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Magnetic and geochemical surveys in the area between Geltsdale, Cumbria, and Glendue Fell, Northumberland

A D Evans, P D Roberts and J H Bateson

BRITISH GEOLOGICAL SURVEY

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SUMMARY

A magnetic survey has been carried out in the north-west corner of the Alston Block, to investigate in detail aeromagnetic features thought to indicate previously unrecorded structures in the Whin Sill dolerite intrusion. This was followed by a geochemical survey to assess whether the causative structures might be mineralised. The magnetic survey, carried out over the Geltsdale-Glendue Fell area, revealed anomalies en-echelon along the line of the aeromagnetic feature. These may represent part of a major NE-SW structural feature extending to the NE across Northumberland. The magnetic data indicate that the Whin Sill may be more extensive than suggested on the geological map, and additional evidence for this is provided by the geochemical data from the Thinhope Burn and Glendue Burn catchments immediately west of the River South Tyne. Stream and soil sampling, undertaken as part of the geochemical survey, provide data which confirm base metal mineralisation in the area

INTRODUCTION

The North Pennine Orefield has been extensively explored but the mineral potential of the area north-west of Alston on the Northumberland-Cumbria border, (Fig. 1) has not previously been examined. Following work carried out as part of the Mineral Reconnaissance Programme (Bateson and others, 1983) in the Settlingstones area (to the north of Haydon Bridge), further geophysical and geochemical investigations were undertaken north-west of Alston, on the basis of a possible structural link between the areas.

The mineralisation of the Alston Block is commonly best developed where faults displace the Whin Sill dolerite intrusion. Such displacements may be detected by magnetic surveys because of the Sill's strong remanent magnetisation (Evans and Cornwell, 1981), as the Sill is otherwise generally concordant with the flat-lying host sediments. Where the Sill crops out as a north or south-facing edge, strong magnetic anomalies are seen, as for example in the Roman Wall district of south Northumberland, and further south in Lunedale. Faults which displace the Sill and which trend within approximately 45 deg. of E-W are likewise evidenced by distinctive anomalies. The value of the magnetic method for exploration allied to follow-up drilling has been demonstrated (Cornwall and Evans, 1986) in areas of Northumberland north of the Stublick Faults. One such area was the small Haydon Bridge Mining Field (Dunham 1948) where the Sill occurs at shallow depth.

The area described in this report is part of an extensive tract of moorland on the Northumberland/Cumbria border, bounded by the South Tyne River to the east, the Stublick Faults to the north, the Pennine Fault to the west and the Alston-Penrith road to the south (Figs. 1, 3). The survey area lies entirely on the Brampton 1:50,000 geological map (Sheet No. 18). The geophysical surveys described here cover a rectangular block, extending 8km from Geltsdale to the River South Tyne (Fig. 6); the geochemical survey covers principally the Thinhope Burn catchment, draining east into the River South Tyne, amounting to approximately two-thirds of the geophysical survey area.

The aeromagnetic contour pattern in the area (Fig. 2) indicates a weak 'trough' trending WSW immediately south of the positive closure centred at [NY 690 585]. The closure itself is related to displacement or other disturbance of the Whin Sill at the Stublick Faults, and is part of a positive anomaly which is seen over a 20km length of the faults in the Haltwhistle area. The 'trough' is evident only to the east of the River South Tyne, but further to the south-west the contours clearly define a locally significant magnetic gradient extending over 5 km, aligned with the 'trough'. These contours then turn north to run approximately along the 360 km grid easting, marking the western extent of the Whin Sill as known from exposures on the Pennine escarpment. The gradient feature is sufficiently well-defined to provide a target for ground survey, and is of interest for several reasons. Firstly there is no structure indicated on this trend from the geological mapping in the area. Secondly, some minor mineral shows occur close to the line of the feature. Thirdly, because of its alignment with the weak 'trough' noted above, the feature may represent a branch of the Stublick Faults. Fourthly and perhaps most significantly, the WSW trend of the feature matches the trend of the major mineral veins of the Haydon Bridge Mining Field (some 30 km to the ENE), which are also associated with distinct magnetic anomalies (Evans and Cornwell, 1981).

The surveyed area is north of 'The Escarpment' section of the North Pennine Orefield described by Dunham (1948) and has never been important in terms of mineral extraction, except for coal. The only reference in Dunham (1948) to ore mineral workings in this part of the Alston Block is that covering Raven Beck (Fig. 3) where barytes is recorded in a vein cutting the Whin Sill and this area would certainly fall in the 'barytes' zone of Dunham (1948). Also some mineral occurrences are noted in the memoir for the Brampton sheet (Trotter and Hollingworth, 1932) namely :

Baryte	: vein in stream section at	[NY 612 529]
Baryte	: in shaft tip material at	[NY 655 496]
Copper ore	: worked from Great Limestone at	[NY 641 503]
Copper ore	: traces on line of fault at	[NY 645 493]

The geological map to the south (sheet 24, Penrith) indicates the presence of barytes and iron minerals in veins (e.g. Haresceugh Fell), which seem to relate to faults trending either east of north, or north-west. Traces of workings for limonite and baryte which run in similar directions are found to the south-east, along Gilderdale Burn and its environs. Smith (1923) refers to lead workings at Barhaugh, south-east of Slaggyford, on the east side of the R. South Tyne, and to minor ochre workings in the same general area.

There were major mineral workings to the south of the area on Rotherhope Fell and Blackburn Bank near Leadgates (Dunham, 1948), where extensive north-east trending fractures were exploited for quartz, lead, iron ores and fluorite. To the south-east of Alston were the major lead and fluorite mines in the Nenthead valley, and some mineral working is recorded in the Whitfield Moor area immediately to the east of the area under study.

LandSat data are of interest in considering the mineral potential of the area, and Figure 4 is reproduced from Bateson and others (1983). It is interesting to note that a major lineament extending south-west from the coast south of the Farne Islands passes through the Haydon Bridge Mining Field, and appears to persist beyond the Stublick Faults as far as the Pennine Fault. This lends support to the geophysical evidence reported here of NE-SW structures in the north-west corner of the Alston Block. It is worth noting that a number of minor mineral occurrences (Smith, 1923) lie along this major lineament through Northumberland (Figure 4).

Topographically the area is typical of the empty, open moorland of the North Pennines, and is the northernmost high ground on the Pennine watershed. Average elevation is about 400m with peaks over 600m, and the R. South Tyne marks the local base height at about 200m AOD. The eastern side of the watershed is drained by several streams flowing roughly W-E with tributaries draining N-S or NW-SE and SW-SE.

GEOLOGY

This part of northern England is underlain by Dinantian and Namurian sediments, with Westphalian strata (Coal Measures) cropping out just to the north of the area investigated (Figs. 3, 5). The area is structurally part of the Alston Block (Fig. 1), lying south of the Stublick Faults, and east of the Pennine Fault. The Pennine Fault forms a major boundary with Permo-Trias sediments to the west, while Westphalian rocks are faulted down north of the Stublick Faults.

The Carboniferous succession is represented by the Namurian (Upper Limestone) and Dinantian (Middle Limestone) Groups composed of shales, sandstones and limestones with occasional thin coals (Yoredale facies). The Middle Limestone Group, which forms the lower part of the sequence, contains several thick limestones and is present on the western margin and in the south-east of the area (Fig. 3). The rest of the area contains Upper Limestone Group sediments dominated by sandstones and shales, with subordinate limestones and coals. All the rocks are sub-horizontal with low dips to the north and east. The limestones and the more resistant sandstones (e.g. Firestone Sill, Thornbrough Grit) form impersistent bench features along the valley sides and caps to some of the hills (Fig. 10). Within the area of detailed study, outcrops in the Thinhope and Glendue Burns contain grey and blue-grey limestones, occasionally with posts up to 1m but more often showing bedding. The sandstones vary from light-coloured clean ganisters to variably iron-stained medium-coarse micaceous types, which may locally form massive beds up to 10m thick, (e.g. Glendue Burn) and elsewhere as thin partings in the softer shales and mudstones. The less competent rocks comprise light grey to black fissile shales and more massive mudstones, which in places show signs of slumping adjacent to stream side outcrops. The overlying sandstones also commonly slip over the softer rocks along the stream margins.

In addition to the sediments, the area contains several outcrops of the Whin Sill dolerite, which appears as lenticular bodies shown by detailed mapping to lie at several horizons in the Namurian sequence, although stratigraphic transgressions are not obvious at outcrop (Fig. 3). The sill does not form any major physical features other than as benches and steps in stream valleys. The outcrop in the Thinhope Burn catchment, within the area of detailed study, is bounded at the western margin by the Faugh Cleugh fault. The grey, fine grained dolerite can be seen in Faugh Cleugh, forming the bed of the stream down almost to the confluence with Thinhope Burn (Fig. 10). To the south-west, Hazely Crags are formed of very weathered Whin Sill, and further west the sill persists north of Thinhope Burn in outcrops in the south flowing tributaries, apparently petering out about 500m east of Faugh Cleugh. The upper margin is overlain by a limestone (Little Limestone), baked only for a few centimetres, along the whole length of the outcrop. It is worth noting that no Whin has been identified on the south side of Thinhope Burn where the same stratigraphy occurs.

Several major and minor faults (Fig. 3) traverse the area, but large throws are not common and the area is not heavily disturbed. The Stublick Faults at the northern boundary are exceptional with a throw of over 200 m, downfaulting the Coal Measures against the Namurian. The other large faults show two main trends: N-S illustrated by the Tarnmonath Fell fault and the South Tyne fault; and a NW-SE direction shown by the Michaelly Sike and

Faugh Cleugh faults. Within the area of detailed study the last-named cuts across the western part of the Thinhope Burn drainage controlling the stream direction of Faugh Cleugh. Two other minor faults are marked on the 1:50k geological map trending SSW-NNE. One crosses the Thinhope Burn to the east of the Faugh Cleugh fault, with a smaller SW-NE trending fault further east (Fig. 10).

Extensive glacial deposits of boulder clay with some sands and gravels overlie the bedrock, possibly representing Devensian stage glaciation. The glacial material is of very variable thickness and is partly local and partly derived from the Southern Uplands of Scotland and the Lake District. Most of the larger stream valleys have an obvious drape of boulder clay close to the valley bottom, forming a step feature and cliffs of up to 15m. The remainder of the hillsides are heather covered or rough grassland with little or thin peat, except in flatter and poorly drained areas, mostly on the crests of hills, where the peat thickness can exceed 1.5m. As a result of the glacial and recent cover, outcrop is intermittent and mainly limited to the valleys.

GEOPHYSICS

Field survey

In order to provide a thorough reconnaissance of the large survey area as rapidly as possible, the magnetic method only was used. Little advantage was seen in supplementing this with (for example) VLF-EM measurements, because there was no evidence of faulting or mineralisation at surface related to the aeromagnetic feature. Interest was centred on the Whin Sill, concealed at depth beneath the high ground across the watershed.

The survey was carried out between 23 July and 8 August 1984. A grid of traverses was measured, to cover the length of the western part of the aeromagnetic feature, with additional traverses covering the area eastwards to the River South Tyne. Though there is no indication from the aeromagnetic data of a link between the two parts of the anomalous feature, ground measurements would be much more likely to detect any weak continuity between the respective parts.

Twenty-two NW-SE traverses totalling 54km, and four NE-SW traverses totalling 10km were measured (Fig. 6 and Fig. 7). In the western part of the area the traverses are of uniform length; further east, the traverse length was limited to trace the principal features, so that full strike-length coverage could be achieved within the survey time available.

Traverses on the grid were generally 400m apart, with observations at 25m intervals. Diurnal variation was measured by periodic observation of a base station during each survey day. However, for logistical reasons it was not always possible to maintain regular observations. Therefore for data reduction, variation calculated from the published hourly mean values of the vertical field recorded at Eskdalemuir were used (British Geological Survey, 1985). There is good consistency between these calculated values and the observed (field) values.

The magnetic data are of good quality. The survey area is almost entirely free of man-made anomaly sources (fences, water pipes); all the magnetic features observed are therefore of geological origin. The instrumental noise level is low (of the order of +/-2nT) and allows even weak magnetic features to be traced from traverse to traverse.

Several of the traverses cross areas of exposed Whin Sill dolerite (Fig. 6 and Fig. 7), and these give rise to very strong short-wavelength anomalies which often cannot be readily traced to adjacent traverses. Contouring the data satisfactorily is thus not possible. The features observed on the individual traverses are described below.

Magnetic profiles: Details

The magnetic profiles are illustrated in Figures 9a, 9b and 9c. Note the overlap provided between Figures 9a and 9b to facilitate tracing the features described below. The profiles are described from west to east across the area.

800W, 400W, 0W: The only feature of note is a negative anomaly which occurs at 375mN, 250mN and 175mN respectively on the three traverses. On traverse 800W this lies close to a faulted outcrop of the Whin Sill. To the east, there is increasing cover above the Sill because of the rising topography, which accounts for the increase in wavelength of the anomaly in that direction. A feature with an ENE strike direction is indicated, and its position is identified on Figure 8 as AA.

400E: There are no significant features on this profile, although the local minimum from 50mN to 50mS may represent a weak extension of the feature AA noted above.

600E: See description for 800E.

800E: North of 400mS on this profile, large amplitude anomalies occur, with a maximum amplitude of approximately 600nT. Trotter and Hollingworth (1932) describe a scree of Whin (dolerite) on the southern slopes of Cold Fell, and its mapped location places it very close to the northernmost 300m of traverse 800E. The magnetic data clearly show that the dolerite here is rather more extensive, and that the scree represents a significant sub-crop. An approximately symmetrical negative anomaly of 150nT amplitude occurs at 1075mN. Additional traverses 600E and 1000E were measured to test the extent of this feature. On 600E the negative anomaly (at 975mN) is linked to a strong positive anomaly related to the Whin Sill outcrop noted above. As the negative anomaly weakens to the east, it seems likely that it marks the southern edge of this limited intrusion, concealed beneath rising topography. This feature is identified as BB on Figure 8.

1000E: See description for 800E.

1200E: North of 400mS there is a lower amplitude continuation of the strongly anomalous features on the northern part of traverse 800E, and at 1075mN the weakening feature BB is seen. This traverse is located approximately on the watershed, and traverses east of here are on progressively lower ground towards the South Tyne River.
Also on this traverse is the westernmost evidence of an anomaly which appears to be the surface expression of the aeromagnetic feature. It is an asymmetric low, with a minimum at 2100mS. It is of interest that there is no evidence of this feature on traverse 800E.

1600E, 2000E, 2400E: The feature noted above on the southern part of traverse 1200E persists (and is the only feature of note) on these three traverses. It varies slightly in form, but the strongest gradient occurs in each case at approximately 1900mS. This gradient feature is identified as CC in Figure 8. The wavelength of the anomaly suggests that the causative feature in the Whin Sill is at a depth of about 200m beneath traverse 1200E, reducing to about 150m beneath traverse 2400E.

2800E: The profile for this traverse shows no resemblance to those for the adjacent traverses to the east and west. There is no reason to doubt the data (for example, because of an instrumental fault during survey), and this traverse is therefore considered to lie approximately along the axis of a narrow, elongate magnetic low. This is confirmed by data from the NE-SW traverses (see below). This feature is identified as DD in Figure 8. The steeper magnetic gradient between 1800mS and 2100mS may represent a continuation of the feature CC (profiles 1200E-2400E).

3200E: This profile repeats the pattern of the profiles from 1600E to 2400E, with undisturbed data to the north of 1700mN. The strong short-wavelength anomalies south thereof are due to the outcropping Whin Sill in Mardy's Cleugh and in Faugh Cleugh.

3600E, 4000E: These profiles are very similar, with the only feature of interest being a strong negative anomaly of approximately 250nT, occurring at 2250mN and 2175mN on the two traverses respectively. The southernmost negative anomaly on traverse 3200E (at 2375mN) appears to be a westward continuation of this anomaly. The anomaly is identified as feature EE in Figure 8, and is clearly due to the outcropping Whin Sill on the north side of the Thinhope Burn.

4400E, 4800E, 5200E: The only feature of interest on these profiles is an approximately symmetrical negative anomaly, of maximum amplitude at 2300mN, 2275mN and 2350mN on the three traverses respectively, and identified as feature FF in Figure 8. On traverses 4800E and 5200E the anomaly has a rather long wavelength, suggesting a source at a depth of perhaps 200m. On traverse 4400E there is a strong (500nT) short-wavelength anomaly (probably an eastward continuation of feature EE), but the positive shoulders to this anomaly suggest that it is superimposed on a longer wavelength feature.

5800E, 6400E: These two profiles show a broad negative anomaly of approximately 50nT amplitude, centred at approximately 1700mN on both traverses. There are no other features of interest on either profile.

Traverses Y and Z: There are a number of minor features of interest on both traverses, but of particular significance are the minima which occur at 2050mS and 1200mS on the two traverses respectively. These minima align with those noted above on traverses 5800E and 6400E, indicating a causative feature (identified as GG in Figure 8) extending over approximately 3km, with approximately the same strike direction as features CC, EE and FF described above.

Base Line: There are three principal features of interest on this 8km traverse. At 2400mW a combined positive and negative anomaly, with total amplitude of 350nT, marks the outcrop of the Whin Sill on the Pennine escarpment. At approximately 700mE a negative anomaly (approximately 350nT) marks the position of the edge of a small dolerite intrusion, evident as a scree on the slopes of Cold Fell, and described for traverse 800E above. At 2600mE, a negative anomaly of approximately 200nT amplitude marks the point at which feature DD crosses the Base Line (see description for traverse 2800E above).

TL1: The profile for this NE-SW traverse confirms the termination of feature CC between traverses 1200E and 800E.

TL2: The profile for this traverse shows the strongest anomaly recorded within the survey area, with a change in total field of over 1000nT between 2900mE and 2950mE. Traverse 2800E is aligned approximately along the negative component of this anomaly. The anomaly is due to the local exposure of the Whin Sill being terminated against the Faugh Cleugh Fault.

TL3: The absence of any feature of interest on this profile clearly shows that feature DD is abruptly terminated approximately where it meets feature CC.

Discussion.

The geophysical survey identified seven distinct linear magnetic features, across the Eden-Tyne watershed between the South Tyne River and the Pennine escarpment. These are indicated on Figure 8. One of these is accounted for by a mapped geological feature (the Faugh Cleugh Fault); the remainder are ascribed to unrecognised structural features affecting the Whin Sill.

Four of the magnetic features lie en-echelon along the trend of the aeromagnetic feature which provided the original stimulus for the survey. Feature CC is considered to be the ground expression of the locally strong aeromagnetic gradient. The pattern of the four en echelon features supports the view that a significant structural axis persists through the area, perhaps related to the Stublick Fault system. This view is supported by data collected by a Durham University survey to the east of the South Tyne River (Smith, 1962). These data show a weak magnetic low (feature HH, Figure 8) running into the much stronger anomaly along the Stublick Faults, whilst further to the north-east, the magnetic anomaly associated with the Stublick Faults is clearly shown to be locally displaced to a north- easterly trend (feature JJ, Fig. 8). Feature HH is aligned with the easternmost feature (GG) identified by the present survey, and the evidence for the orientation of feature JJ is supported by data from a detailed low-level aeromagnetic survey (Evans and Cornwell, 1981) which includes this locality at its south-west corner.

The apparent interaction between NE-SW features and the Stublick Faults suggests that these structural features may be the southwestern extension of a major NE-SW axis extending across Northumberland, and along which the mineral veins of the Haydon Bridge Mining Field are located. There is therefore, a basis for mineral potential in the area spanning the Eden-Tyne watershed.

The absence of any mapped NE-SW faults through the survey area, probably due to poor surface exposure, does not detract from the geophysical evidence. Figure 3 shows that faulting with this trend is present to the south. However, as noted by Trotter and Hollingworth (1932), in this north-west corner of the Alston Block even quite minor structural features have controlled the emplacement of the Sill, but these may still cause significant magnetic anomalies.

Interpretation of the magnetic anomalies in terms of the disposition of the Whin Sill is difficult, as the Sill hereabouts is apparently developed as a series of laccolithic intrusions. Trotter and Hollingworth (1928) present a relatively simplistic map of the position of these intrusions with respect to the position of the Tyne Bottom Limestone; the evidence from the present survey suggests that the pattern of the intrusion is more complex than this.

Of the magnetic features identified in Figure 8, AA and BB are isolated and probably due to fairly minor features; they are nevertheless significant in that their trends reflect those of the other more important anomalies. Feature CC is of interest, as the lower background values to the south of this feature suggest that the Whin Sill there is locally absent, or much thinner. The aeromagnetic data support this view. If this is the case then a controlling structure may be present, though such a structure need not necessarily be a major fault. It is of interest that this feature terminates approximately at the northern limit of the Michaelly Sike Fault (Fig. 3).

Anomaly DD is due to the effect on the Whin Sill of the Faugh Cleugh Fault. This is a negative anomaly, and the Whin Sill is therefore considered to be downfaulted to the south-west along the fault, although an equivalent change in level (i.e. transgression) would produce the same magnetic effect at surface. There is no indication of this anomaly from the aeromagnetic data, perhaps due to the flight line spacing being too large; the anomaly is located between the flight lines which follow (approximately) the 362km and 364km grid eastings. A small exposure of Whin Sill dolerite is reported in the headwaters of the Black Burn immediately east of the northern end of traverse 2400E. This exposure is high in the local sedimentary succession, and it is not clear how it is related to the nearest large exposure (in the Thinhope Burn). The absence of any short wavelength anomalies at the northern end of traverse 2400E, and in this vicinity on the baseline profile, suggests that the Black Burn exposure is probably a very restricted leaf of the Sill, which has perhaps exploited the Faugh Cleugh Fault to reach this level.

