.89	18	34	13	167	3	155	14

MgO, K_2O, CaO, TiO_2, MnO and total Fe as Fe_2O_3 in %, Au in ppb, other elements in ppm

Dykes or sheets of leucogranite occur in the same area and the only analysed sample of this material also shows enrichment in gold and a greater degree of enrichment in As. The Au/As ratio is therefore higher in the vein material than in the igneous rock. This could indicate similarity with the Glenhead area of Galloway where widespread low-grade enrichment in Au and As is associated with sheets of granitoid rock but much higher enrichment in Au is associated with later discordant quartz veining in the aureole of the Loch Doon granite (Leake et al., 1981). Considerable enrichment in Mo (Table 10) is present in a greywacke sample (PSR 339) from scree on the south side of Stob Law (Figure 33) which also contains fragments of leucogranite.

Table 10 Chemical analyses of rock samples from Stob Law area

Sample	Rock type	Au	MgO	K_2O	CaO	TiO_2	Fe_2O_3t	Ni	Cu	Zn	As	Zr	Mo	Ba	Pb
PSR234	leucogranite	24	0.6	3.32	0.09	0.402	2.56	1	15	34	1719	118	8	779	23
PSR235	vein quartz	59	0.05	0.03	0.03	0.001	0.4	1	5	1	276	<1	<1	18	5
PSR335	greywacke	6	3.6	1.85	1.59	0.729	5.25	58	15	49	5	292	2	586	21
PSR336	red greywacke	6	1.5	2.72	0.07	0.876	7.53	86	27	74	125	313	5	457	24
PSR337	vein quartz	33	0.1	0.29	0.05	0.004	0.5	3	6	4	513	10	4	53	1215
PSR338	quartz vein breccia	2	1.4	0.95	0.08	0.329	2.23	18	3	20	5	144	1	193	8
PSR339	altered greywacke	1	0.1	1.78	0.15	0.025	0.35	3	3	5	14	29	50	342	10
PSR340	altered greywacke	1	0.1	2.24	0.1	0.068	0.55	3	9	13	15	67	7	551	12
PSR341	hornfelsed greywacke	0.5	4	4.09	2.28	0.913	5.54	37	56	63	5	319	3	1194	16
PSR342	hornfelsed greywacke	2	3.9	2.42	1.72	0.714	4.8	60	8	57	5	302	5	485	5
PSR369	felsite dyke	4	0.1	3.06	0.05	0.051	1.04	3	3	17	5	63	1	697	10

MgO, K_2O, CaO, TiO_2, MnO and total Fe as Fe_2O_3 in %, Au in ppb, other elements in ppm

Secondary target areas

Limited rock sampling was carried out in eight of the secondary target areas and the results of their chemical analyses are shown in Table 11 and discussed in turn below. Samples were collected from the best exposures available, but the sample set is too meagre and selective to give an adequate indication of the presence or absence of gold-bearing mineralisation.

Area 2 Glaisters Forest

Rock samples were obtained from track-side exposures and a quarry within Glaisters Forest at [277456 58120]. The greywackes exposed in the quarry contain a zone of red colouration trending approximately north-east. Associated with the red rocks are thin hematitic planes and calcite veining. No gold is present in significant amounts in the samples taken from this zone, and other metallic elements are not enriched except for Cu at 94 ppm in one sample of red greywacke (PSR 275, Table 11). No gold was found in the unoxidised greywackes and shales obtained from roadside exposures in the forest, though one greywacke sample (PSR 282) from south of the quarry showed slight enrichments in As (44 ppm) and Mn (0.233 %).

Area 3 Walls Burn

Four samples collected from this area were of veined and brecciated rock including examples of both carbonate and quartz-filled breccias. None of these samples show enrichment in Au or any other metallic or potential pathfinder element.

Area 4 Euchan

Samples were collected from exposures in the Whing Burn which flows northwards into the Euchan Water. Most of the samples were taken from a complex black shale belt containing small lenses of massive pyrite, cherty shale and a microdioritic rock. Slight enrichment in gold (14 ppb) is evident in one sample of greywacke (PSR 201) from the area but all the other samples contain background concentrations of the element (Table 11) and the sample of massive pyrite is enriched in As but not Au. The high Ni levels in samples PSR 204–206 suggest that mafic volcanic material is present within the sequence. Copper shows slight enrichment in two samples of cherty black shale (PSR 206 + 207) but in other respects the rocks from the belt do not show enrichment in base metals or gold pathfinder elements.