Features EE and FF are due to outcropping Whin Sill dolerite and perhaps also a change in the stratigraphic level of the Sill approximately along the line of the Thinhope Burn. It can be argued from the geological mapping that the Whin Sill exposures in the Thinhope Burn were the sole representation of the Sill hereabouts, but the geophysical evidence suggests that the Sill is present both north and south of the Thinhope Burn, between the Faugh Cleugh Fault and the River South Tyne. The Sill as exposed around the Thinhope Burn/Faugh Cleugh confluence is therefore perhaps the southern edge of a more extensive upper leaf of the Sill, with the Sill also present as a continuous intrusion at depth. Alternatively, the Sill has been downfaulted (or transgresses downwards) to the south-east along a fault approximately coincident with the course of the Thinhope Burn, with the present exposure being due to erosion of the upfaulted edge.

Feature GG is the most significant of the magnetic features identified by the present survey, by reason of its extent, location and orientation. The anomalies on the respective profiles vary somewhat in form, but all are negative and of long wavelength. The background values to the north of each anomaly are generally slightly higher than those to the south. The feature is aligned approximately along Small Cleugh, and appears to be a continuation west of the River South Tyne of feature HH (see above), which is likewise a weak 'low'. Trotter and Hollingworth (1928) identify an occurrence of the Whin Sill at Tow's Bank, at the west end of feature HH. But the long wavelength of the anomalies hereabouts suggests that they are due to structures in the Sill at a depth of at least 100m. The Tow's Bank exposure must therefore be of a minor intrusion, and the absence of any short-wavelength anomalies in that vicinity shows that it is of very limited extent. By analogy with results from the Settlingstones area (Bateson and others, 1983) an approximately symmetrical 'low', as seen in feature GG, is indicative of faulting in the Sill with a downthrow to the south. This could represent either a WSW splay from the Stublick Faults, or a separate WSW-trending fault.

GEOCHEMISTRY

Previous work

B.G.S. has carried out a stream sediment survey in the north Pennines as part of the Regional Geochemistry Research Programme (RGRP), including the area described here (not yet published). Investigations as part of the Mineral Reconnaissance Programme were undertaken to the north and east of the Stublick Faults in 1978-79 (Bateson and others, 1983). Data from both programmes were used as the basis for the more detailed investigations, based on stream and soil sampling, described here.

Aims of the survey

The stream sediment and water samples collected as part of the RGRP provided a dataset of some 186 samples covering all the fells north-west of Alston. These had been analysed for over 30 elements, and these data were investigated using standard statistical techniques to determine which, if any, showed anomalous concentrations of elements indicative of mineralisation. These initial studies highlighted the areas of known mineral working, but also revealed a pattern of anomalous lead, zinc, copper and barium anomalies in the Glendue Burn-Thinhope Burn catchments (Figs. 3, 10) where the results of a geophysical survey indicated a line of en-echelon anomalies running NE-SW (Fig. 8)

The geochemical investigations were designed to obtain any evidence of buried mineralisation. The techniques employed were detailed stream sampling (collection of water, panned concentrates and sediments), and soil sampling in areas with poor exposure and in areas crossed by the geophysical anomalies. The catchments of Thinhope Burn and Glendue Burn in particular were sampled intensively by these methods.

Fieldwork

The main survey was carried out in November 1984. A total of 223 soil samples, 33 stream sediment samples and panned concentrates, and 64 stream waters were collected in the course of three weeks.

Streams

The stream sample sites are indicated on Figure 11 and are listed in Table 1. All bar one are from the Glendue Burn and Thinhope Burn catchments, the exception being from a stream draining into Knar Burn, south of Thinhope Burn. The stream courses were sampled where possible for stream sediment, and a panned concentrate obtained from the coarser stream sediment at the same site using standard techniques (Plant 1971). Water samples were taken at sediment sampling sites and also from small watercourses with insufficient sediment to be sampled. The water samples were acidified as soon as possible after collection and the measurement of pH and conductivity.

Soils

The lines along which soil samples were collected are shown on Figure 14. The majority of lines were sited to cross the geophysical anomaly and across the geological succession. They were, therefore, aligned roughly N-S. Line 9 was designed to tie several of these lines together and line 11 to traverse a section of Whin Sill. Line 5 was intended to give background values over the same succession relatively distant from the geophysical anomalies.

Samples were collected at intervals of 25 or 50 metres (see table 5) using a 1" diameter hand auger. Depths of sampling were variable, dependant on the type of cover, but were taken at the greatest depth possible up to a maximum of about 1.5m. Soil types encountered ranged from silt and sandy silt to boulder clay, with peaty areas on hill tops and poorly drained slopes.

Sample analysis

The stream sediment and panned concentrate samples were dried, ground and analysed by the XRF method in BGS laboratories. Analysis for Sb, Ba, Ca, Cr, Co, Cu, Fe, Pb, Mn, Ni, Rb, Sr, Sn, Ti, V, Zn was carried out for the sediments and for Sb, Ba, Ca, Cr, Co, Cu, Fe, Pb, Mn, Mo, Ni, Si, Ag, Sr, Sn, Ti,U, V, Zn, Zr for the panned concentrates. The stream waters were analysed by specific ion electrode for fluoride ion at Keyworth; pH and conductivity were measured at field base. Soil samples were analysed by XRF for Ba, Ca, Co, Cr, Cu, Fe, Pb, Mn, Ni, Rb, Sr, Ti, V, Zn. Values below detection limit are replaced by 0.5 in tables and statistical analysis.

Stream sample results

Stream waters

Summary statistics for pH, conductivity and Fluoride ion concentration are presented below:-

No of samples - 63

ELEMENT	MIN	MAX	MEAN	STANDARD DEVIATION	MEDIAN
pH	4.2	7.0	6.0	0.5	6.1
Conductivity	31	200	58.1	30.9	46
Fluorine	30	73	44	9	42

Conductivity in micromhos.
Fluorine ion concentration in ppb.

Correlation coefficients

F	: pH	-0.11
F	: conductivity	0.53
pH	: conductivity	0.28

Comments

The stream water data cover small drainage channels and streams in addition to those sampled for sediment (Fig. 11). Some of the former are near the headwaters of the stream systems, close to crests of the interfluves. High acidity and conductivity in some samples reflect significant peat deposits in some areas. The most acid samples are from small streams draining north from Knarsdale Forest (502, 605, 600, 601), east and west of Mardy's Cleugh and, showing highest acidity of all (4.2), from the SW flank of Larchet Hill (500) in a poorly drained peaty area. Some tributaries of Glendue Burn show slightly enhanced acidity, notably sample 516 (pH. 5.1) which drains from an area of coniferous forest.

A cumulative percentage plot of the Fluorine values indicates an anomalously high group above 50 ppb. Most of these lie in the Glendue Burn catchment with a cluster on the NW flank of Larchet Hill in Small Cleugh and its tributaries (503, 71 ppb; 509, 53 ppb; 716, 57 ppb) and in a stream to the east (623, 51 ppb). Three other high Fluorine values are found to the west of these, 718 (63 ppb) from a stream draining the N flank of Larchet Hill, 513 (61 ppb) from a small S. flowing tributary immediately to the west and 516 further to the west (56 ppb). The Thinhope Burn catchment contains only three sites with Fluorine values greater than 50 ppb. Two of these are in Running Sike, 615 (56 ppb) and 610 (73 ppb), the latter being the highest value recorded; and further west, a small stream to the east of Small Cleugh (503, 51 ppb). The only remaining value above 50ppb is to be found at the one site sampled in the Knar Burn catchment, Well Burn, site 704 (59 ppb).

The correlation between fluorine and conductivity is not high but is more significant than any other intercorrelations in this set.

Stream sediments

Summary statistics for the stream sediment determinations are presented below:-
No of samples - 33
All values in ppm.

ELEMENT	MIN	MAX	MEAN	STANDARD DEVIATION	MEDIAN
Antimony *1		3			
Barium	120	1370	421.2	256.9	360
Calcium	100	7200	2069.7	1818.2	1700
Chromium	60	110	91.2	10.2	90
Cobalt	2	51	19	11.9	17
Copper	0.5	24	6.5	5.0	5
Iron	9000	61900	38136.4	14108.7	38500
Lead	8	612	96	131.9	46
Manganese	80	7110	1635.2	1662.8	1170
Nickel	7	58	25.5	13.6	23
Rubidium	39	125	74.6	20.3	72
Strontium	34	196	72.5	39.7	63
Tin *2		2			
Titanium	4180	10200	5761.8	970.8	5690
Vanadium	30	160	63	21.9	60
Zinc	13	417	97.4	91.8	72

*1 Only 13 values above detection limit (1 ppm.)
*2 Only 12 values above detection limit (1 ppm.)

Figure 15 illustrates the range, median and mean for each element.

Correlation coefficients (Pearson, untransformed data) were calculated for the entire dataset but few good correlations are present. The highest positive values are tabulated below:

R> +0.7

V	:	Ti	0.93
Co	:	Mn	0.88
V	:	Cu	0.87
Ni	:	Mn	0.78
Cu	:	Ti	0.76
Ni	:	Co	0.75
Ni	:	Zn	0.72
Cu	:	Sr	0.73
Ba	:	Rb	0.72

R > +0.6 < +0.7

Sr	:	V	0.69
Rb	:	Cu	0.69
Sr	:	Ni	0.66
Zn	:	Ca	0.65
Ba	:	Cu	0.65
Zn	:	Mn	0.64
Sr	:	Ca	0.63
Zn	:	Co	0.63
Zn	:	V	0.61

Cumulative percentage distribution plots were prepared for those elements with a reasonable range of concentrations and these used to define the threshold values for anomalous populations (Sinclair, 1976). These are considered below.

Panned concentrates

The summary statistics are presented below:-

No. of samples - 33
All values in ppm.

ELEMENT	MIN	MAX	MEAN	STANDARD DEVIATION	MEDIAN
Antimony *1					
Barium	24	37890	2913.6	7625	125
Calcium	0.5	1200	242.5	282.8	100
Chromium	15	127	46.4	22.6	44
Cobalt	1	15	5.94	3.3	6
Copper	0.5	29	3.6	6.3	0.5
Iron	3600	81600	27367	21693	21900
Lead	3	9979	400.7	1724	11
Manganese	10	1570	374.9	400.3	240
Molybdenum	0.5	3	0.85	0.58	0.5
Nickel	0.5	20	5.6	5.4	3
Silica	290000	440000	408181	32516	420000
Silver	0.5	4	1.13	1.07	0.5
Strontium	11	141	26.8	28.9	19
Tin *2					
Titanium	1040	2860	1856.1	477.4	1850
Uranium	3	9	5.8	1.6	5
Vanadium	7	90	21.8	16.6	16
Zinc	1	692	45.6	119.2	21
Zirconium	198	3041	1118.8	802	954

*1 Only 2 samples above detection limit (1 ppm.)
*2 Only 3 samples above detection limit (1 ppm.)

Figure 16 illustrates the range of values, with mean and median for each element.

Correlations

R > +0.7

Pb	:	Zn	0.99
Ba	:	S	0.97
Ba	:	V	0.90
Sr	:	V	0.88
Ni	:	Co	0.84
U	:	Zr	0.84
Ni	:	V	0.83
Ni	:	Fe	0.80
Co	:	Fe	0.78
Cr	:	Zr	0.75
Cr	:	Ti	0.74
Cu	:	V	0.74
Ba	:	C	0.73

Selected stream water, panned concentrate and sediment intercorrelations

R > +0.6

(S) indicates sediment
(P) indicates panned concentrate

Pb(S)	:	Zn(P)	0.76
Pb(S)	:	Pb(P)	0.75
Ba(S)	:	Ba(P)	0.74
Ba(S)	:	Cu(P)	0.68
Ba(S)	:	Ni(P)	0.64
F	:	Pb(P)	0.63
Rb(S)	:	Ni(P)	0.62
F	:	Zn(P)	0.61

Antimony

The sediment values are all close to the detection limit and give no clear pattern. Only two sites have panned concentrate values above the detection limit. The highest, 46 ppm, is the most southerly site on Running Sike (Thinhope Burn, 610) and the other (7 ppm) from a north flowing tributary of Glendue Burn (718). These results are seen to be significant when taken together with the lead and zinc values at the same sites (see below)

Barium

The sediment values show a distribution close to a normal single population with a range of values roughly comparable to those obtained from the Northumberland Trough (155-1413 ppm; Bateson and others, 1983). Anomalously high values above a threshold of 790 ppm are limited to two sites (600, 605). Of these 605, on Small Cleugh, is the highest at 1370 ppm and site 600 a tributary of Y Cleugh, contained 800 ppm The panned concentrates have a lower range than found in the Northumberland Trough where barytes mineralisation produced values up to 6.5% in pans. The threshold value of 4000 ppm is exceeded at 8 sites (600, 604, 605, 607, 700, 710, 720, 723). Of these, two (604 Mardy's Cleugh and 605 Small Cleugh) are very much higher (24406, 36890 ppm) than the rest. The anomalous sediment and concentrate sites are shown on Figure 12.

Calcium

Two populations can be inferred from a cumulative percentage curve for the stream sediment, eight samples falling into the upper class above 3500 ppm. Three of these (701, 705, 706, 707) are from south flowing tributaries of Thinhope Burn, three are from Glendue Burn (715, 716, 718) catchment with the remaining site being Well Burn (724). This latter has the highest value (7200 ppm). No anomalous population can be defined for the panned concentrates.

Chromium

The sediment data contain no anomalous values, and only a weakly defined group of three anomalous samples (>75 ppm) in the panned concentrates. The highest of these (site 710, 127 ppm) is from a north flowing tributary at the eastern end of the Thinhope Burn catchment. The other site in this catchment is in Faugh Cleugh (700) and the third is found on the eastern flank of Larchet hill (713) from a tributary of Small Cleugh.

Cobalt

Five samples have anomalously high concentrations (greater than 19 ppm; 610, 707, 716, 722, 724). Two of these are from the Thinhope Burn catchment, one (610) on Running Sike and the other (707) on a tributary draining from Glendue Fell. Two sites in the Glendue Burn catchment are from adjacent streams, Small Cleugh (716), and from the stream to the west (722). The fifth site (724) is from the Knar Burn catchment. The panned concentrate values have a threshold at 9 ppm with four sites exceeding this. Three of these are at the western end of the Thinhope Burn catchment, on Mardy's Cleugh (604), Y Cleugh (603) and Faugh Cleugh (700), and the fourth coincident with one of the anomalous sediment sites on Small Cleugh (716)

Copper

The sediment samples have a threshold of 10 ppm. Four sites fall in the high group, three from Thinhope Burn (603, 605, 705) and one from site 724 in the Knar Burn catchment. Comparison with the Northumberland Trough indicates a lower range for this survey (3-41 ppm), which relates to the greater variety of rock types encountered in the larger survey.

The panned concentrate values are low (cf. Northumberland Trough, 3-263 ppm) but four sites with values above 9 ppm are defined as anomalous. Three are coincident with the sediment highs; Mardy's Cleugh (604) and Small Cleugh (605) in the Thinhope Burn catchment, and the Knar Burn site (724). The remaining site (700) is on Faugh Cleugh.

Iron

A cumulative percentage curve for Iron in sediment shows no well defined anomalously high group, but indicates the presence of a separate low population below 20000 ppm, samples from which do not form a coherent group, though most are in the Thinhope Burn catchment. Two of the highest sediment values are from the Glendue Burn catchment, one from Small Cleugh (716, 58800 ppm) and from a north flowing stream to the west (718, 61800 ppm). In addition the Knar Burn site (724, 60400 ppm) is high.

The panned concentrate values show a multi-population distribution, with a poorly defined high group above 40000 ppm and a low population below 9000 ppm. The high values show a concentration of three sites at the western end of the Thinhope Burn on Y Cleugh (603), Mardy's Cleugh (604) and Small Cleugh (605). Further east, site 710 is high, although upstream from this 608 is low. Other sites within the high group are all upland sites in the Glendue Burn catchment (714, 81600 ppm -highest, 715, 716).

Lead

In sediments an anomalous group of values above 150 ppm is defined within the range of 8-612 ppm (cf. Northumberland Trough, range 13-174 ppm). The anomalous samples are from five sites at the eastern end of the Thinhope Burn and one from the Glendue catchment. Two streams provide four of these; Running Sike (615, 160 ppm, 610, 612 ppm - highest) and 400m west a small stream (710, 161 ppm, 608, 399 ppm). The samples between (611, 613) were both below 50 ppm Mill Cleugh, east of Running Sike, provides the fifth site (609, 358 ppm). In the Glendue Burn catchment a north flowing stream sampled close to the main burn (718, 280 ppm) is anomalous, 714 and 715 upstream are both below 50 ppm. The panned concentrate values indicate an anomalously high group (5) above 150 ppm. Four of these are coincident with the sediment highs (610, 615, 710, 718) and one relatively weak high occurs on Proudyhill Sike (723, 219 ppm). The highest value for the panned concentrate (9979 ppm, site 610, Running Sike) coincides with the highest sediment concentration (galena was noted in the pan). Galena was not noted in the Glendue Burn sample (718, 1843 ppm).

Manganese

The sediments contain two anomalously high sites (threshold=3800 ppm) both in the Thinhope Burn catchment (610 and 707). The panned concentrates show a clear anomalously high group above 600 ppm. Of these five samples, four are from the Thinhope Burn catchment (604, 700, 707, 710) and the remaining sample in the Glendue catchment (720).

Molybdenum

Determinations were only undertaken on the panned concentrates, most of which are close to the detection limit. Three sites show a level of 2 ppm (709, 714, 720) and one, three ppm (607).

Nickel

A threshold value of 50 ppm was determined for sediments and three samples contain greater than this, two from Thinhope Burn (610, 707) and the Well Burn sample (724). The panned concentrate distribution shows an anomalous group of 11 samples above 6 ppm obtained from two geographical areas. The first of these (714, 715, 716) within the Glendue Burn catchment are from relatively long tributaries and relatively elevated sites (between 1000ft and 1200 ft.). The second area is within the western part of the Thinhope Burn drainage. Here samples from lower Y Cleugh (603), Small Cleugh (605), Mardy's Cleugh (604), lower Faugh Cleugh (700) and a tributary west of Mardy's Cleugh (600) cluster together, and two sites to the east are also anomalous (607, 707). The Well Burn site (724), in the Knar Burn drainage also lies in this group.

Rubidium

Only the sediments were analysed and four sites with greater than 100 ppm are defined as anomalous. These are widely scattered, and provide no pattern.

Silica

This was analysed in the panned samples only and no significant trends can be discerned from the cumulative percentage distribution.

Strontium

Three sites yield sediment concentrations above 150 ppm. Two of these high values are from the Thinhope Burn catchment (705, 707), both from south flowing streams. The third site is from Well Burn (724). The panned concentrate values contain two anomalously high values (threshold=50 ppm). These are both to be found at the western end of the Thinhope Burn catchment, from north flowing tributaries adjacent to each other - Mardy's Cleugh (604) and Small Cleugh (605).

Tin

All values in both sediment and panned concentrates are close to the detection limit and no pattern is evident.

Titanium

The distribution in sediments is log-normal with a threshold of 6300 ppm. Five sites exceed this value of which 603, 605, 700 and 705 are at the western end of the Thinhope Burn catchment, and site 723 on Proudyhill Sike to the NW. The panned concentrates population shows an obvious break at 2300 ppm with 7 sites above this. Two of these are coincident with the sediment highs (605, 705), two others are in the Thinhope Burn catchment (704, 710) and three in the Glendue Burn catchment, on and north of Small Cleugh (716, 720, 722).

Uranium

Analysis was carried out for the panned concentrates only but values close to the detection limit were obtained for all the sites.

Vanadium

The sediment distribution is log-normal with only one significantly high value (threshold=100 ppm) from a site in the Thinhope Burn catchment (705), a very short south flowing tributary. The panned concentrate threshold is well defined at 30 ppm and four sites have concentrations greater than this. All are from the western end of the Thinhope Burn catchment and form a tight geographical group (603, 604, 605, 700) - Small Cleugh, Y Cleugh, Mardy's Cleugh, Faugh Cleugh.

Zinc

Four sites have anomalously high values (threshold=190 ppm) in stream sediment, the range being comparable with that determined in the Northumberland trough (31-589 ppm). Two from the Thinhope Burn catchment (610, 288 ppm, 705, 417 ppm) are on Running Sike and a short south flowing tributary 500m west; and two from the Glendue catchment, though both of these are on the same long tributary (715, 198 ppm, 718, 213 ppm). Three sites are anomalous in the panned concentrates (threshold=60 ppm), two of which (610, 692 ppm, 718, 142 ppm) are coincident with the sediment highs. The third site (615, 67 ppm) is the lower sample from Running Sike and is obviously related to 610.

Zirconium

Only the panned concentrates were analysed and the cumulative percentage curve indicates a complex population with an anomalously high group (5) with more than 2000 ppm. Four of these are in the Glendue Burn catchment (713, 716, 720, 722), all on relatively extended tributaries e.g. Small Cleugh draining from areas in excess of 1000 ft. O.D. The remaining site is from a north-flowing short tributary of Thinhope Burn (710).

Discussion

The stream sampling data provide clear evidence of lead/zinc mineralisation indicated by high values in samples taken from the SE part of Thinhope Burn and high values from the Glendue catchment. The map (Fig. 12) shows the geographic relationships between Pb, Zn, Ba and F anomalies. Two samples from Running Sike (610, 615), the more southerly of which contained the highest lead panned concentrate value, have multiple lead, zinc and fluorine anomalies together with one (of two) antimony values above detection limit. The position of the upper site on Running Sike (610) suggests mineralisation higher in the succession than the Little Limestone (Fig. 10), the sample downstream (615) probably representing the dispersion train. Weaker lead anomalies in other streams to the west (608, 710) and east (609) indicate a possible lateral extension of a mineralised zone over several hundred metres. In Glendue Burn a south flowing tributary contains similar anomalies (718) and galena was noted in the pan. Samples taken further upslope (714, 715) do not show enhanced levels of lead or zinc indicating that any mineralisation must lie either below or possibly to the west. This area lies higher in the succession than the Thinhope catchment and any mineralisation would outcrop below the Thornbrough Limestone, which is mapped as cropping at about the 1400 ft. contour. In addition a weakly enhanced concentrate value (site 723) was found on Proudyhill Sike to the east. Study of the RGRP stream sediment data shows weak lead anomalies from tributaries on the north side of Thinhope Burn, but the survey for the present report produced low values for both the sediment and concentrates from the nearest sites (705, 707). The RGRP data also suggests a weak lead anomaly in the Glendue catchment from a site 100m below site 716, but this could not be confirmed.

The stream data show the value of fluorine in water measurements in this part of England. The anomalous values highlight streams with high base metal content; the correlation coefficient reflects this relationship (R=0.63, F:Pb(pan)). The highest fluorine value (73 ppb) is coincident with the highest lead pan value at site 610, and the fluorine value NE of Larchet Hill (71 ppb) at site 505 (where no sediment or concentrate was collected) may well be an indication of further mineralisation, perhaps supporting the RGRP data taken downstream at 716 (see above).

Some evidence of barium mineralisation is provided by the pan concentrate anomalies in the western part of Thinhope Burn (see Fig. 12), especially sites from Mardy's Cleugh (604) and Small Cleugh (605) where barium pan anomalies are accompanied by strontium. Most other elements fall within expected ranges for lower Carboniferous sediments, but the titanium values in both panned concentrates and sediments are high from a number of sites and are taken to indicate of the presence of Whin Sill. Higher values occur in both sediments and concentrates in those streams intercepting known Whin outcrop e.g. Faugh Cleugh (700) and to the east 705, 706, 707, (see Figs. 11, 13) but the anomalous sediment values in Y Cleugh (603), Small Cleugh (605) to the west and south in the Thinhope catchment, and from Proudyhill Sike (723) to the north-east indicate the presence of Whin, either as outcrop or as boulder concentrations in the drift. The presence of anomalous vanadium concentrate values in 603, 604, 605 and the high correlation in sediments between vanadium and titanium (R=0.93) provides more evidence for the presence of Whin, although the vanadium in sediment values should be treated with caution since the concentrations are low. The high Ti values in concentrates 704 and 705 reflect proximity to the outcrop of Whin Sill and it is possible that similar 'highs' (610, 715, 718) may also indicate the presence of Whin. These latter sites also contain high Zr values possibly derived from drift. Other metals are high in panned concentrate in the western part of the Thinhope catchment e.g. Co (603, 604, 700), Ni (600, 603, 604, 700, 607, 707), Cu (604, 605, 700) and may also reflect the proximity of the Whin Sill. Stream sediment values on the whole echo the concentrates and there is little evidence of significant secondary concentration and scavenging effects often associated with high iron and manganese values, although cobalt and nickel show strong correlation with manganese (Co:Mn 0.88, Ni:Mn 0.78). The high correlations of vanadium with copper should be treated with caution since vanadium has low variability.

Soil sample results

Summary statistics for the soil samples are shown below:

No of samples - 203
All values in ppm

ELEMENT	MIN	MAX	MEAN	STANDARD DEVIATION	MEDIAN
Barium	40	820	310.7	121.6	290
Calcium	0.5	4400	567.5	700.3	300
Chromium	60	200	108.5	15.7	110
Cobalt	0.5	74	9.2	8.1	8
Copper	0.5	33	8.4	6.2	7
Iron	3200	135400	38346.4	18671.9	40900
Lead	10	362	39.2	43.0	28
Manganese	40	6630	388.9	676.3	190
Nickel	0.5	49	20.2	10.3	19
Rubidium	12	160	95.6	25.4	96
Strontium	28	321	79.2	35.4	68
Titanium	5240	24590	7270.5	1392	7120
Vanadium	10	150	75.4	17.1	80
Zinc	6	250	35.7	28.8	32

The distribution of element concentrations was examined by plotting cumulative percentage curves of the log-transformed values where possible; threshold values defining anomalously high samples were defined from these. The range, median and mean values for all the elements are illustrated on Figure 17.

Correlations
(Pearson, untransformed data)

R > +0.55

Co	:	Mn	0.80
Rb	:	V	0.72
Rb	:	Ba	0.67
Cr	:	V	0.66
Ba	:	Ni	0.63
Ni	:	V	0.59
Pb	:	Zn	0.59
Cu	:	Ni	0.58
Rb	:	Cu	0.57
Co	:	Ni	0.55
Cu	:	V	0.55

Barium

The range of values obtained here compares with the range (min=80 ppm, max=1760 ppm, median= 215 ppm) obtained from those in the Settlingstones area (Bateson and others, 1983) where though the maximum is higher the median is only slightly lower, indicating a similar background distribution for the soils in both areas. The threshold value of 590 ppm derived in this survey defines five sites. All but one of these lie in the Thinhope catchment (*2*, 1099; *13*, 1288; *14*, 1300, 1314 (italic figures are line numbers)) and lie on the central and eastern lines (see Fig. 14). The remaining site is found on the western of the two Glendue lines (*7*, 1351).

Calcium

Six sites lie above the threshold of 3000 ppm. Of these, five occur on the northern slope of Thinhope Burn (*8*, 1143; *10*, 1207; *12*, 1259; *13*, 1287; *14*, 1300). Values just below the 3000 ppm threshold are associated with most of these, often forming a run of several sites. The remaining anomalous site is from line 7, 1351, above Glendue Burn at the same site as the barium high.

Chromium

The distribution of values indicates a normal population with only two sites with anomalous concentrations (over 150 ppm). Both of these lie on the north side of Thinhope Burn (*2*, 1114; *8*, 1148)

Copper

Values for copper are low, and are similar to those obtained in the Ewesley area 55km to the north-east (Bateson and others, 1985, over a similar succession of Upper Limestone sediments. The threshold for copper of 20 ppm identifies a group of eight samples. Three of these lie on the line east of Mardy's Cleugh, which crosses the Faugh Cleugh fault (*12*, 1260, 1261, 1264). Two others lie on lines north of Thinhope Burn (*8*, 1280; *2*, 1099). The remaining sites lie on line 7, above Glendue Burn (*7*, 1354, 1358, 1360).

Iron

The analytical results define several populations, reflecting major changes in soil type. A small number of samples (11) have concentrations greater than 60000 ppm. Six of these are scattered along the Thinhope Burn lines (*2*, 1097; *8*, 1144; *11*, 1230; *12*, 1261; *13*, 1271; *14*, 1308). The remainder fall on lines NW of Larchet Hill; two from line 7, (1354, 1360) and three contiguous sites on line 6, (1372-5).

Lead

Values obtained during this survey include a higher maximum than at Settlingstones (min=25 ppm, max=150 ppm) but the median value of 35 ppm compared with 28 ppm obtained here indicates a similar distribution of soil concentrations. Most samples fall into one log-normal population, but the cumulative percentage curve indicates a second higher population, with values greater than 50 ppm, and a threshold of 90 ppm defines eleven sites. The latter all lie in the Thinhope catchment, several being clustered together on and around line 8 (Fig. 14). Proceeding round the catchment in an anti-clockwise direction the sites are as follows (*1*, 1044; *14*, 1300; *8*, 1136, 1137, 1139; *9*, 1172, 1174; *13*, 1275; *11*, 1230; *12*, 1264; *15*, 1339).

Manganese

A threshold value of 1000 ppm, slightly higher than the 'average' value for soils (Levinson, 1974) identifies fifteen samples. Seven of these are on lines NW of Larchet Hill (*7*, 1345, 1347, 1354, 1360; ***6***, 1370, 1372, 1374). The remainder are scattered through the Thinhope lines (*2*, 1094; ***8***, 1143; ***10***, 1215, 1220; ***13***, 1287, 1288; ***11***, 1230; ***5***, 1325).

Nickel

The mean is close to crustal average for temperate soils (25 ppm, Levinson 1974). Five sites contain values over the threshold of 41 ppm. Two of these lie between Mardy's Cleugh and Small Cleugh in the Thinhope catchment (***12***, 1261, 1263), the remainder NW of Larchet Hill (*7*, 1354, 1360; ***6***, 1373).

Rubidium

Two populations are well defined from the cumulative percentage curve; a low population with less than 50 ppm and the rest of the samples which form a log normal population. No anomalously high samples are evident.

Strontium

This element also shows two major populations with the break between them at about 100 ppm. Above a threshold of 170 ppm are five samples, all of which lie on the north side of Thinhope Burn. Adjoining sites have slightly elevated values, e.g. line 1, 1041 (173 ppm) has seven sites to the north over 100 ppm (1042–8). Similarly line 9, 1174 (175 ppm) with three sites southwards (1170–3) over 120 ppm and line 10, 1207 has high values on both sides. Of the remaining sites (***13***, 1289; ***14***, 1300, 1312) only 1300 has a group of higher values associated.

Titanium

The mean of 7270.5 ppm is significantly higher than the crustal average for soils of 5000 ppm (Levinson, 1974). A threshold value of 8500 ppm defines ten samples. In contrast to the previous element (Sr) most of the high values lie further upslope north and west of Thinhope Burn. Three lie on line 2 (1102, 1113, 1114), with sites either side of the latter above 8000 ppm Slightly lower down slope is one site on line 1 (1051) and three on line 8 (1126, 1139, 1148). To the west of these and upslope lies 1282 on line 13, and further to the west on Hazely Crags are the remaining two (***11***, 1240, 1241).

Vanadium

Lack of analytical precision makes the vanadium data statistically imprecise, although the mean is close to that of 80 ppm quoted for soils (Levinson, 1974). Four samples have greater than a threshold value of 100 ppm. Two of these are from Thinhope Burn (***8***, 1136; ***2***, 1114) and the remainder from line 7 above Glendue Burn (1354, 1360).

Zinc

A comparison with results from Settlingstones indicates generally both a higher range and median value for that area (min=18 ppm, max=440 ppm, median=60 ppm). The distribution of values for zinc in this survey shows a single population and six sites are anomalous with greater than the threshold of 90 ppm. Most of these are from the central zone (see Fig. 14), line 8 containing three sites in a group (1136, 1137, 1139) having the highest value at the latter site. Close to these are (*14*, 1300) and to the west (*9*, 1172) with the remaining site further west (*11*, 1230).

Discussion

The distribution of geochemical values along the soil lines tends to reflect a combination of effects such as the soil characteristics (e.g. peaty, clay), the source of the soil (drift, residual) and bedrock. The organic-peaty soils present in areas of poor drainage such as the area sampled NW of Larchet Hill and the elevated sections of the N-S lines above Thinhope Burn led to sampling problems and some sites did not provide enough material for analysis. These areas contain high Fe and Mn values resulting from the acid conditions and some secondary concentrations have resulted as described below. It is difficult to define any distinct geochemical difference between drift derived and residual soils; negative evidence such as values not reflecting underlying bedrock variations is perhaps the only distinguishing feature. The variations in calcium values on lines 1, 8, 9 and 10 where contiguous samples with elevated values are found (e.g. *1*, 1041-1045) reflect the presence of limestone. Soil derived from drift at the lower end of lines running up slope from Thinhope Burn have values of calcium (e.g. line 2) never above 500 ppm even though this the bedrock sequence here is the same as that on line 1.

High values of strontium exhibit a similar pattern to that of calcium, with high values often in blocks of sites closely related to the calcium highs (e.g. *1*, 1041-1048; *9*, 1170-1174) although the correlation coefficient does not reflect this ($R<+0.55$). The high values for strontium are taken to be indicative of limestone bedrock.

Although the limestones often give a clear geochemical signature, that for the Whin Sill is less easy to identify, but titanium values seem to be the most reliable indication. High Ti values occur above known Whin outcrop near Hazely Crags (*11*, 1240, 1241) and north of Thinhope Burn, (*8*, 1136, 1139). Other high Ti values lie away from mapped Whin outcrop (e.g. *2*, 1102, 1113, 1114 - the latter being the highest value recorded, 24590 ppm) and *1*, 1051, which lies in a similar stratigraphic position as 1102 - as well as line 8 (1148) which is further down slope and lower stratigraphically. Further to the west, sample 1282 (line 13) lies at a similar level in the sequence to 1148 on line 8. The association in some of these sites of high V and Cr values (e.g. *2*, 1154) gives a geochemical signature which is most readily explained by the presence of Whin Sill.

The high manganese and iron values scattered throughout the Thinhope catchment, and on the lines NW of Larchet Hill reflect poorly drained soils and also give rise to secondary concentration of other metals such as nickel, copper and vanadium. The high correlation coefficient of Co:Mn ($R=0.80$) clearly demonstrates this and line 7 shows this with sites 1354 and 1360 in particular containing high values of Fe, Mn, Ni, Cu, V with the addition of Co in 1360. Similarly line 6 where the section from 1370 to 1373 shows high Fe, Mn, Co and Ni values. Line 12 on the south side of the Thinhope catchment illustrates the effect to a lesser degree, with site 1261 in particular containing high Fe, Mn, Ni, and Cu concentrations.

The high Rb:V correlation ($R=0.72$) probably reflects clay content; although the high vanadium correlations with Cr, Ni, and Cu ($R=0.66, 0.59, 0.55$) may reflect the low variability of vanadium rather than any geochemical association. High barium values are also probably related to a combination of high clay and secondary concentration (e.g. *13*, 1288-1290; *7*, 1351-1353). There is no clear evidence that the soil values in general indicate barytes mineralisation.

Lead and zinc values in contrast almost certainly relate to mineralisation and a correlation of 0.59 suggests lead-zinc mineralisation. Enhanced values of these metals are only found in the lines sampled in the Thinhope catchment. The maximum lead concentration is found in sample 1300, line 14 (Fig. 14) and is accompanied by high zinc, rubidium, strontium, calcium and barium. This is the westernmost site on the roughly E-W line and there is no suggestion in the soil values of mineralisation to the east. To the west however, line 8, aligned almost normal to line 14, contains a set of high lead and zinc values close together (1136, 1137, 1139). High Ca, Ti, V and Ni concentrations are associated with 1136 and 1139 but these probably reflect the presence of Whin Sill. These sites lie close to the presumed base of the Whin Sill and to the east of a N-S fault indicated on the geological map. Line 9 also contains two high lead values (1172, 1174) the former associated with an anomalous zinc value. In contrast to line 8, these sites are stratigraphically higher than the Whin Sill as mapped and the high Ca and Sr values (between 1170 and 1174) indicate an underlying limestone, presumably the Little Limestone. An isolated lead high to the NW on line 13 (1275) is only accompanied by a slightly enhanced value for calcium, and other elements only in low concentrations. This site is probably underlain by the Lower Oakwood Limestone which is generally reflected in the high Ca values in samples 1272-1275. The second highest lead value (341 ppm) is found south of this at the eastern end of line 11 (1230) and is accompanied by a high zinc value (236 ppm) and anomalous strontium, calcium and barium. This site overlies the base of the Whin and also contains high Sr, Co, Mn and Fe values, the latter two probably being responsible by scavenging for the high cobalt. To the south an isolated lead high occurs at the southern end of line 12 (1264), close to the line of the Faugh Cleugh fault but is not accompanied by enhanced values for other elements. The remaining anomalous lead value lies at the southern end of line 5 (5, 1339, 125 ppm) but is isolated, and without any accompanying zinc enhancement. There is added interest here since there are high lead values in streams to the north and east implying possible mineralisation masked by drift.

CONCLUSIONS

The geophysical data demonstrate that persistent structural features are present in the survey area, affecting the Whin Sill, along the axis indicated by the aeromagnetic data. It is not possible to assess the significance of these features in terms of vertical displacements of local strata, because of the clear evidence that, in this north-west corner of the Alston Block, the interplay of folding and intrusive mechanisms can have a major influence on sill emplacement. Thus apparently important discontinuities in the Sill may be due to features which affect the local stratigraphy in a comparatively minor way. Nevertheless, the en echelon arrangement of the ground magnetic features does indicate that a single structural axis does extend south-west from the Stublick Faults as far as the Pennine escarpment, as suggested by the aeromagnetic data. The NE-SW structural features suggested by the airborne and ground magnetic data may represent a continuation south of the Stublick Faults of the fault-vein system of the Haydon Bridge Mining Field, which itself seems to be a local development of a major mineralised lineament extending over many tens of kilometres from the north Northumberland coast. It is not possible to judge from the geophysical data whether the structural features identified in the present survey area provide a suitable environment for significant mineralisation; the latter would have been dependent on the availability of mineralising fluids in the area, the suitability of any fracture system for fluid migration, and the suitability of the country rocks for the development of ore veins. The irregular distribution of Whin Sill intrusions in the area prevents predictive modelling of the magnetic anomalies; unlike surveys in the Settlingstones area, where good depth control is available from mine records, it is not possible here to interpret the anomalies accurately in terms of displacement and alteration along fault/veins. The geophysical data cannot therefore be used to determine drilling sites for more detailed investigation of structures in the Whin Sill; neither would more detailed geophysical surveys assist in this respect. However the ground geophysical survey has located much more precisely than is possible from the aeromagnetic data the magnetic anomalies of interest providing a reference against which to judge the significance of the geochemical and geological data. It is clear, for example, that some of the streams are developed close to the axes of the magnetic anomalies; this has significance for the assessment of the geochemical data.

The stream survey has confirmed and increased the base metal anomalies previously indicated in the RGRP survey. The soil sampling does not establish a real relationship between the chemical anomalies and the geophysics but generally reflects the underlying geology. Some mineralisation may be associated with the N-S fault, mapped crossing Thinhope Burn, or associated with the margins of the Whin Sill. Lead-zinc mineralisation detected by the stream sampling is present on the NE slopes of Black Hill and associated with Running Sike. The available geochemical and geophysical data indicate that the Whin sill may be present over a larger area than shown on the geological map.

ACKNOWLEDGEMENTS

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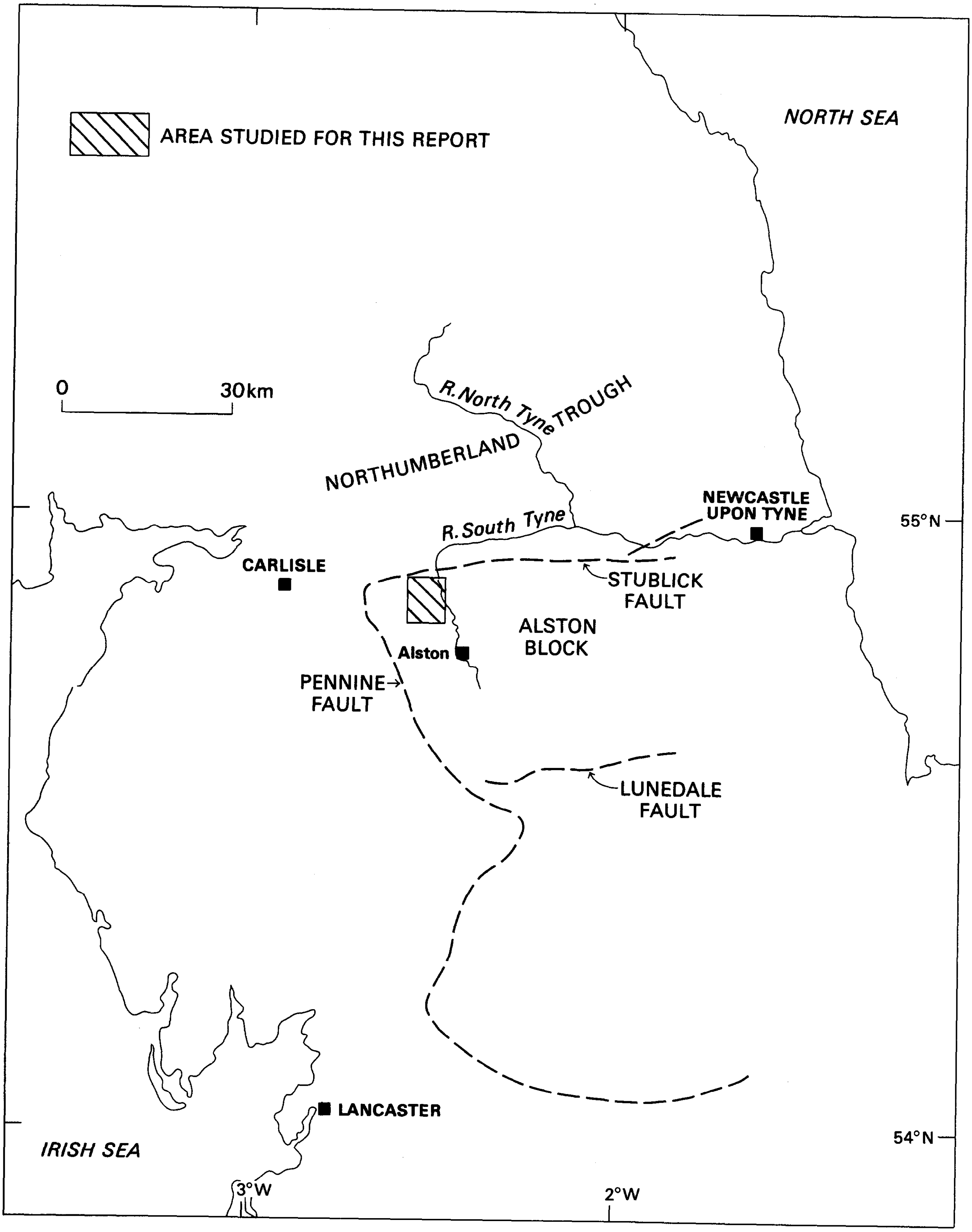


Figure 1 Location and structural setting of the Geltsdale/Glendue Fell survey area.