Area 5 Clauchrie Plantation

This area is distinctive in that all the outcrops of Lower Palaeozoic greywacke are stained red due to oxidation by fluids derived from the overlying Permian. In the old quarry at [29144 58870] and elsewhere there are also conspicuous green reduction spots within the red greywacke. The reduction spots are zoned with an outer deep green zone and an inner pale green zone. No gold was found by analysis in any of the samples analysed from this area. Similarly there is no enrichment in other metallic elements. However, several samples are relatively enriched in K and Ba with maxima of 5.7% K_2O and 3411 ppm Ba respectively in a finer grain horizon at [29262 58927]. Enrichment in Ba to this level suggests some hydrothermal activity.

Area 7 Little Clyde

Samples were taken from the side of forest tracks mostly running near east-west. No significant enrichment in Au, As or metallic elements was detected by chemical analysis of quartz vein, mafic dyke, breccia and greywacke (Table 11). Slight enrichment in Ba is apparent (Table 11) in one sample of slate (PSR 306).

Area 8 Hawkshaw Burn

A sample of greywacke taken from a streamside exposure close to the site from which alluvial gold was extracted shows no enrichment in Au or other elements of potential interest. Exposure is absent upstream of this and the whole upper reaches of the stream is a drift-filled basin. The second sample analysed from the area is a loose block from stream debris of red-stained greywacke which shows slight enrichment in Ba but not Au (Table 11).

Area 9 Auchencat Burn

A sample of black shale with malachite from debris near to the old trial by the side of Auchencat Burn showed no enrichment in Au and no enrichment in metallic elements except for Cu and Mo (Table 11). This supports the evidence from the drainage sampling that the source of the alluvial gold is upstream of, and unrelated to, the mineralised structure that was investigated by the old trial.

Area 12 Hopes Water

Only two rock samples were taken from this area, comprising greywacke and a quartz vein. Although neither showed significant enrichment in gold, both are enriched in As (Table 11).