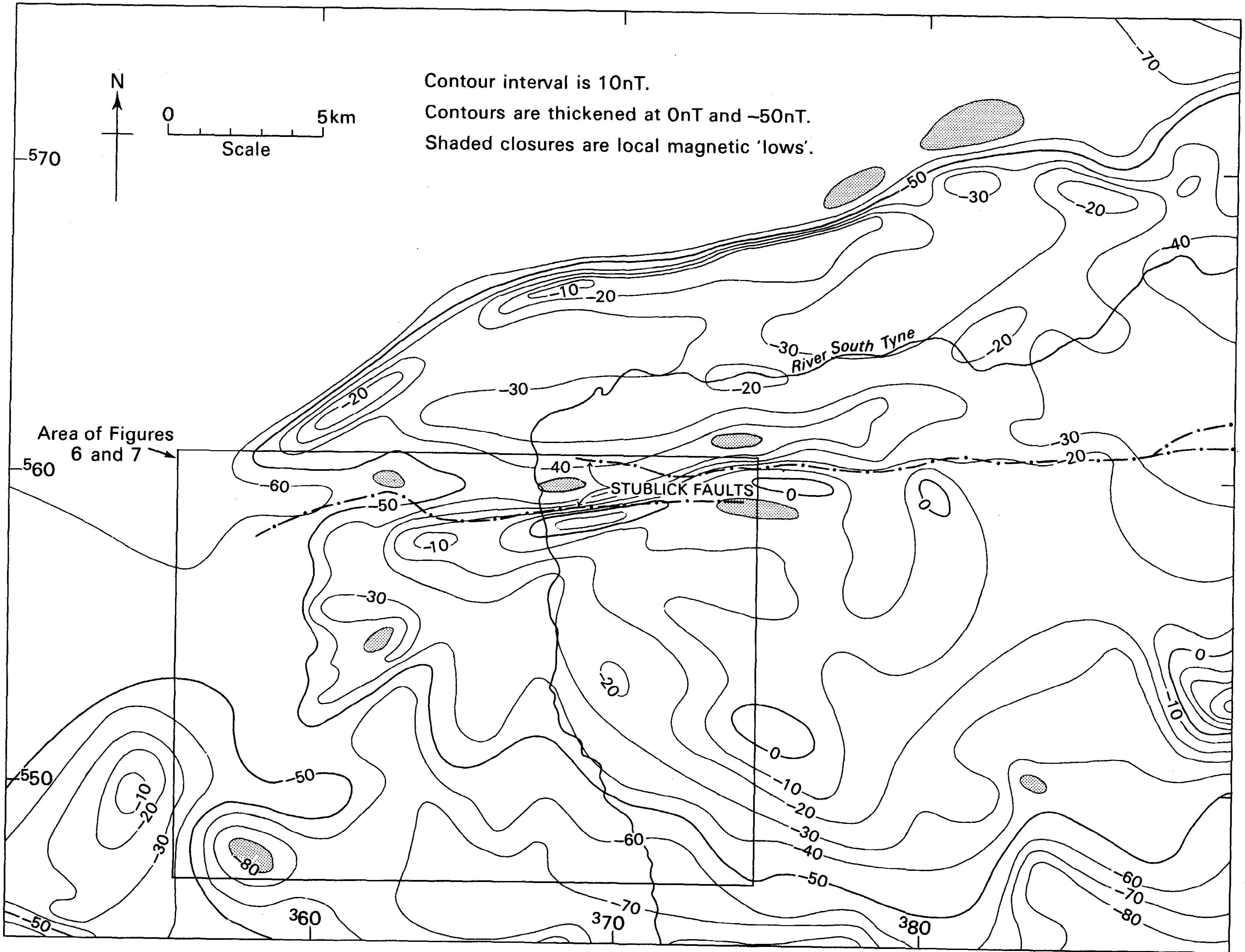


Figure 8 Contours of total magnetic field anomaly for the north-western part of the Alston Block and surrounding area.

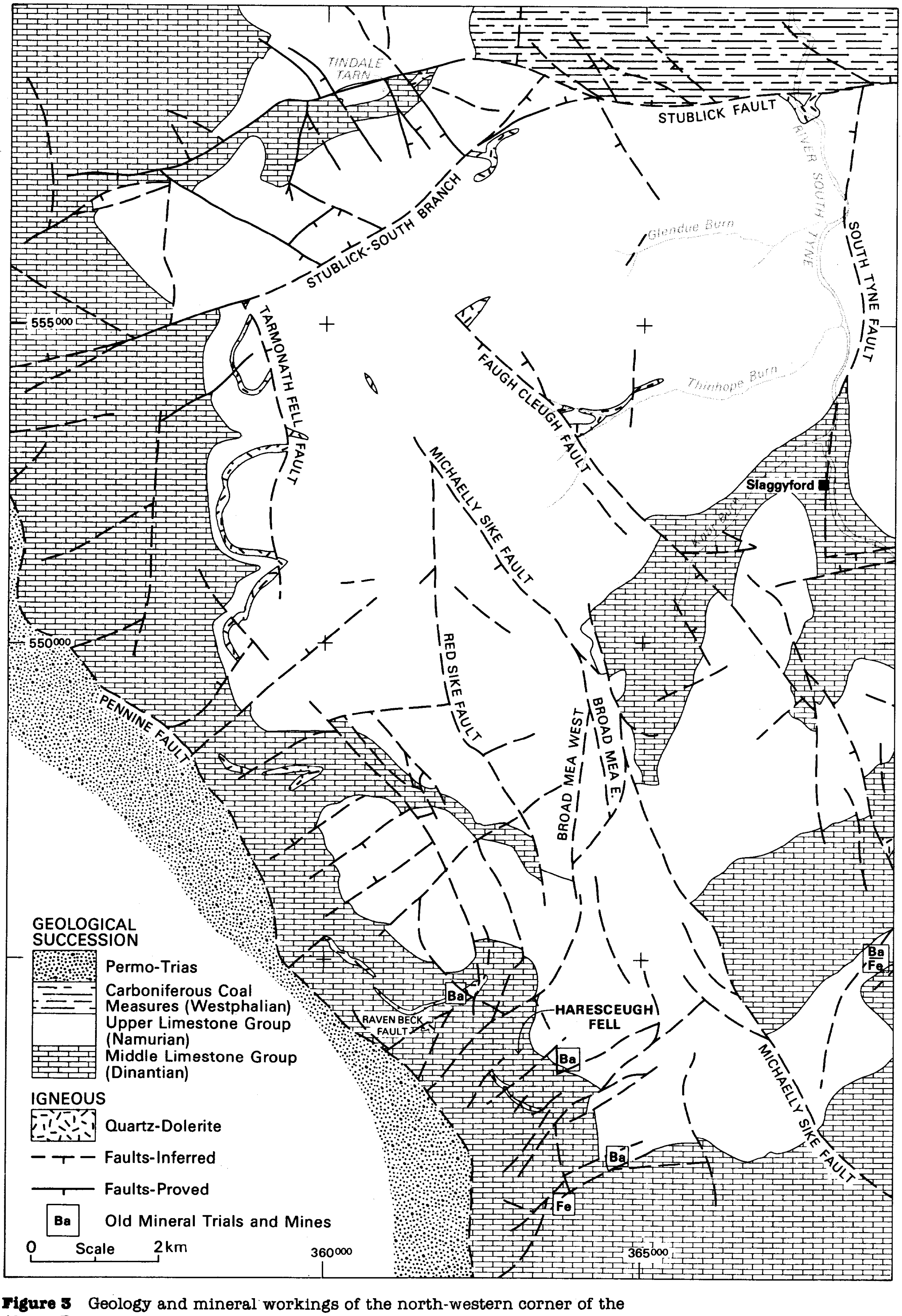


Figure 3 Geology and mineral workings of the north-western corner of the Alston Block.

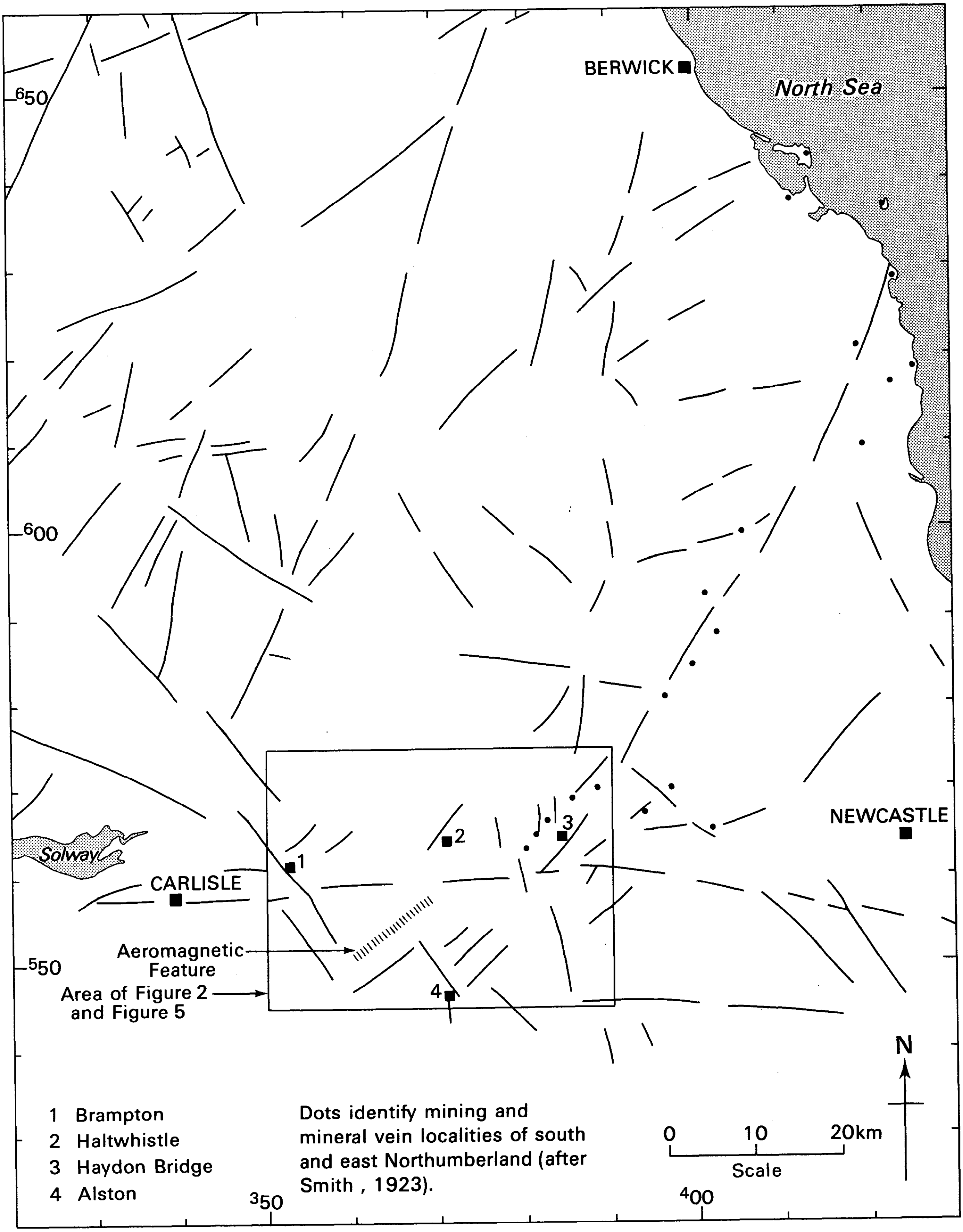


Figure 4 Main elements of structure in Northumberland and southern Scotland from LandSat imagery.

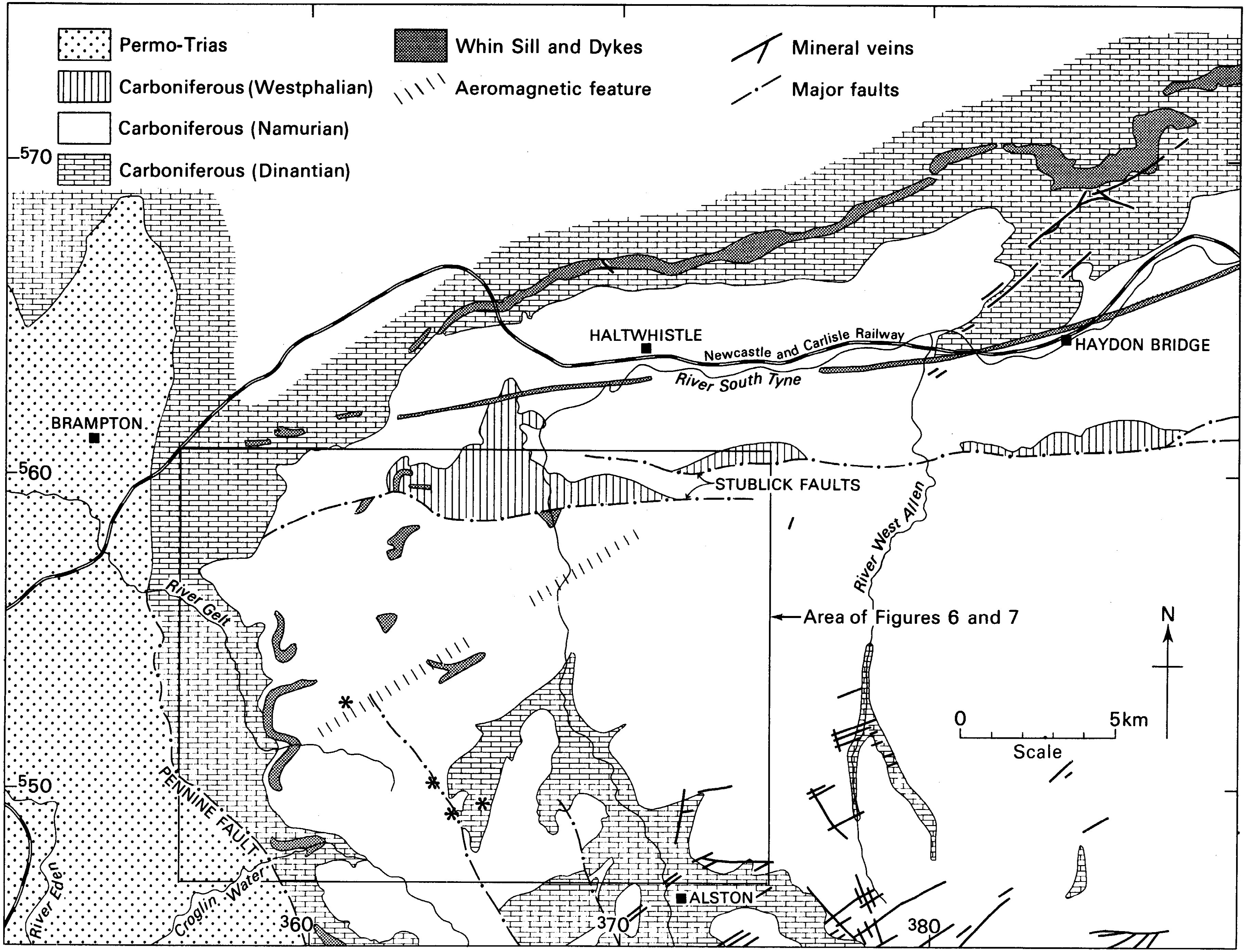


Figure 5 Geology of the north-western part of the Alston Block and surrounding area.

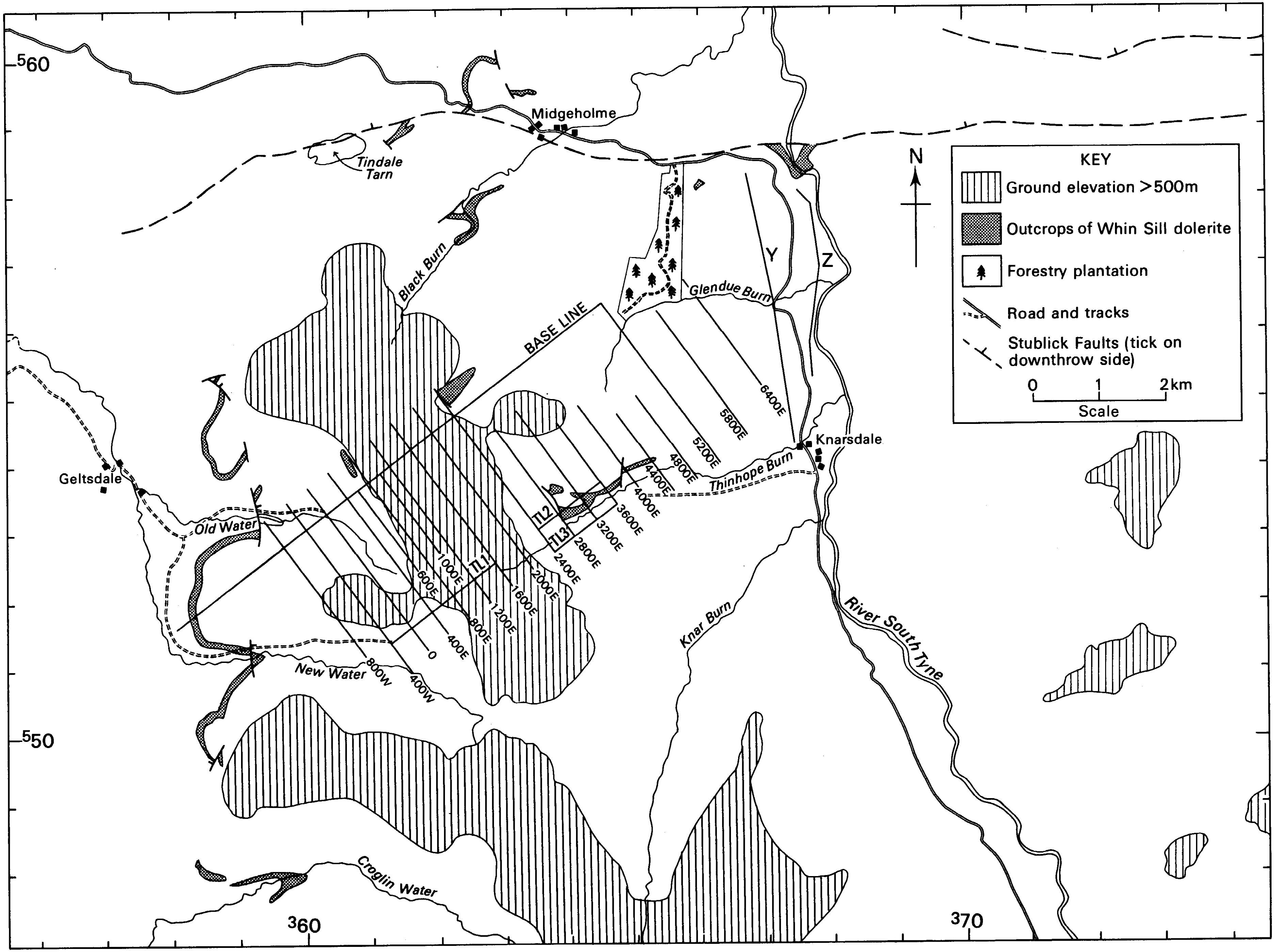


Figure 6 Topography of geophysical survey area and surroundings, and location of magnetic survey traverses.

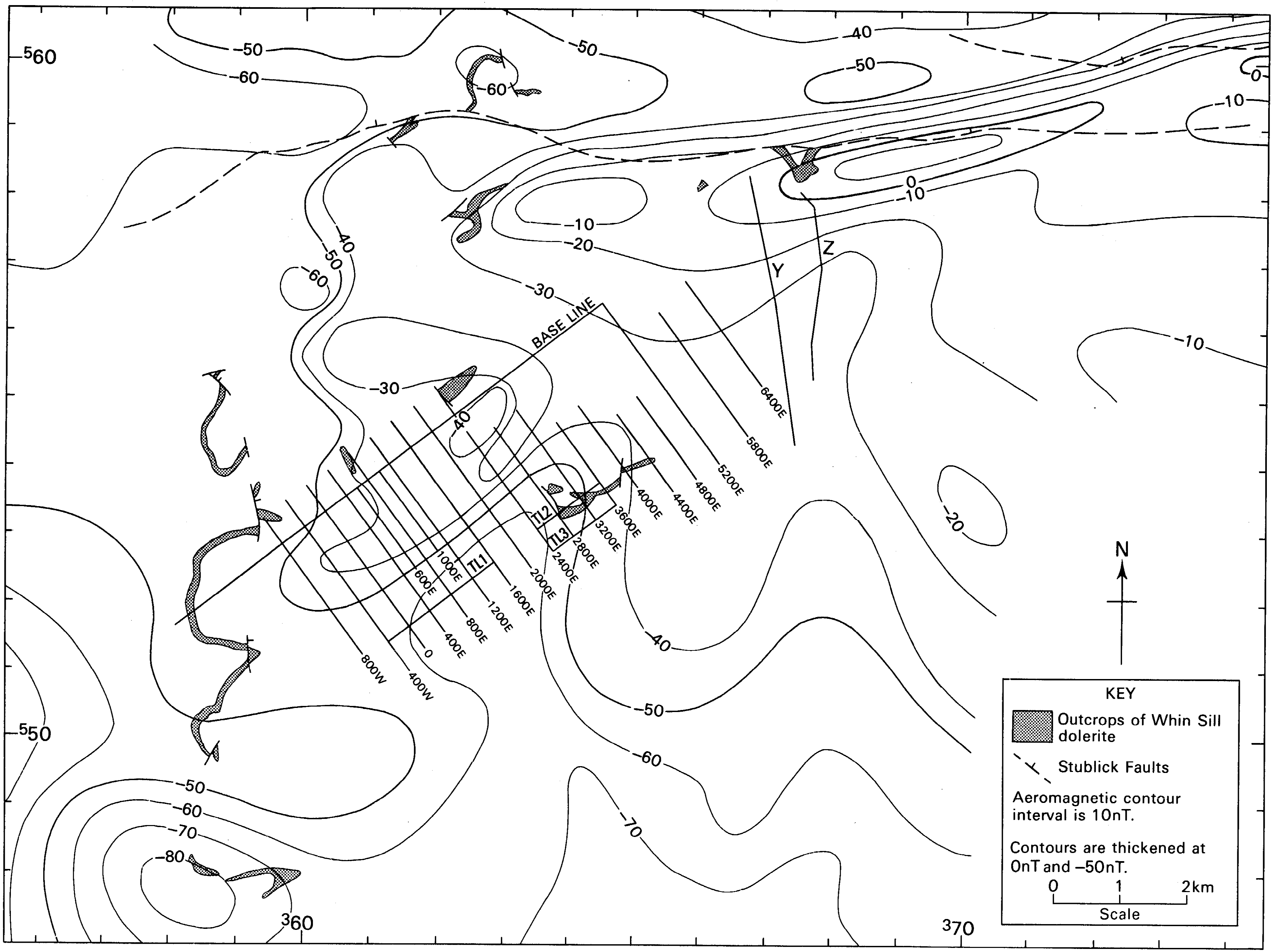


Figure 7 Location of magnetic survey traverses with respect to aeromagnetic contours and outcrops of Whin Sill.

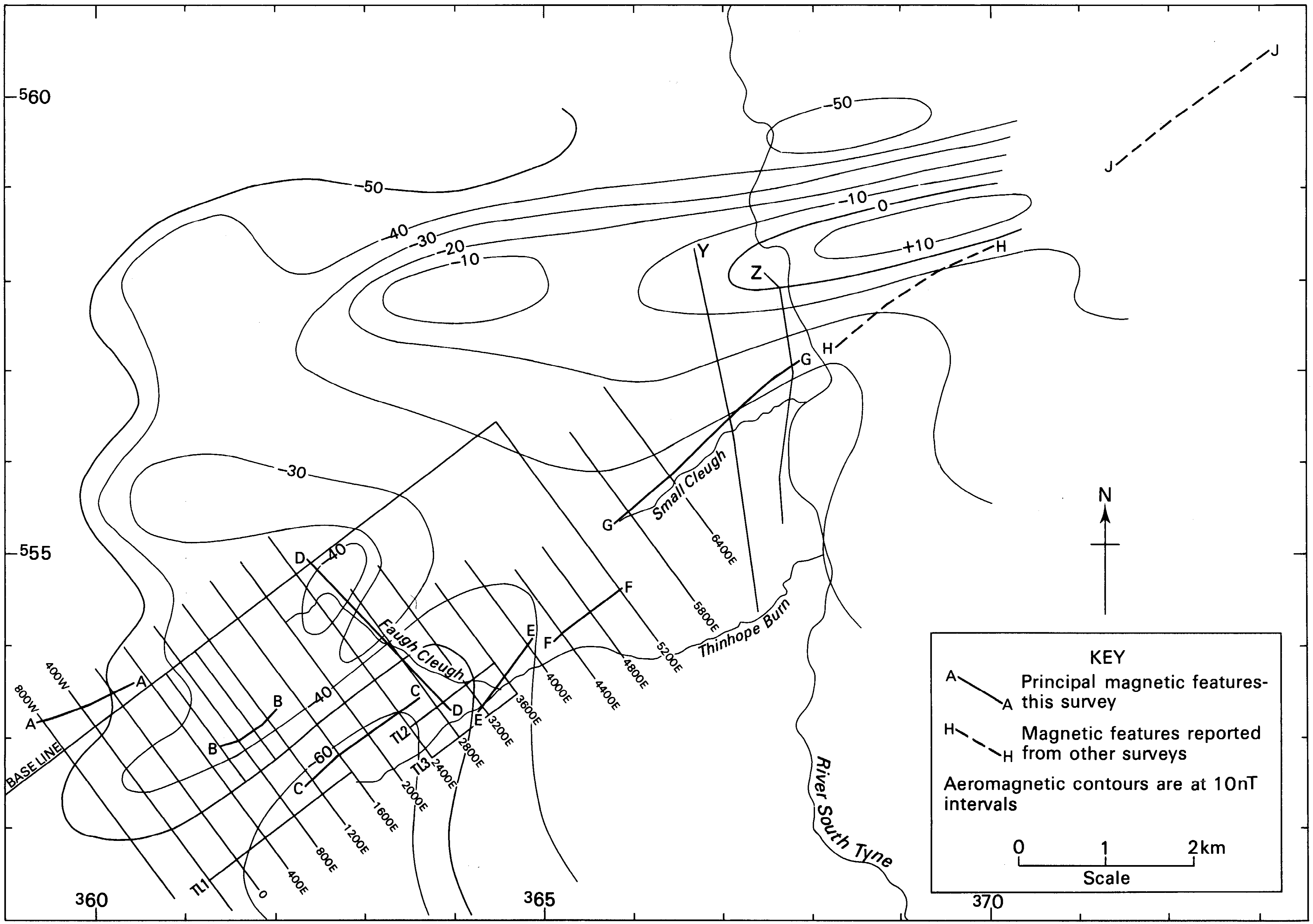


Figure 8 Summary map: location of principal magnetic anomalies in the Geltsdale/Glendue Fell area.

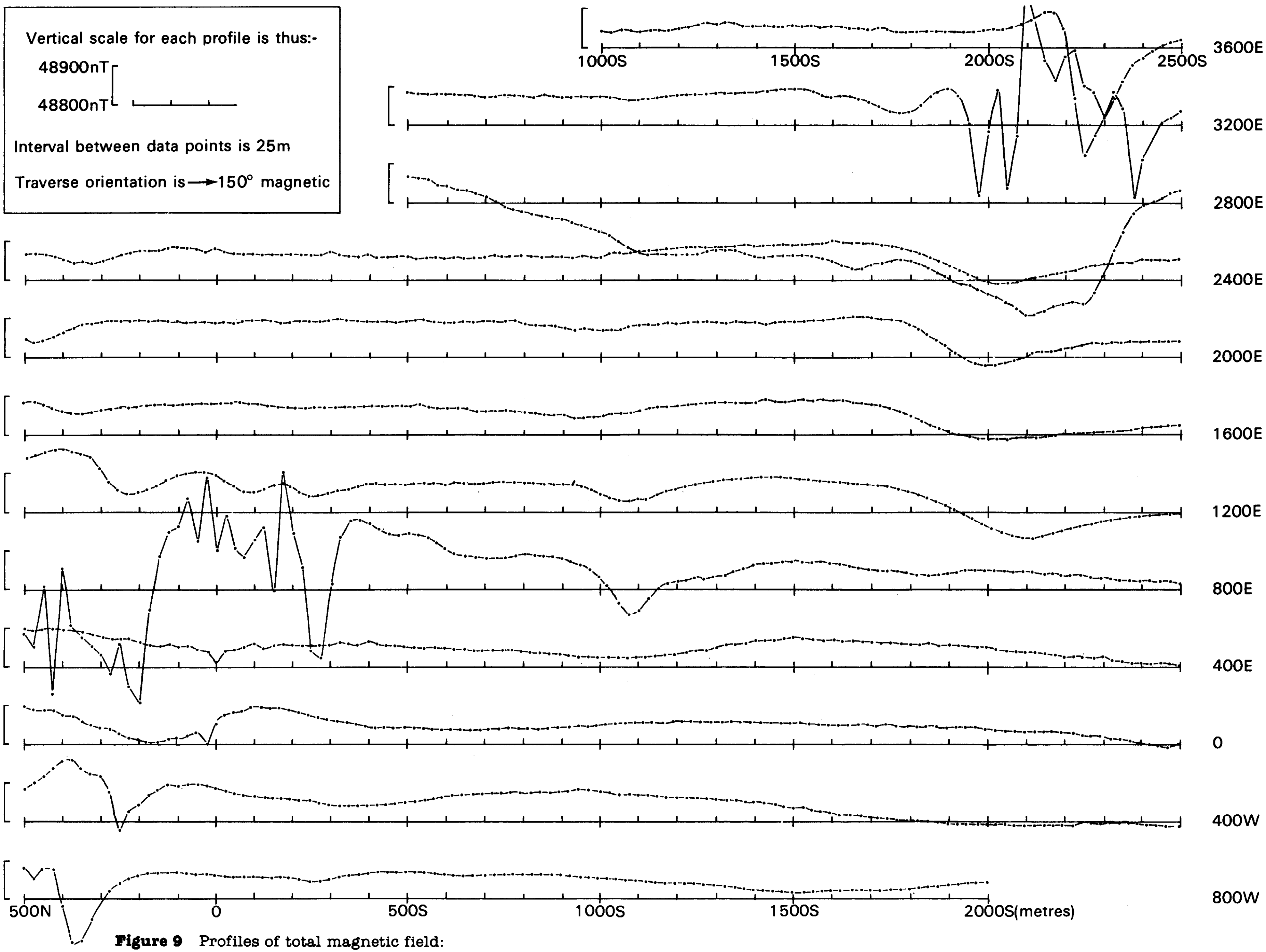
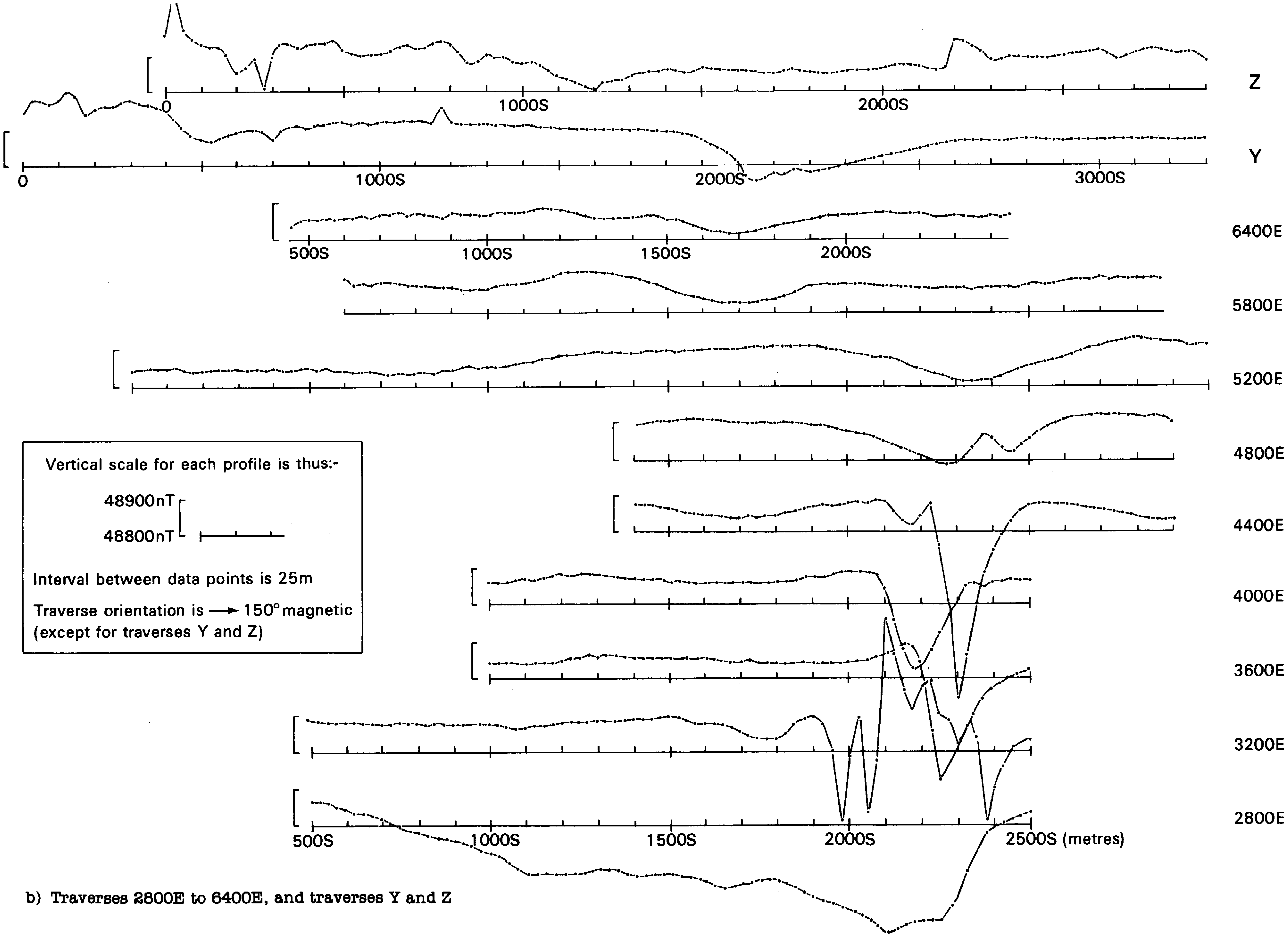
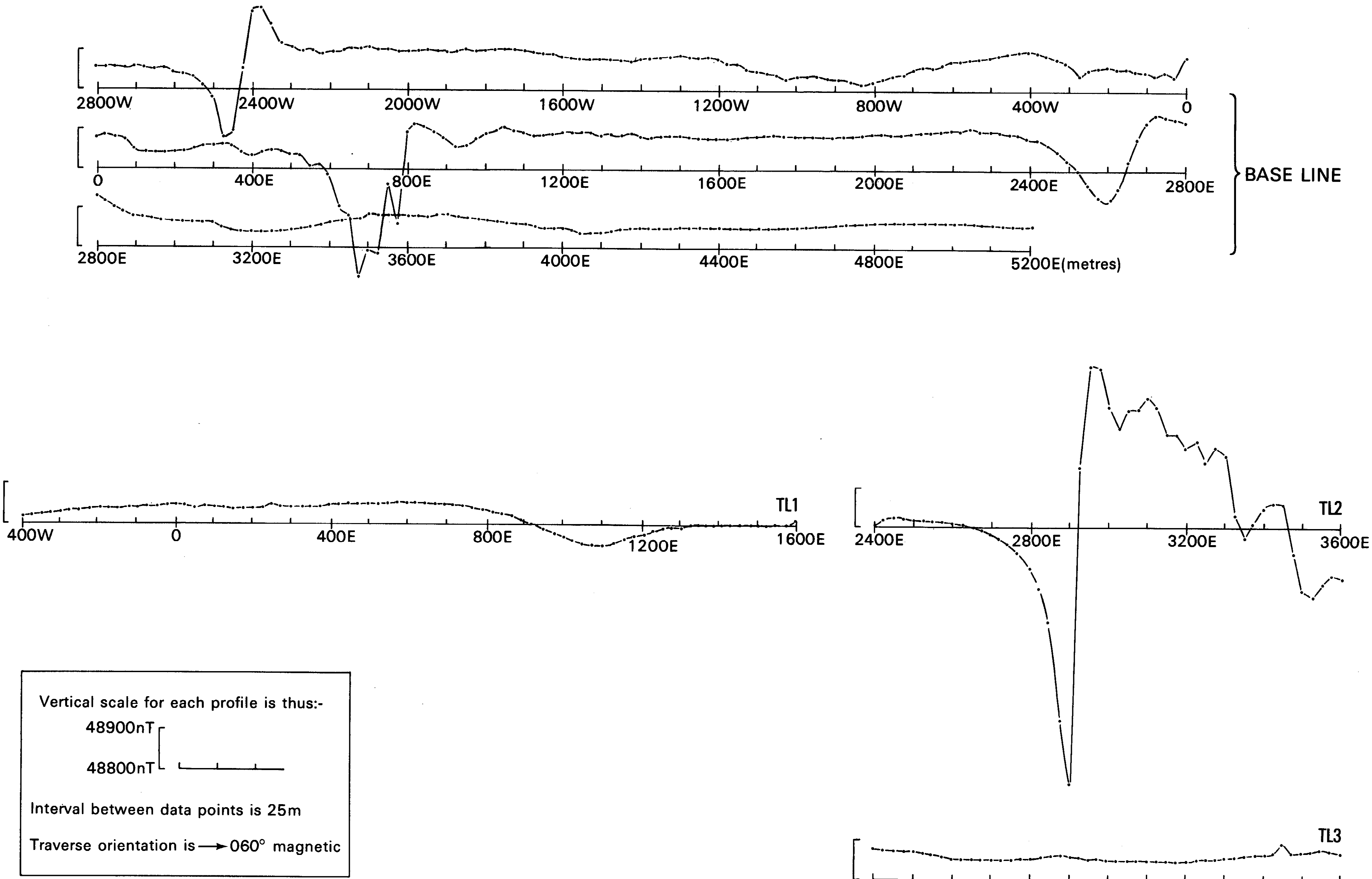


Figure 9 Profiles of total magnetic field:
a) Traverses 800W to 3600E



b) Traverses 2800E to 6400E, and traverses Y and Z



c) Base Line and traverses TL1, TL2, TL3.