Table 11 Chemical analyses of rock samples from secondary areas

Sample	Area	Rock type	Au	MgO	K_2O	CaO	TiO_2	MnO	Fe_2O_3t	Ni	Cu	Zn	As	Zr	Mo	Ba	Pb
201	4	greywacke	14	2.5	1.95	3.52	0.98		5.99	44	21	46	7	297	2	325	10
202	4	greywacke	6	1.3	1.23	1.31	1.009		4.79	42	9	25	5	294	<1	245	4
203	4	greywacke	2	3.9	1.44	10.13	0.531		6.44	29	10	11	2	177	6	185	6
204	4	pyrite lens	1	4.1	0.09	6.16	0.157		22.68	168	29	61	173	15	16	43	27
205	4	chert	<1	3.9	0.59	5.92	1.273		7.8	164	93	44	2	87	3	156	3
206	4	cherty black shale	2	5.1	1.05	6.96	1.117		12.31	185	81	31	2	69	3	178	<3
207	4	black shale	2	5.5	2.46	10.78	0.386		4.99	47	37	21	18	62	9	303	32
208	4	microdiorite?	2	2.7	1.12	1.87	1.359		12.16	40	30	78	6	173	4	133	7
209	4	chert	<1	0.2	0.7	0.03	0.175		1.29	7	12	7	11	28	3	135	4
210	4	chert	1	0.2	0.54	0.03	0.259		2.51	13	16	12	18	40	2	127	<3
215	8	greywacke	3	1.6	2.53	7.78	0.753		3.76	58	25	27	2	187	2	187	3
216	8	greywacke	2	4.3	1.68	0.37	0.746		6.39	71	7	43	2	201	<1	1231	5
273	2	greywacke	4	4.9	3.75	0.59	0.856	0.06	6.28		5	54	6	240		680	10
274	2	greywacke	5	4.3	2.51	0.99	0.951	0.052	6.47		3	50	2	418		578	6
275	2	red greywacke	2	0.5	3.65	1.82	0.426	0.034	1.76		94	25	6	219		768	6
276	2	red greywacke	2	1	3.66	2.7	0.39	0.053	2.56		16	26	2	214		740	4
277	2	green greywacke	5	3.3	1.73	4.28	0.565	0.049	4.23		2	34	2	220		359	<3
278	2	carbonate vein	1	0.9	0.41	21.36	0.107	0.116	1.03		2	8	2	39		46	<3
279	2	green greywacke	2	2.6	1.37	0.76	0.437	0.036	3.73		3	23	2	125		193	5
280	2	green greywacke	2	3.2	2.51	3.87	0.685	0.14	4.99		29	29	5	261		558	3
281	2	greywacke + qtz vein	5	3.3	1.63	0.64	0.607	0.055	4.89		3	32	2	215		445	<3
282	2	greywacke	3	2.6	3.27	5.23	0.589	0.233	3.82		14	44	44	203		479	11
283	2	shale	4	3.4	4.62	0.45	0.816	0.071	7.11		52	79	10	204		774	16
284	2	shale	2	3.7	4.35	0.84	0.793	0.083	7.41		37	95	11	229		824	39
286	3	carbonate breccia	1	2.2	1.76	25.94	0.257	0.235	3.07		6	29	8	106		186	5
287	3	greywacke+vein quartz	3	2.7	2.17	0.38	0.514	0.087	3.7		11	27	11	193		365	9
288	3	quartz breccia vein	1	0.7	1.34	0.05	0.122	0.009	1		4	6	2	36		204	<3
289	3	brecciated greywacke	1	2.7	2.03	0.12	0.474	0.027	3.26		6	28	2	157		348	<3
292	5	oxidised greywacke	1	4.2	4.16	1.18	0.692	0.091	4.7		14	58	5	220		1029	7
293	5	oxidised greywacke	1	3.9	3.49	0.68	0.725	0.087	5.61		11	57	2	231		910	10
294	5	oxidised greywacke	1	3.5	3.48	0.57	0.715	0.072	4.97		16	55	2	229		918	13
295	5	oxidised greywacke	1	3.2	3.18	0.35	0.725	0.084	5.33		13	62	6	232		718	7
296	5	oxidised greywacke	2	4	4.33	0.6	0.733	0.081	5.15		14	60	2	239		855	8
297	5	brecciated shale	1	3.5	2.93	0.59	0.71	0.094	5.17		13	58	2	222		765	7
298	5	oxidised greywacke	1	2.5	2.98	0.75	0.632	0.062	4.37		8	56	2	246		1119	9
299	5	oxidised greywacke	1	2.7	3.27	1.04	0.703	0.072	4.75		13	53	5	220		744	7
300	5	oxidised greywacke	1	3.8	3.83	0.8	0.739	0.079	5.46		12	57	8	227		1843	12
301	5	oxidised greywacke	1	3.3	5.7	0.4	0.802	0.057	6.22		17	75	12	214		3411	11
302	7	vein quartz in slate	2	1.1	0.67	0.03	0.231	0.031	2.73		10	23	10	60		152	6
303	7	mafic dyke	1	4.1	1.21	7.59	1.216	0.137	10.88		50	92	2	126		282	11
304	7	schistose slate	5	2.4	1.45	0.06	0.641	0.195	7.18		22	64	16	203		330	34
305	7	brown greywacke	9	2.3	1.77	0.09	0.931	0.066	6.14		17	57	2	358		321	10
306	7	slate	2	4.1	3.71	0.09	0.983	0.042	8.09		44	87	10	216		2676	8
307	7	breccia	2	3.5	1.79	1.1	0.664	0.062	5.6		19	57	8	149		682	10
308	7	mafic dyke	2	3.5	1.82	6.87	1.204	0.122	10.19		54	79	2	164		527	7
309	7	greywacke	3	3.7	1.79	0.64	0.878	0.071	6.37		21	59	2	271		439	10
310	7	greywacke	1	3.8	1.72	2.88	0.699	0.081	6.16		19	57	6	190		345	10
311	7	vein quartz	3	0.4	0.4	0.03	0.046	0.028	1.52		8	12	2	7		432	5
355	9	black shale+malachite	6	1.6	2.57	0.05	0.485		3.59	13	>2%	14	5	104	14	450	39
367	12	greywacke	3	1.9	2.38	0.09	0.846		6.89	64	64	48	78	312	3	438	5
368	12	Vein quartz	10	0.3	1.03	0.05	0.142		1.41	7	10	4	68	43	1	112	5

All samples have PSR prefix. MgO, K_2O, CaO, TiO_2, MnO and total Fe as Fe_2O_3 in %, Au in ppb, other elements in ppm

CONCLUSIONS + RECOMMENDATIONS

The results of the approach used in this study to identify targets with potential for gold mineralisation within a large region have been sufficiently promising to suggest that the method should be used further. The analyses of the drainage and rock samples collected in the three main target areas have provided evidence for the presence of gold and other mineralisation which merits additional follow-up, and in this respect the project was very successful. The amount of sampling carried out in the secondary target areas has generally been too little to assess properly whether gold mineralisation is likely to be present. Six of the areas were not sampled at all. However, significant amounts of alluvial gold occur in three of the secondary target areas (8, 9, 12) which merit detailed follow-up. This represents a third of the sites visited. In addition, lower-amplitude gold in drainage was found in two other secondary target areas (7, 11) and further drainage sampling is merited in these because of the small number of drainage samples collected.