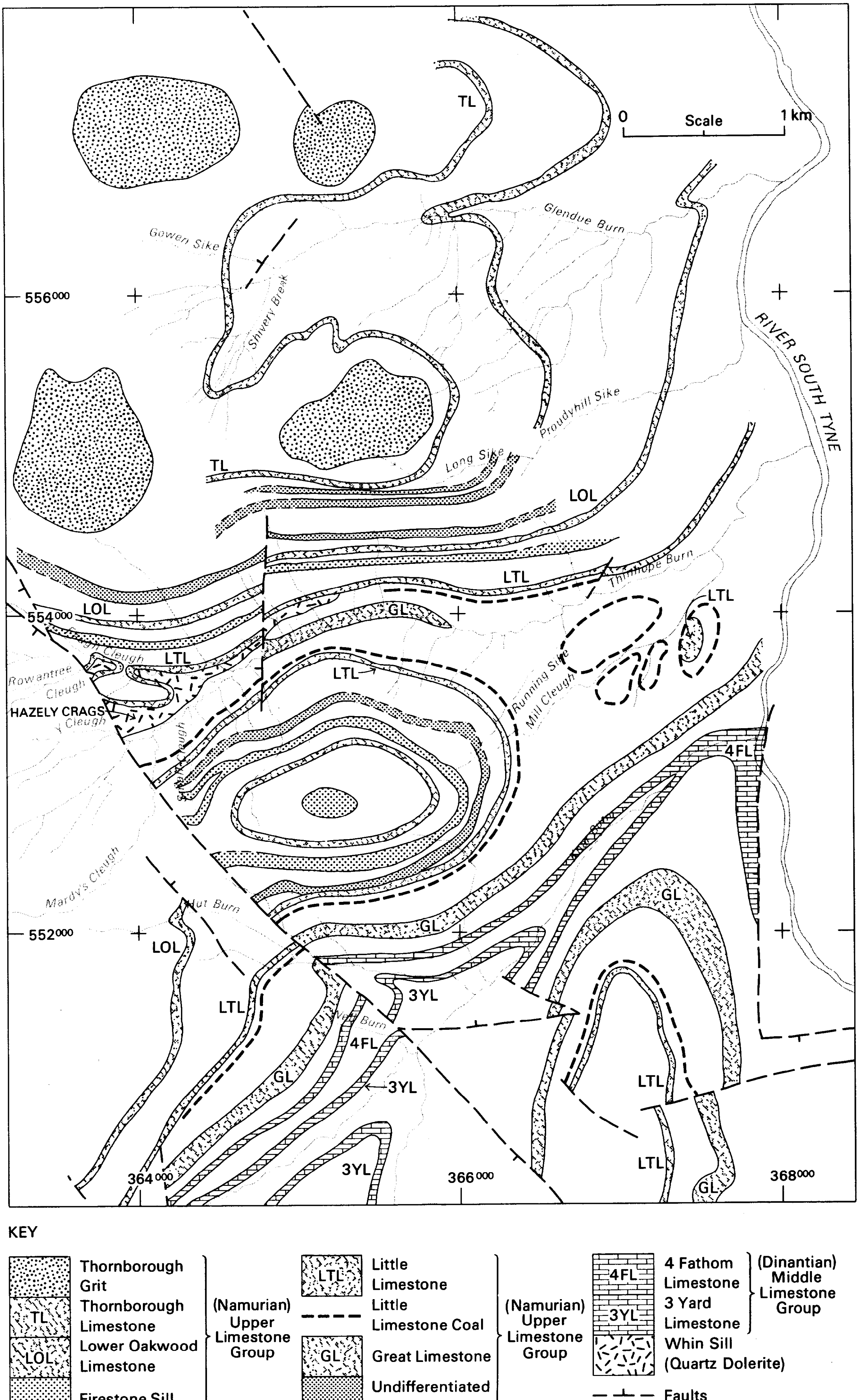
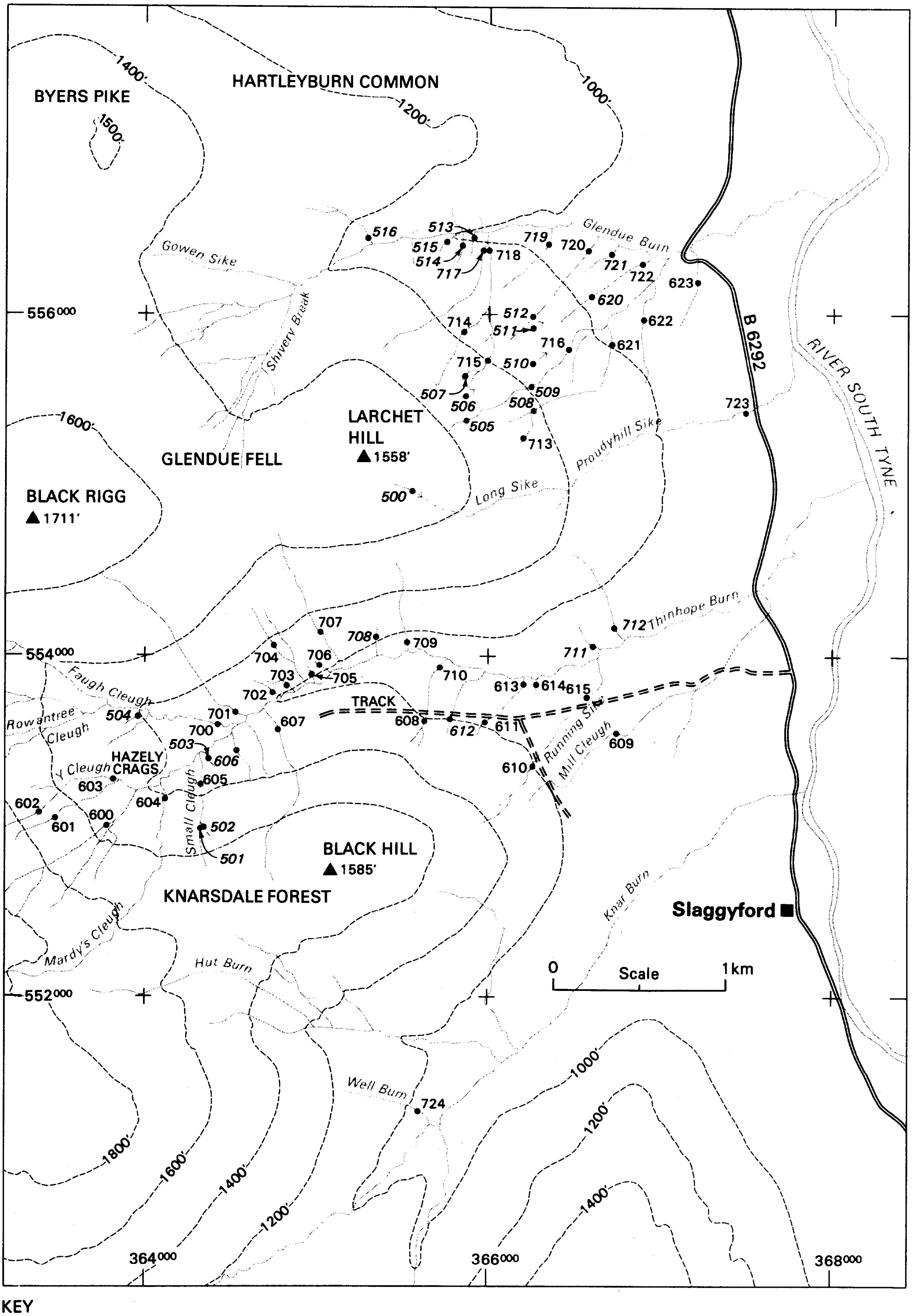


Figure 10 Geology of Glendue Burn–Knar Burn area.

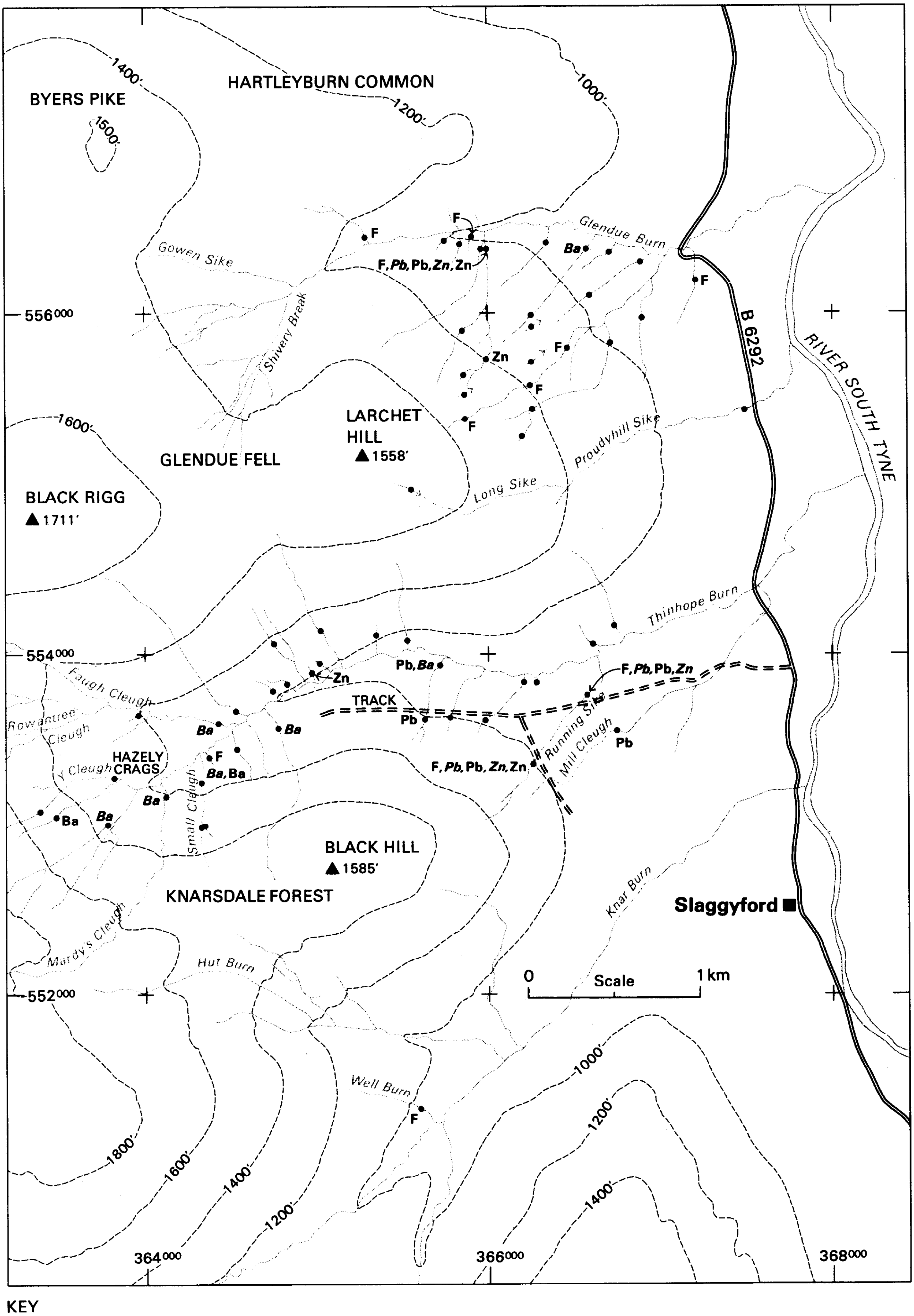


KEY

700 Stream sediment pan concentrate and water samples

510 Water samples only

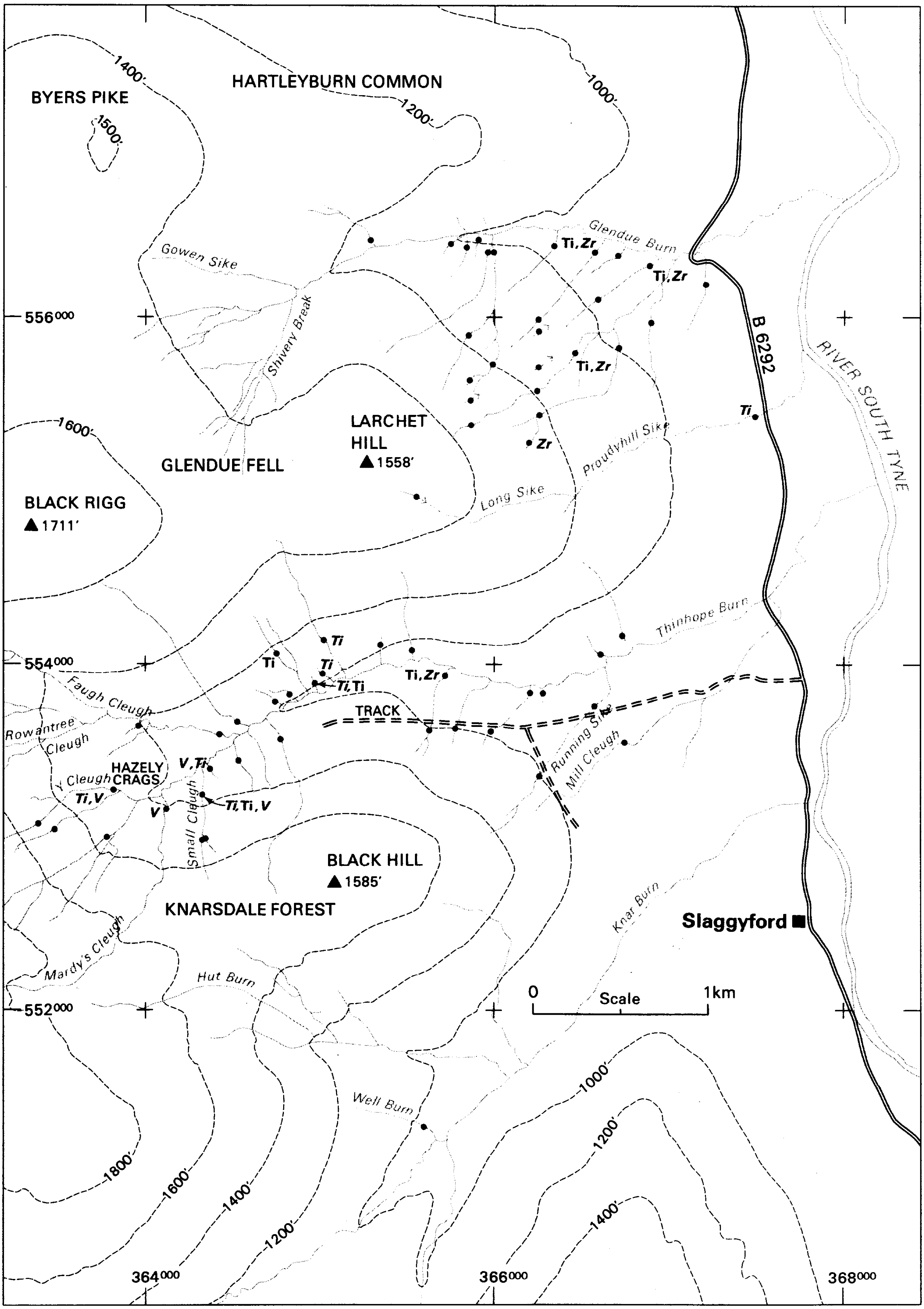
Figure 11 Topography and stream sample sites, Glendue Burn–Knar Burn.



KEY

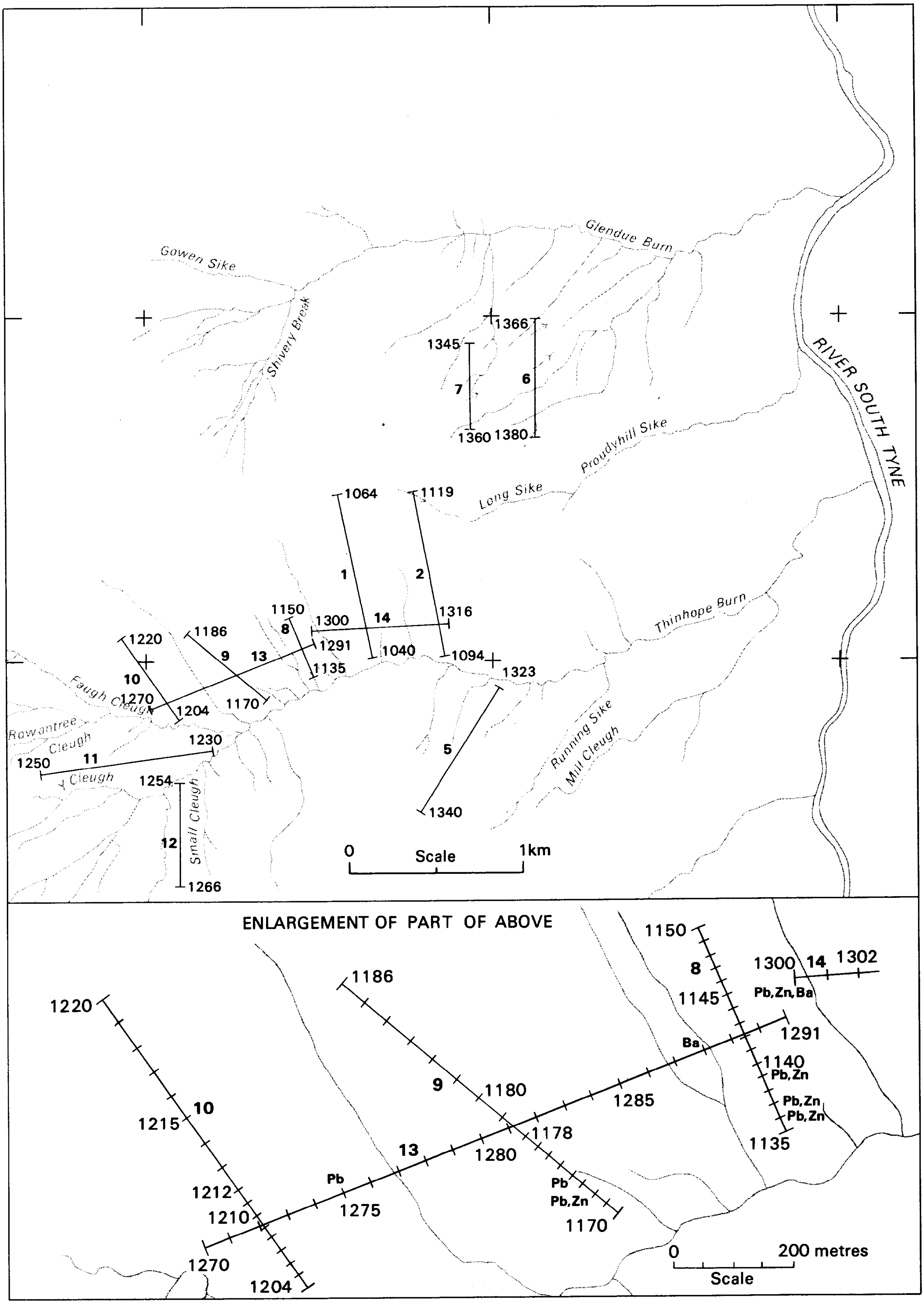
- F Fluorine > 50ppb
- *Pb* Lead in pan > 600ppm
- Pb Lead in sediment > 150ppm
- *Zn* Zinc in pan > 60ppm
- Zn Zinc in sediment > 190ppm
- *Ba* Barium in pan > 4000ppm
- Ba Barium in sediment > 800ppm

Figure 12 F, Pb, Ba, Zn stream anomalies.



KEY
Zr Zircon in pan > 2000ppm
Ti Titanium in pan > 6300ppm
Ti Titanium in sediment > 2300ppm
V Vanadium in pan > 30ppm

Figure 13 Zr, Ti, V stream anomalies.



KEY

3	Line number	Pb	Lead > 90ppm
1170	Sample number at end of line	Zn	Zinc > 90ppm
		Ba	Barium > 590ppm

Figure 14 Soil sampling lines in Glendue Burn/Thinhope Burn area.

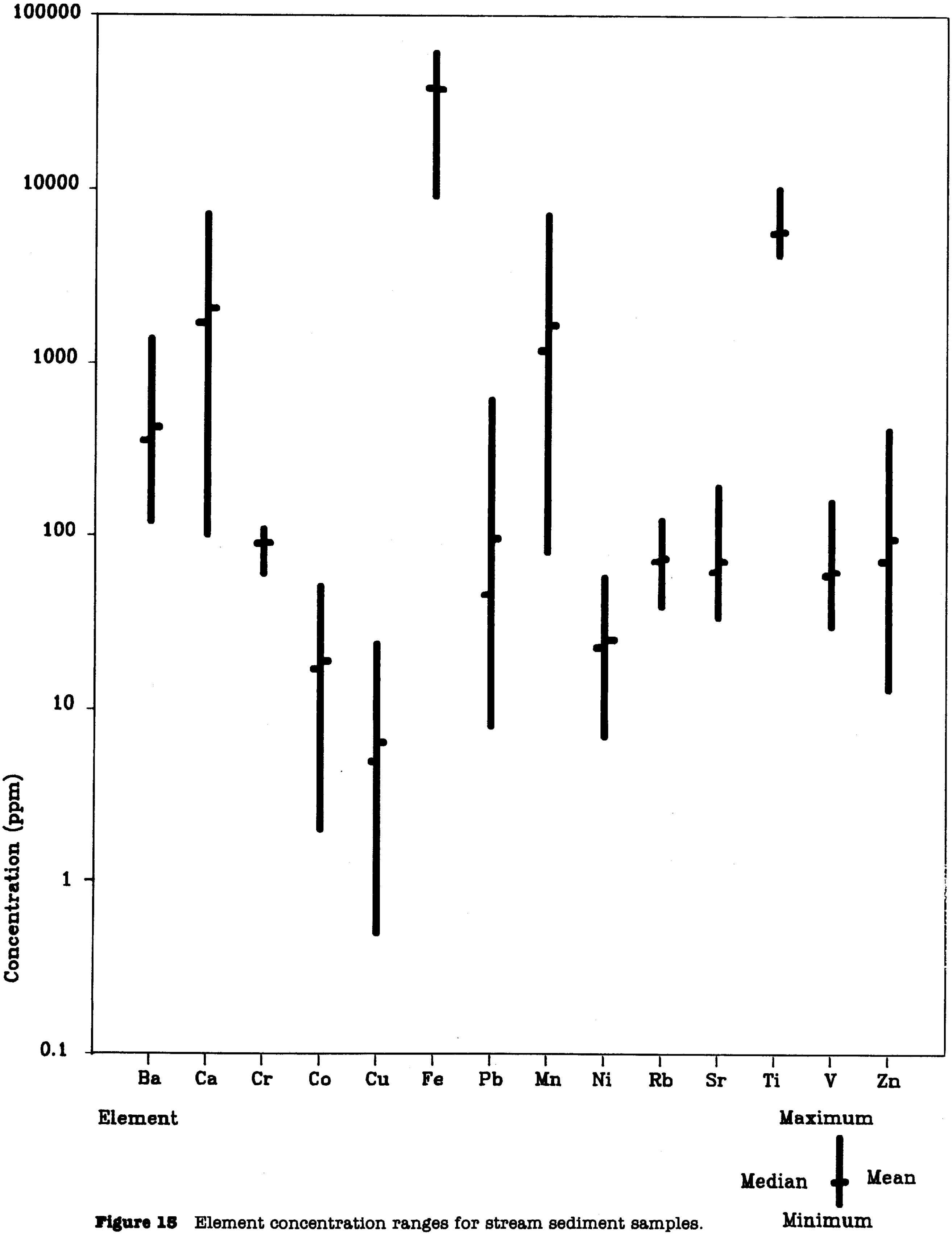


Figure 15 Element concentration ranges for stream sediment samples.

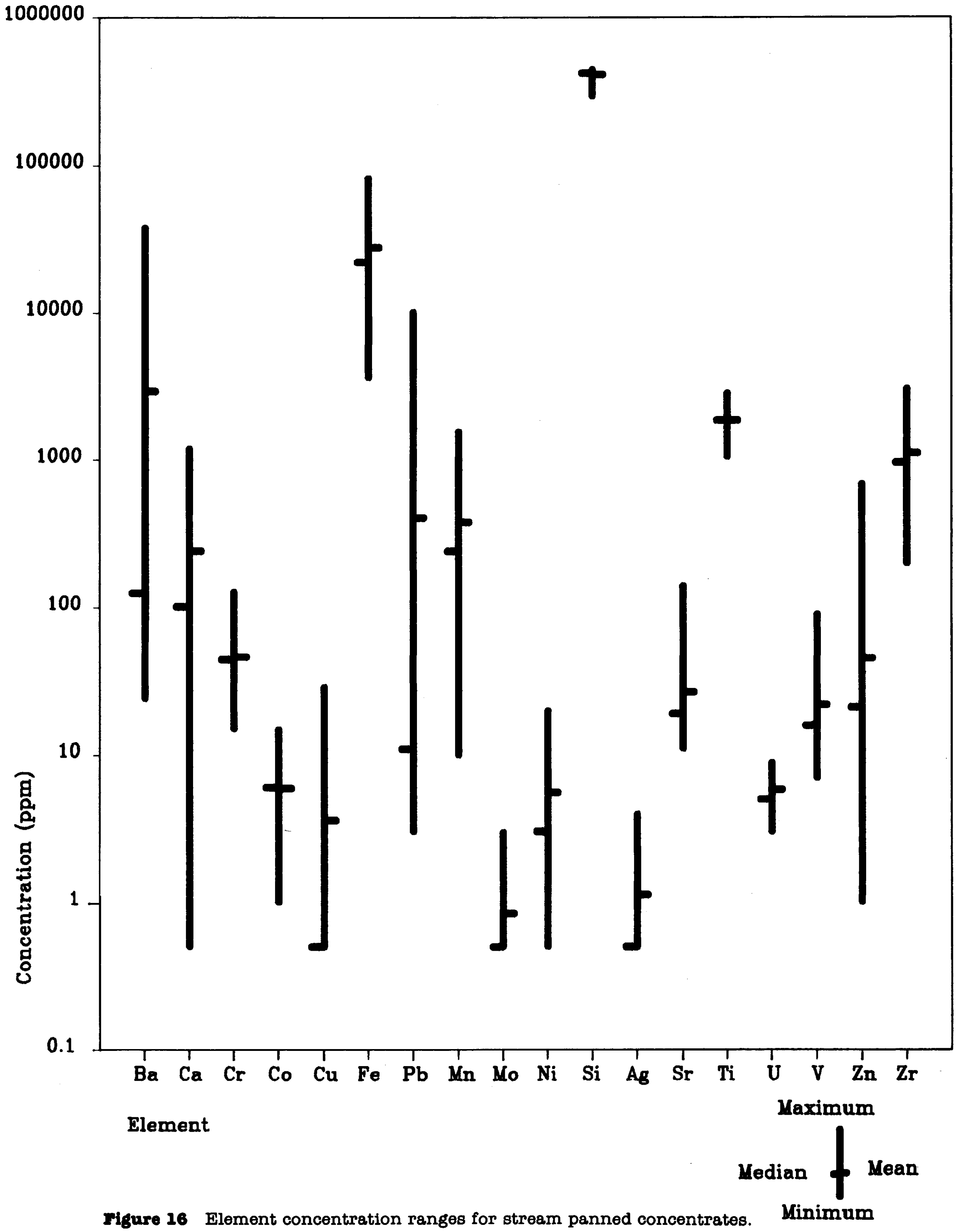


Figure 16 Element concentration ranges for stream panned concentrates.

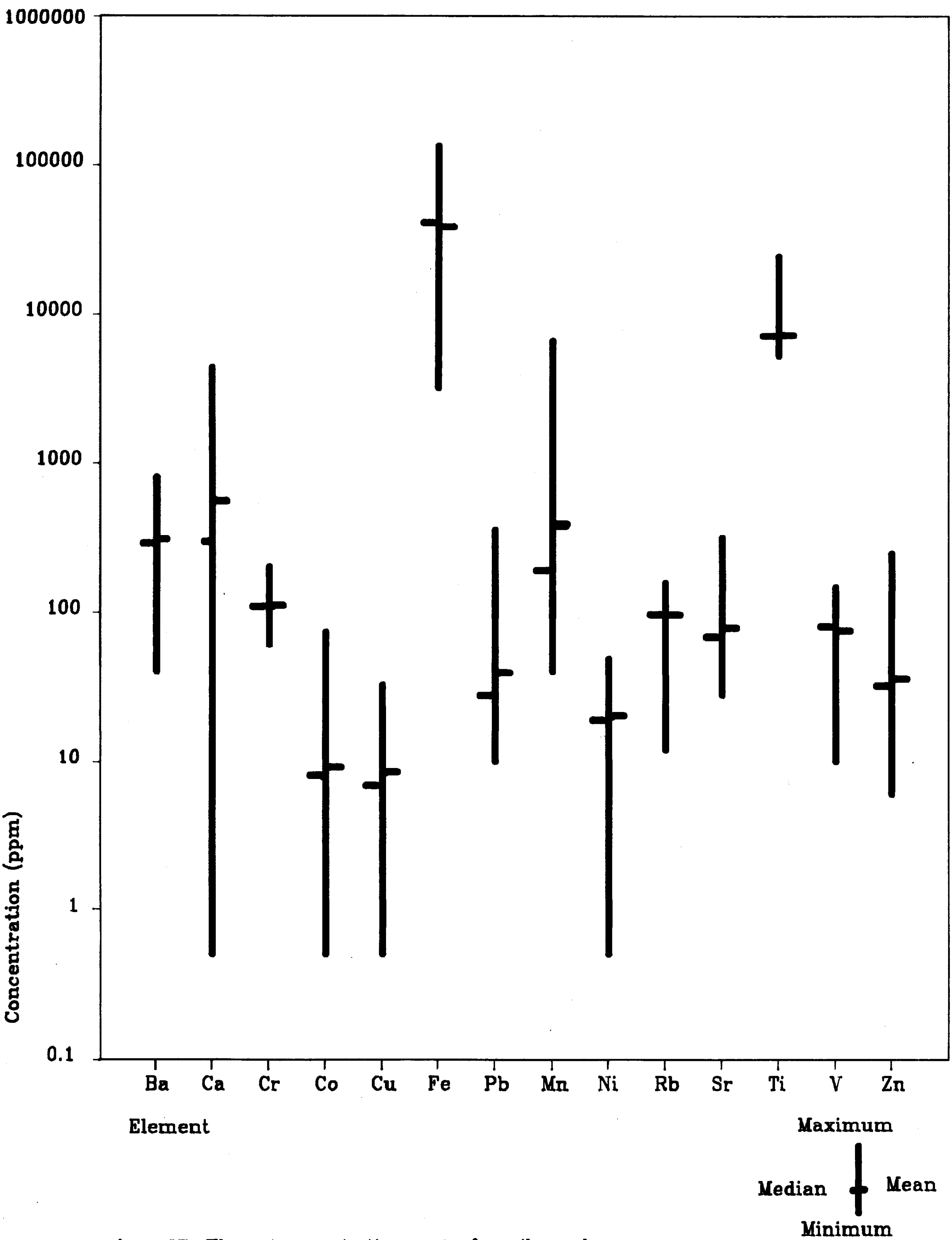


Figure 17 Element concentration ranges for soil samples.

TABLE 1 - Stream sediment and panned concentrate positions

SAMPLE NUMBER	EASTINGS	NORTHINGS
600	363755	552960
601	363460	553015
602	363370	553025
603	363840	553240
604	364130	553150
605	364335	553240
607	364760	553550
608	365645	553620
609	366748	553520
610	366290	553355
611	365930	553605
613	366210	553795
615	366570	553710
621	366700	555780
622	366890	555970
623	367215	556200
700	364415	553570
701	364540	553655
704	364750	554060
705	364980	553860
706	365030	553920
707	365040	554120
709	365535	554060
710	365730	553910
713	366190	555270
714	365860	555880
715	365995	555700
716	366440	555820
718	366000	556380
720	366570	556360
722	366890	556290
723	367490	555420
724	365610	551320

TABLE 2 Stream water sample sites and results

SAMPLE NUMBER	EASTING	NORTHING	FLUORINE ppb	pH	CONDUCTIVITY umhos
500	365555	554930	58	4.2	53.0
501	364340	553000	44	6.0	34.0
502	364350	553000	41	4.4	44.0
503	364380	553390	51	5.8	32.0
504	363985	553660	41	6.3	34.0
505	365885	555390	71	6.3	110.0
506	365890	555550	42	6.2	73.0
507	365880	555820	46	6.3	48.0
508	366265	555410	49	6.4	73.0
509	366260	555560	53	6.3	66.0
510	366265	555710	42	5.3	38.0
511	366260	555925	42	6.3	40.0
512	366270	555980	39	5.9	38.0
513	365910	556420	61	6.4	200.0
514	365860	556400	37	5.7	43.0
515	365750	556400	48	6.0	150.0
516	365320	556400	56	5.1	46.0
517	365600	551310	33	6.5	85.0
600	363755	552960	41	5.4	31.0
601	363460	553015	35	4.9	46.0
602	363370	553025	37	5.3	39.0
603	363840	553240	35	5.2	36.0
604	364130	553150	36	5.8	35.0
605	364335	553240	36	4.7	49.0
606	364540	553410	41	5.8	46.0
607	364760	553550	30	6.0	36.0
608	365645	553620	41	5.9	54.0
609	366748	553520	46	5.8	60.0
610	366290	553355	73	5.8	75.0
611	365930	553605	45	5.7	42.0
612	365800	553620	42	5.7	39.0
613	366210	553795	40	7.0	48.0
614	366290	553810	36	6.5	70.0
615	366570	553710	56	6.5	75.0
620	366590	556095	39	6.3	45.0
621	366700	555780	47	6.3	75.0
622	366890	555970	40	6.1	44.0
623	367215	556200	51	5.3	48.0
700	364415	553570	33	6.1	38.0
701	364540	553655	41	6.5	80.0
702	364780	553770	34	6.2	38.0
703	364830	553770	33	6.3	40.0
704	364750	554060	33	5.6	40.0
705	364980	553860	34	6.3	42.0
706	365030	553920	33	6.1	35.0
707	365040	554120	35	6.8	72.0
708	365370	554090	46	6.3	38.0
709	365530	554060	44	6.5	44.0
710	365730	553910	45	6.6	72.0
711	366630	554035	40	6.3	44.0
712	366780	554100	48	6.3	43.0
713	366190	555270	46	6.2	100.0
714	365860	555880	33	6.1	38.0
715	365995	555700	42	6.1	95.0

TABLE 2 Stream water sample sites and results (cont.)

SAMPLE NUMBER	EASTING	NORTHING	FLUORINE ppb	pH	CONDUCTIVITY umhos
716	366440	555820	57	5.9	61.0
717	365980	556390	39	6.0	50.0
718	366000	556380	63	6.2	110.0
719	366580	556370	42	6.0	46.0
720	366570	556360	45	6.3	53.0
721	366700	556360	46	6.2	46.0
722	366890	556290	48	5.4	46.0
723	367490	555420	41	6.3	48.0
724	365610	551320	59	6.3	140.0

TABLE 3 Stream sediment results

SAMPLE	Sb	Ba	Ca	Cu	Co	Cr	Fe	Pb
600	0.5	810	2200	8.0	27	90	35000	35
601	0.5	130	300	0.5	2	80	9000	8
602	2	130	100	1.0	16	60	15300	26
603	2	220	1000	8.0	11	100	38200	21
604	0.5	760	1500	13.0	29	90	28100	57
605	2	1370	200	14.0	3	110	18200	27
607	2	630	800	7.0	14	80	61900	29
608	1	280	2400	2.0	24	80	24200	399
609	0.5	230	2800	1.0	20	90	40300	358
610	2	430	2100	4.0	51	90	48100	612
611	1	120	300	0.5	3	90	18400	22
613	1	160	800	6.0	6	90	34800	49
615	0.5	360	2600	11.0	27	100	45900	160
621	0.5	310	2900	2.0	16	80	30900	59
622	0.5	140	200	2.0	7	80	34500	28
623	0.5	170	200	3.0	5	80	18100	35
700	0.5	460	1700	9.0	19	110	38500	36
701	0.5	330	7200	4.0	12	90	34300	70
704	1	330	400	5.0	6	100	26000	16
705	1	570	4300	24.0	21	90	48700	87
706	0.5	390	3700	5.0	25	90	39800	108
707	0.5	760	4800	11.0	38	100	42500	68
709	0.5	290	900	5.0	17	100	49500	36
710	0.5	480	2400	4.0	29	90	40500	161
713	0.5	350	2400	2.0	13	90	27600	34
714	1	270	900	4.0	13	90	51300	31
715	3	510	4000	8.0	17	100	53500	46
716	1	630	3900	9.0	42	100	58800	71
718	0.5	600	3900	9.0	27	90	61800	280
720	0.5	360	500	4.0	10	80	31400	17
722	0.5	310	300	6.0	33	100	52900	48
723	0.5	500	800	7.0	15	100	40100	93
724	0.5	510	5800	14.0	31	100	60400	41

NOTE A value of 0.5 denotes element not detected or below detection limits

TABLE 3 Stream sediment results (cont.)

SAMPLE	Ni	Mn	Rb	Sr	Sn	Ti	V	Zn
600	41	2260	91	74	0.5	5930	70	164
601	9	90	62	34	1	5100	40	15
602	9	1090	68	46	0.5	4180	40	13
603	25	380	83	50	0.5	6460	70	47
604	23	3350	89	86	1	5530	70	73
605	18	120	125	94	1	6550	80	17
607	24	550	72	58	1	5110	60	26
608	24	1610	39	38	1	4580	30	163
609	19	810	55	66	2	5390	50	102
610	53	5580	65	63	0.5	5030	50	288
611	7	80	40	42	0.5	4840	40	14
613	10	140	60	53	1	5580	60	22
615	34	2610	77	78	1	5360	60	136
621	14	1290	52	47	0.5	5180	50	72
622	8	210	50	42	0.5	5440	50	14
623	13	100	60	46	2	5110	50	21
700	29	1170	93	71	0.5	6340	70	81
701	17	400	81	101	0.5	6160	70	103
704	28	190	92	61	2	6160	60	42
705	39	2320	88	179	0.5	0200	160	417
706	27	3410	61	88	0.5	6080	70	166
707	58	7110	103	196	0.5	6140	70	176
709	19	710	78	99	0.5	6070	70	40
710	28	1540	63	67	0.5	5220	50	96
713	17	1450	65	55	0.5	5830	50	59
714	21	540	75	47	0.5	5720	70	42
715	37	1010	88	63	0.5	5970	70	198
716	35	3880	94	65	1	5970	80	168
718	38	3320	70	58	1	5690	70	213
720	20	410	50	38	0.5	5390	40	23
722	19	1950	61	47	0.5	5850	60	31
723	20	1380	107	67	0.5	6370	70	33
724	58	2900	105	174	0.5	5610	80	138

NOTE A value of 0.5 denotes element not detected or below detection limits

TABLE 4 Stream panned concentrate results

SAMPLE	Ca	Ti	Mn	Fe	V	Sr	Zr	U
600	200.0	1850	500	20500	23	27	861	7
601	100.0	1530	20	11400	15	20	383	6
602	0.5	1120	50	4400	11	13	255	4
603	100.0	1940	90	65500	40	28	599	4
604	400.0	1900	970	51900	59	128	211	5
605	100.0	2380	200	66100	90	141	198	5
607	100.0	1040	100	31200	23	36	211	5
608	100.0	1270	140	5000	8	13	598	5
609	100.0	1060	80	8500	7	13	312	4
610	800.0	1910	460	21900	14	28	1105	5
611	0.5	1850	70	13900	10	17	1479	7
613	0.5	1600	10	3600	10	14	1490	5
615	300.0	1640	330	24400	17	19	954	5
621	100.0	1210	190	16800	10	13	551	4
622	0.5	1390	100	29600	13	11	536	6
623	0.5	1710	40	6100	11	20	1161	6
700	400.0	2150	870	49000	43	23	928	5
701	300.0	2060	30	6000	11	13	1472	7
704	0.5	2380	10	5500	13	12	1485	7
705	1000.0	2710	180	7100	29	22	928	4
706	300.0	1790	290	25100	22	24	603	5
707	300.0	1800	1570	14300	14	24	1207	7
709	100.0	1620	60	22600	19	13	637	6
710	1200.0	2860	1360	69200	29	36	2758	9
713	100.0	2120	520	11200	13	13	2037	8
714	100.0	2080	410	81600	28	16	1001	5
715	400.0	1920	380	58800	21	13	1566	7
716	300.0	2390	850	44000	25	21	2872	9
718	300.0	1720	440	17100	11	11	1208	5
720	400.0	2530	1030	35200	29	41	2705	9
722	0.5	2470	240	20700	16	15	3041	8
723	100.0	1190	380	25500	18	31	293	3
724	300.0	2060	400	29400	16	17	1274	6

NOTE A value of 0.5 denotes element not detected or below detection limits

TABLE 4 Stream panned concentrate results

SAMPLE	Cr	Co	Ni	Cu	Zn	Ba	Pb
600	29	8	9.0	6.0	31	4080	10
601	26	2	2.0	0.5	4	46	5
602	15	1	1.0	0.5	1	34	5
603	39	10	17.0	3.0	20	375	19
604	39	15	18.0	10.0	39	24406	23
605	49	9	20.0	29.0	21	37890	26
607	18	6	7.0	3.0	7	4602	8
608	29	4	2.0	0.5	24	98	40
609	23	3	0.5	0.5	24	24	56
610	60	6	4.0	6.0	692	717	9979
611	53	3	0.5	0.5	5	37	3
613	44	2	1.0	0.5	1	82	4
615	59	6	4.0	0.5	67	98	632
621	28	4	2.0	0.5	13	178	7
622	34	5	3.0	0.5	6	40	6
623	54	3	0.5	0.5	5	42	28
700	84	10	11.0	12.0	55	4775	14
701	44	2	2.0	0.5	12	39	5
704	54	2	2.0	0.5	3	30	3
705	34	4	3.0	0.5	45	86	6
706	32	6	3.0	2.0	34	419	14
707	35	9	8.0	0.5	32	236	11
709	31	4	2.0	0.5	5	46	7
710	127	9	4.0	2.0	31	5228	170
713	76	3	1.0	0.5	5	125	5
714	50	9	13.0	5.0	29	90	17
715	50	9	13.0	4.0	57	151	17
716	67	12	8.0	2.0	38	806	18
718	47	5	3.0	2.0	142	83	1843
720	70	6	5.0	1.0	9	8470	7
722	69	6	4.0	2.0	6	71	5
723	19	5	3.0	0.5	18	2554	219
724	43	8	8.0	21.0	22	193	10

NOTE A value of 0.5 denotes element not detected or below detection limits

TABLE 5 Soil line locations

LINE NUMBER	START POSITION E	N	DIRECTION Deg. Mag.	SAMPLE NUMBERS	SPACING Metres	NO OF SAMPLES
1	365290	554020	357	1040-1050	25	
				1050-1064	50	25
2	365720	554020	357	1094-1100	50	
				1100-1112	25	
				1112-1119	50	26
8	364990	553890	346	1135-1150	25	16
9	364710	553760	317	1170-1178	25	
				1178-1186	50	17
10	364090	553630	334	1204-1212	25	
				1212-1220	50	17
11	364390	553480	269	1230-1250	50	21

TABLE 6 Soil sample results

SAMPLE	Ca	Ti	V	Cr	Mn	Fe %	Co
1040	600	7560	90	120	310	5.72	11.0
1041	1800	6950	80	120	390	4.48	13.0
1042	1300	7330	90	110	450	5.47	5.0
1043	1200	7430	80	100	300	4.77	6.0
1044	1300	6980	80	110	700	5.46	7.0
1045	1400	7440	80	110	650	4.68	10.0
1046	600	7430	80	100	100	4.26	3.0
1047	700	6860	80	110	170	4.69	7.0
1048	600	6910	80	110	320	5.09	6.0
1049	300	7290	80	110	160	5.04	4.0
1050	200	7550	80	120	160	5.81	6.0
1051	100	8650	80	110	260	4.92	6.0
1052	200	7100	70	110	560	4.45	10.0
1053	200	7270	80	110	130	3.73	5.0
1054	200	7170	70	110	420	5.34	9.0
1055	200	7390	70	100	400	4.21	8.0
1056	100	7870	80	120	340	4.54	8.0
1057	200	7760	70	110	400	4.33	8.0
1058	1	7130	80	110	180	4.05	5.0
1059	400	7250	70	110	460	4.25	9.0
1060	200	5240	80	100	530	3.41	9.0
1061	300	7760	70	110	80	1.43	3.0
1094	100	7110	80	110	1760	4.54	21.0
1095	300	7190	90	110	160	3.12	12.0
1096	100	6960	90	120	100	5.20	9.0
1097	100	6390	70	110	110	13.54	7.0
1098	1	6430	80	120	410	5.84	9.0
1099	100	6890	80	120	100	4.33	4.0
1100	100	6690	60	110	540	3.05	8.0
1101	500	5320	20	70	170	0.93	2.0
1102	200	9210	10	60	140	0.48	0.5
1103	500	8010	30	60	230	0.92	2.0
1104	200	7140	70	100	410	4.92	7.0
1105	100	7480	50	80	100	3.58	2.0
1106	200	7060	70	110	590	5.45	9.0
1107	300	7130	50	80	60	2.79	1.0
1108	100	7590	70	100	200	5.14	4.0
1109	200	7630	80	100	60	3.17	3.0
1110	100	7320	70	100	90	4.37	3.0
1111	100	6980	70	100	80	4.34	5.0
1112	100	8380	80	120	150	4.23	5.0
1113	100	11640	80	120	620	3.69	6.0
1114	100	24590	150	200	250	5.89	10.0
1115	200	8140	70	130	710	4.47	8.0
1116	400	6840	50	90	40	0.32	0.5
1135	400	8010	80	110	90	2.63	6.0
1136	1500	9420	110	100	160	2.73	9.0
1137	1400	7810	90	110	100	3.04	6.0
1138	800	7720	70	110	110	3.94	6.0
1139	700	8710	100	110	110	3.46	10.0
1140	1100	7200	70	110	100	1.62	7.0
1141	900	7250	40	80	100	0.44	3.0
1142	800	7380	60	100	200	1.35	7.0
1143	4400	5630	30	70	2650	1.69	30.0

TABLE 6 Soil sample results (cont.)