Additional work needs to be done to establish the type of mineralisation that is giving rise to the alluvial gold enrichments. Information concerning the type of source mineralisation can be obtained from electron microprobe gold characterisation studies of the alluvial gold grains, and this has been carried out for some of the occurrences (areas B, 8 and 9). Further details of this approach are given in Leake and Chapman (1996). More target areas should also be examined, together with areas which show no features of potential interest in the datasets used. Drainage and rock sampling in such blank areas is important as a means of testing the approach, since there should be no evidence of mineralisation there. Further sampling at adequate density to cover all the areas selected should also provide an indication of which are the more important of the various criteria used. If greater understanding of the relationship between deep structure, igneous activity and hydrothermal activity can be obtained then the approach can progress beyond the generally empirical stage. It is clearly worthwhile developing the approach and methodology further, as there are potentially great cost savings for exploration if mineralisation targets can be identified from computer-based desk studies using existing regional-scale datasets.

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APPENDIX 1 Location of drainage sampling sites

Project code	Site no.	Pan sample	Sed sample	Easting	Northing	Target area
PS	4	P	F	267010	565520	A
PS	5	P	F	266970	565530	A
PS	6	P		266970	565530	A
PS	7	P	F	265030	563080	A
PS	8	P	F	265910	563260	A
PS	9	P	F	264940	563110	A
PS	10	P	F	264360	563590	A
PS	11	P	F	265490	562970	A
PS	12	P	F	264000	563000	A
PS	13	P	F	263970	561760	A
PS	14	P	F	265300	564920	A
PS	15	P	F	264410	564770	A
PS	16	P	F	264410	564770	A
PS	17	P	F	264660	565180	A
PS	18	P	F	265330	563080	A
PS	19	P	F	276270	581680	2
PS	20	P	F	276290	581670	2
PS	21	P	F	276750	586900	3
PS	22	P	F	276600	586620	3
PS	23	P	F	276430	586680	3
PS	24	P	F	291940	589970	5
PS	25	P	F	298580	616155	7
PS	26	P	F	298620	617180	7
PS	27	P	F	299580	616760	7
PS	28	P	F	316670	603640	B
PS	29	P	F	264400	564760	A
PS	30	P	F	354890	661700	12
PS	31	P	F	355840	662590	12
PS	32	P	F	356170	662280	12
PS	33	P	F	355870	663070	12
PS	34	P	F	323600	634075	C
PS	35	P	F	323550	634020	C
PS	36	P	F	323025	634690	C
PS	37	P	F	323480	635215	C
PS	38	P	F	323060	632305	C
PS	39	P	F	323015	632075	C
PS	40	P	F	322610	631990	C
PS	41	P	F	322675	631480	C
PS	42	P	F	322520	632500	C
PS	43	P	F	323560	635880	C
PS	44	P	F	322060	632460	C
PS	45	P	F	308680	629705	11
PS	46	P	F	308850	629740	11
PS	47	P	F	315460	602220	B
PS	48	P	F	315090	600340	B
PS	49	P	F	316720	598720	B
PS	50	P	F	316620	601355	B
PS	51	P	F	316680	601340	B
PS	52	P	F	314340	598780	B
PS	53	P	F	314180	599480	B
PS	54	P	F	313790	599440	B
PS	55	P	F	314350	601830	B
PS	56	P	F	307820	610380	9
PS	57	P	F	308940	611030	9

Project code	Site no.	Pan sample	Sed sample	Easting	Northing	Target area
PS	58	P	F	309540	611440	9
PS	59	P	F	309620	611300	9
PS	60	P	F	313130	600010	B
PS	61	P	F	313220	600170	B
PS	62	P	F	313290	600355	B
PS	63	P	F	313440	600680	B
PS	64	P	F	313290	600280	B
PS	65	P		313220	600170	B

APPENDIX 2 Location of rock sampling sites

Project code	Site no.	Easting	Northing	Target area
PS	201	276580	607930	4
PS	202	276580	607930	4
PS	203	276430	607480	4
PS	204	276430	607500	4
PS	205	276430	606500	4
PS	206	276430	607500	4
PS	207	276430	607510	4
PS	208	276430	607510	4
PS	209	276430	607510	4
PS	210	276430	607510	4
PS	215	308090	620100	8
PS	216	307940	619880	8
PS	217	312250	604290	B
PS	218	314580	604030	B
PS	219	314590	604030	B
PS	231	314580	604030	B
PS	234	322600	632500	C
PS	235	322600	632500	C
PS	236	266770	564470	A
PS	237	266770	564470	A
PS	238	266770	564470	A
PS	239	266770	564470	A
PS	240	266770	564470	A
PS	241	266770	564470	A
PS	242	266770	564470	A
PS	243	266770	564470	A
PS	244	266770	564470	A
PS	245	266770	564470	A
PS	246	266770	564470	A
PS	247	266770	564470	A
PS	248	266770	564470	A
PS	249	266770	564470	A
PS	250	266770	564470	A
PS	251	264970	563110	A
PS	252	264970	563110	A
PS	253	264970	563110	A
PS	254	265460	563200	A
PS	255	265460	563200	A
PS	256	265460	563200	A
PS	257	265120	563860	A
PS	258	265120	563870	A
PS	259	265020	563890	A
PS	260	265020	563890	A
PS	261	265020	563890	A
PS	262	265020	563890	A
PS	263	265020	563890	A
PS	264	265020	563890	A
PS	265	262980	561670	A
PS	266	263940	563050	A
PS	267	264100	562820	A
PS	268	265340	562740	A
PS	269	265480	562740	A
PS	270	265430	562960	A
PS	271	265040	562940	A

Project code	Site no.	Easting	Northing	Target area
PS	272	276200	580880	2
PS	273	277390	581390	2
PS	274	277490	581290	2
PS	275	277560	581200	2
PS	276	277560	581200	2
PS	277	277560	581200	2
PS	278	277560	581200	2
PS	279	277560	581200	2
PS	280	277560	581200	2
PS	281	277560	581200	2
PS	282	277800	580400	2
PS	283	277800	580400	2
PS	284	277800	580400	2
PS	285	265980	563840	A
PS	286	276450	587130	3
PS	287	276150	587610	3
PS	288	276540	587100	3
PS	289	276160	587550	3
PS	290	265020	563855	A
PS	291	265040	564020	A
PS	292	291440	588700	5
PS	293	291440	588700	5
PS	294	291440	588700	5
PS	295	291440	588700	5
PS	296	291440	588700	5
PS	297	291930	589370	5
PS	298	292340	589370	5
PS	299	292340	589370	5
PS	300	292240	588800	5
PS	301	292620	589270	5
PS	302	298420	617730	7
PS	303	298480	617720	7
PS	304	298480	617720	7
PS	305	298530	617680	7
PS	306	298610	617630	7
PS	307	298950	617610	7
PS	308	299190	617370	7
PS	309	299240	617330	7
PS	310	299760	617150	7
PS	311	299910	617120	7
PS	312	617290	603800	B
PS	313	617290	603800	B
PS	314	617290	603800	B
PS	315	617290	603800	B
PS	316	617020	604120	B
PS	317	617020	604120	B
PS	318	616980	604100	B
PS	319	616930	604000	B
PS	320	616890	603940	B
PS	321	616640	603360	B
PS	322	616700	603180	B
PS	323	616530	601160	B
PS	324	616530	601160	B
PS	325	616540	600940	B
PS	326	616540	600940	B
PS	327	616540	600940	B
PS	328	616540	600940	B

Project code	Site no.	Easting	Northing	Target area
PS	329	617130	599400	B
PS	330	616530	599400	B
PS	331	266710	564890	A
PS	332	266710	564890	A
PS	333	266680	564890	A
PS	334	266680	564890	A
PS	335	323360	634670	C
PS	336	323050	632320	C
PS	337	323010	632350	C
PS	338	322770	631950	C
PS	339	322570	632610	C
PS	340	322570	632610	C
PS	341	322570	632610	C
PS	342	322570	632610	C
PS	345	315920	602665	B
PS	346	315920	602665	B
PS	347	313980	600580	B
PS	348	313980	600580	B
PS	349	314340	601180	B
PS	350	314345	601185	B
PS	351	314320	599160	B
PS	352	314320	599140	B
PS	353	314580	599200	B
PS	354	313790	599440	B
PS	355	308960	611040	B
PS	356	313600	599640	B
PS	357	313320	600680	B
PS	358	313295	600295	B
PS	359	313290	600305	B
PS	360	313220	600170	B
PS	361	313280	600250	B
PS	362	313290	600310	B
PS	363	313285	600315	B
PS	367	356480	661820	12
PS	368	356480	661820	12
PS	369	323380	634650	C