SAMPLE	Ca	Ti	V	Cr	Mn	Fe %	Co
1144	1100	6590	80	110	790	8.69	21.0
1145	300	7180	20	80	70	0.49	1.0
1146	200	7030	70	110	150	4.18	18.0
1147	1200	7390	60	100	220	1.60	10.0
1148	1000	9720	40	190	80	0.63	3.0
1149	1700	7310	60	110	130	1.56	11.0
1150	1500	6280	50	90	140	2.22	6.0
1170	800	7090	90	120	130	3.07	9.0
1172	900	7060	80	120	220	4.60	10.0
1173	900	7260	80	110	90	3.23	4.0
1174	1900	6840	80	110	140	3.41	9.0
1175	300	6910	80	100	480	5.22	8.0
1176	100	6780	90	100	140	3.94	5.0
1177	100	6330	80	100	110	5.93	4.0
1178	100	7950	60	80	80	1.82	4.0
1179	300	6920	80	110	790	5.84	12.0
1180	100	6880	70	90	740	4.72	10.0
1181	200	7120	70	110	510	4.75	12.0
1182	100	7330	70	110	470	4.58	11.0
1183	100	7020	70	100	180	5.35	7.0
1184	300	7210	70	100	520	4.31	9.0
1185	100	7860	80	120	400	5.22	11.0
1186	300	7140	70	100	360	4.58	9.0
1204	200	7450	90	120	100	4.44	9.0
1205	900	6920	80	100	120	2.51	8.0
1206	800	6990	80	110	170	4.47	6.0
1207	3100	6840	80	120	230	2.72	3.0
1208	600	6970	70	110	230	5.14	5.0
1209	1200	7500	90	120	110	2.64	5.0
1210	1000	6800	70	120	200	3.27	6.0
1211	100	7370	80	100	60	1.62	2.0
1212	100	7050	80	110	400	5.16	11.0
1213	200	7270	80	110	520	5.39	9.0
1214	1	7290	100	130	130	5.62	8.0
1215	200	7300	80	120	1020	4.69	18.0
1216	100	6820	70	110	490	5.00	8.0
1217	100	6930	70	100	210	3.92	4.0
1218	100	7080	80	110	610	4.70	12.0
1219	100	7120	70	110	120	4.09	4.0
1220	200	6490	70	90	1530	3.19	31.0
1230	700	6790	90	120	3960	6.46	47.0
1231	100	7540	70	110	140	3.68	9.0
1232	100	7440	80	110	70	2.91	6.0
1233	700	7510	90	130	410	5.94	13.0
1234	700	7660	90	120	280	4.84	9.0
1235	100	7890	100	130	90	4.68	9.0
1236	100	7670	90	130	100	3.86	9.0
1237	100	7580	80	100	50	1.42	3.0
1238	200	7580	100	130	190	4.72	15.0
1239	100	7980	90	120	70	2.75	5.0
1240	100	8150	90	130	150	2.76	7.0
1241	1	8330	60	100	50	0.56	2.0
1247	100	7970	60	100	50	0.64	2.0
1250	1	7360	80	130	270	3.34	9.0

TABLE 6 Soil sample results (cont.)

SAMPLE	Ca	Ti	V	Cr	Mn	Fe %	Co
1254	200	7680	80	110	90	2.10	8.0
1256	200	7010	80	110	90	2.94	5.0
1257	100	7540	70	100	90	1.63	7.0
1258	100	7350	90	120	210	4.42	9.0
1259	3000	5350	60	80	210	1.05	13.0
1260	200	6850	90	120	150	3.21	12.0
1261	200	6830	80	110	680	6.71	35.0
1262	200	6980	50	90	80	0.64	1.0
1263	900	6540	70	150	220	2.18	15.0
1264	700	6850	70	110	650	1.48	19.0
1266	1000	6740	50	90	260	2.88	6.0
1270	200	7850	80	110	190	4.35	9.0
1271	300	7050	100	120	230	7.38	11.0
1272	1600	6630	80	120	230	5.25	5.0
1273	600	7310	90	120	270	4.54	6.0
1274	700	7110	80	110	90	1.85	3.0
1275	1400	5800	30	60	110	0.56	1.0
1276	100	6790	70	110	560	4.59	11.0
1277	200	7540	70	100	430	4.09	7.0
1278	100	7050	80	110	630	5.67	14.0
1279	200	7000	90	110	700	5.39	14.0
1280	400	7380	100	120	170	4.90	23.0
1282	200	8390	60	100	80	1.65	2.0
1283	700	6690	70	90	130	3.00	6.0
1284	500	7430	40	100	70	0.54	3.0
1285	1000	7990	50	100	330	0.70	10.0
1287	3400	6180	70	90	6630	5.50	74.0
1288	2100	6770	60	100	1980	2.18	14.0
1289	2700	7100	90	120	330	2.90	14.0
1290	2400	6790	60	100	300	1.92	15.0
1291	300	7500	70	110	130	5.89	9.0
1300	3600	6860	90	120	400	3.86	11.0
1301	800	7360	70	100	270	4.08	6.0
1302	900	7220	80	110	120	3.89	5.0
1303	1200	7580	70	100	70	1.06	2.0
1304	1100	6810	80	110	140	4.18	6.0
1305	1000	6090	80	110	380	5.82	7.0
1306	500	7040	70	100	230	4.85	6.0
1307	300	7580	80	110	350	5.57	5.0
1308	600	6550	80	100	360	6.72	6.0
1309	600	7240	70	100	490	5.94	10.0
1310	700	7620	90	130	150	2.42	8.0
1311	200	7560	80	120	140	4.96	7.0
1312	200	7670	100	130	90	2.50	5.0
1313	200	6810	50	110	70	0.53	1.0
1314	200	7560	80	120	70	1.94	3.0
1315	100	7050	80	120	200	3.81	6.0
1316	100	6810	80	110	220	3.88	5.0
1323	200	7600	60	90	70	2.37	2.0
1324	300	6850	90	110	180	4.40	11.0
1325	1200	6750	80	110	1020	4.21	13.0
1326	1400	6890	80	100	130	1.77	6.0
1327	900	6760	90	120	730	5.49	11.0
1328	300	6890	70	100	180	4.54	7.0

TABLE 6 Soil sample results (cont.)

SAMPLE	Ca	Ti	V	Cr	Mn	Fe %	Co
1329	600	7210	80	120	410	3.68	13.0
1330	800	6820	90	120	600	4.93	18.0
1331	500	6880	80	120	130	4.11	10.0
1332	2000	7140	80	110	290	3.33	9.0
1333	200	7160	70	100	70	1.56	6.0
1334	400	6620	50	90	60	0.91	2.0
1335	200	7080	80	120	210	4.18	16.0
1336	400	7420	70	110	150	4.09	10.0
1338	100	6950	60	90	190	3.24	4.0
1339	300	6430	30	90	100	1.09	1.0
1340	100	7650	80	120	60	1.08	4.0
1345	100	7090	70	100	1230	4.49	10.0
1346	100	7050	40	100	340	3.33	6.0
1347	1100	6830	70	100	1500	5.30	14.0
1348	1000	6600	80	100	150	3.52	12.0
1349	600	6220	80	110	130	3.87	12.0
1350	400	6170	80	100	120	3.12	7.0
1351	3100	6810	90	110	250	4.40	14.0
1352	500	6760	90	110	300	5.71	12.0
1353	200	7030	90	120	160	4.95	8.0
1354	100	6630	110	120	3800	7.79	18.0
1355	1	6710	100	120	170	4.12	6.0
1356	1	6890	90	120	110	3.51	6.0
1357	100	7120	90	110	190	3.89	4.0
1358	200	6280	90	110	230	4.06	15.0
1360	400	7610	120	120	2280	8.54	29.0
1366	400	6460	80	100	100	3.76	8.0
1367	300	6850	80	110	180	4.91	17.0
1368	400	6670	80	100	190	3.85	11.0
1369	600	7230	70	100	130	2.87	6.0
1370	400	6840	90	110	1050	5.44	17.0
1371	300	7280	90	120	160	5.57	10.0
1372	200	7210	90	110	1480	6.61	36.0
1373	400	6480	80	110	360	6.51	19.0
1374	500	6840	90	110	1160	8.81	30.0
1375	400	7030	80	110	350	5.50	24.0
1376	300	6940	70	110	80	1.42	6.0
1377	300	7520	40	90	60	0.45	1.0
1378	500	7260	90	120	480	4.89	18.0
1379	100	7220	70	100	60	0.80	3.0
1380	100	7350	70	110	260	0.97	4.0

TABLE 6 Soil sample results (cont.)

SAMPLE	Ni	Cu	Zn	Pb	Rb	Sr	Ba
1040	27.0	15.0	47	42	90	84	250
1041	23.0	17.0	69	57	104	173	380
1042	10.0	8.0	55	51	109	121	260
1043	13.0	9.0	50	41	111	136	310
1044	13.0	10.0	49	128	100	126	280
1045	18.0	7.0	58	40	128	158	340
1046	7.0	3.0	19	28	105	116	270
1047	19.0	12.0	41	24	109	135	360
1048	16.0	8.0	36	40	119	106	310
1049	16.0	4.0	29	24	112	89	320
1050	18.0	9.0	29	26	108	70	360
1051	15.0	4.0	26	19	92	43	300
1052	22.0	12.0	41	22	102	71	320
1053	14.0	5.0	31	28	96	64	260
1054	15.0	7.0	32	24	79	53	240
1055	16.0	4.0	35	23	92	59	280
1056	19.0	9.0	36	20	113	66	340
1057	16.0	7.0	36	31	110	61	320
1058	13.0	16.0	33	37	126	64	380
1059	21.0	6.0	37	21	96	69	300
1060	22.0	3.0	34	24	116	48	290
1061	8.0	0.5	17	42	69	62	180
1094	24.0	11.0	28	32	110	72	250
1095	20.0	3.0	33	56	106	84	340
1096	28.0	12.0	29	32	108	73	360
1097	17.0	18.0	19	18	99	81	420
1098	24.0	9.0	27	28	103	91	250
1099	15.0	21.0	20	24	136	78	630
1100	9.0	6.0	13	36	104	39	250
1101	2.0	11.0	18	71	26	28	60
1102	0.5	0.5	10	30	12	42	40
1103	1.0	1.0	22	68	16	42	60
1104	16.0	6.0	27	18	80	58	250
1105	3.0	1.0	12	16	59	66	140
1106	16.0	4.0	36	27	75	54	240
1107	1.0	0.5	17	35	42	41	110
1108	8.0	2.0	21	23	74	50	210
1109	6.0	0.5	18	24	85	55	230
1110	14.0	4.0	36	28	89	60	260
1111	15.0	3.0	38	15	75	50	220
1112	14.0	7.0	32	31	95	60	290
1113	9.0	0.5	23	54	74	75	200
1114	33.0	6.0	59	64	83	141	290
1115	17.0	5.0	28	13	77	51	270
1116	1.0	0.5	10	15	66	50	180
1135	13.0	1.0	34	48	76	69	210
1136	31.0	5.0	170	119	69	89	290
1137	18.0	6.0	105	204	85	150	330
1138	24.0	3.0	83	67	95	93	290
1139	38.0	11.0	250	102	79	82	300
1140	28.0	8.0	48	62	99	102	350
1141	6.0	0.5	16	25	53	62	200
1142	24.0	2.0	25	24	93	60	320
1143	12.0	0.5	80	83	32	55	330

TABLE 6 Soil sample results (cont.)

SAMPLE	Ni	Cu	Zn	Pb	Rb	Sr	Ba
1144	35.0	13.0	40	34	100	78	440
1145	3.0	0.5	13	38	35	49	100
1146	40.0	10.0	48	29	94	61	290
1147	28.0	1.0	33	26	78	72	310
1148	10.0	0.5	25	29	56	61	160
1149	31.0	5.0	42	22	89	78	310
1150	21.0	3.0	44	60	60	52	200
1170	29.0	8.0	70	65	99	127	370
1172	26.0	15.0	144	120	100	143	370
1173	12.0	11.0	35	57	109	129	310
1174	18.0	13.0	58	177	112	175	460
1175	17.0	7.0	27	31	113	81	350
1176	16.0	9.0	28	37	132	87	380
1177	14.0	8.0	21	24	94	44	310
1178	10.0	5.0	16	14	72	71	200
1179	19.0	13.0	35	36	81	75	260
1180	21.0	4.0	39	18	88	81	230
1181	28.0	10.0	54	21	107	64	350
1182	20.0	11.0	38	22	105	64	290
1183	17.0	4.0	39	19	89	54	280
1184	19.0	12.0	38	20	107	63	320
1185	39.0	6.0	67	15	98	48	320
1186	19.0	8.0	36	26	103	62	280
1204	26.0	15.0	37	32	103	76	290
1205	15.0	6.0	27	28	94	111	310
1206	21.0	15.0	39	37	100	113	360
1207	11.0	14.0	39	33	120	217	440
1208	16.0	8.0	32	43	94	99	300
1209	18.0	12.0	33	27	103	139	340
1210	21.0	9.0	29	35	99	155	350
1211	9.0	0.5	15	34	102	61	290
1212	22.0	8.0	32	26	96	65	320
1213	13.0	12.0	18	46	78	75	240
1214	36.0	18.0	40	23	140	113	370
1215	28.0	14.0	46	26	112	76	380
1216	17.0	7.0	32	24	91	54	250
1217	11.0	4.0	28	31	77	49	230
1218	19.0	14.0	41	22	117	60	330
1219	14.0	4.0	24	27	76	51	240
1220	14.0	8.0	23	20	95	59	230
1230	19.0	14.0	103	341	100	135	210
1231	21.0	14.0	21	20	81	52	210
1232	16.0	8.0	15	23	72	53	170
1233	26.0	14.0	16	22	92	60	280
1234	20.0	9.0	18	25	87	60	240
1235	31.0	19.0	31	25	124	75	290
1236	27.0	15.0	34	26	119	68	240
1237	11.0	0.5	10	31	66	59	120
1238	35.0	17.0	24	29	105	65	280
1239	22.0	10.0	15	26	91	62	210
1240	24.0	9.0	16	23	90	62	230
1241	8.0	1.0	6	12	52	55	120
1247	6.0	0.5	9	14	54	55	130
1250	23.0	15.0	25	25	113	65	230

TABLE 6 Soil sample results (cont.)

SAMPLE	Ni	Cu	Zn	Pb	Rb	Sr	Ba
1254	19.0	16.0	18	20	111	82	270
1256	13.0	14.0	17	22	126	80	200
1257	13.0	10.0	14	21	88	69	190
1258	24.0	15.0	26	30	114	70	220
1259	18.0	4.0	24	44	59	55	200
1260	39.0	24.0	28	28	120	82	370
1261	47.0	23.0	37	31	99	62	320
1262	6.0	0.5	11	15	63	53	170
1263	45.0	14.0	37	41	56	60	270
1264	18.0	33.0	17	177	56	65	190
1266	9.0	6.0	25	39	56	61	190
1270	23.0	11.0	49	22	95	59	250
1271	31.0	15.0	35	29	108	66	340
1272	16.0	10.0	36	25	107	132	370
1273	18.0	16.0	22	33	133	156	550
1274	14.0	7.0	21	30	109	147	330
1275	0.5	0.5	46	232	24	34	50
1276	24.0	11.0	34	26	109	54	360
1277	16.0	4.0	32	21	88	69	270
1278	26.0	13.0	44	35	104	79	310
1279	27.0	16.0	43	29	112	80	360
1280	37.0	26.0	53	31	128	133	490
1282	9.0	5.0	17	39	75	70	200
1283	19.0	3.0	35	46	68	59	260
1284	10.0	0.5	13	10	83	60	260
1285	20.0	0.5	25	13	93	64	300
1287	34.0	5.0	65	69	72	64	430
1288	37.0	1.0	50	24	85	57	820
1289	37.0	8.0	37	27	130	178	580
1290	40.0	5.0	32	36	86	75	510
1291	26.0	8.0	32	20	85	69	270
1300	21.0	19.0	236	362	133	321	600
1301	13.0	7.0	36	37	80	106	250
1302	17.0	10.0	30	41	94	100	300
1303	7.0	0.5	17	70	98	150	280
1304	19.0	12.0	35	33	95	133	350
1305	14.0	2.0	44	32	86	105	250
1306	14.0	4.0	32	21	86	93	270
1307	8.0	2.0	19	24	103	85	290
1308	12.0	5.0	32	40	94	95	260
1309	19.0	9.0	35	39	95	86	250
1310	28.0	8.0	36	17	118	124	510
1311	23.0	6.0	34	27	111	86	420
1312	22.0	5.0	25	32	147	180	490
1313	7.0	0.5	12	31	91	57	270
1314	20.0	7.0	14	22	143	90	680
1315	14.0	7.0	20	24	100	71	320
1316	15.0	13.0	24	37	124	72	370
1323	6.0	2.0	12	21	78	74	190
1324	27.0	16.0	26	29	125	86	390
1325	29.0	12.0	28	22	120	86	430
1326	20.0	4.0	22	25	108	86	570
1327	30.0	13.0	26	29	115	80	460
1328	14.0	5.0	19	27	74	67	230

TABLE 6 Soil sample results (cont.)

SAMPLE	Ni	Cu	Zn	Pb	Rb	Sr	Ba
1329	31.0	18.0	34	26	120	84	430
1330	36.0	15.0	35	27	117	80	430
1331	24.0	9.0	27	29	108	72	350
1332	26.0	4.0	25	22	97	81	550
1333	16.0	0.5	19	22	93	66	260
1334	7.0	0.5	11	19	71	55	180
1335	38.0	14.0	45	23	137	96	480
1336	16.0	0.5	28	29	103	64	260
1338	7.0	0.5	19	29	84	63	180
1339	2.0	0.5	11	125	39	42	80
1340	15.0	3.0	17	20	124	83	250
1345	15.0	5.0	30	28	104	52	250
1346	8.0	3.0	19	27	53	39	120
1347	22.0	6.0	54	22	95	60	350
1348	39.0	7.0	61	25	99	59	430
1349	41.0	7.0	51	22	111	61	430
1350	26.0	5.0	29	21	96	56	450
1351	37.0	12.0	36	44	127	78	790
1352	31.0	19.0	33	38	130	68	550
1353	36.0	18.0	35	32	121	70	520
1354	45.0	29.0	34	58	160	64	390
1355	31.0	13.0	69	26	160	74	350
1356	27.0	19.0	39	26	137	64	300
1357	21.0	7.0	27	28	141	62	270
1358	41.0	21.0	48	27	155	72	450
1360	44.0	27.0	47	63	127	88	380
1366	27.0	7.0	31	39	80	57	350
1367	33.0	5.0	47	30	87	62	360
1368	23.0	4.0	34	36	87	62	370
1369	20.0	2.0	27	21	94	64	350
1370	27.0	15.0	31	29	117	67	410
1371	27.0	13.0	41	26	115	65	390
1372	22.0	11.0	29	37	117	71	390
1373	49.0	11.0	72	24	118	64	510
1374	31.0	9.0	45	35	108	64	480
1375	32.0	14.0	46	18	90	61	420
1376	17.0	1.0	20	20	74	60	240
1377	5.0	0.5	15	23	44	53	110
1378	39.0	14.0	26	33	109	71	570
1379	11.0	4.0	9	22	90	67	180
1380	12.0	3.0	9	22	80	63	190